Chapter 4

Diel Patterns of Dissolved Oxygen, Fluorescing Dissolved Organic Matter and Turbidity and Their Relationship to Seasonal Runoff and Storm Events in the Jordan River

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August 2019

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Introduction

Large quantities of both organic and inorganic material are delivered to the Jordan River regularly (Chapters 3 and 4). The inorganic silt -to very fine to large sand -to gravel fractions are largely deposited upstream from the 2100 S diversion. This deposition follows a continuum from larger to smaller substrate size as the channel gradient gradually decreases through the valley. Chronic severe dewatering of the Jordan River channel at the 2100 S diversion to the Surplus Canal vastly reduces stream velocity and allows for the settling of small sand, silt and clays as well as substantial quantities of coarse particulate organic material (CPOM). These materials are also deposited along a continuum from larger to smaller particle sizes and density or mass of organic matter as the channel velocity further decreases. The great majority of the Jordan River downstream of 2100 S. is characterized as a depositional zone of inorganic fine material and CPOM.

There are notable nutrient inputs from Utah Lake and three POTWs along the middle and lower reaches of the river and these high nutrient concentrations had been blamed for the occasional low DO violations in the lower Jordan River. The naïve paradigm of this linkage is that nutrients cause excessive algal blooms (or benthic periphytic growth). In turn this large biomass experiences considerable evening respiration rates and, upon senescence, contributes to further oxygen consumption as decomposition proceeds. The Jordan River is one anomaly. actual water column (phytoplankton) and benthic chlorophyll a (Chl a) concentrations (attached algal communities) are far less developed than the potential growth that the nutrients provide for (Jordan River Phase I TMDL, 2010), which is far less algal biomass that has been associated with low DO excursions (e.g. Smith and Peidrahita, 1988). The relatively low benthic algal biomass can be attributed to the near-constant shifting and scouring of the unstable bedload material upstream from 2100 S, as well as the shifting and near-constant settling and smothering of benthic communities downstream from the 2100 S diversion. These factors inhibit the establishment of substantial quantities of periphytic growth. In turn, these low quantities of periphyton led to the search for other possible causes for the occasional DO violations that are known to occur.

Early on, there were two important observations: 1) The depositional sediments below the 2100 S diversion are rich in organic material that exists in many stages of decomposition (from identifiable leaves, twigs, seeds, etc. to black unconsolidated organic mud layers rich in sulfide odors). Release of considerable amounts of gas bubbles, undoubtedly comprised of methane, hydrogen sulfide, ammonia or N_2 gases, were observed while sampling. The majority of these gases have potentially huge contributions to BOD; or sediment oxygen demand (SOD) if the aerobic/anaerobic interface occurs below the sediment surface; and 2) The low DO excursions have irregular patterns - on a diel basis or seasonally as most of them appear to be associated with isolated storm events. Hence, the occasional violations of the DO standards do not agree with the paradigm that links low DO excursions to diel patterns of elevated evening respiration or to the eventual elongated periods of depressed DO due to decomposing of dead algal cells. These observations led to a detailed investigation of the other sources of organic matter (i.e. VSS and CPOM; Chapters 3 and 4), and how this organic matter ultimately affects the DO patterns and the occasional violations of the DO standard.

Our group has performed standard measures of organic matter and oxygen dynamics, including BOD, CBOD, and VSS since 2009. These parameters remain quite stable throughout the year while the DO record shows considerable variability. In other words, these parameters were not correlated with the DO record except for the rare occasion when samples were collected during storm events. Yet, the Phase I TMDL (Utah DWQ, 2011) identified VSS as the pollutant of primary concern by assuming that this VSS is the source of sediment oxygen demand (SOD), by assuming that all VSS settles out of the water column. However, our data shows that VSS is high at the Utah Lake outlet and, although there may be some exchange of VSS between the sediment and water column, there is no net loss from the water column throughout the entire river. Hence, this investigation was extended to include the potential contribution of CPOM to the benthic organic matter and the subsequent elevated sediment oxygen demand; and finally, to its contribution to the episodic low DO events. The deposition and fate of sediment organic matter remains of critical importance. This chapter begins to elucidate the fate of settled organic matter and the important role that it plays in the oxygen dynamics of the river.

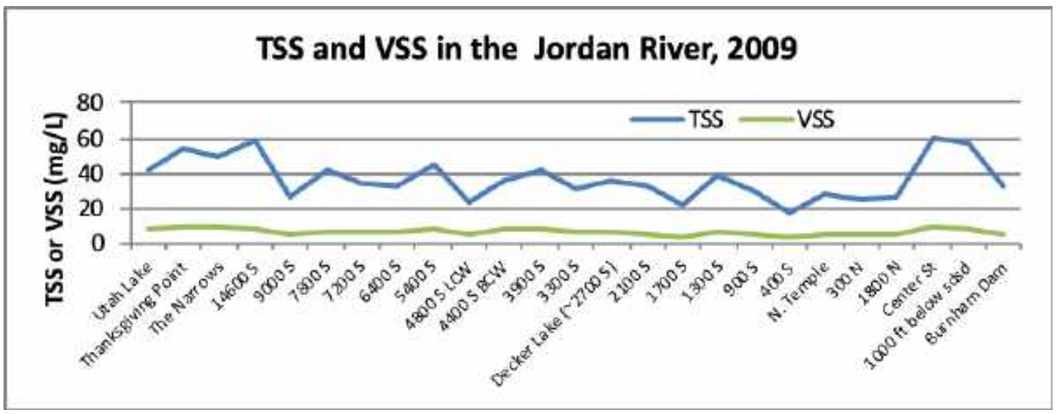
Summary of Methods

On average, 25 sites were sampled monthly along the Jordan River, at the mouth of major tributaries, the surplus canal and upstream and downstream from The South Valley, Central Valley, and South Davis South and South Davis North facilities. All water quality samples were collected as grabs, immediately placed on ice and transported to the Central Valley Water Reclamation Facility Laboratory where all analysis were performed following EPA methods. In addition, In-Situ® data recording sondes were placed in specific locations starting in 2009 to start recording DO, pH, temperature and conductivity. These sondes were used primarily during summer months, from 2009 to May, 2013 and were primarily set at 2100 S, 300 N, inside the Legacy Nature Preserve and at Burnham Dam. In May of 2013 these sondes were replaced by permanently installed YSI (model) sondes fitted with solar panels and real-time cellular transmission of data to a secure web site at 15-minute intervals. These sondes were installed at 9 locations (Utah Lake outlet, 3300 S, 2100 S, Surplus Canal at the SLC airport, 800 S, 300 N, Center Street (Cudahay Lane) and Burnham Dam). sondes. Of these nine sondes, six are fitted with the four standard parameters mentioned above and a turbidity probe. The other three sondes included the five probes plus chlorophyll a and fluorescing dissolved organic matter (FDOM). In addition to comparison of the data between the probes at a single station, these data can track episodic events from upstream to downstream and in relation to the flow, BOD and VSS data throughout the river and major tributaries. All sondes were calibrated every 30 days to maintain QA goals. Throughout the calibration procedures very little drift of any of the parameters was recorded.

Results and Discussion

Total suspended solids, volatile suspended solids, biological oxygen demand and carbonaceous biological oxygen demand

One of our initial goals was to characterize the seasonal and annual variability and sources of TSS, VSS, BOD, CBOD and nutrients. Here I summarize those parameters that are related to the oxygen dynamics of the River. Figure 1 includes the mean of monthly, and some cases biweekly samples of TSS, VSS, BOD and CBOD for the entire length of the Jordan River from May to December of 2009. There are some points worth noting. The Jordan River is initially controlled at the outlet of Utah Lake. It flows through low gradient agricultural and then increasingly urbanized landscapes until just upstream from Thanksgiving Point. At that point the gradient increases substantially as the river flows through the Narrows.



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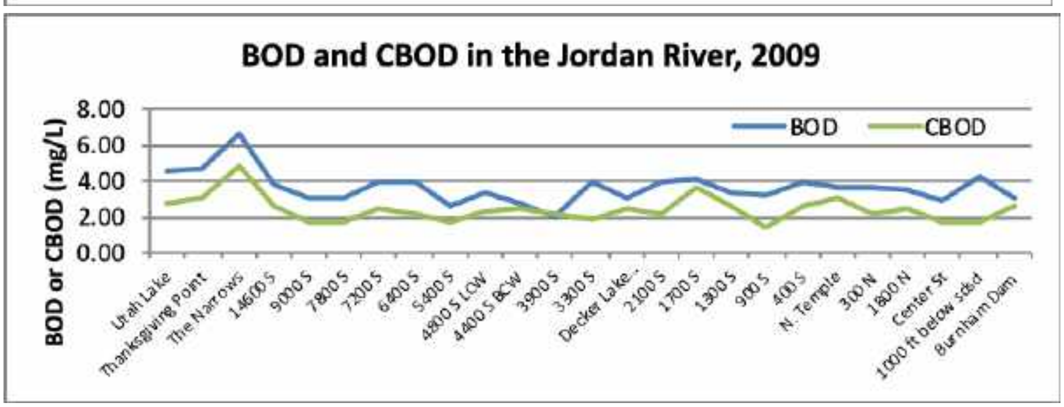

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Figure 60. Mean concentrations of total suspended solids and volatile dissolved solids (a.) and BOD and CBOD (b.) in the Jordan River during 2009. Data include the means of monthly samples collected May through December. The peak in TSS at Center St and Burnham Dam was due to a single spike in the river samples measured on July 29 of 299 mg/L. The small peak in BOD and CBOD at the Narrows was due to a single grab sample on August 11 of 13.6 mg/L and 8.6 mg/L for BOD and CBOD respectively.

This is a "gaining" reach as there are known sources of springs/groundwater. This reach also flows through loose alluvial material and during 2009 and 2010, active construction of the Frontrunner train was occurring immediately adjacent to the river through the entire area of the Narrows. This was a constant source of inorganic TSS, although not so much VSS. The South Valley Water Reclamation Facility discharges to the Jordan between 7800 S and 7200 S and grab samples were collected from the effluent on the same day that other river samples were collected. The mean value of BOD for the South Valley plant was 3.1 mg/L, equal to the mean value measured at 7800 S. Therefore, the small increase in BOD between 7800 S and 7200 S was not likely due to the discharge of the South Valley plant. In addition, the sites labeled 4800 S LCW and 4400 S BCW represent samples collected from Little Cottonwood and Big Cottonwood creeks respectively, immediately upstream from their confluence with the Jordan River. Despite the apparent dilution from these tributaries, the mean TSS, VSS and BOD in the Jordan River increased slightly between 5400 S and 3300 S. Similarly, the Decker Lake sample was collected from the Decker Lake outlet immediately upstream from its confluence with the Jordan River. Mill Creek, which receives the discharge from the Central Valley Water Reclamation Facility, enters the Jordan River at about 2700 S. During low flow periods of the year (basically all months except May and June), the majority of Mill Creek flow (50 to 80%) is comprised of the Central Valley discharge. In turn, Mill Creek comprises about 1/3 of the Jordan River flow during low-flow periods. Yet, the discharge of Mill Creek has no perceptible influence on the BOD or CBOD in the Jordan River. The mean BOD and CBOD are virtually identical between 3300 S (upstream from Mill Creek), and 2100 S (downstream from Mill Creek; Figure 1 b.). The downstream TSS is also similar to upstream values and the mean VSS downstream was actually lower by a small amount (from 6.6 to 5.4 mg/L; Figure 1 a.). Because of the recent interest on influence of Central Valley Water Reclamation Facility on Mill Creek and the Jordan River, Figure 2 provides more detail of these important water quality parameters. Except for the August 11 sample, Mill Creek upstream from the discharge point was lower in BOD than the downstream location. The effluent elevated the BOD somewhat, but the data were variable, including a lower BOD than the downstream site in Mill Creek (Figure 2). Similarly, VSS was much higher downstream from the discharge than in the effluent itself. This was certainly unexpected and led us to investigate the source of this additional BOD and VSS. Our field technicians had observed a storm drain that discharged immediately adjacent to the 900 W bridge was flowing during most sampling events, even though there had been no recent rainfall events. Further, this discharge was quite turbid and discolored the stream water as it mixed. More recently, during a site visit with DWQ personnel during December 2013, discolored water was discharging from this same culvert. We now believe that this discharge was the cause of increased turbidity, VSS and BOD downstream from the Central Valley facility discharge. In turn, this additional load of BOD and VSS is substantial and contributes to Jordan River loading when it is flowing. It may be discharges like this that contribute to the overall variability of these constituents in the Jordan River. Overall, however, and despite this contribution of Mill Creek's load to the Jordan River, the BOD and VSS experience little change from upstream conditions. There is a slight increase in BOD during August, September, and October from upstream to downstream of the Mill Creek confluence and a slight reduction in BOD during November and December. There was very little change in VSS from upstream to downstream during the entire sampling period.

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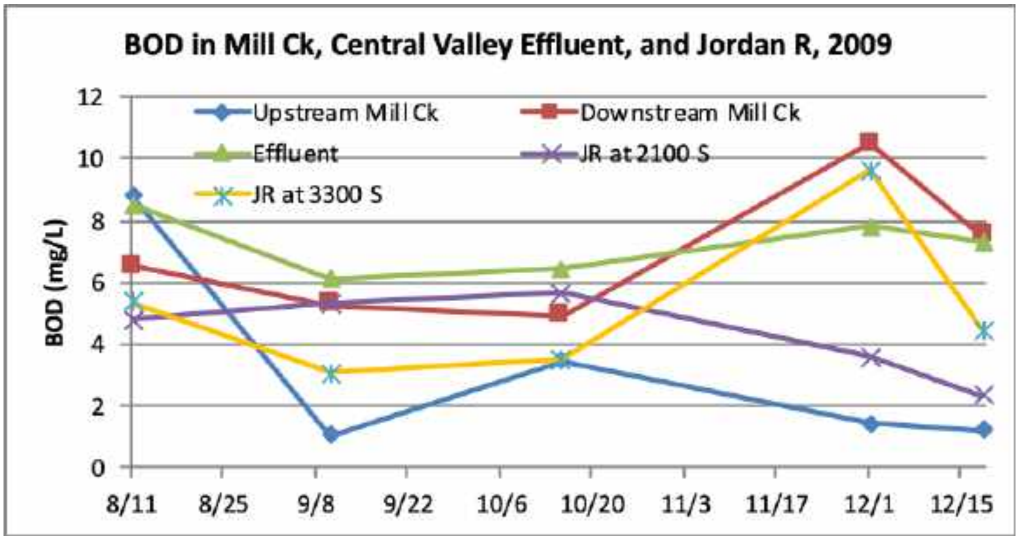

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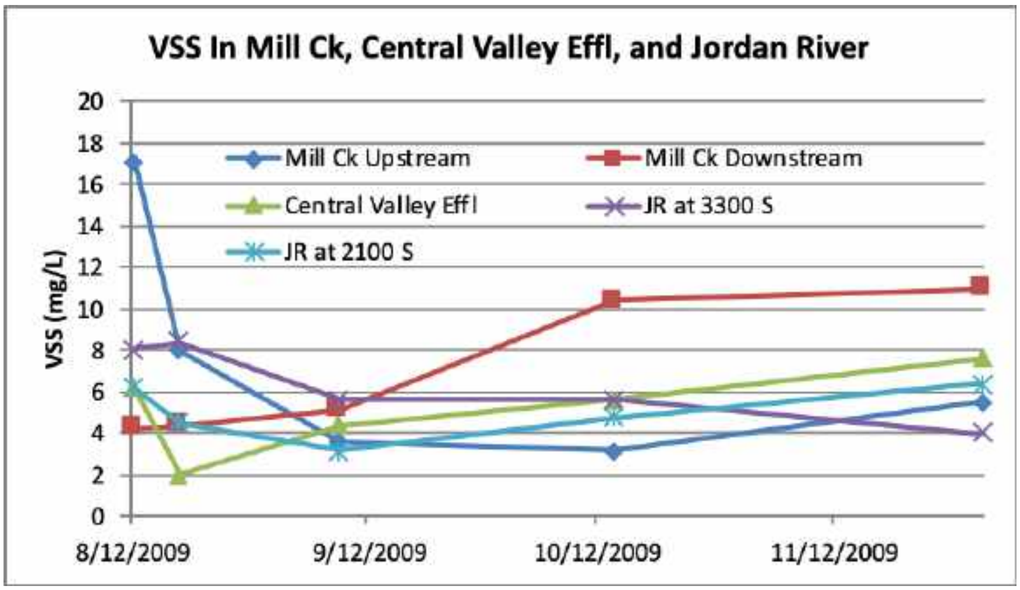
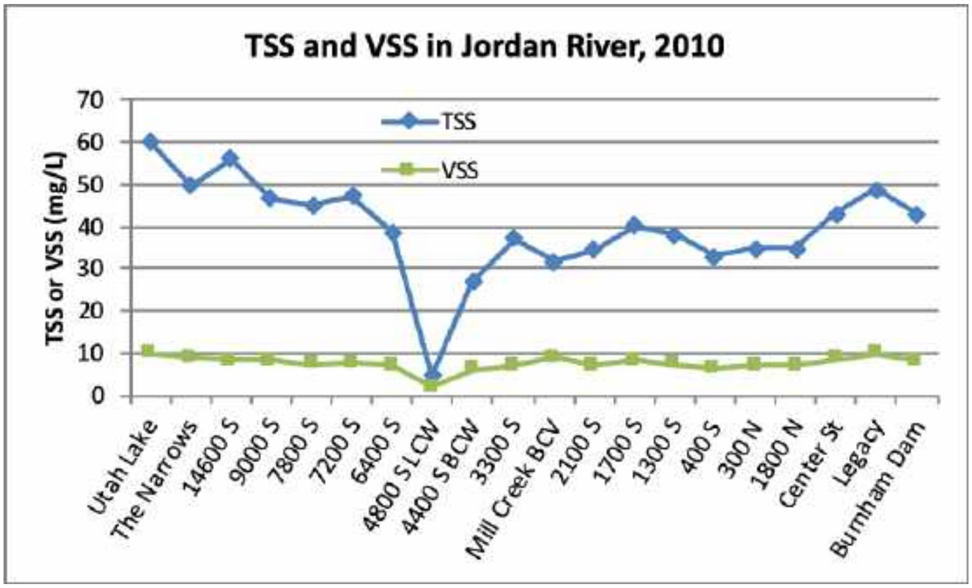


Figure 61. Detailed tracking of BOD (a.) and VSS (b.) at sampling sites in Mill Creek, located upstream and downstream from the Central Valley Water Reclamation Facility, the facility effluent itself and in the Jordan River upstream and downstream from the confluence with Mill Creek.

Similar samples were collected during 2010. These data are summarized in Figure 3. Average concentrations TSS and VSS were very similar to the 2009 samples. TSS remained relatively high through the narrows during 2010 as construction on the light rail train was continuing. Also similar to 2009, there was a general rise in TSS downstream from Center Street although VSS remained quite stable throughout the entire River. The dip in both TSS and VSS at 4800 S LCW is again, from sampling in Little Cottonwood Creek immediately above the confluence with the Jordan River.



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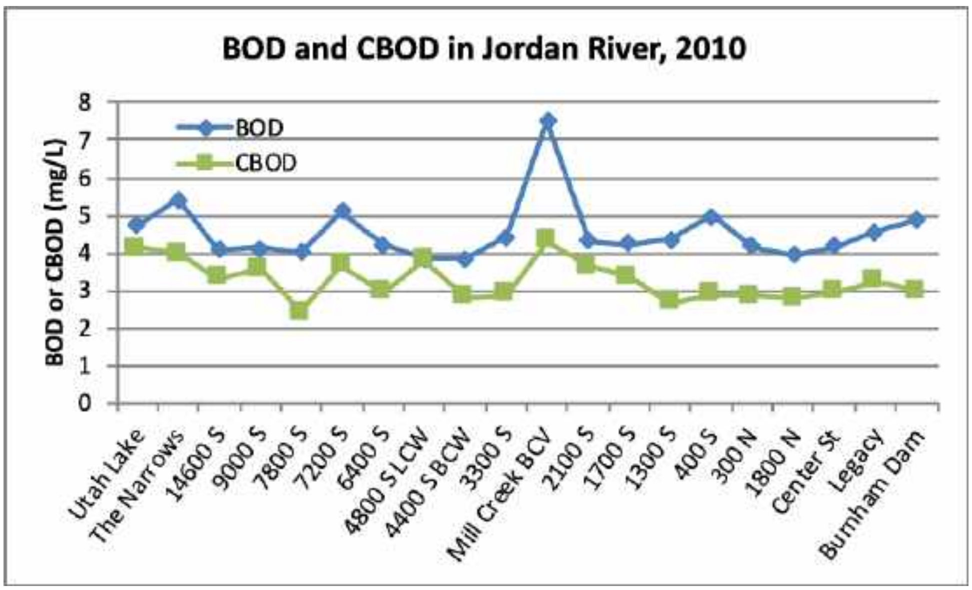
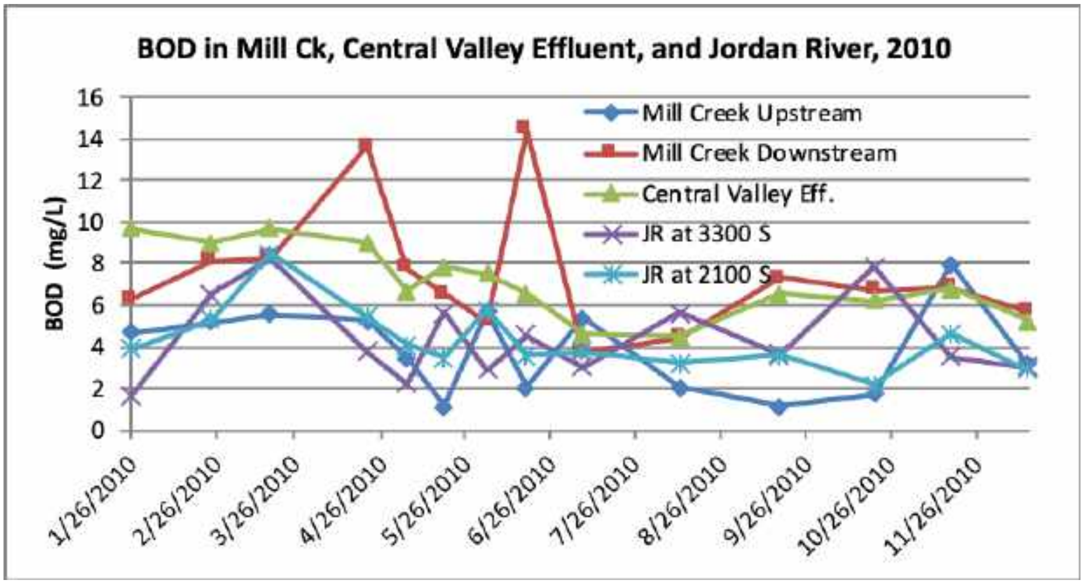


b.

Figure 62. Mean of monthly total dissolved solids and volatile dissolved solids (a.) and BOD and CBOD (b.) samples in the Jordan River during 2010. Data include the means of monthly samples collected January through December.

The annual average concentration of BOD and CBOD in Mill Creek was also elevated during 2010. However, this was due to two very high measurements that likely also attributed to the storm drain near the 900 West Bridge (See figure 4). In the 2010 monthly data set, the average values in Mill Creek downstream from the Central Valley facility are also included (Figure 4). While some BOD and CBOD are being added from the Central Valley Discharge, the downstream values are often greater that the Central Valley discharge itself – indicating additional source(s) such as the illicit release from the storm drain described above.



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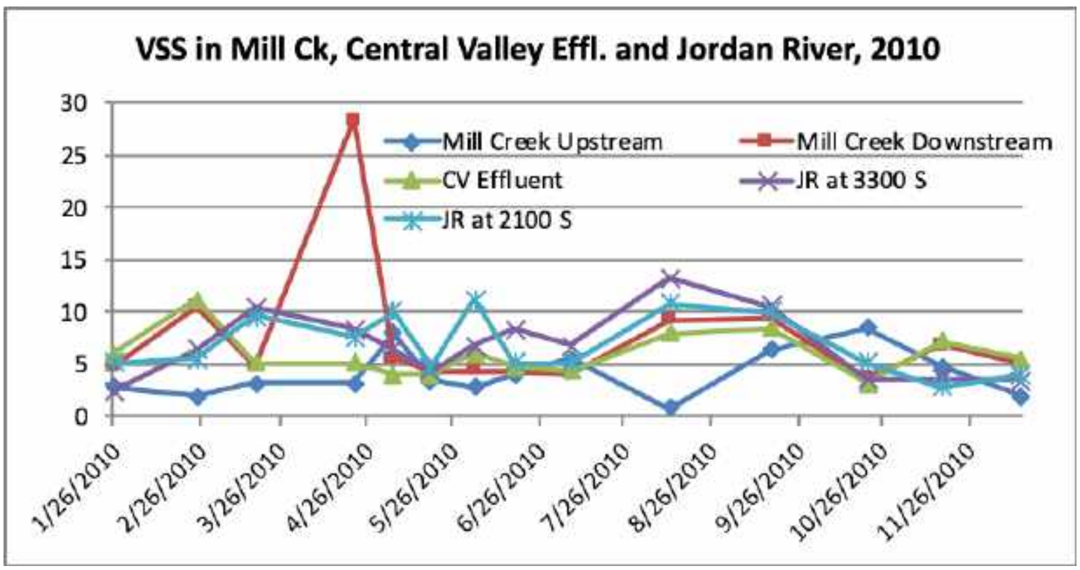


Figure 63. Detailed tracking of BOD (a.) and VSS (b.) at sampling sites in Mill Creek, located upstream and downstream from the Central Valley Water Reclamation Facility, the facility effluent itself and in the Jordan River upstream and downstream from the confluence with Mill Creek.

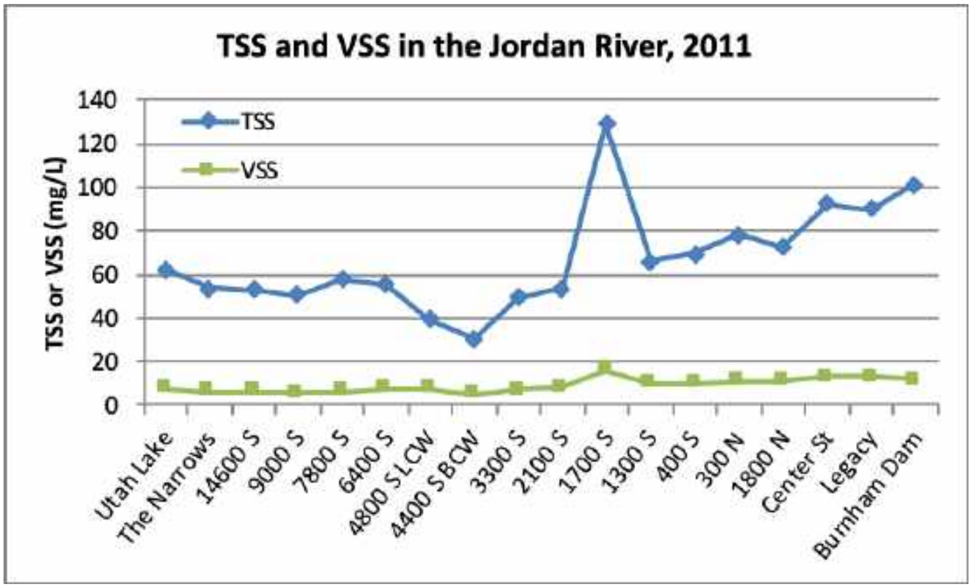
The two spikes in BOD downstream from the Central Valley discharge, in April and in June, reached much higher values than effluent concentrations. This suggests again, that the storm drain that discharges near the 900 W Bridge, or perhaps one of more of the others that discharge in the same vicinity are adding some BOD to Mill Creek.

Even so, neither the POTW effluent or the storm drain(s) appear to have a significant influence on the Jordan River downstream from the Mill Creek confluence. The BOD averages about 4 mg/L throughout the entire length of the river. The VSS was very similar between all sampling locations throughout the year. The only exception was the spike in VSS in the April sample collected downstream from the Central Valley effluent.

This was the same timing and location of the April spike in BOD. Finally, it should be noted that overall flows during 2009 were close to the long-term average for the Jordan River and surrounding watershed. The 2010 flows were only about 70% of normal flows. Although this would reduce overall loads and dilution capability, there was not a discernible difference in concentrations.

The 2011 data were similar to the previous years. BOD and CBOD remained in the 2.5 to 4 mg/L range throughout the length of the river (Figure 5). The TSS was somewhat higher and continued to increase through the downstream locations. Flows were about 40% above normal during 2011 due to a very wet and late spring. Indeed, for about three weeks, flows down the surplus canal were approaching the 1984 all time high record flows (USGS stream flow historic data). These unusually high flows likely suspended additional inorganic sediments (silt and clay material) that would normally be more stable under normal flows and velocities. Notably, the TSS actually increased at downstream locations, indicating that the resuspension of these fine inorganic materials was continually increasing in zones that were typically dominated by the settling of this material under the normal flows. Interestingly, there was not a concomitant increase in the VSS, which suggests that the two are independent (Figure 5).

We evaluated the local site-specific characteristics of BOD and VSS in lower Mill Creek again during 2011 (Figure 6). BOD and VSS were similar to previous years. There was an excursion of BOD in the April sample in the Central Valley Facility discharge that was also apparent in the downstream Mill Creek Sample. Also, BOD was elevated in the November and December samples, although this was not reflected as strongly in the downstream samples. In addition to the increase of BOD in April, there was an increase in VSS in the upstream Mill Creek samples later in the spring of 2011. This increase was likely associated with the unusually high runoff, but notably, was diluted by the lower VSS concentrations of the Central Valley Facility effluent. However, other than these brief excursions, BOD and VSS did not vary from previous years in either Mill Creek or the Jordan River.



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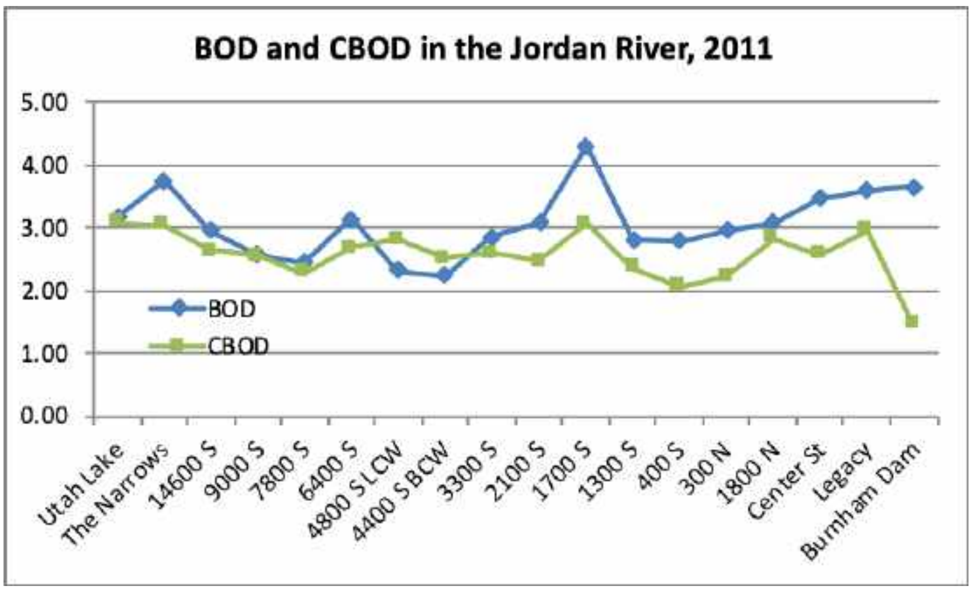

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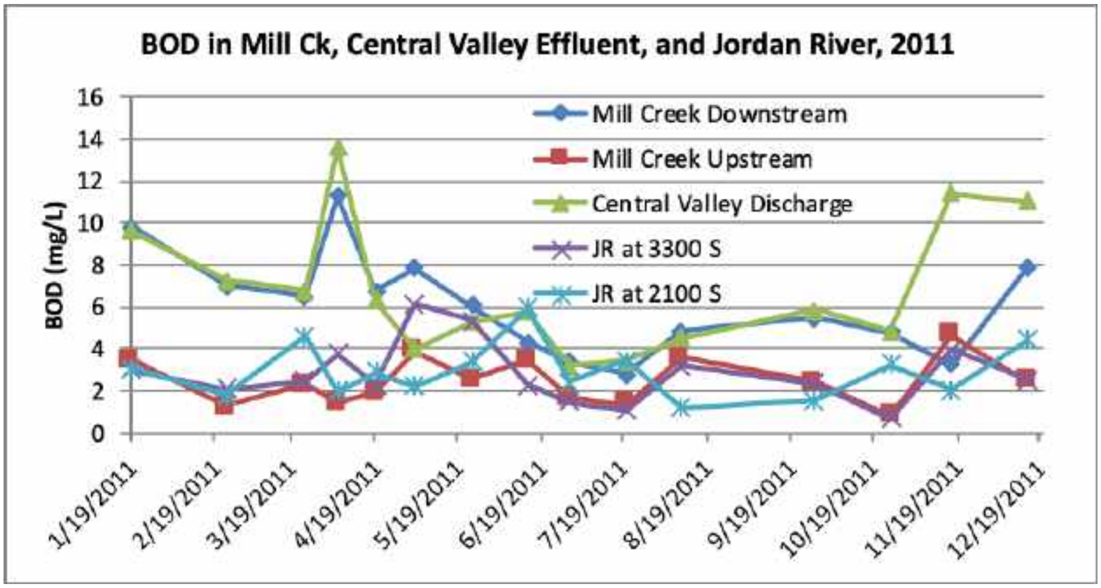
Figure 64. Mean of monthly total dissolved solids and volatile dissolved solids (a.) and BOD and CBOD (b.) samples in the Jordan River during 2010. Data include the means of monthly samples collected January through December. Fifteen samples were collected from each site and included at least one sample each month.



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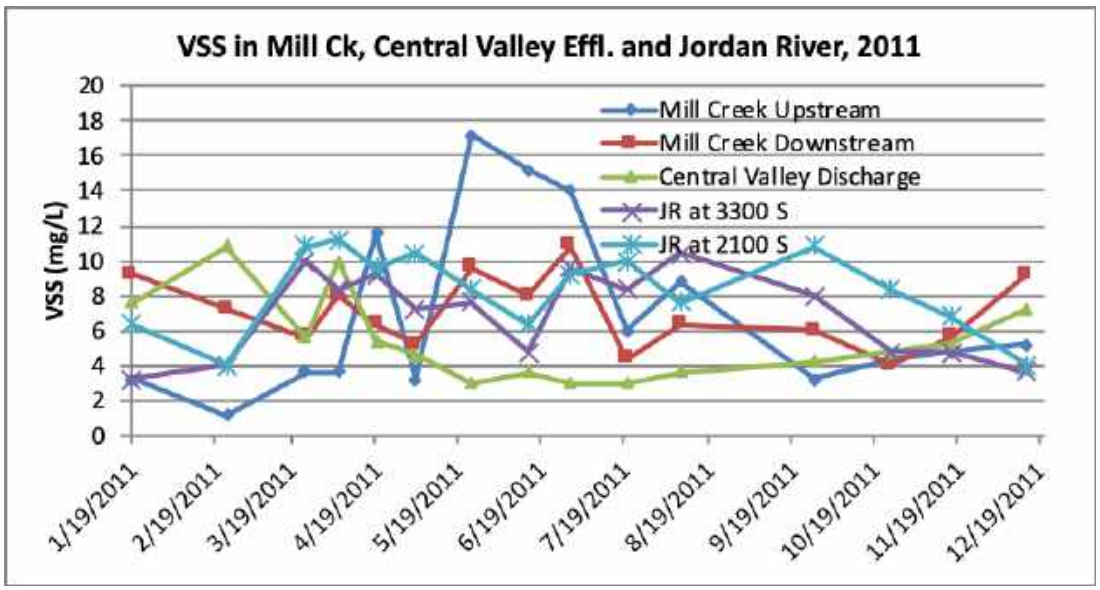

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Figure 65. Detailed record of BOD (a.) and VSS (b.) at sampling sites in Mill Creek, located upstream and downstream from the Central Valley Water Reclamation Facility discharge, the facility effluent itself and in the Jordan River upstream and downstream from the confluence with Mill Creek during 2011. Data represent approximate monthly grab samples.

During 2012 flows were once again below average. For 2012 data, the BOD, CBOD and VSS are reported separately for winter and summer to determine if season or temperature influenced these characteristics of the river. BOD and CBOD are illustrated in Figure 7. There were clearly no seasonal differences between BOD or CBOD.

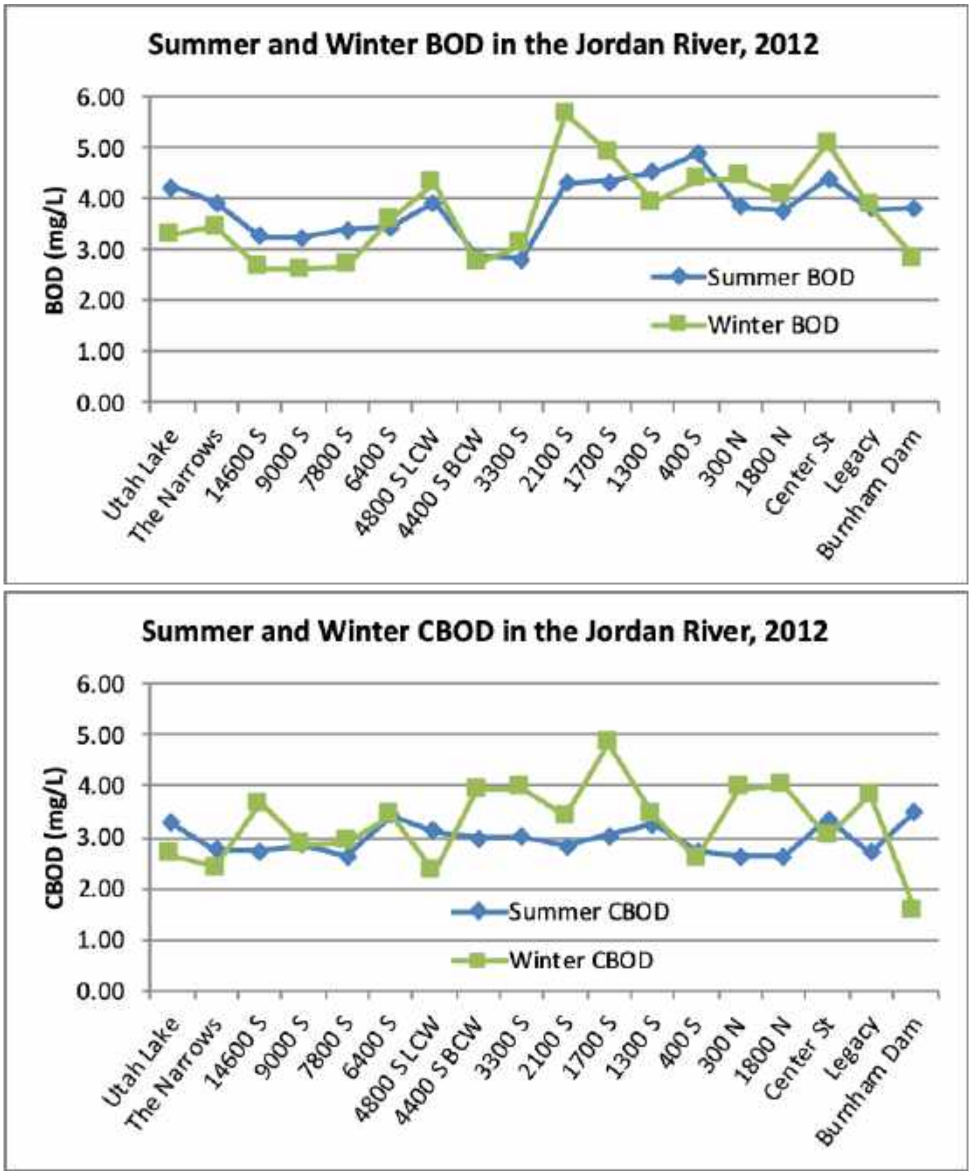

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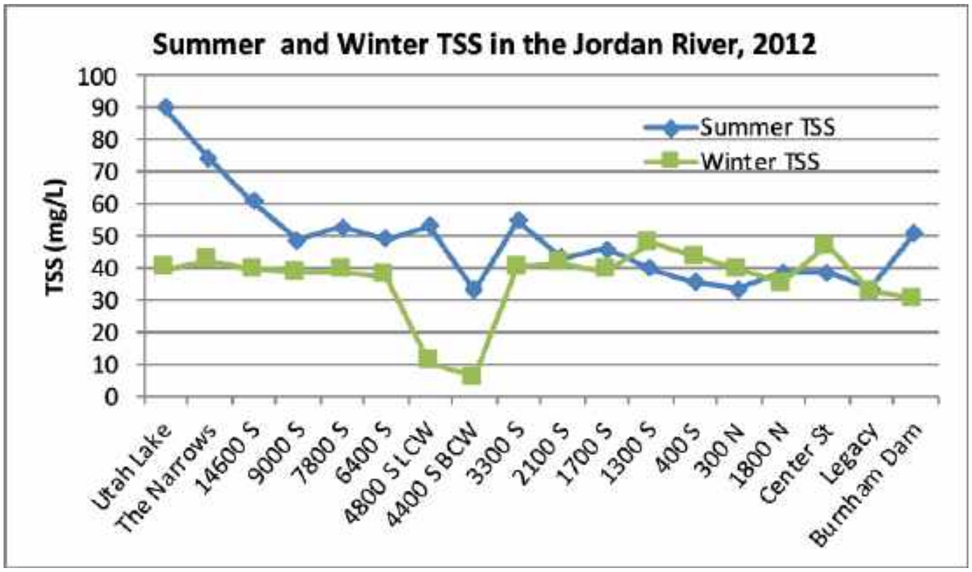
Figure 66. Mean of monthly BOD (a.) and CBOD (b.) samples collected from the Jordan River during 2012. Fifteen samples were collected from each site and included at least one sample each month.

Seasonal separation of TSS and VSS data was also performed (Figure 8). In these graphs, summer sampling was defined as May through October and winter was defined as November through April. As such, the elevated spring runoff months were likely responsible for the elevated VSS and TSS. Summer values were elevated until about the area of the Surplus Canal diversion where the channel and Surplus Canal flows would be more equalized and hence might be expected to moderate the difference between seasons. It should also be noted that for both seasons, Little Cottonwood and Big Cottonwood creeks contained lower concentrations of VSS and TSS. Yet, the samples collected at 3300 S were similar to those collected upstream from these two tributaries- suggesting there was not a lot of dilution.



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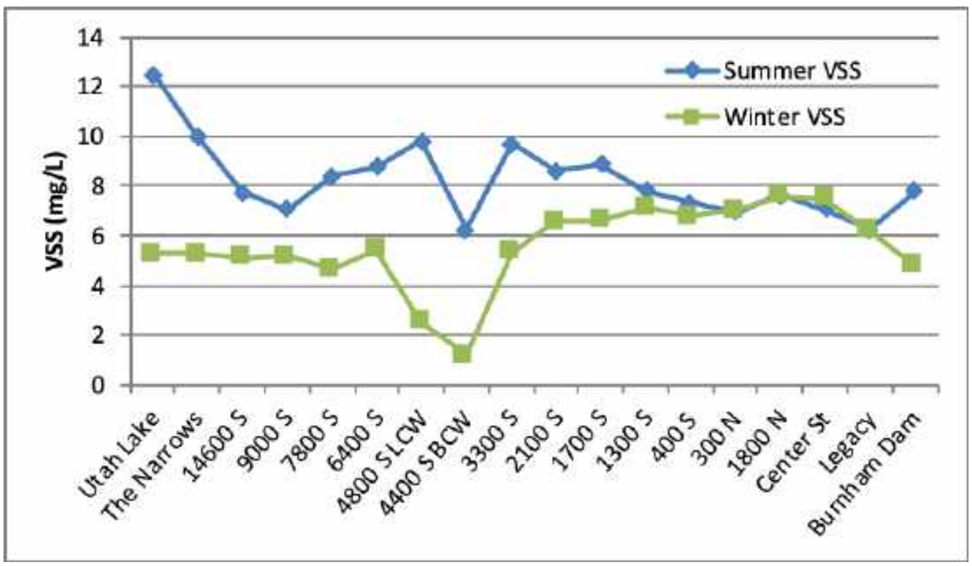

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Figure 67. Mean of monthly TSS (a.) and VSS (b.) samples collected from the Jordan River during 2012. Fifteen samples were collected from each site and included at least one sampling event each month.

DO and Temperature Recordings

Another key goal of the Council was to elucidate the dissolved oxygen dynamics in the reach that DWQ listed as impaired and more fully ascertain whether this reach should actually be listed as impaired. In their assessment decision, the DWQ did not use EPA's recommended dissolved oxygen assessment method (described in EPA's Water Quality Criteria for Dissolved Oxygen, 1986 document) to determine beneficial use support before they concluded that the lower reach is impaired. As such, we requested all of the available data that DWQ used for this assessment. Figure 9 illustrates a summary of all of the instantaneous data collected at Cudahy Lane (the designated compliance point). The acute water quality standard is 4.0 mg/L. To account for natural variability and to satisfy concerns over measurement accuracy and to avoid type I (false positive) errors, the assessment criteria states that if 10 percent or greater of the sample data acquired during the assessment period is less than the 4.0 mg/L standard, the water body is impaired. Because the Integrated Report (305(b) assessment and 303(d) list of impaired waters) is submitted every two years to EPA, an assessment period is usually the 2-year period prior to the reporting year, but data within the previous five-year period is often used. A minimum of ten samples must be used and is preferably collected within a one-year time period and the data are expected to represent seasonal data. In some cases, if ten samples have not been collected during the previous two years, the assessment period is extended to five years. Yet, "data as old as ten years may be used if information is available to validate that there has not been a significant disturbance in the watershed during the ten years that would significantly change the results of the assessment." We reviewed all of the data that DWQ provided and a summary of this data collected at Center Street (the compliance point) is presented in Figure 9. Over the 14-year period of record, there were five violations of the 4.0 mg/L standard. Further, all of these violations occurred during drought years when low flows allow greater stream warming and provide for less turbulence and surface reaeration. In addition, the overall lower mass of water in the stream channel causes it to be more exposed to sediment oxygen demand and susceptible to short-term changes in DO. Such extremely low flow data are displayed for the summer and fall of 2008 in Figure 10. Flows were held to only 40 to 80 CFS during the normal runoff period of May and June and remained below about 140 CFS for the remainder of the year. Hence, any CPOM that was transported to this lower reach settled and proceeded to decompose, along with the previous years' CPOM-contributing to elevated SOD values. For comparison, there has never been a recorded DO violation in the Surplus Canal, where the majority of water is diverted, even though this is the exact same water as that which continues down the river channel.

We also received data from the State Canal, a constructed canal that transports water from the Burnham Dam to Farmington Bay Waterfowl Management Area (Figure 11). This site used to be included in the assessment process. In this case there were only two violations of the 4.0 mg/L DO standard and they occurred during the same low-flow period of 2008.

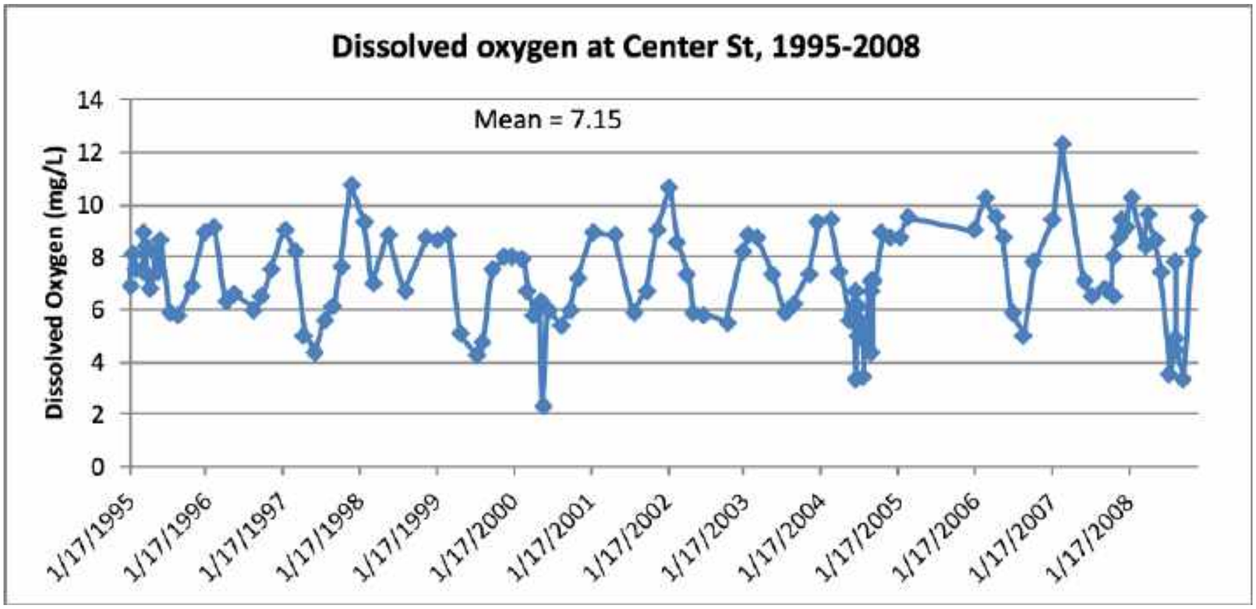


Figure 68. Dissolved oxygen recordings in the Jordan River at Cudahy Lane (Center Street) from 1995 to 2008. Note a total of 5 violations of the DO criterion or 4% of the 125 samples collected.

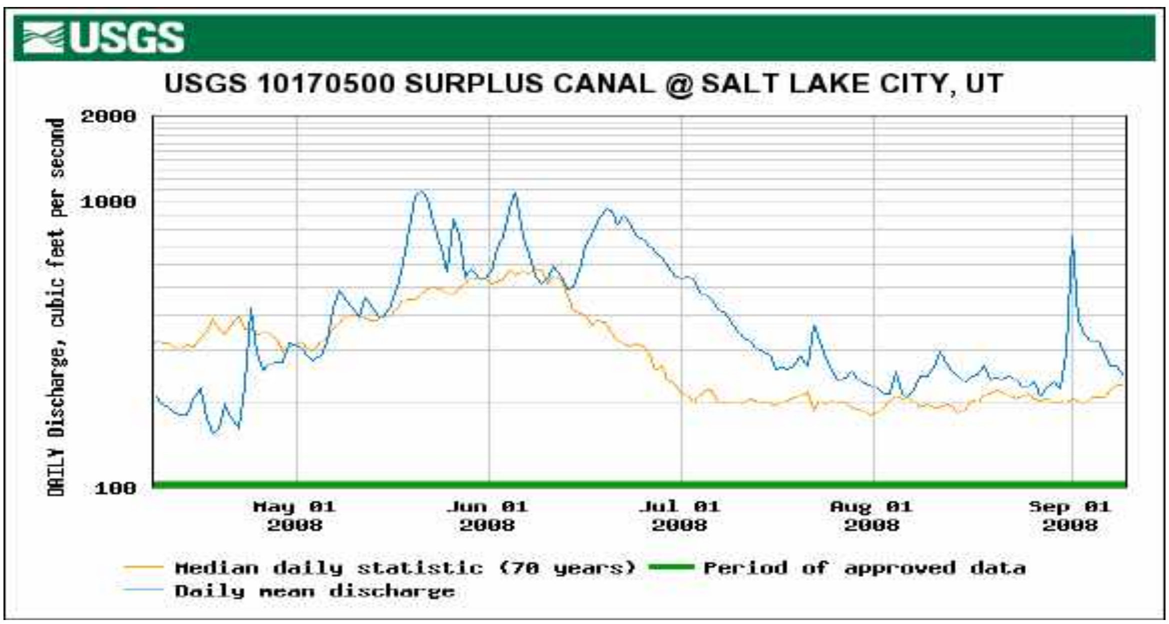


Figure 69. USGS flows recorded in the Surplus Canal (upper) and at 1700 S (lower), during 2008. Note although above average flows occurred in the surplus Canal, only very minimal flows were allowed to continue down the river channel – particularly during the normal runoff period. Flows were held at less than half the average flows for the entire year exacerbating warmer temperatures, lower re-aeration and elevated SOD rates.

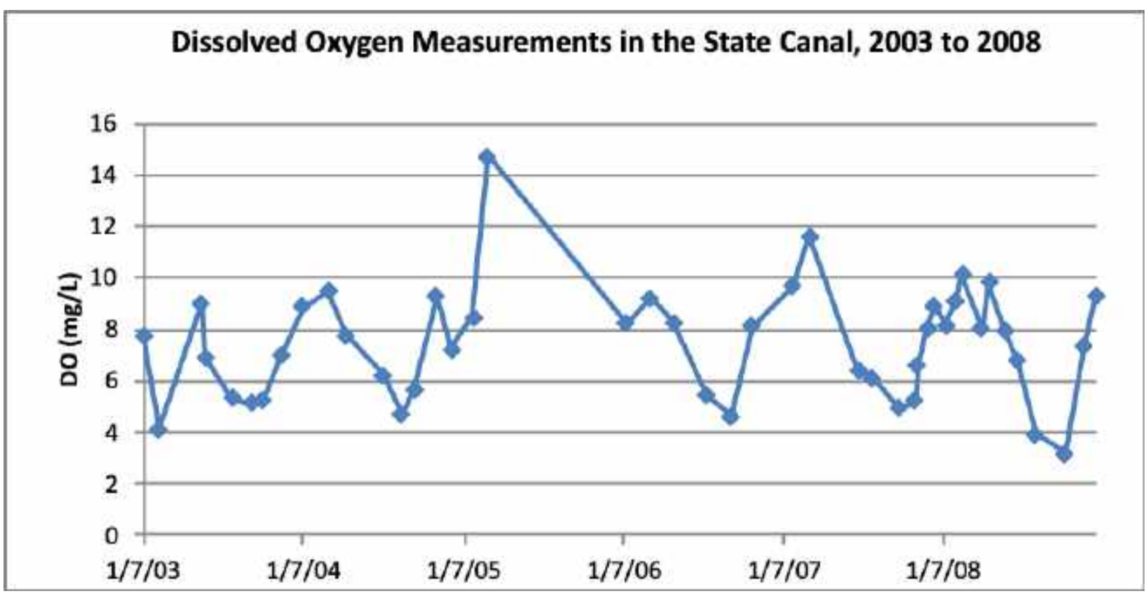


Figure 70. Dissolved oxygen measurements in the State Canal. Note only two violations throughout this six-year period.

This was 4.5% of the total sample data. Data from the Jordan River at Center Street and the State Canal were used by the state DWQ in the determination that the lower Jordan River was impaired. Yet, these data clearly indicate that with the low number of exceedences, there is no apparent violation of the DO standard. However, DWQ also used these data to assess against the chronic criterion and used this comparison to justify that the lower Jordan was impaired. However, DWQ did not use EPA's recommended methodology for making such a determination. Instead, DWQ developed a unique but controversial, and imprecise manner of applying grab sample data to the more stringent 7-day and 30-day average criteria. The 2008 Integrated Report states "Dissolved oxygen follows a diurnal cycle with the highest values occurring during the day. The AU (assessment unit) is listed on the 303(d) list if two or more samples are less than the 30-day standard and if the standard is violated in more than 10% of the samples." This creates a defacto rule that allows the much more stringent chronic criteria to be used in place of the acute criterion for assessment purposes. Not only is this imprecise, but it is directly discordant to the methods prescribed in EPA's criteria document for dissolved oxygen (US EPA 1986). Briefly the document states "If daily cycles of dissolved oxygen are essentially sinusoidal, a reasonable daily average is calculated from the day's high and low dissolved oxygen values. A time-weighted average may be required if the dissolved oxygen cycles are decidedly non-sinusoidal.

Determining the magnitude of the daily dissolved oxygen cycles requires at least two appropriately timed measurements daily and characterizing the shape of the cycle requires several more appropriately spaced measurements." (US EPA 1986). Because EPA recognized the importance of a longer-term chronic criterion, it provided these specific instructions for calculating this value. Clearly, this method would need to be used to develop a truly accurate assessment against the 7-day or 30-day average. Also, it is obvious that these instructions were provided prior to the availability of data recording sondes, but also prior to the listing of the Lower Jordan as impaired, so these instructions were available prior to the assessment decision.

Also, recording data sondes have been available now for at least ten year and DWQ has owned such probes for nearly that long. Yet, no effort has been made to either acquire the necessary data according to EPA's instructions, or to use the sondes to confirm whether the lower Jordan actually violates the 7-day or 30-day chronic criterion. Where such a high profile and expensive TMDL would be imminent, this simple confirming step should have been required. Further yet, with DWQ's apparent belief in the paradigm that low DO concentrations result from eutrophication, all of the POTWs along the Jordan River would be held accountable as the source of nutrients and subjected to extremely expensive (in the range of $1,000,000,000 total) upgrades or new construction costs for advanced nutrient removal. With such a price tag at stake, which would essentially double most sewer rates, along the Wasatch Front, DWQ should have performed additional monitoring and analyses to document that there was truly an impairment based upon EPA's assessment protocols. Because of this paucity of essential data, whether the lower Jordan River belongs on the 303(d) actually remains dubious.

Yet, because there were actually an insufficient number of acute DO violations, the initial drafts of the TMDL and even the Phase I TMDL document erroneously reported numerous violations of the chronic 5.5 mg/L criterion based on its arbitrary assessment method. This prompted the Council to purchase and deploy recording data sondes to begin collecting the appropriate data to elucidate the frequency, duration, and cause(s) of low DO and ascertain whether conditions exist that qualify the lower Jordan to be listed as impaired. These sondes were deployed throughout most months of the year.

Monitoring sites located upstream and downstream from 2100 S were included, although greater emphasis was placed on sites below 2100 S because this is the reach identified as impaired and indeed experienced episodes of low DO. Following are representative graphs of data collected during the critical summer months.

A total of four sondes were deployed at these various locations 2009 to 2012. Most of these sondes were fitted with temperature and DO probes only. One sonde was fitted with temperature, DO and pH. One of the first recordings was performed August 18 at 2100 S. Even though this deployment lasted for only 20 hours it reveals the typical diel pattern of DO and pH (Figure 12). The swing from the late afternoon peak to the early morning minimum is the result of the cessation of photosynthesis and oxygen production. Respiration continues, however, consuming oxygen while producing and releasing CO_2 which also lowers the pH. In the morning hours, after the sun angle is high enough to penetrate the water column with enough light energy, photosynthesis resumes. Shortly thereafter, there is enough oxygen produced to overcome the rate of respiration, causing the oxygen to rise again. Hence the daily DO minimum actually occurs shortly after sunrise.

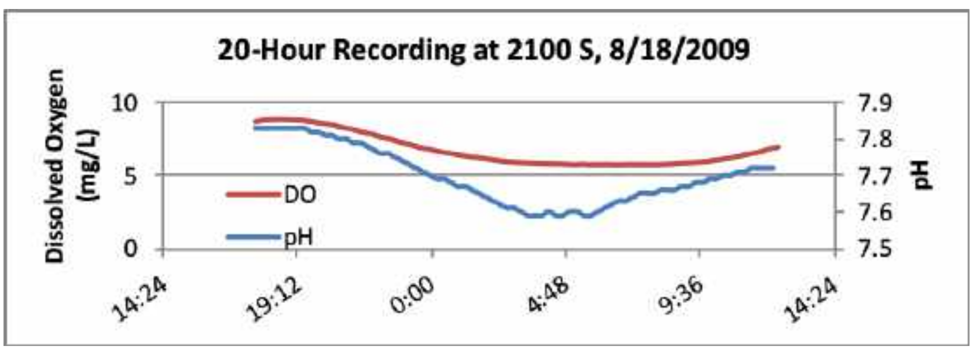
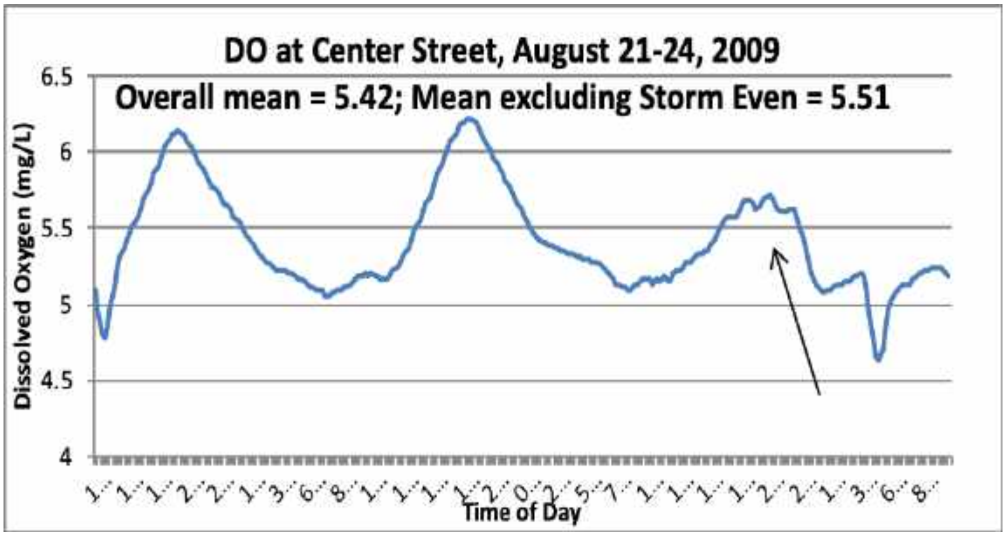


Figure 71. Twenty-hour recording of DO and pH at 2100 S, August 18, 2009.

A second DO recording was performed at 2100 S later in August (Figure 13). Maximum and minimum values were similar to the earlier recording. However, the recording performed at 400 S during this same time period indicated that while the range between maximal and minimum values remained at about 3 mg/L, the range was actually much lower with maximum and minimum values between about 7.6 and 4.7 respectively, (Figure 4.13). At sampling stations further downstream the diel range of DO began to decrease, as well as the average DO concentration. At Center St the difference between the maximum and minimum values was less that 2.5 mg/L with the maximum and minimum values ranging between about 6.2 and 5.2. (Figure 4.14 a.) At Burnham Dam, the range further declined to a fluctuation of about 1 mg/L (Figure 4.14 b.). More notable however, the maximum and minimum of this range declined to between 5.5 mg/L and 4.5 mg/L respectively.



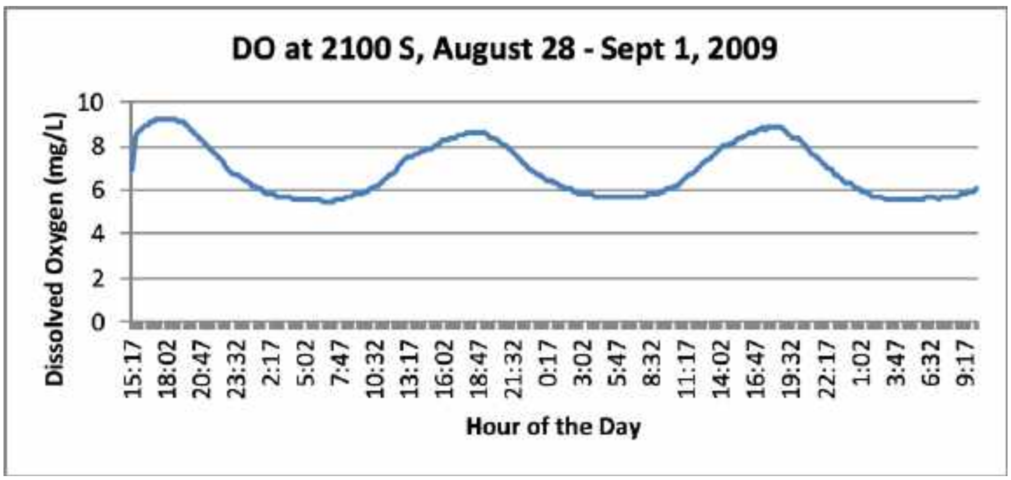


Figure 72. Record of DO between August 28 and September 1, 2009.

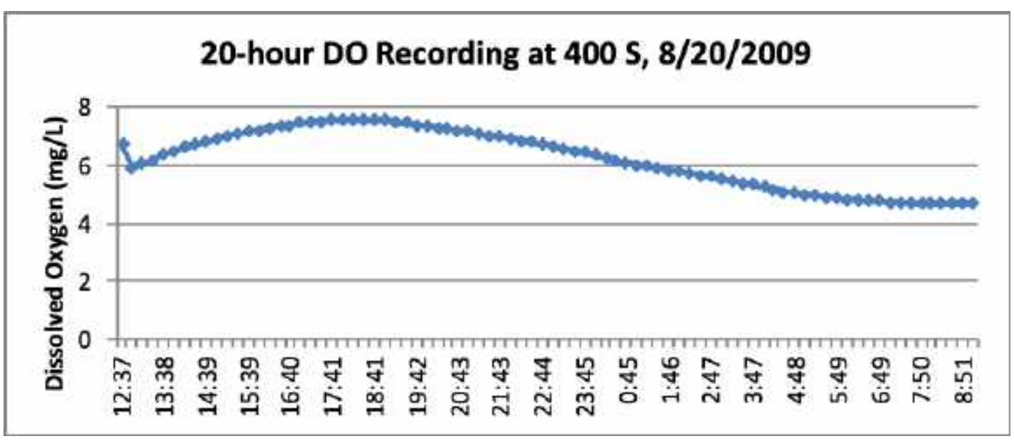
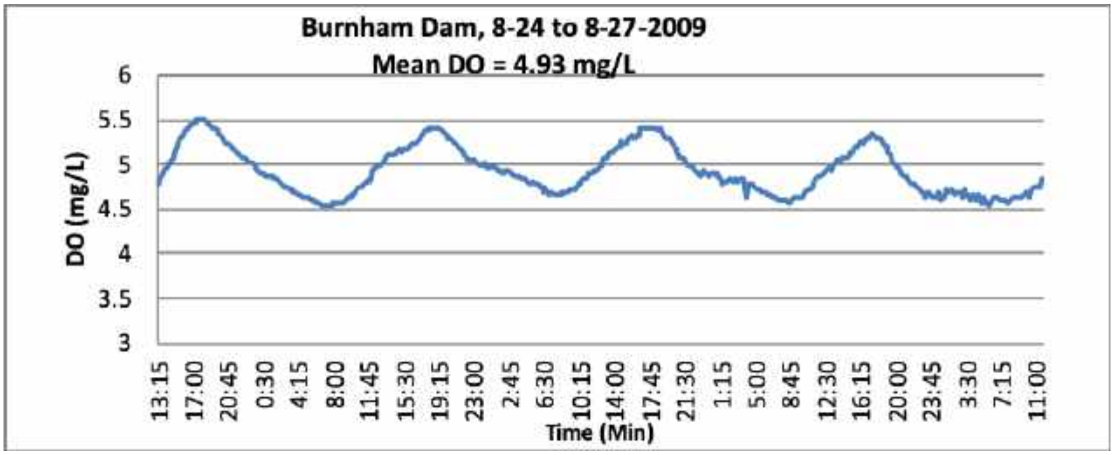


Figure 73. Twenty-hour recording of DO starting on 8/20, 2009 at 400 S.

a.



b.

Figure 74. Dissolved oxygen records measured at Center St. (a.) and at Burnham Dam (b.), during late August 2009. Both the range and the average of DO declined between these two stations and between these and upstream stations.

Flows during this time period and the previous few weeks averaged about 250 CFS in the Surplus Canal (USGS stream flow data; Figure 15) and averaged about 220 CFS at the Salt Lake County 500 N gage (data not shown). This was somewhat above average late summer flows. However, spring flows during 2009 started in early May and continued until early July and ranged between 3 and 4 times average spring runoff. This above-average runoff undoubtedly transported above average and considerable quantities of suspended and bedload organic debris to the lower Jordan even though the majority of flow was diverted to the Surplus Canal (See Chapter 3, 2011 CPOM data).

Settling/deposition would similarly occur following these high flows as large amounts of organic sediments have been documented starting with the SVAP study of 2009 (See Chapter 1) and observed in virtually every sampling event since that time. Also, as mid to late summer flows diminished, this fresh sediment smothers any existing benthic algae, limiting primary production to the remnants of Utah Lake algal populations and a small amount of dislodged periphyton from upstream sources that remained in the water column (See Chapter 3). These low flows also reduced the effectiveness of surface reaeration as turbulence diminished which limited the frequency of surface boundary reformation (See Chapter 5). We have hypothesized, as with other researchers, that if greater flows were allowed to remain in the lower Jordan River Channel, this would provide for more effective flushing and less settling of organic matter. In turn, this might reduce the magnitude of sediment oxygen demand and improve reaeration rates. Although it is possible to maintain somewhat higher flows in the channel, these flows are limited by the potential for flooding adjacent neighborhoods and, hence, the requirement to maintain some channel capacity in the event of thunderstorms in the local Salt Lake City watersheds. Nevertheless, the level to which elevated flows can be maintained is the subject of a proposed study by River Network and DWQ. The data acquired thus far indicates that this continual diversion and dewatering of the channel diminishes the flushing ability and exacerbates the sedimentation of fine sediments and organic debris. This greatly degrades the aquatic habitat, both physically and with respect to the DO because of elevated SOD.

Such man-caused or natural degradation of aquatic habitat conditions have been addressed in the Code of Federal Regulations with respect to the ability to achieve Clean Water Act goals and this has become one of the issues raised by the Council to the Utah DWQ. Specifically, in addition to questioning the initial action of listing the Jordan River based on the number of DO violation, we also raise the question of whether to beneficial uses are being maintained due to severe habitat alteration and dewatering. The over-arching issue is the diversion of the great majority of flow, and particularly the potential flushing flows. Even under low flow conditions at least half of the water is still diverted. Although this provides water for vast acreages of wetland habitat and prevents flooding of northern Salt Lake City neighborhoods, this diversion drastically dewaters the river which severely alters its aquatic habitat.

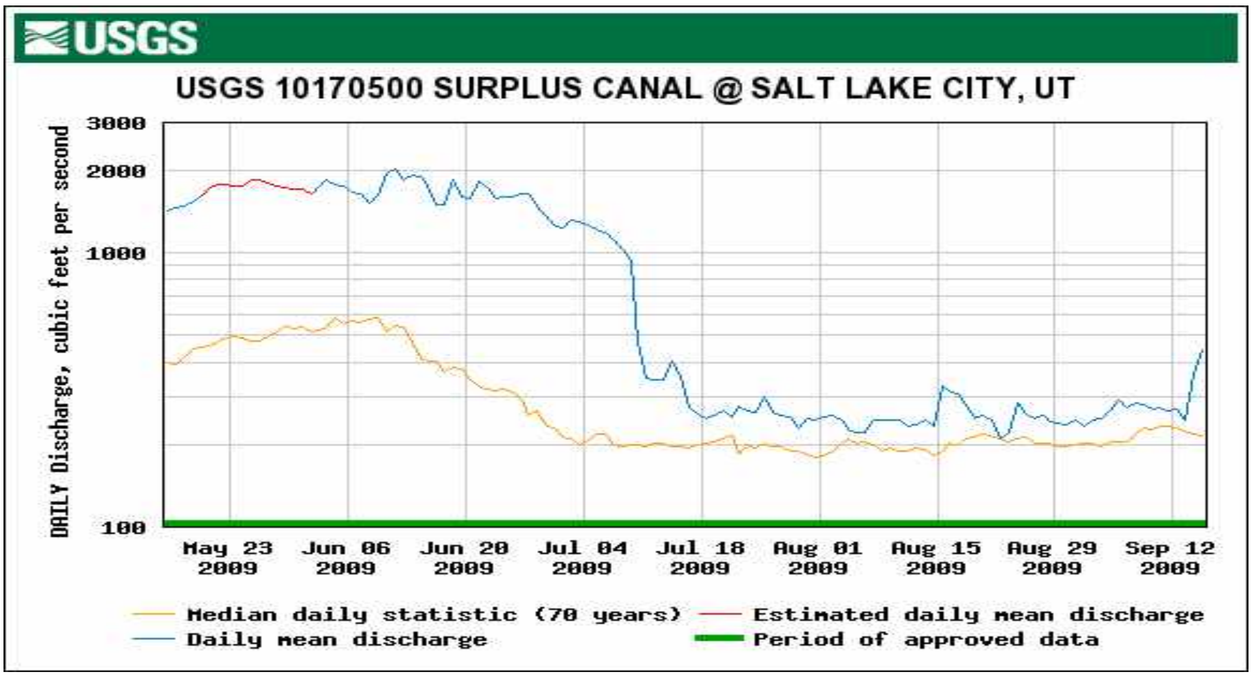


Figure 75. Spring and summer flows measured in the Surplus Canal during 2009. The yellow (lower) tracing is the 70-year median value.

To account for natural background conditions or man-caused impacts on streams which prevent the water body from achieving water quality goals, the Clean Water Act provides for off ramps or exemptions to 303(d) listing of impaired waters (40 CFR § 131.10(g). These (g) factors include a list of physical or chemical conditions that prevent the attainment of designated beneficial use. In other words, these “g factors” constitute irreparable impacts that cannot be restored or would cause undue economic hardship on the community. Performing a Use Attainability Analysis is the proper procedure for this determination. The lower Jordan River qualifies for at least three of the six “g” factor off ramps: Factor number (2) “Natural, ephemeral, intermittent or low flow conditions or water levels prevent the attainment of the use, unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating State water conservation requirements to enable uses to be met”; Factor number

(4) “Dams, diversions or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the water body to its original condition or to operate such modification in a way that would result in the attainment of the use”; and Factor number (5) “Physical conditions related to the natural features of the water body, such as the lack of a proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life protection uses”. Due to the dominance of the 2100 S diversion, these factors are inextricably linked.

The Council began addressing Factor (5) with the Stream Visual Assessment Protocol (Chapter 1) in 2009 and documented severely degraded habitat due to channelization, frequent dredging, riparian loss, dewatering and sedimentation. Factors (2) and (4) are of equal importance. An illustration of the impact of the 2100 S diversion on the hydrology (Factor 4), of the Jordan River is displayed in Figure 16. The diversion of flow represents a significant impact in that any flows above base flow (150-175 CFS) is diverted to the Surplus Canal; Prevention of flushing flows allows increased settling of organic and inorganic debris that has been identified as the cause of high sediment oxygen demand values Chapter 3. As well, there are times when nearly all flows are diverted to the Surplus Canal in anticipation of a storm event in Salt Lake City’s watershed (Figure 17).

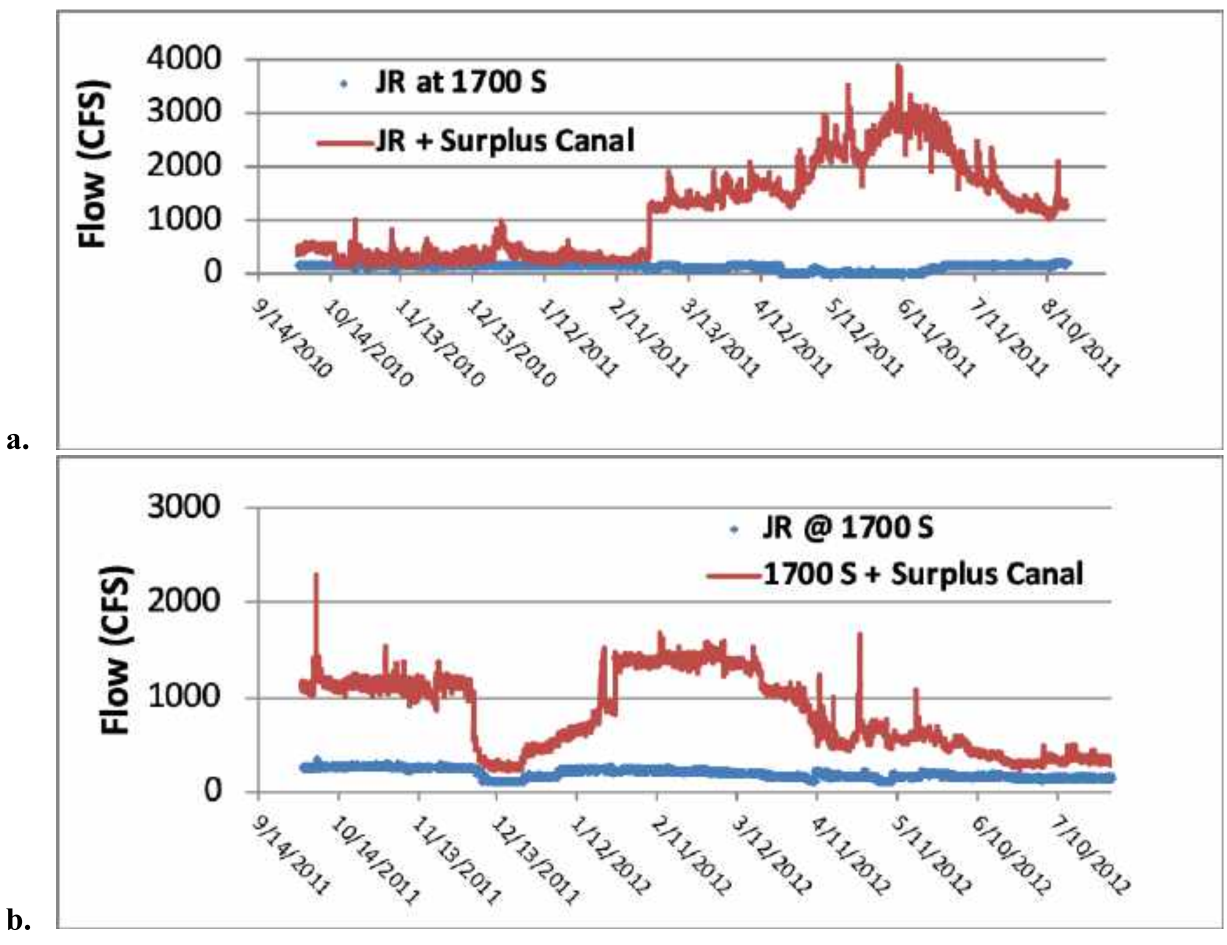


Figure 76. Detailed recordings of flow measured at 1700 S and the combination of this flow with the Surplus Canal flow. Figure 16a. is the annual flow from September of 2010 to September of 2011.

Note the near-record flows during June (exceeding 3000 CFS) yet flows in the river channel were reduced to between 20 and 100 CFS – eliminating the potential for beneficial flushing flows through the lower Jordan River. (b.) is a continuation of (a.) and ends at August 1, 2012. Because of the accumulation of water in Utah Lake from the high 2011 flows, water was released throughout most of the winter to create additional capacity in anticipation of potential high spring flows in 2012. However, this did not occur, resulting in unnatural and very low runoff flows during the 2012 spring.

This severe loss of flow from the channel transforms the lower Jordan River into a nearly exclusively depositional segment. The slow laminar flow has filled in potential pool areas with fine silts and clays that are mixed with 5-15% organic debris (Mitch Hogset, University of Utah, personal communication). These fine anaerobic sediments preclude colonization by a variety of stream organisms typical a stream with diverse particle sizes, proper pool to riffle ratios and a proper riparian corridor. Additional evaluation of Factors (2) and (4) included deployment of recording sondes in the Surplus Canal, as well as the lower Jordan River. Except for the rare occasion when storm water collects in watersheds and storm drains that flow through the city, the water in the Canal is identical to the water in the river channel. Yet, the Canal has never experienced a violation of the acute or 30-day average DO criteria. A representative recording is illustrated in Figure 18.

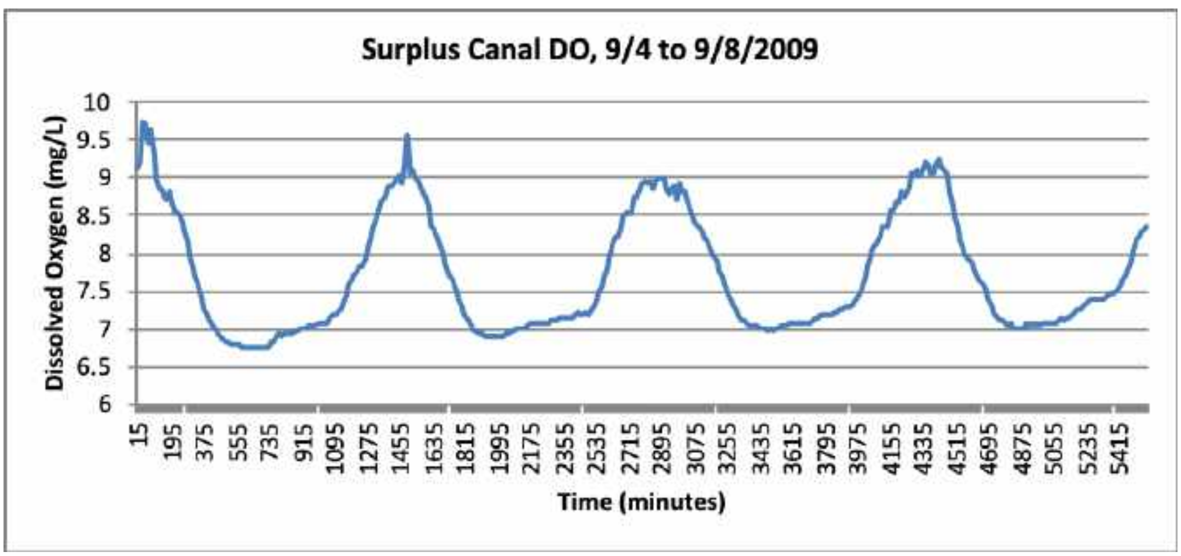
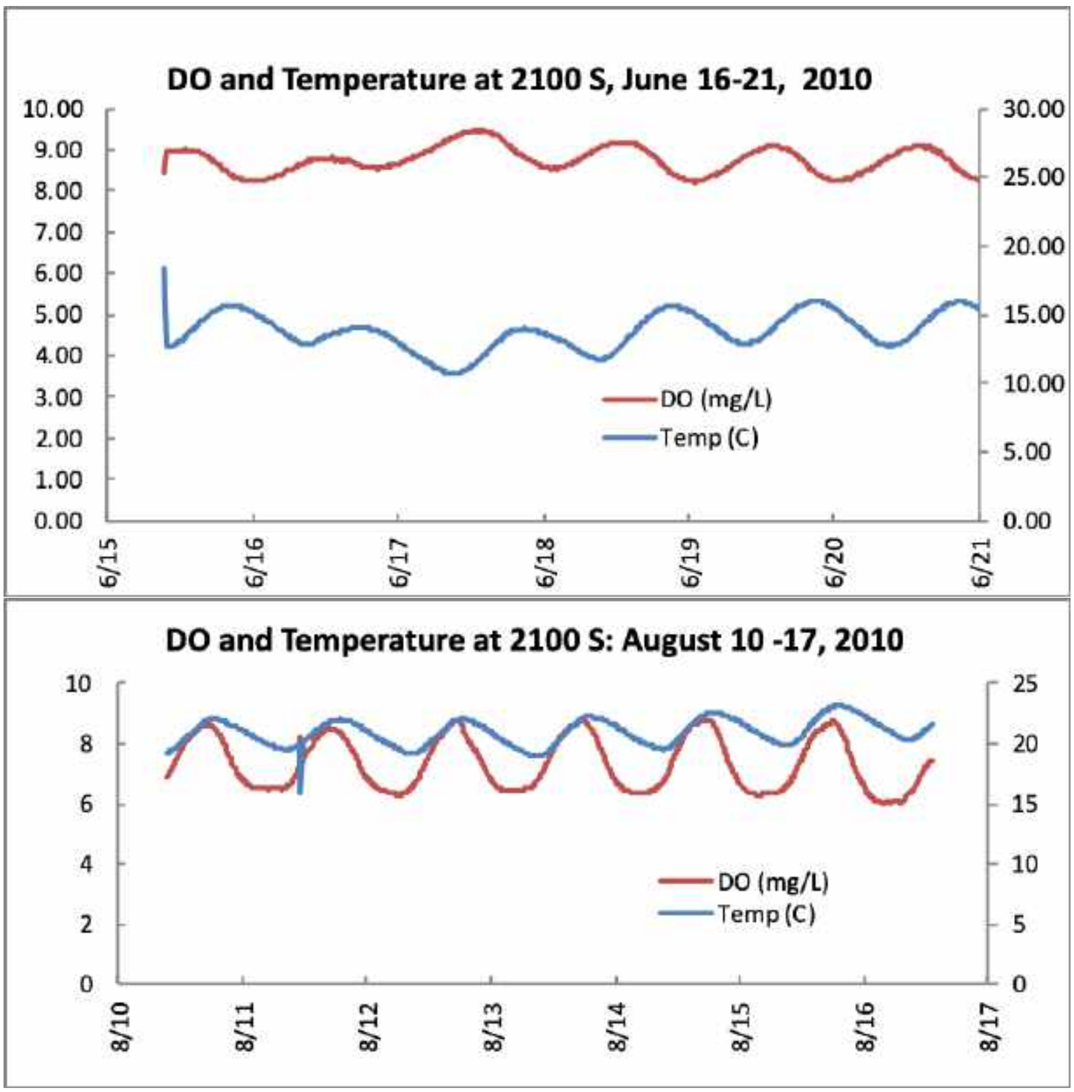


Figure 77. Dissolved oxygen concentrations recorded in the Surplus Canal at the USGS gage near the Salt Lake City international airport.

Contrary to the lower river, the greater velocity, depth and mass of water results in greater atmospheric reaeration, a much lower settling rate of organic debris and a greater volume of water that is removed from the exposure to even this lower sediment oxygen demand (greater volume:sediment surface ratio; See Chapter 6).

Additional late spring, summer and fall DO and temperature recordings were made during 2010, 2011 and 2012 using the portable data recording sondes. Dissolved oxygen concentrations at 2100 S remained near saturation throughout the summer even though temperatures increased to above 20 C (Figure 19).

Figure 20. is the first recording of DO during a high flow event – a common event that highly influences the oxygen dynamics of the lower Jordan River. This was a relatively small storm event which resulted in a relatively small dip in DO. There was an increase in flows at the USGS Surplus Canal gage of about 35% (from 210 to 282 CFS) on August 24, although elevated flows were not observed at 1700 S or the 500 N gage. This suggests that the storm event occurred in one or more of the local watersheds that join the Jordan River upstream from the surplus Canal diversion (e.g. the Cottonwood canyons). Yet, although the Surplus Canal received all the increased flow, the elevated concentrations of the highly reactive organic carbon that was mobilized during the storm was still in the water that continued down the river channel as well. This dissolved organic carbon has been found to correspond to a rapid and often deep depression in DO in the lower reaches of the river (See Permanent Data Sonde section below).



a.

b.

Figure 78. Dissolved oxygen and temperature recorded at 2100 S during June (a.) and August (b.).

At 1700 S there were three excursions from the typical sinusoidal diel pattern for DO (Figure 20). The two earlier events were of short duration and were not correlated with changes in the flow pattern. These short-term aberations were not uncommon and perhaps are likely due to short-term disturbance of the sediment upstream or perhaps to an occassional illicit dumping of organic chemicals. The low-DO event recorded on August 20 was of longer duration and was accompanied with a typical reduction in stream temperature. Indeed, the USGS flow record indicates a high-flow event on that day (Figure 21).

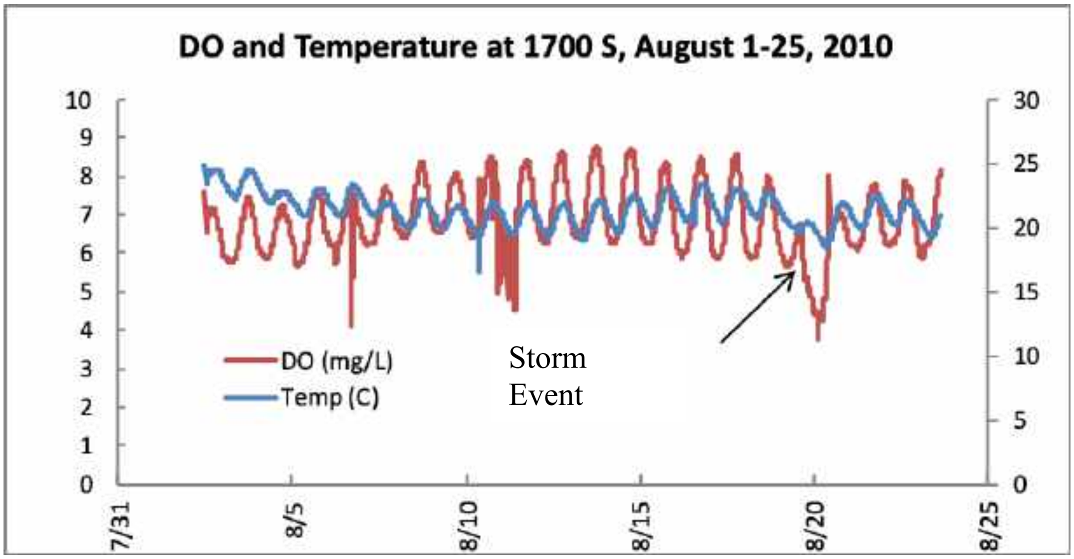


Figure 79. DO and Temperature values recorded August 1 to 25, 2010 at 1700 S.

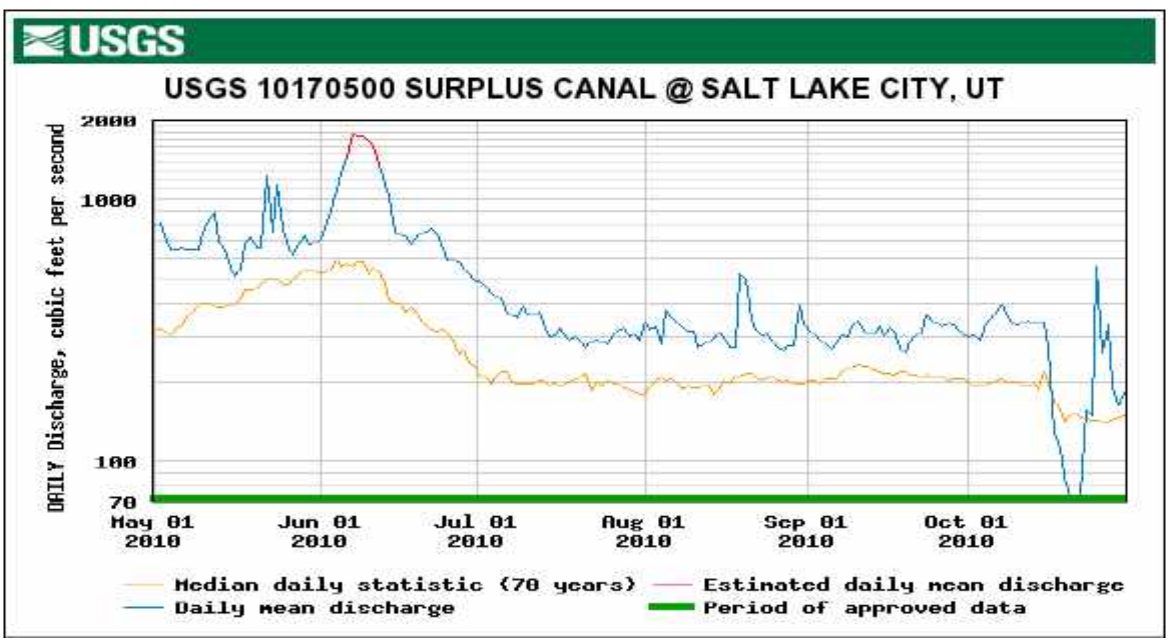


Figure 80. Recorded flows in the Surplus Canal near the Salt Lake City international airport from May 1 to October 30, 2010. Note the y axis is on a log scale.

Additional recordings of DO and temperature were conducted at Center St and Burnham Dam. The average and diel range of DO was noticably less than that recorded at 1700 S. Dissolved oxygen at Center St ranged from 5.2 to 6.2 during most of the recording. However, a storm event occurred on 8/23 to 8/24 which depressed the DO and reduced the temperature (Figure 22). This storm event was also recorded in the USGS data (Figure 20) where flows in the Surplus Canal doubled for a short duration.

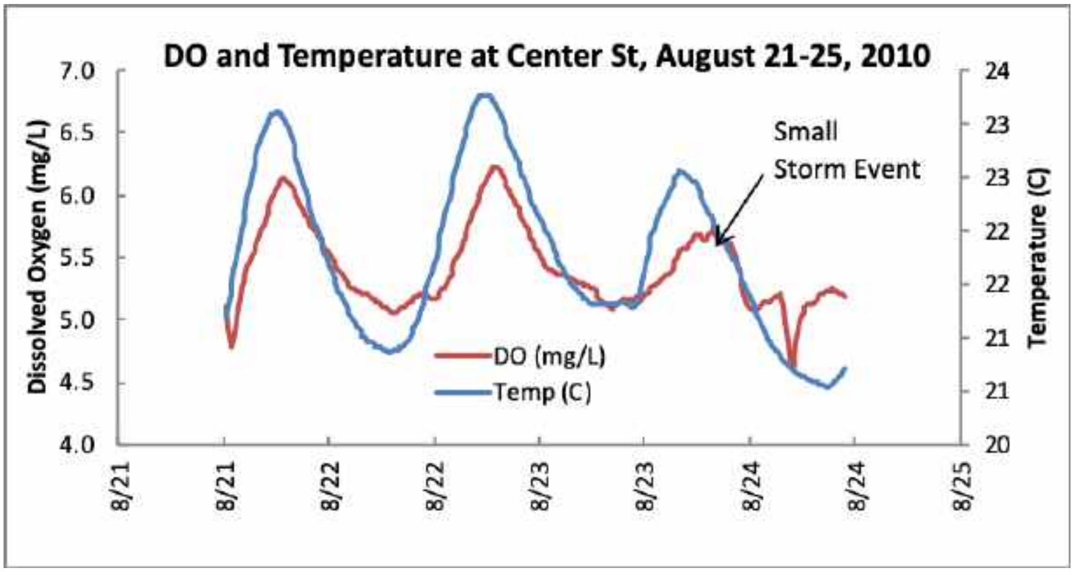


Figure 81. Dissolved oxygen and temperature recorded at Center St from August 21 to August 24, 2010.

Flows at the 500 N gage were not available during the summer of 2010 due to maintenance requirements and the shut down due to the Chevron oil spill. By the end of September, the temperature had declined by several degrees and although the daily range of DO continued to fluctuate only by about 1 mg/L, the average DO increased considerably. At 300 N the average DO was approximately 7 mg/L (Figure 23). Dissolved oxygen at Burnham Dam had increased to an average of about 6.3 mg/L (Figure 24). There was another minor storm event that occurred between 9/22 and 9/24, an occurrence that was also recorded in the USGS data (Figure 24).

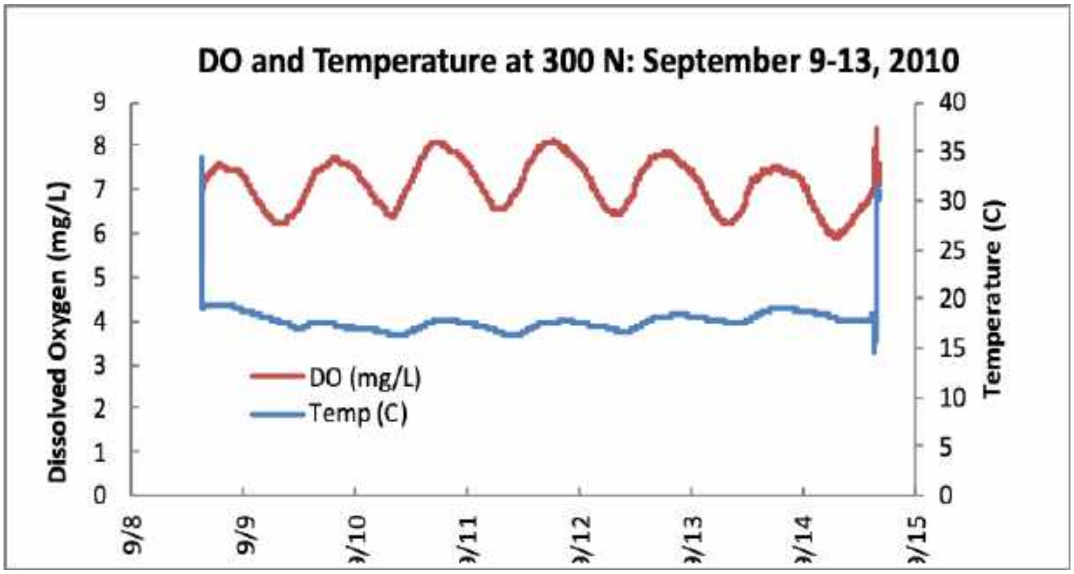


Figure 82. Temperature and DO values recorded at 300 N from September 9 to 13, 2010.

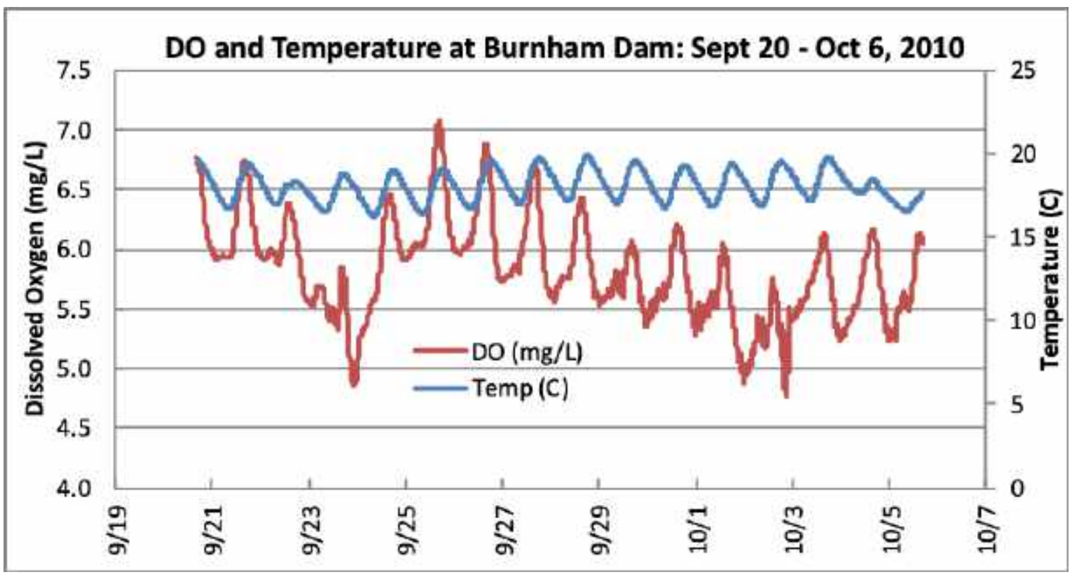


Figure 83. Dissolved oxygen and temperature recorded September 20 to October 6, 2010 in the Jordan River at Burnham Dam.

The sonde that was placed at Burnham Dam was to be deployed from July to October. Apparently however, the diminishing flows through July allowed for sediments to accumulate. The probe sensors became buried shortly after deployment and even though data was downloaded, batteries changed and probes recalibrated approximately every two weeks, the sondes were reattached at the same height on the stake. However, with the poor water clarity, and extremely soft new sediments it went unnoticed that the tip of the sonde was being reset just a few cm below the surface of the sediments. Of course, this invalidated most all the late July and August data.

Additional recordings were performed during 2011 and 2012. Sondes were deployed nearly every month of the year. However, for the sake of brevity, only recordings where storm flows and low DO episodes were likely to occur are reported here. Figure 25 displays the diel patterns of DO, along with temperature or pH during June, July and August at Legacy Nature Preserve.

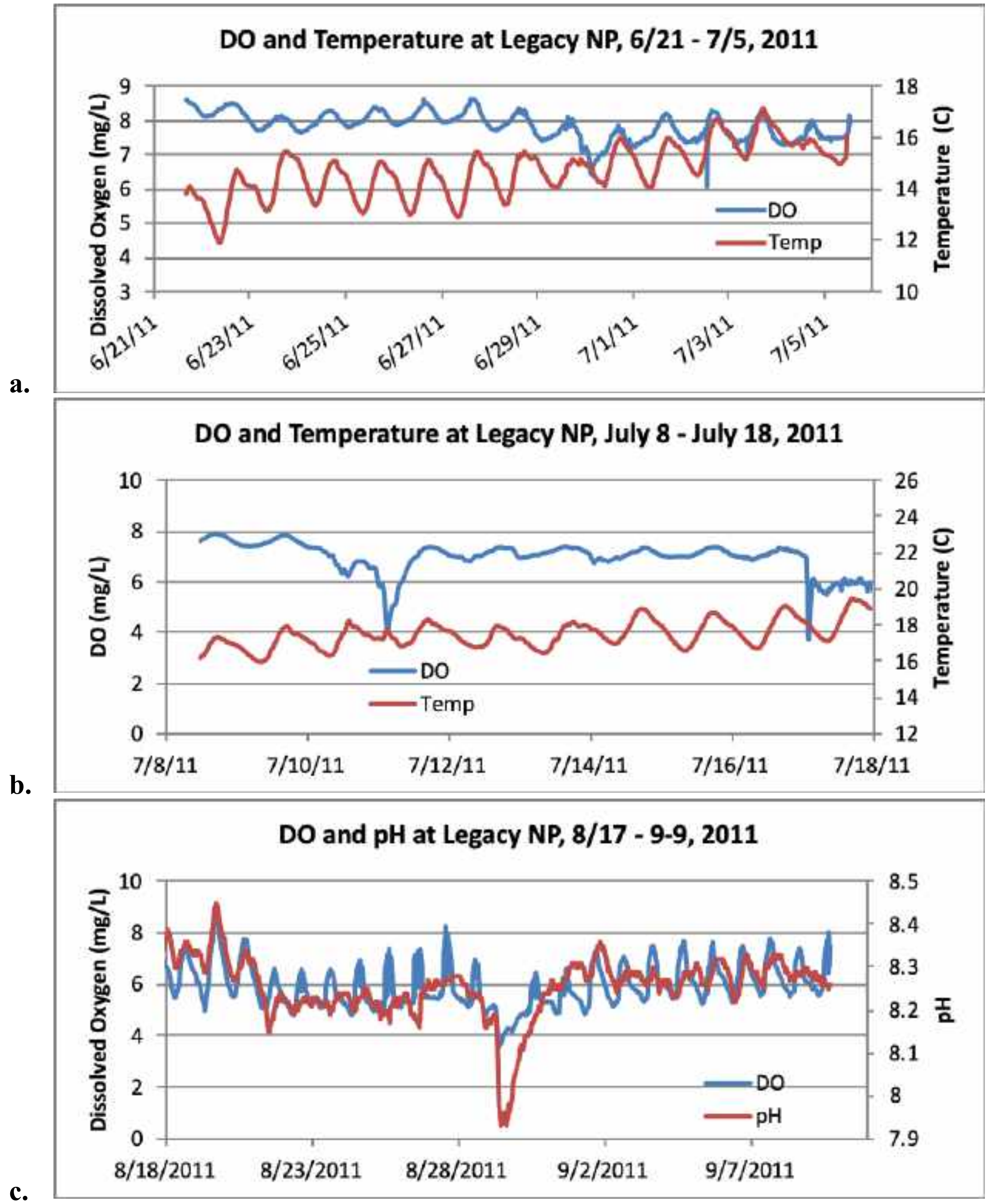


Figure 84. DO, temperature and pH values recorded at Legacy Nature Preserve during June, July and August 2011.

There was always a general trend that as water temperatures warmed up, DO values declined. However, this was also related to the fact the flows were diminishing to summer minimum values during this same time. Such low flows are of critical concern. They lead to diminished reaeration rates, greater exposure to the SOD (the sediment surface area to volume ratio increases) and the warming temperatures will continually enhance biochemical reactions (respiration rates) (Figure 25a.). The DO continued to decline as temperature increased through July. Also at this time the flow rapidly decreased from near-record highs of 3000 CFS in the Surplus Canal to the 2011 summer minimum flows of about 320 CFS. This was about double the normal summer flows through the lower Jordan River and, except for the occasional storm events, these elevated flows maintained the DO above the minimum DO standard (4.0 mg/L), as well as above the 7-day and 30-day standard. Still though, these low DO dips are important to note. For example, when flows increased a relatively small amount for the short duration of August 28-29, (Figure 26.), there was a concurrent reduction in DO in the lower Jordan, suggesting that these short-term spikes in flow are mobilizing some highly reactive organic compounds, likely from the stormwater vaults, drains, etc. that immediately consume oxygen. Overall, however, mean DO values remained at or above 6 mg/L during 2011– likely as a result of the much-higher than average summer flows.

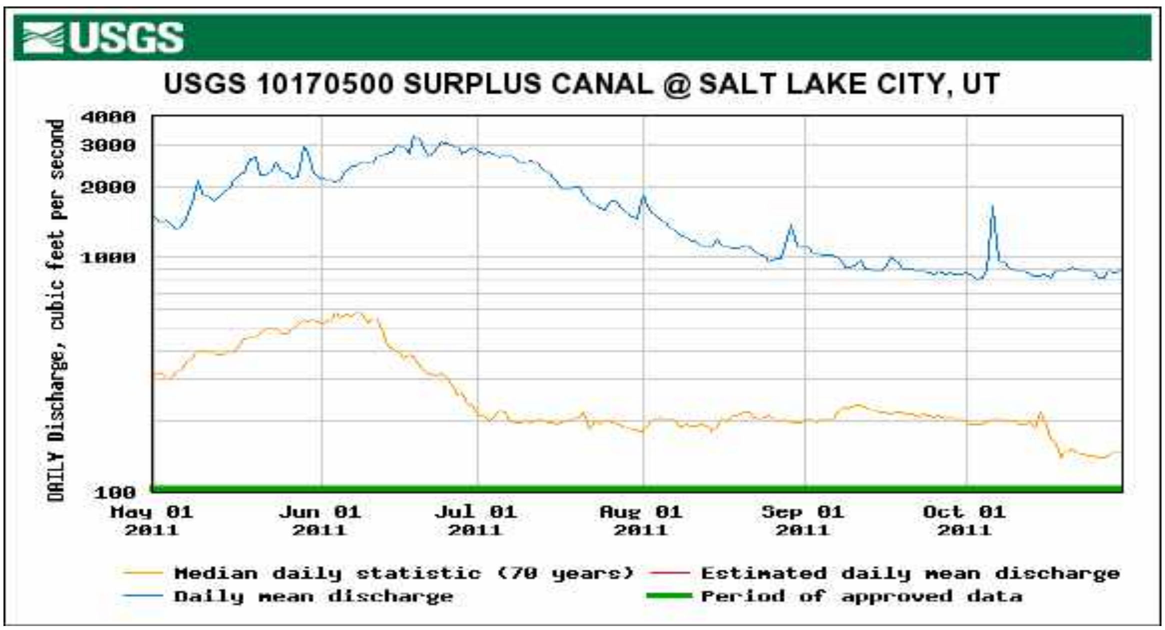


Figure 85. Flow recorded in the Surplus Canal at the Salt Lake City International Airport from May 1 to October 30, 2011.

In most respects the data sonde recordings of 2012 were similar to the previous three years. However, the hydrograph was significantly altered from normal winter and spring flows. Utah Lake elevation was still well above the compromise line as a result of the very high 2011 flows, so substantial releases were made during winter when normally there is no water released from the lake. As described above, these releases were made in anticipation for potential high runoff flows in the 2012 spring. However, the 2011/2012 snowpack was well below normal and the high and sustained winter and early spring releases ended up being the highest flows of the year (Figure 27). Normal spring flows were below normal as a result of Utah Lake retaining much of the runoff flows.

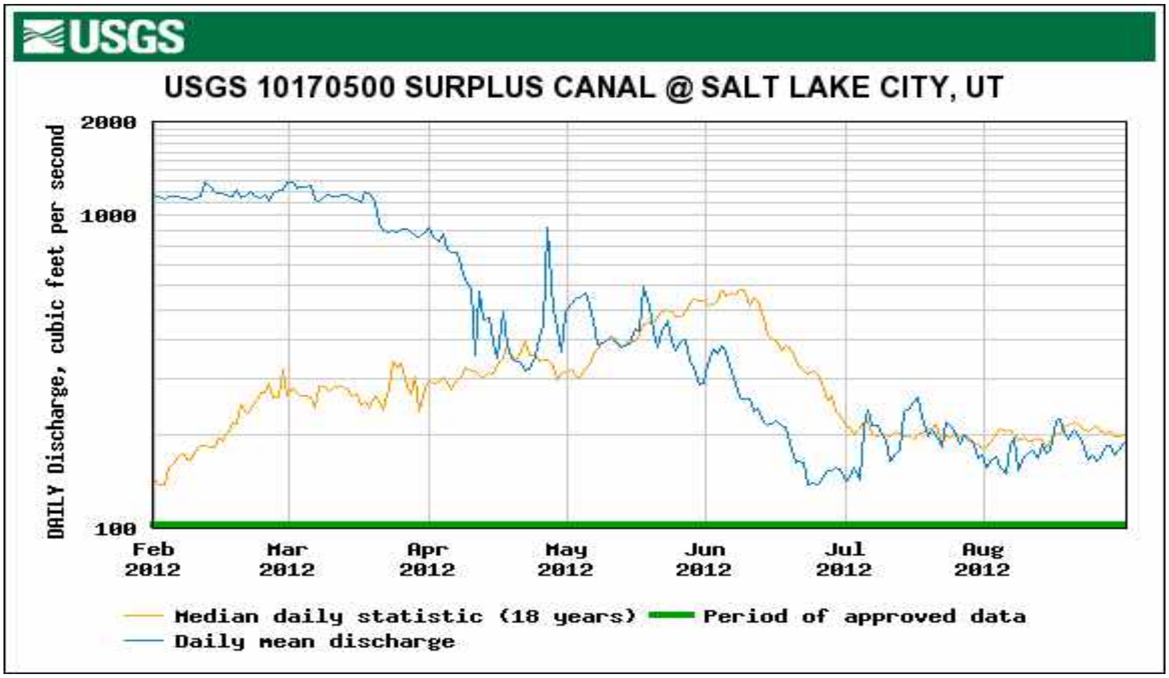
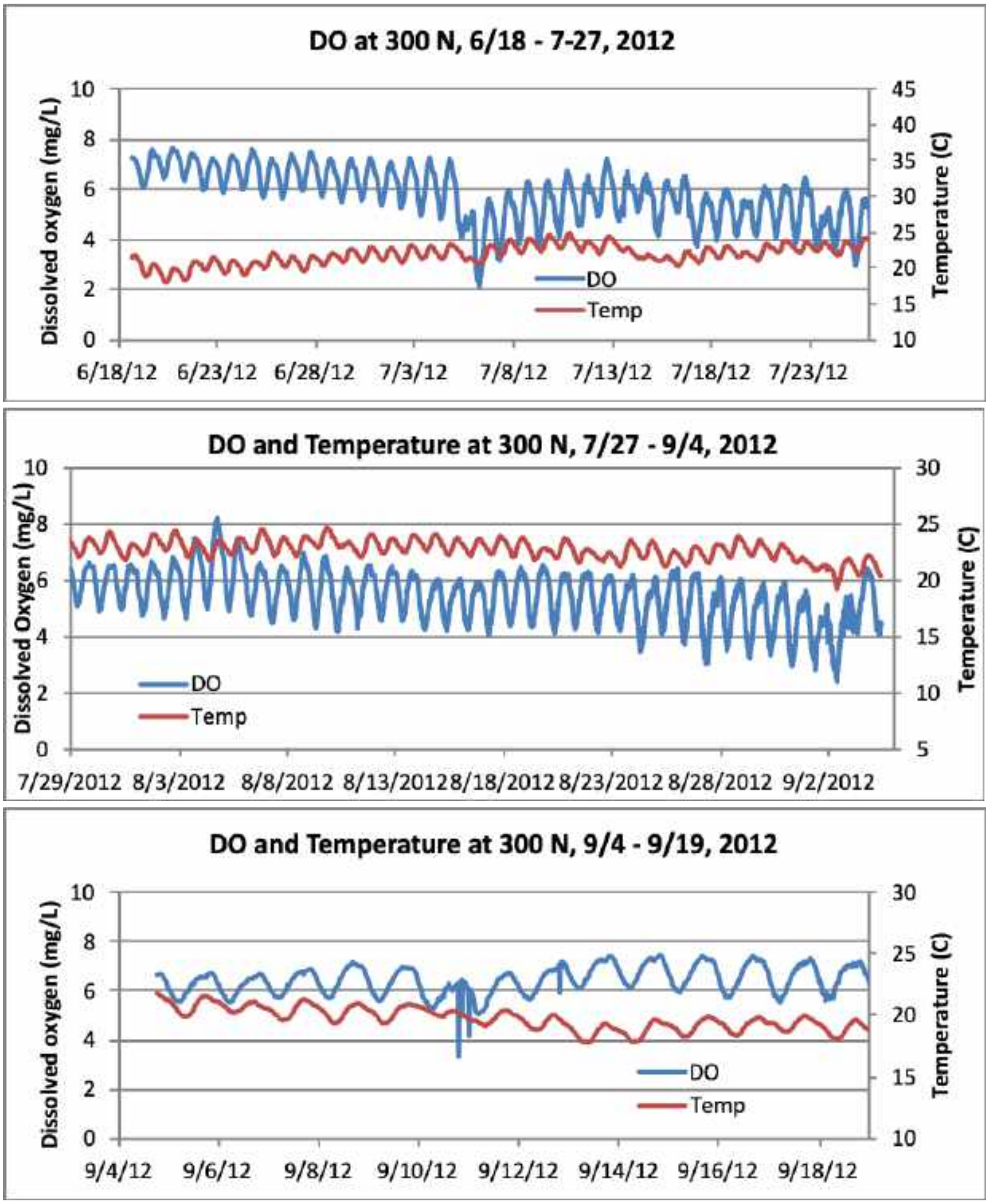


Figure 86. Hydrograph of the Surplus Canal from February 1 to August 31, 2012.

During 2012 there was again a correlation between increasing temperature values and decreasing mean daily DO concentrations (Figure 28a.) There were two recognizable storm events that were recorded during spring and summer 2012. One occurred on about July 6 and was recorded by the probe set at 300 N (Figure 28a.). It took several days for the DO pattern to recover to pre-storm values (until about July 13) at which time the mean DO began to decrease again. Elevated and erratic flows occurred again, starting on July 13, which lasted for several more days (Figure 27) and DO began to decline once again (Figure 28). This elevated flow also caused a decrease in stream temperature (Figure 28a). As flows declined in June (Figure 27), the stream temperature began to increase again, and this increase was accompanied by continued decline in DO (Figure 28a). Figure 28b. is a continuation of Figure 28a. However, between these two recordings the probes were removed, cleaned and recalibrated and the batteries replaced – all according to the manufacturer's recommendations. In fact, except for the DO probe, all of the probes remained very stable. But after the probes were replaced, the DO began recording values that averaged about 1.5 mg/L higher (Figure 28b.). This same pattern occurred between the recordings of Figure 28b. and 28c. All other parameters (e.g. pH and temperature) remained predictably in their same ranges. We attributed this decline to the buildup of biofilm with its associated debris on the new optical DO probe.



a.
b.
c.

Figure 87. Dissolved oxygen and temperature recordings at 300 N. Note, b. and c. are a continuation of the previous record. The sonde was removed, cleaned, recalibrated and replaced in the river at the end of each record.

This biofilm was clearly visible and was carefully removed when the probe was serviced. However, we believe that this film gradually accumulates, obscures the optical pathway and weakens the signal to the detector. The 2012 year was the first time these long-term deployments (i.e. greater than 2-3 weeks) were performed and because we knew the batteries lasted this long, we tried this monthly cleaning as a time-and-materials-saving practice. We later increased our cleaning schedule to once every two weeks as we did not believe the biofilm interference during this time-scale caused any inexplicable decline in DO.

The other storm event occurred on May 26/27 at Burnham Dam (Figure 29). This high flow event was not recorded in the stream gage data from the USGS Surplus Canal gage (Figure 26) or from the 1700 S USGS gage (data not shown). However, the Salt Lake County gage at 500 N recorded an increase from about 230 CFS to 380 CFS during this time-indicating that a local storm occurred in one or more of the City Creek, Red Butte, Immigration, or Parleys Creek watersheds. The drop in DO on 6/6 was associated with another high-flow event recorded at the USGS gage on the Surplus Canal. However, elevated flows were not recorded at the 500 N gage. This adds further support to the concept that, although elevated flows are diverted over the top of the weir to the Surplus Canal, the exact same constituents (i.e. mobilized sediment-derived oxygen consuming compounds), are passing through the gate and are affecting downstream conditions in the lower Jordan River channel.

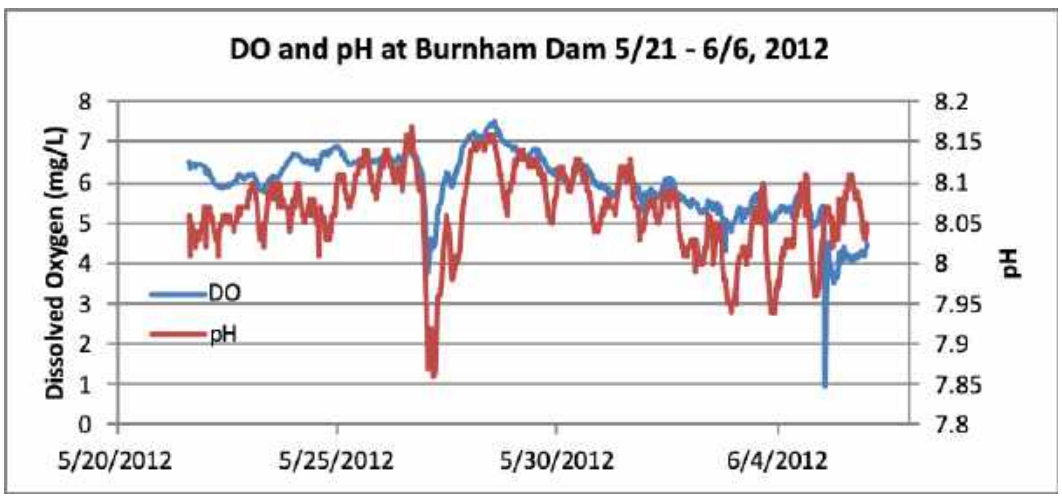
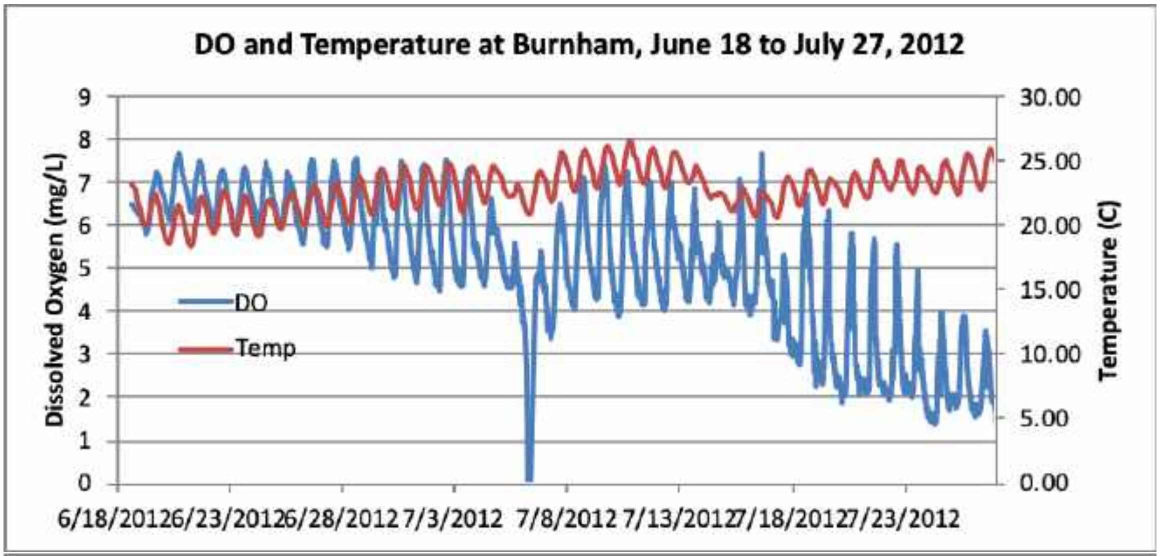
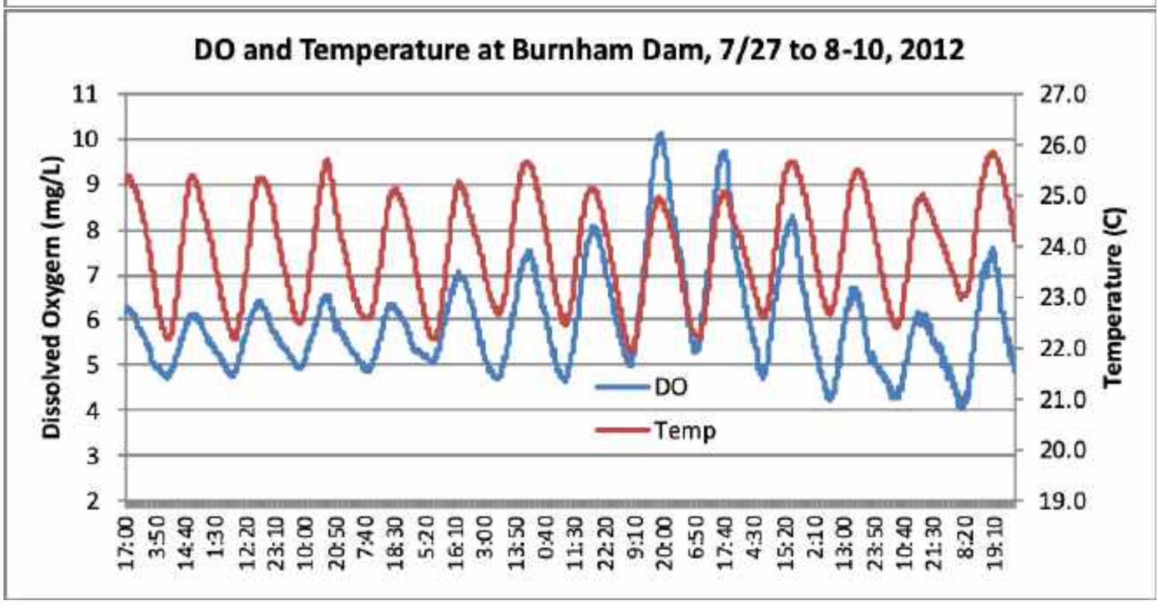


Figure 88. Dissolved oxygen and temperature recorded at Burnham Dam, May 21 – June 6, 2012.

The same high flow event and DO sag recorded at 300 N on July 6, 2012 (Figure 28a.) was recorded by the sonde set at Burnham Dam (Figure 30a). However, while the DO at 300 N only fell to about 2.0 mg/L, the DO at Burnham Dam fell to 0 mg/L for a few minutes. It also took several days for the DO at Burnham Dam to recover to approximate pre-storm values. Also, as described above, the gradual decline in DO to a mean of about 3 mg/L was likely due to the accumulation of biofilm and associated debris (i.e. the deployment extended beyond the 3-4-week period). Cleaning and recalibration of the probes immediately followed by re-deployment resulted in much higher DO values (about 5 mg/L), than the previous several days (Figure 30b.). Notably, if the recording where interference by the biofilm is disregarded, the average DO remained slightly above the 30-day average chronic criterion – even on a moving average basis. The probes that were permanently installed in 2013 are fitted with automatic wipers that clean the sensor surfaces immediately prior to recording of data, eliminating the fouling problem (see below).



a.



b.

Figure 89. Dissolved oxygen and temperature in the Jordan River at Burnham Dam from June 18 to July 27 (a.) and from July 27 to August 10 (b.), 2012. Note that the DO probe was cleaned, recalibrated and replaced on July 27, resulting in much higher DO values. See text above for explanation.

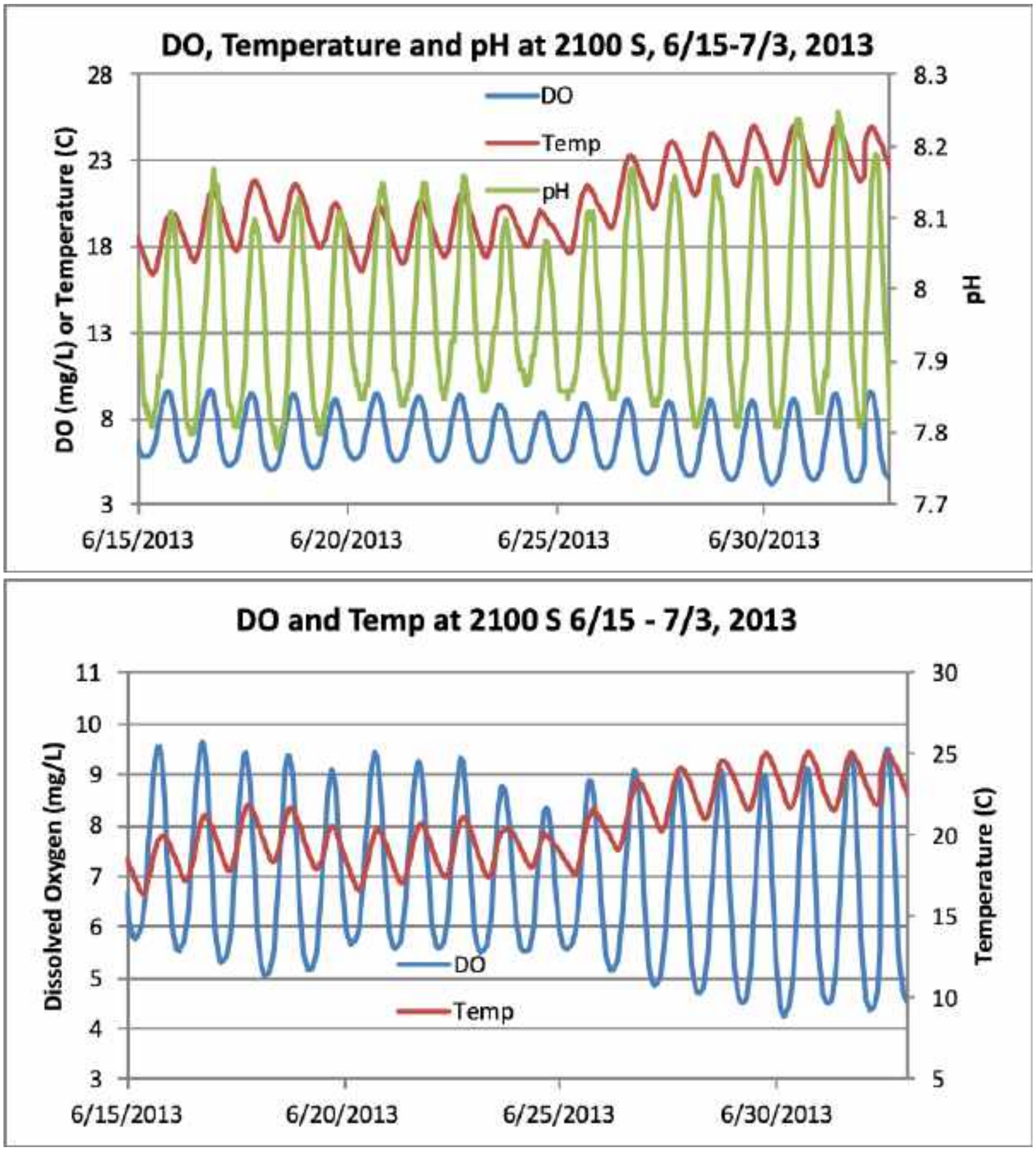
Placement and Recordings from Permanent Sondes

In March 2013 the Council installed an array of 8 data recording sondes. Five of these sondes are fitted with DO, Temperature, pH and conductivity, and turbidity. In addition to these parameters, the other three were fitted with fluorescing dissolved organic matter (FDOM) and chlorophyll a. Notably, these new sondes were fitted with wiper blades that rotate several times just a few seconds before the parameter values are recorded and these recordings are again, scheduled for every 15 minutes. This resolved one of the biggest issues we found with long-term deployment of the portable sondes – that of fouling the probes with excessive biofilm accumulation. These sondes are permanently mounted on bridge crossings, or concrete abutments or footings and are fitted with solar panels and cellular transmission equipment. The primary purposes of these installations are twofold: 1) provide long term indisputable records of these basic water quality parameters primarily with respect to the frequency, duration and degree of DO violations of water quality standards; and 2) to provide associated records of water quality changes that may be associated with such DO excursions. For example, as indicated in several recordings above, DO excursions are associated with storm events. In addition, there may be occasions in the lower, high-depositional reaches of the river where unusually low, late summer flows combine with warm temperatures and high SOD rates to drive the daily mean DO below the 5.5 mg/L 7-day or 30-day average DO standard for a few days. However, as with the July 4 and July 7 storm events, several days may be required for the DO to recover to pre-storm values and thus far, regular/seasonal violations of the 7-day or 30-day standards have not been observed outside of these storm events. Again, because such events, and resultant DO sags and recovery times are unavoidable; this supports the question as to whether an impairment due to a true DO standard violation exists. This further supports the suggestion that a UAA is warranted based on hydrologic diversion to extremely low levels that are accompanied by unavoidable summer storm events that depress the DO.

Following are selected recordings of DO, temperature, turbidity and FDOM during normal to low flows, as well as during storm events at several sites are included. Particular attention is paid to 2100 S, 300 N and Center Street – the extended reach of the Lower Jordan River that is currently listed as impaired. Center Street is of particular value because this is the compliance point – or the location at which assessment against water quality standards is performed for the entire reach below 2100 S.

Figure 31 is a recording at 2100 S from June 15 to July 3. After about June 25 temperature is trending upward quite rapidly and the pH range is expanding. Before June 25, DO was experiencing a diel range from about 5.5 mg/L to very near saturation at 9.5 mg/L. This indicates the presence of both significant primary production as well as considerable respiration. The rising temperature logically increases biological activity as indicated by an increasing range of pH. Elevated daytime pH is a result of the consumption of CO_2 and HCO_3 during photosynthesis (primary production), while respiration of both algae and heterotrophic bacteria during evening releases CO_2 – decreasing pH. Further, however, although there is increasing primary production throughout this time, the peak of the DO curve remains

a.

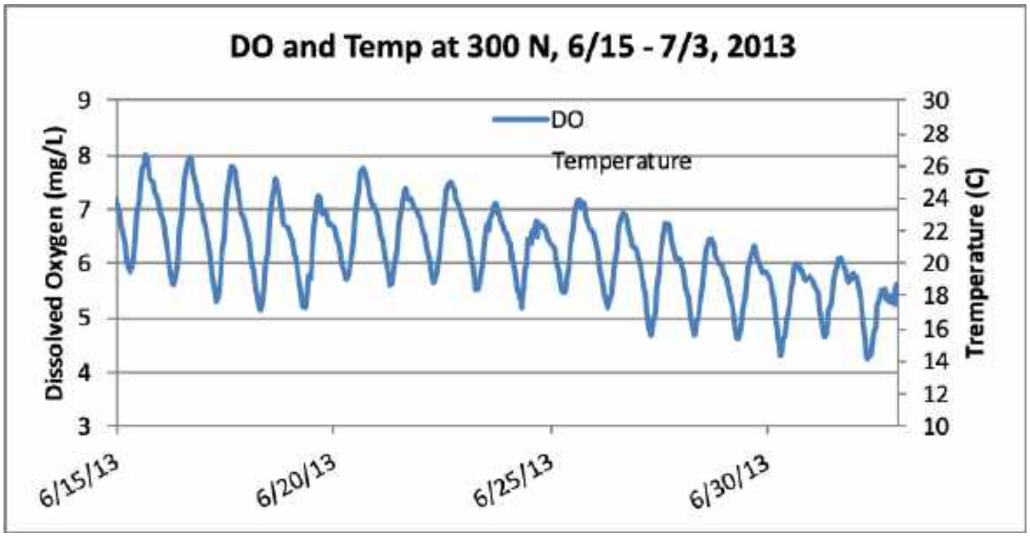


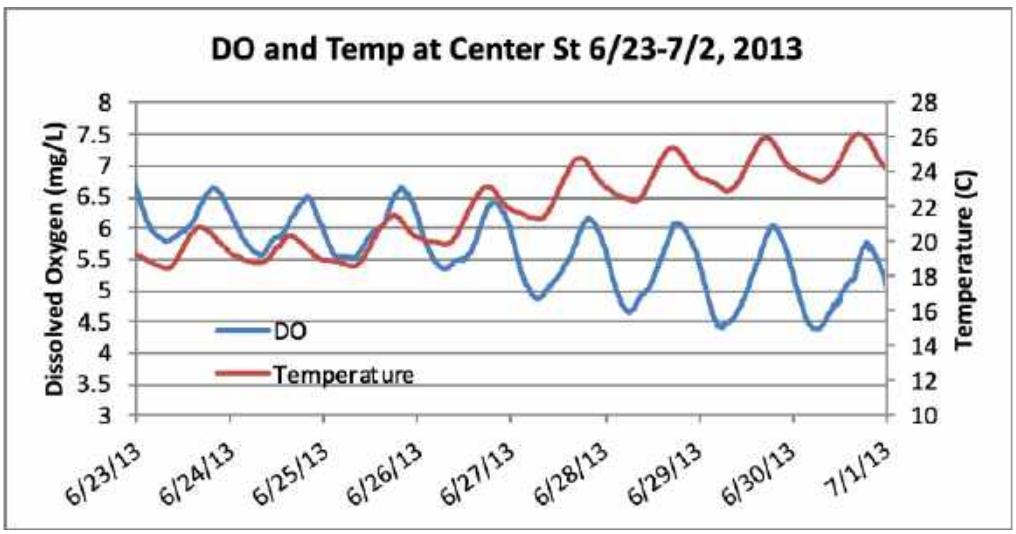
b.

Figure 90. Recordings of dissolved oxygen, temperature and pH (a.) and dissolved oxygen and temperature (b.) at 2100 S from June 15 to July 3, 2013. The pH record in (b.) was removed to more clearly illustrate the relationship between DO and temperature.

Flat. Yet, the minimum DO values continue to sag further each day until it reaches a minimum of about 4.5 (Figure 31b.). This same phenomenon occurred at 300N (Figure 31a.). However, while the temperature values were nearly identical, as were the minimum values in DO, the maximum values in DO also declined- causing a decrease in the daily mean DO. These dips and even average values for DO are substantially below saturation, which would increase the rate of atmospheric oxygen transfer. This suggests that of the daily balance, respiration has a greater influence on DO than photosynthesis or atmospheric reaeration and this is particularly true for 300 N (Figure 32a.) and Center St (Figure 32b.), where there were both lower DO maxima and minima.

a.





b.

Figure 91. Recordings of dissolved oxygen and temperature in the Jordan River at the 300 N Foot Bridge and at the Center St crossing during June and early July, 2013.

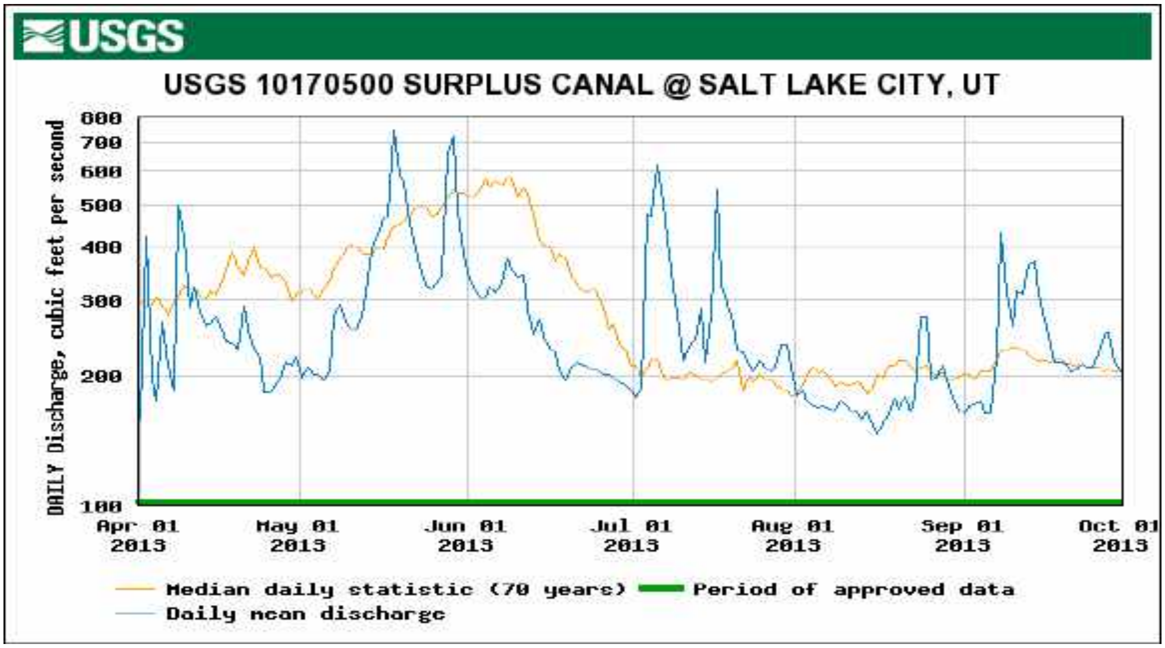
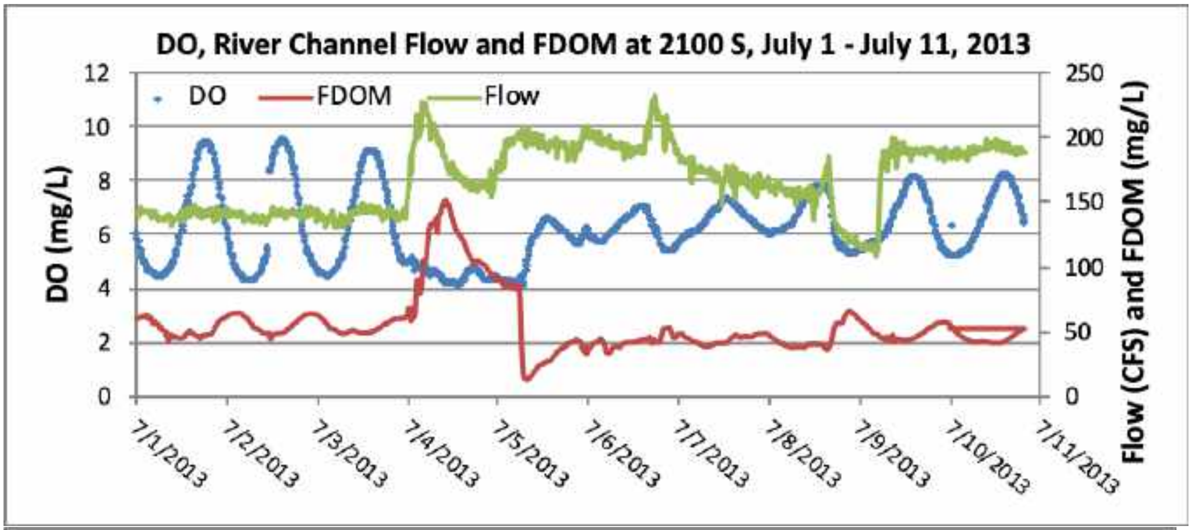
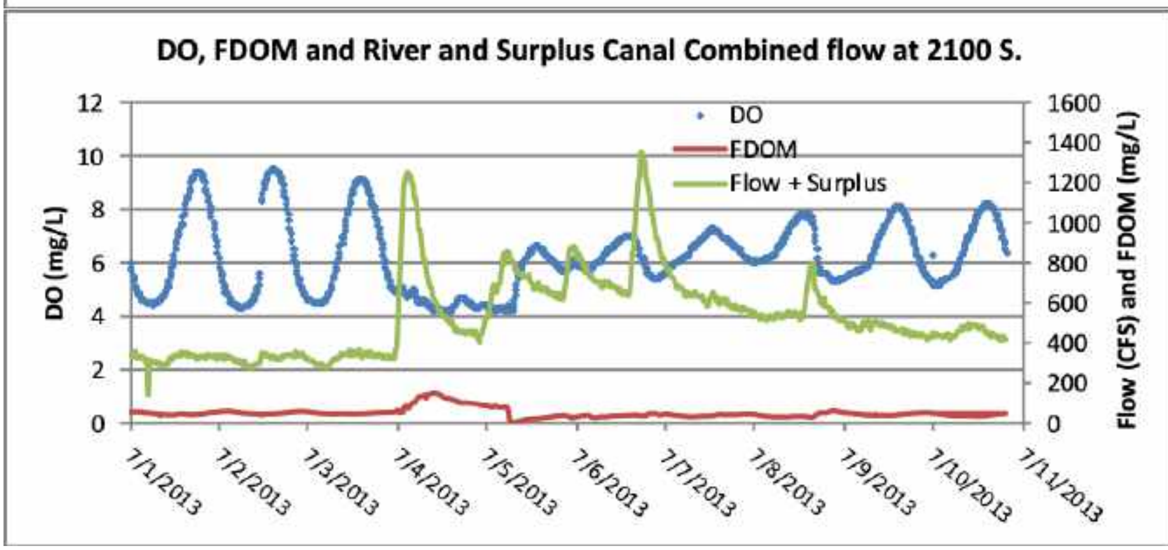


Figure 92. Flows recorded in the Surplus Canal, April 1 to October 1, 2013.

The tracings that include July 4 are of particular interest as there are several important observations from these graphs. First, a large storm event occurred during the afternoon of July 4, when flows actually approached the spring runoff level (Figure 33). Figures 34a. and 34b. are both included to display the flow management that occurred at the 2100 S diversion to the Surplus Canal. Also note that these figures reflect the instantaneous flow while figure 33 is a plot of the daily average flows. The river peaked at just over 200 CFS while the combined Surplus and river flow peaked at nearly 1000 CFS (Figure 33). This high-flow event dramatically affected various aspects of the water quality of the river. Most notable, there was an obvious sag in DO at 2100 S that occurred simultaneously with the high flow from a storm event and the depth and duration of this sag worsened at downstream stations. Secondly, there was a large increase in fluorescing dissolved organic matter (FDOM) that was concurrent with the elevated flows and with the DO sag and this correlation continued at downstream stations (Figures 35 and 36, 37 and 38).



a.



b.

Figure 93. Dissolved oxygen, fluorescing dissolved organic matter and flow at 2100 S. The river channel flow is illustrated in (a.) while the combined river and surplus Canal flow is illustrated in (b.).

Tracking pH had not been a high priority in previous studies. Indeed, it was always thought that with the high alkalinity of Utah Lake, came the strong buffering capacity that stabilizes pH between about 8.0 and 8.3. Yet the storm event dropped pH temporarily all the way down to 7.28 (Figure 35). This suggests that large amount of CO_2 has been produced and released from the anaerobic sediments and the immediate oxidation of reduced organic compounds and ammonia and the concomitant release of H^+ ions in addition to CO_2. It was also apparent that the degree of the oxygen depletion worsened with downstream distance.

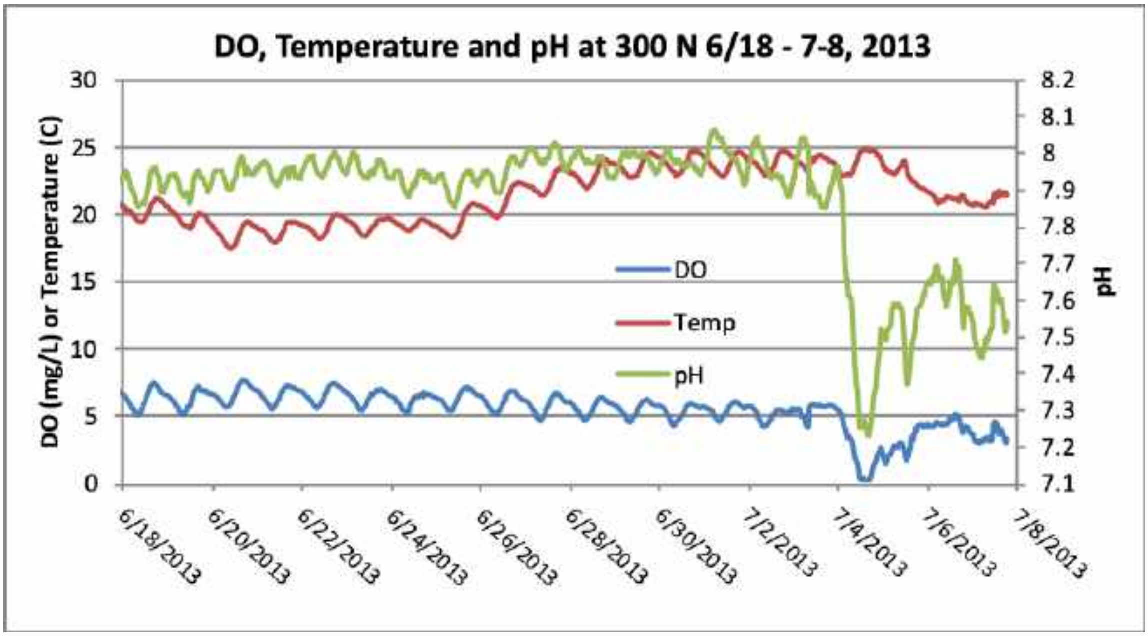


Figure 94. DO temperature and pH in the Jordan River at the 300 N foot bridge. Flow is removed from this graph to more clearly illustrate the change in pH associated with the high flow event.

This is undoubtedly due to continual oxygen consumption and CO_2 consumption in the water column as it travels downstream as well as the potential for increased mobilization of local sediments, including chemically reduced, oxygen-demanding compounds as the high flow reached these sites. For example, while the USGS gage recorded flows of about 200 CFS and 1700 S, the 500 N gage recorded flows exceeding 500 CFS. Hence, additional flow/scouring ability as well as mobilized sediments within the local storm drains and tributaries provided additional labile organic compounds for immediate oxidation. Accordingly, the longest period of anoxia (about fourteen hours) occurred at Center St.

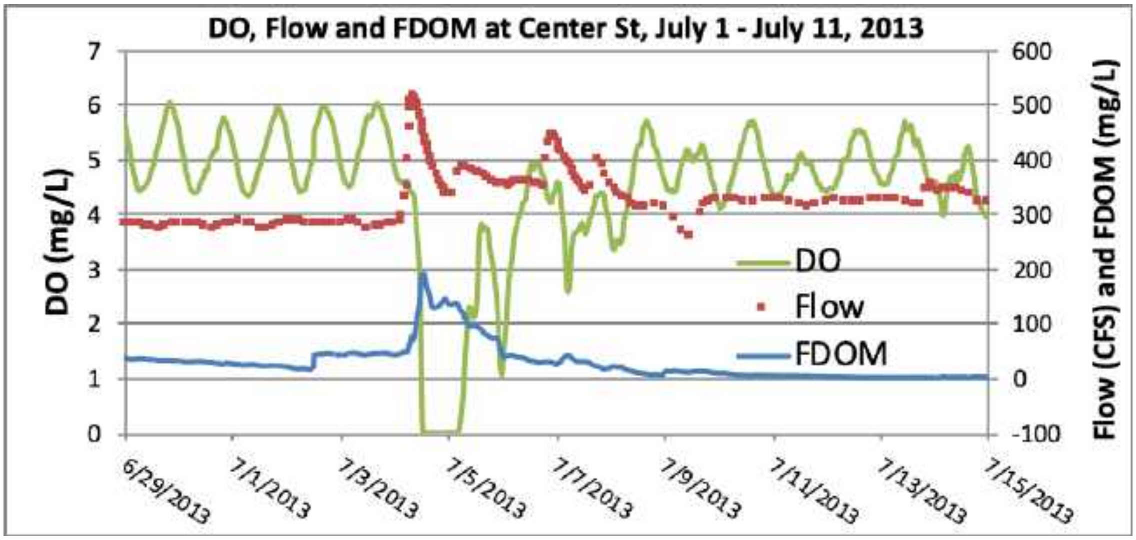


Figure 95. DO, fluorescing dissolved organic matter, and flow in the Jordan River at the Center St. crossing. Note exactly correlated timing of the arrival of high flow, elevated FDOM and DO decline. Flows recorded in this graph were obtained from the 500 N gage operated by Salt Lake County.

There were other high flow events that were associated with abrupt declines in DO. A record of these high flow events from upstream watersheds was best recorded in the Surplus Canal because that's where all of the "excess" flows are diverted (refer to figure 33). As described above, flows measured at 500 north crossing account for additional contributions from tributaries and storm flows that enter the river downstream from 2100 S.

Figure 37 displays DO recordings in late August and September at Center St. Both of these events were marked with increased flows measured at the Surplus Canal, although there was also an increase in flows measured at 500 N - from an average of about 190 CFS to about 300 CFS (data not shown). It should be mentioned that it is difficult and very time-consuming to align County flow data from 500 N with our sonde data, because the flow gage only records flow events that are different from the previous time step. Hence, there are occasions where recordings have skipped 30 to 200 minutes or more.

Also, it appears likely that the high flows that occurred on July 4 mobilized and removed a considerable amount of the oxygen-demanding organic compounds that had accumulated in the river, tributaries, and storm drains up until that time. For example, the DO sag recorded at all three sites during the July 7 high flow event was not nearly as low as that caused by the high flow event of July 4 – even though flows were slightly higher on July 7 (Figures 34, 35 and 36). However, this "cleansing" affect is brief. For example, the prominent low-DO event marked on July 4 occurred only about 5 weeks after higher spring flows had occurred in late May. This suggests that there is both considerable settling of "fresh" organic debris and that decomposition progresses rapidly to form the amount of reduced and labile organic matter that would be necessary to cause such low DO events. In turn, this labile organic matter consists of dissolved organic carbon (here measured as FDOM), that readily diffuses to the water column in storm water vaults and the countless other pools that are created by the incongruities throughout the storm drain system and underground conduits that transport tributary and storm water. Hence the initial storm surge or flushing flow first transports the stagnant water and we believe that this initial flush is the cause of the instantaneous drop in DO that occurs simultaneously with arrival of elevated flows at our monitoring sites. Thereafter, if flows reach a high-enough values, they can be remobilized the sediments themselves from the stormwater vaults, etc. and cause lingering low DO values as well as contribute to the turbidity. As storm flows subside, these organic-rich sediments will also settle and resume forming highly reactive organic compounds that will accumulate in pore spaces and diffuse into surface water. As a further example of the rapid formation of labile dissolve organic carbon, high flow events also occurred in August and September and even though the magnitude of these elevated flows were much less than the July 4/7 flows, there was still a substantial reduction in DO. The September flow was slightly higher than the August flow (Figure 33), resulting in a predictable mobilization of greater amounts of FDOM and a concomitant greater sag in DO (Figure 36). Further, this occurred even though seasonal temperatures were beginning to cool down.

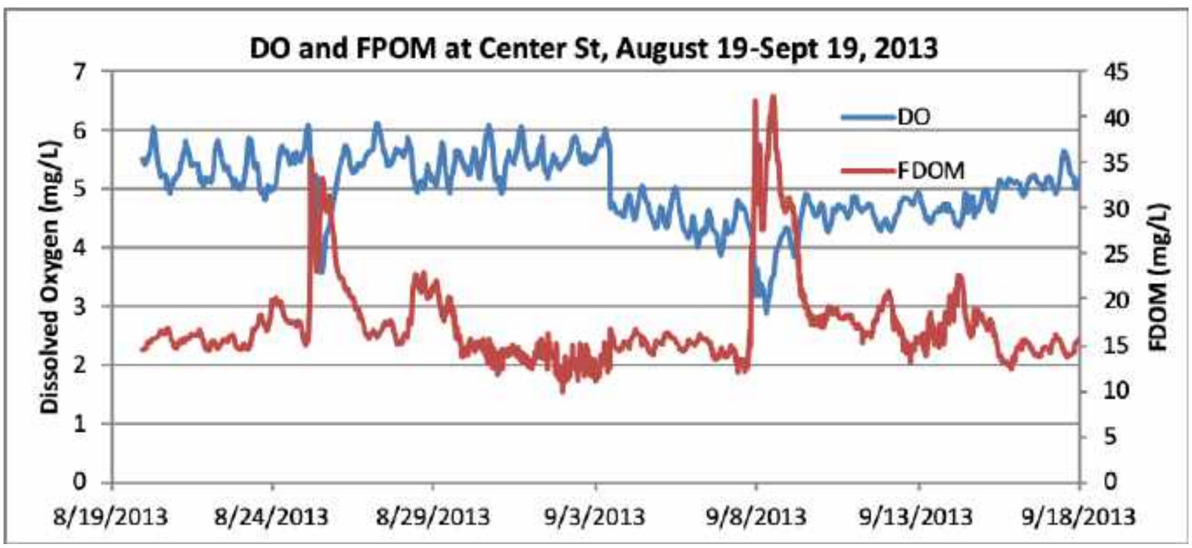


Figure 96. Dissolved oxygen and FDOM at Center St. from August 19 to September 19, 2013.

Is There a Role of VSS/Turbidity in Determining Oxygen Depletion?

It was originally assumed that the drop in DO during high flow events was the result of mobilized volatile suspended solids (VSS). Figure 38 is a time-correlated record of turbidity, a reasonable surrogate for VSS, at locations upstream and downstream from 2100 S during the July 4 storm event. Between each site, there is a 30 to 120-minute lag time – indicating the travel time of this high-turbidity event. First, there is a dramatic decline in turbidity between the 3300 S and 2100 S sites. This is likely due to settling of inorganic and organic material within the fore bay of the diversion dam for the Surplus Canal. Additional settling occurs with downstream distance until the value at Center St is a small fraction of that experienced at 3300 S or 2100 S. In fact, the second high flow event on July 6/7, which had similar high flows as on July 4-5 (see Figure 33), caused relatively tiny peaks at 3300 S and 2100 S, and resulted in no measurable increase in turbidity at 300 N or Center St, again suggesting that the July 4 event was a major flushing/cleansing flow that removed a lot of both organic and inorganic material.

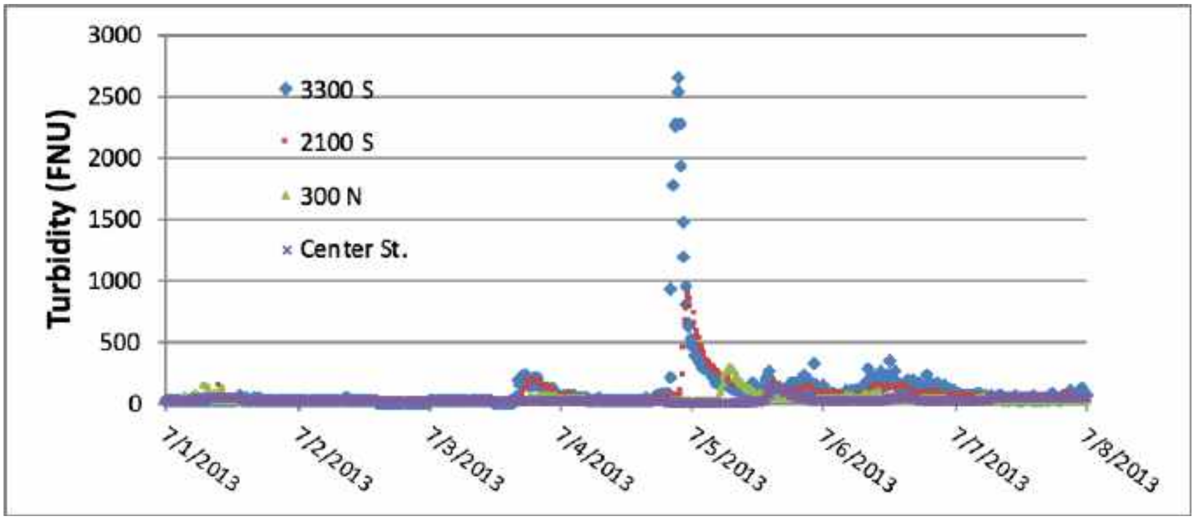


Figure 97. Time-correlated record of turbidity and 3300 S and successive monitoring stations downstream. Note how peaks could be identified with time and downstream distance as this "plug" or turbidity travelled downstream.

Secondly, a more detailed and time related recording of turbidity and DO at 300 N during the July 4 storm event shows that while the DO initially dropped at the onset of the first (small) peak in turbidity, the DO continued to drop while the turbidity was declining to near pre-storm values (Figure 39). The second and much higher peak in turbidity on July 5 is largely inexplicable. There was a concurrent slight increase in flow and slight increase in FDOM, along with a small decrease in DO. However, careful review of the data indicates that this drop in DO is initially occurring simply because it is night time. However, The DO actually begins to increase again at 02:40 - long before sunrise and at the exact moment that the turbidity is peaking. So, although these two parameters appear to co-vary, it is hard to imagine that the source of turbidity was actually a strong-enough oxidant as to raise the river DO during the middle of night. Regardless of whether there is a relationship, it has no predictable value with regard to DO values.

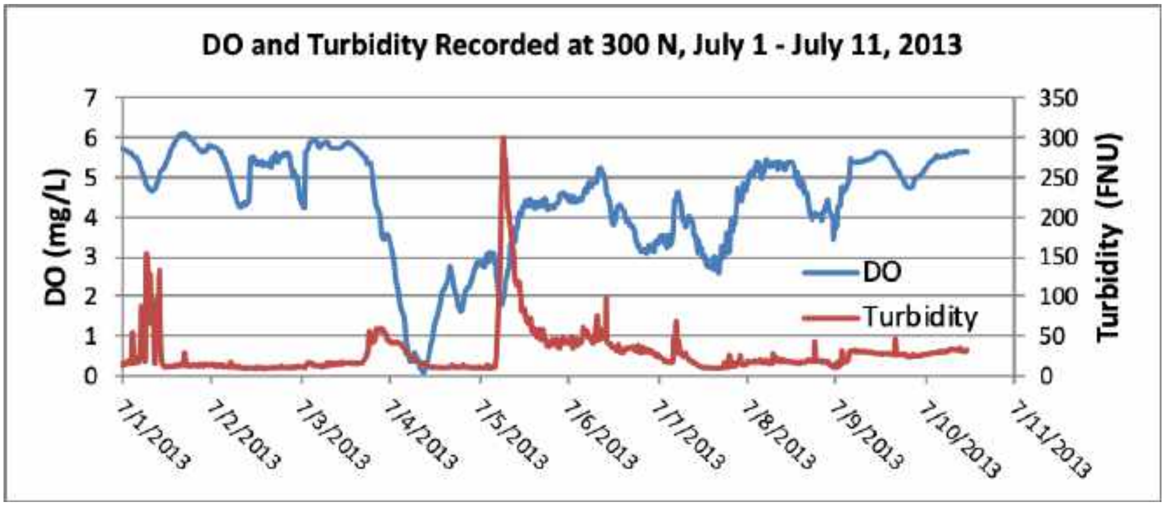


Figure 98. Recording of dissolved oxygen and turbidity at 300 N, July 1 – July 10, 2013.

A much more detailed illustration of the relationship between DO, FDOM and Turbidity is displayed in Figure 39. Particularly, this is the site that experienced the greatest impact on DO.

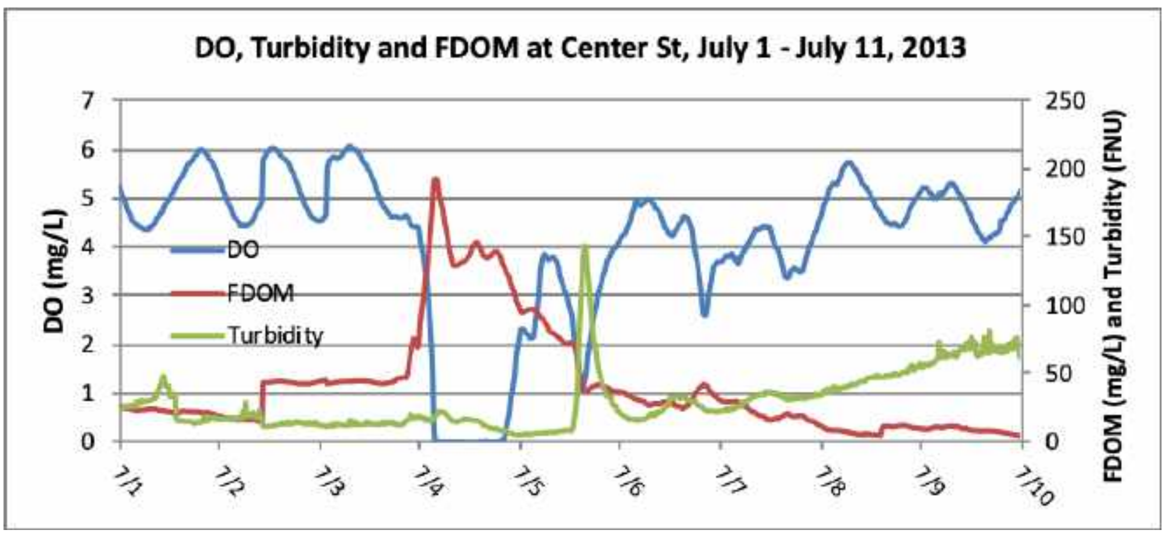
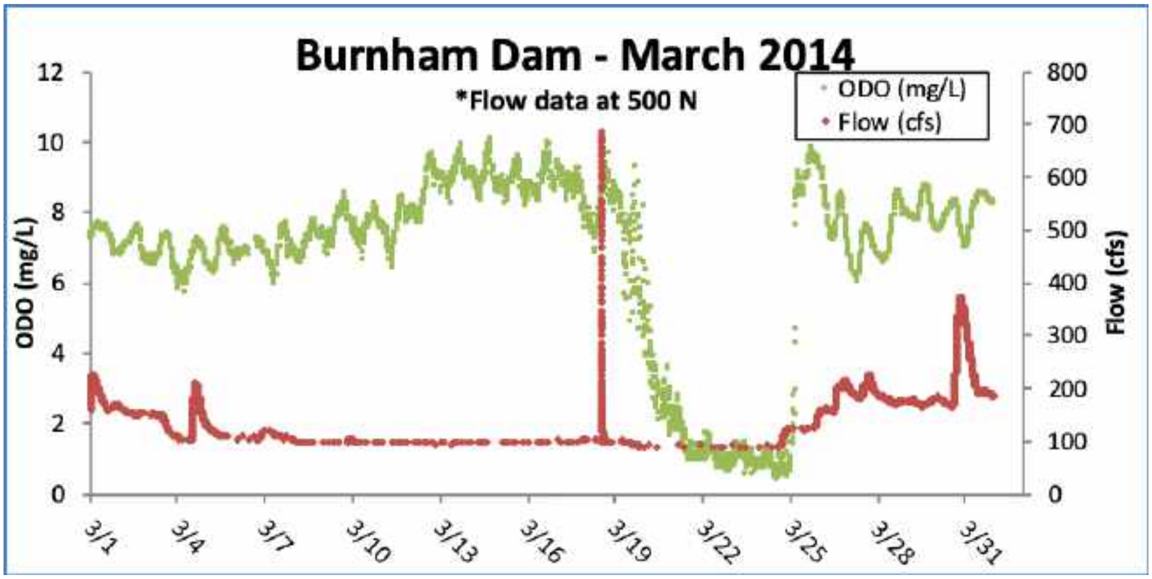


Figure 99. Recording of DO, turbidity and FDOM at Center St, July 1 to July 11, 2013.

Although there is some movement in the turbidity there is a much stronger relationship between DO and FDOM, suggesting that the fluorescing dissolved organic matter is a much more accurate surrogate than turbidity for the organic compounds that are actually responsible for the low-DO events. Additional recordings in 2014, 2015, 2016 2017 and 2018 displays a similar reaction to high flow events. Two examples, Figures 41 and 42 show the same relationship between high flow spikes and DO and FDOM.

a.



b.

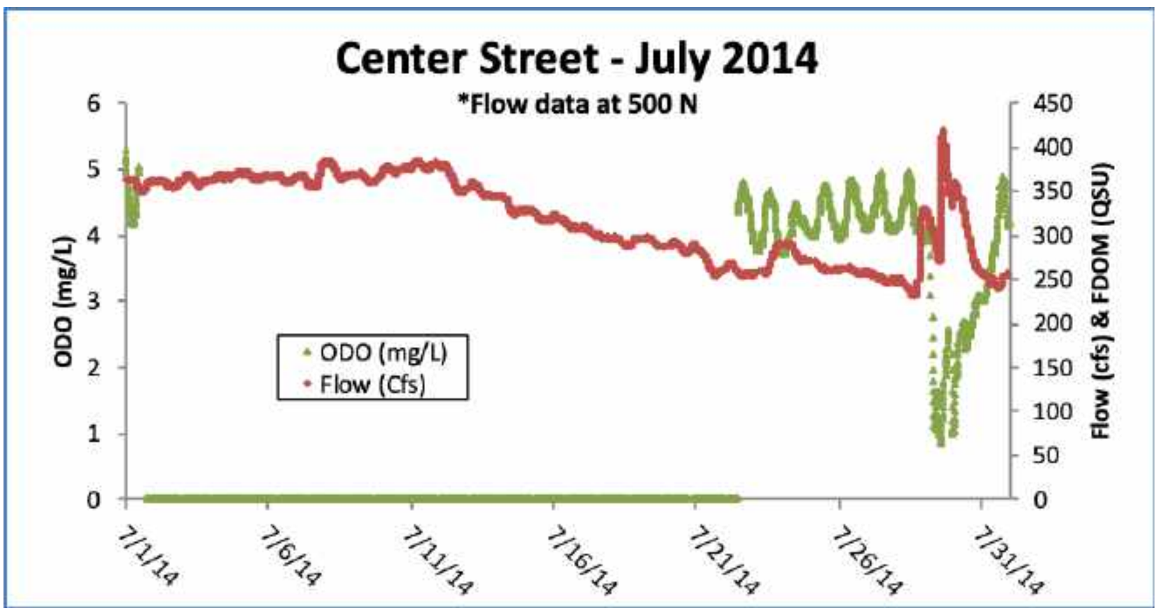
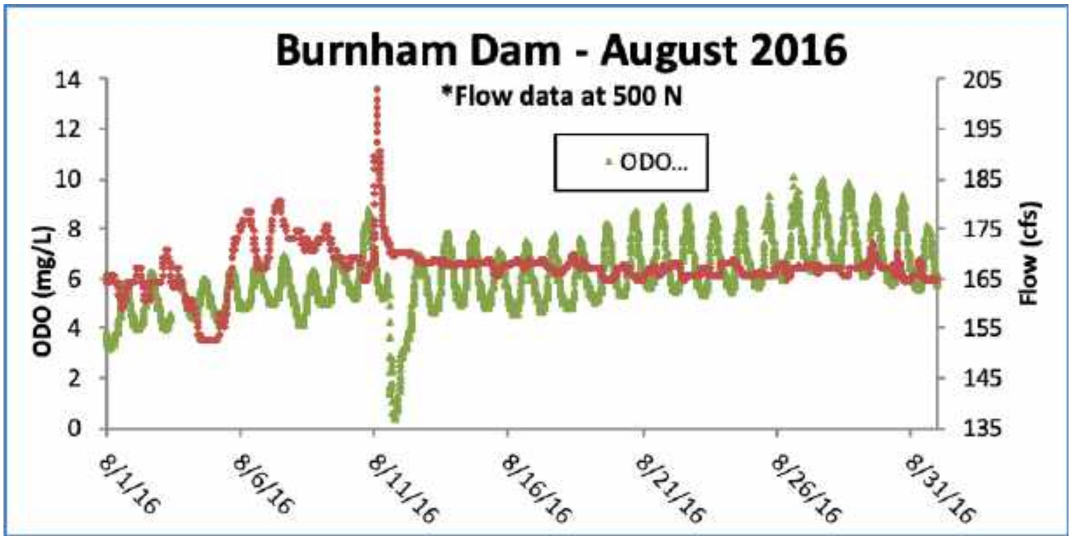


Figure 100. The effect of a spike in flow on dissolved oxygen March 18 (a.) and July 27, 2014 (b.). Note, even though there may be a relatively short interval between high flow events, the resultant immediate sag in DO is evident.



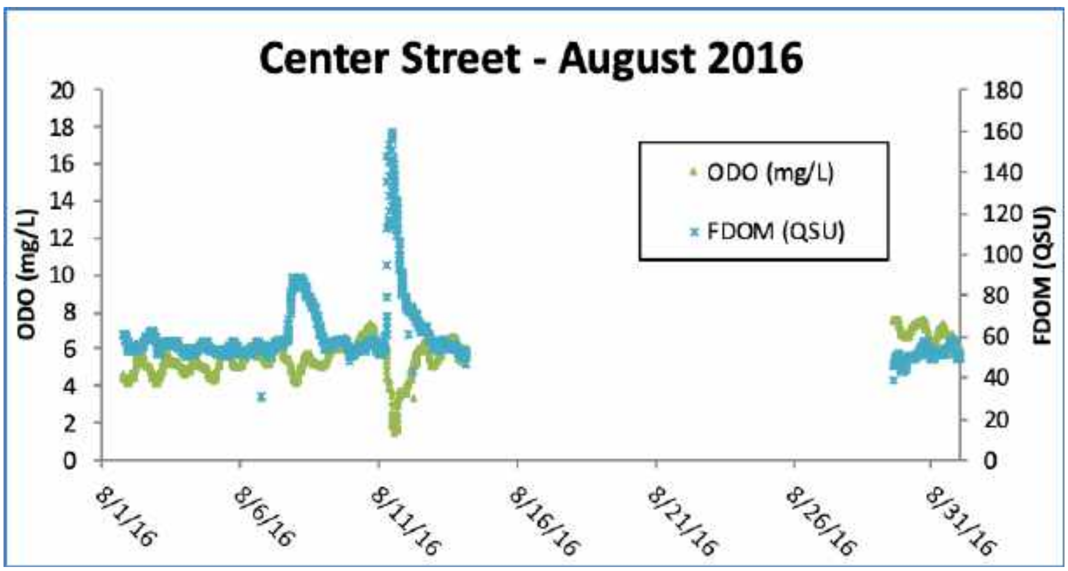


Figure 101. Flow and DO data (a.) and DO and FDOM data (b.) during the high flow even of August 11, 2014.

Although the fluorescing fraction of the total amount of dissolved organic matter (FDOM) is an unknown fraction of the total dissolved organic carbon, it has been shown to be a convenient and predictable surrogate for the portion that is highly reactive with oxygen. In general, various DOM fractions fluoresce within a broad excitation range from 250 and 400 nm and a broad emission range from 350 to 500 nm (Stedmon et al. 2003). Stedmon et al. (2003) were able to isolate specific fractions of DOC based on the adjustment of excitation and emission spectra. The results reveal that at least five different fluorescent DOM fractions are present (in significant amounts) in their study watershed and that the relative composition is dependent on the source (e.g. agricultural runoff, forest soil, aquatic production). Four different allochthonous fluorescent groups and one autochthonous fluorescent group were identified. Stedman et al. (2003) concluded that use of scanning spectroscopy allows the ability to trace the different fractions of the DOM pool and represents a significant advance within the fields of aquatic ecology and chemistry and will prove to be useful for catchment management. Cory and Kaplan (2012) reviewed the recent literature and suggested that all of the studies suggest that the proportion of the amino acid–like fluorescence components relative to the total FDOM pool represents a proxy for the biodegradable fraction of DOM, while amounts of fluorescent moieties associated with the humic fraction of DOM are a proxy for slowly cycling, more recalcitrant DOM.

The FDOM sensor used in our Sonde is adjusted to excite at 365 nm and detect an emission wavelength of 480 nm. This is somewhat in the mid-range, and thus reacts to both recalcitrant and labile compounds (YSI technical team, personal communication). Also the fact that the fluorescence signal from one or more similar components may be greater than that from other components of the total FDOM does not equate to the first having a higher concentration than the other, only higher fluorescence (Stedmon and Bro 2008). This suggests that engagement in studies that use a scanning UV spectrophotometer and the necessary DOC and TOC analyses to better characterize the source needs to be a part of the study. It would be particularly informative to elucidate the sources of the organic matter (i.e. allochthonous vs autochthonous) and which fraction may be more labile and hence responsible for the DO sag. For example, Baker (2001) was able to distinguish the FDOM signature on streams receiving POTW effluent from those that didn't. He identified the labile compounds as being metabolized within several hours. These were identified as within the smaller molecular weight fraction that includes fulvic acid, amino acids and peptides within the humic substances. It should be pointed out, however, that in our data the dissolved oxygen rapidly began to sag nearly instantaneously with the arrival of the FDOM signal and the elevated flow. This indicates that the organic compounds consumed in the low DO event were extremely reactive. It has been speculated that this fast reaction must be the result of COD and not biological.

However, it seems improbable that a chemical oxidant that could react so quickly and powerfully wouldn't absolutely decimate the biological community in the river. A logical alternative is methane oxidation. For example, I have observed the destruction of several mg/L of methane (CH_4) begin within minutes of introducing oxygen to anaerobic hypolimnetic samples of eutrophic lakes in Northern Alberta and nearly complete removal of about 10 mg /L of methane within an hour (personal observations). In addition, two moles of O_2 are required to oxidize one mole of CH_4, making this a highly oxygen-demanding reaction. Other biologically-mediated reactions are nearly as fast (i.e. nitrification of ammonia and oxidation of H_2S). Finally, research performed by Goel and Hogsett (Chapter 5), has revealed the presence and flux of considerable amounts of CH_4 and NH_4 to the water column from undisturbed sediments of the lower Jordan River. It is most likely that the first flush of stormwater moves stagnant anaerobic methane-rich water that overlies organic sediments in stormwater vaults, oil/water separators and other incongruities in storm drains and underground tributary conduits. In turn, when these large concentrations of labile compounds reach the Jordan River, they immediately depress the Jordan River DO. Secondly, if storm flows are sufficiently high, the organic-rich sediments that had previously settled in the same stormwater vaults, oil/water separators, etc. will be mobilized and transported to the river, including additional reduced and labile compounds that are contained in these anaerobic sediments. These sediments will re-settle as storm flows diminish and the water reaches the low-velocity, lower reaches of the river. Evidence for this phenomenon includes the several days required for the Jordan River DO to recover to pre-storm ranges (Figures 38, 39, 40 and 41), and the 30-100 cm or organic-rich sediments present throughout the lower Jordan River. Because this can occur multiple times throughout a summer season, renewed accumulation and decomposition begins immediately following a high-flow event –likely even on the descending limb of any peak flow in the hydrograph. New research by the Council will focus on 1) following the methods of Stedmon et al. (2012) to determine if allochthonous vs autochthonous sources of dissolved organic carbon can be determined in the Jordan River watershed and 2) identifying the compounds within the DOM that are responsible for such immediate consumption of oxygen.

Finally, while certain BMPs may improve water quality, another critical outcome of this study will be the assembly of the type of information prescribed in 40 CFR §131.10(g), to write a scientifically sound Use Attainability Analysis that will document the severe consequences associated with extreme flows, extreme diversions, and the transport and deposition of large amounts of inorganic sediments and organic debris (CP0M). Particularly there is no conceivable way to eliminate the deposition and accumulation of inorganic and organic debris during or following storm events as flows subside and the lower Jordan is so massively dewatered (>90% or more). Further, there is already an active dredging program designed to remove accumulated sediments. Yet, our data reveals that mobilization, deposition, decomposition cyclex continuously as even high flow events just a few days apart result in the same FDOM/DO response (Figure 38). Under these current managed flow conditions, spring runoff and each storm event, of almost any size, will continue to cause short-term excursions of DO and occasional violation of the acute dissolved oxygen criteria and perhaps even the chronic DO criteria.

Recommendations

Overall, the inability to control the delivery, accumulation and decomposition of organic debris will preclude the ability to consistently maintain water quality standards for DO. While debris basins have been shown to be effective in eliminating some CPOM (Chapter 3), their success depends on sizing the basin large enough to provide sufficient retention time to allow for settling. In addition, an active means of removing accumulated material is essential to avoid rapid filling of the basin with excessive debris, precluding success. In addition, the continued sampling of tributaries, particularly Big Cottonwood and Mill Creeks has demonstrated that stream reaches downstream from debris basins rapidly collect and transport large amounts of CPOM along with inorganic sands, silts and clays from the unconsolidated alluvial sediment that comprises the East Bench of Salt Lake Valley. Therefore, it is apparent that numerous debris basins, with regular maintenance schedules, including real-time dredging during high flow events, would be necessary to more effectively remove this debris. However, this kind of effort, in coordination with other BMPs, such as creating bioswales, and installing more oil/water/sediment separators on public and private properties would be essential. Yet, because the costs and participation of these projects would be enormous, several tens to hundreds of millions of dollars (the success would be proportional to the funds dedicated), to acquire private lands and perform these installations, public "buy in" would be a major obstacle.

Another alternative, and much less costly would be a major overhaul of the surplus Canal diversion dam. This renovation would include constructing a wier-type structure that provides for water over-toping the dam – much like the weir that currently controls the flow down the Surplus Canal; only that the flow-control gate would regulate flow over the dam instead of underneath. This change in design would create and improve the settling properties of the forebay – turning it into a much more effective settling basin than currently exists. Secondly, the current dam provides about 8 feet of hydraulic head. The bottom release basically "wastes" this valuable potential stream gradient. We propose to modify the stream channel to take advantage of this "gift" by elevating the stream bed to the approximate 8 ft height and provide enough fill to create a gradient of 3 to 4 ft per mile for the next 2-4 miles to the vicinity of the Pacific Corp diversion. Two to three additional sedimentation basins should be construction along the flow path to collect additional debris in localized, specifically designed basins for easy debris removal. Hence, any CPOM that flows over the weir, will continue to be transported to the designated sedimentation basins – rather than being deposited along every inch of the stream bottom. This will reduce the need to dredge many miles of stream bottom, destroying the benthic biota and destroying stream habitat in general and trampling miles of stream bank and piling thousands of tons of sediment that needs to dry for several weeks before final removal – only to be repeated every 2 – 3 years. In addition, the stream bed should be covered with appropriately-sized cobble and gravel (suited for stability in the resulting increased velocity), Finally, and most importantly, this greater gradient will provide for a tremendous improvement in natural re-aeration and enhanced "processing" of stream BOD and potential SOD. Ultimately these processes will likely maintain DO above existing criteria, greatly enhance aquatic habitat and biota and return the river to some semblance of its natural condition, help attain State designated beneficial uses, and improve ecological integrity as designated by the Clean Water Act. This entire project may cost 40 to 50 million dollars. However, this is a small fraction of what is planned or is currently being constructed for the misguided goal of improving DO using the assumption that reducing POTW nutrients will somehow improve the DO.
In the meantime, with the stream conditions that currently exist, and in cooperation with DWQ we need to modify and improve the DO assessment criteria to align more appropriately with EPA guidelines and move forward with a Use Attainability Analysis to remove the lower Jordan River from the 303(d) list. Also, the Council suggests that DWQ coordinate to further the investigation new innovative alternatives merits of installing an aeration system which could mitigate these storm-caused DO excursions and late summer, low flow DO sags.

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