Jordan River Research 2010-2015

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ACRONYMS AND ABBREVIATIONS

BOD	biochemical oxygen demand
BOD_5	5-day biochemical oxygen demand
C	carbon
cBOD	carbonaceous oxygen demand
Chl-a	chlorophyll-a
COD	chemical oxygen demand
CPOM	coarse particulate organic matter
CR_{24}	24-hour community respiration
DO	dissolved oxygen
DOC	dissolved organic carbon
DOM	dissolved organic matter
DWQ	Division of Water Quality
EPA	U.S. Environmental Protection Agency
ER	ecosystem respiration
FBOM	fine benthic organic matter
FPOM	fine particulate organic matter
fDOM	fluorescent dissolved organic matter
GPP	gross primary production
kg/yr	kilograms/year
km^2	square kilometer
LJR	Lower Jordan River
m^2	square meter
mg/L	milligrams/liter
N	nitrogen
O^2	oxygen
OM	organic matter
QA/QC	quality assurance/quality control
QUAL2Kw	water quality model
SIAR	isotope mixing model
SMI	stream metabolism index
SOD	sediment oxygen demand
TAC	Technical Advisory Committee
TDN	total dissolved nitrogen
TMDL	total maximum daily load
TOC	total organic carbon
TOD	tray oxygen demand flux (g DO/m^2/day)
TOM	total organic matter

TP	total phosphorous
TPP	tray gross primary production (g DO/m^2/day)
TSS	total suspended solids
UJR	Upper Jordan River
VSS	volatile suspended solids
WC_{dark}	water column dark respiration rate (g DO/m^3/day)
WC_{light}	water column gross primary production rate (g DO/m^3/day)
WRF	water reclamation facility
%VS	percent volatile solids

1.0 INTRODUCTION

The Jordan River Phase 1 Total Maximum Daily Load (TMDL) was approved by the Environmental Protection Agency (EPA) in 2013. A phased approach was used to develop the TMDL. A phased approach is recommended "where available data only allow for 'estimates' of necessary load reductions" (EPA 2006). This approach "is limited to TMDLs that for scheduling reasons need to be established despite significant data uncertainty and where the state expects that the loading capacity and allocation scheme will be revised in the near future as additional information is collected" (EPA 2006).

The current focus of the TMDL process is on gathering additional data to support a more accurate assessment of organic matter (OM) loading, both temporally and spatially, in support of the second phase of the TMDL. Since Phase 1 was completed, a number of research and monitoring projects have been completed that characterize OM pollutant sources, the linkage between water-quality impairment and OM pollution, and the dissolved oxygen (DO) impairment. A request for research was submitted by DWQ to members of the Techncial Advisory Committee and the following list of publications were submitted for review:

1. Peterson J. (2010) – *Preliminary CPOM Data Summary, Summer of 2010*.
2. SWCA (2013) – *Lower Jordan River Phase 1 Report*.
3. Epstein D. and M. Baker (2014) – *A Preliminary Organic Matter Budget for the Jordan River, Salt Lake County, Utah. Progress Report 3.* February 28, 2014. 24 pp.
4. Richardson (2014) – *Impact of Organic Matter Composition From Urban Streams and Storm Water on Oxygen Consumption in the Jordan River*. Master's thesis submitted to Utah State University. 64 pp.
5. DWQ (2015a) – *Jordan River 2014 Synoptic Survey and Model Validation Report*, Utah Division of Water Quality, December 2015.
6. DWQ (2015b) – *Continuous DO and fDOM Monitoring Data (2014) Collected from In-situ Probes installed at four locations on the lower Jordan River.*
7. Epstein D., J. Kelso, and M. Baker (2015) – *Beyond the Urban Stream Syndrome: Organic Matter Budgets for Diagnostics and Restoration of an Impaired Urban River*. 45 pp.
8. Hogsett, M. (2015) – *Water Quality and Sediment Biogeochemistry in the Urban Jordan River, UT*. PhD dissertation submitted to University of Utah. 211 pp.
9. Kelso, J. (2015) – *Characterization of sources and transformations or riverine organic matter in an urban landscape.*
10. Miller (2015) – *Coarse Particulate Organic Matter Measurements in the Jordan River and its Major Tributaries*, 2010–2012.
11. Salt Lake City (2015) – *Monitoring Results of DO Profiling and Water Quality Sampling During Storm Water Events and Dredging Activities*.

The purpose of this document is to review and synthesize these publications. It provides an organized review of the qualitative information and quantitative data generated by these efforts and informs members of the TAC on DWQ's interpretation of research results. Finally this document suggests ways in which this new information can be used to support load allocations to be included in the Phase 2 TMDL.

The remainder of this document is organized into three sections that discuss the linkage between water quality and chronic DO impairment, describe Total OM and OM sources, and summarize the important conclusions and application to the Phase 2 TMDL. The discussion refers to upper and lower segments of the Jordan River, tributaries to the River, the Surplus Canal, and Utah Lake. Figure 1 shows the locations of these features.

2.0 LINKAGE - WATER QUALITY AND CHRONIC IMPAIRMENT

Water quality linkage is the connection between water quality impairment and the pollutants and processes that cause it. This connection is best defined by scientific research on the impaired water body that identifies processes and sources that influence water quality. Additional understanding can be obtained with monitoring data collected from the impaired water body that characterizes water quality between seasons and across years.

Efforts to define the linkage between OM and DO began when the Phase 1 TMDL was prepared. Section 2.1 summarizes sections of the water quality linkage discussion in the Phase 1 TMDL that correspond to areas of new research. The remainder of section 2 describes the results of new research in regard to sediment oxygen demand (SOD), stream metabolism, oxygen demand in the water column, reaeration, chronic DO impairment, and water quality modeling.

2.1 PAST UNDERSTANDING

The Phase 1 TMDL utilized available data to define four major processes that were believed to influence DO at that time including: organic and inorganic processes that consume DO at the water-sediment interface; organic and inorganic processes that consume DO in the water column; processes related to algal growth; and physical processes in the stream channel such as reaeration (Figure 2). A water quality model (QUAL2Kw) was used to define the effect of various processes that influenced DO. This model suggested that OM in the sediment and water column had the most influence on DO levels in the Jordan River.

Water quality modeling in the Phase 1 TMDL indicated that SOD was a major source of oxygen loss in the lower Jordan River (LJR, Figure 3), defined as the river from 2100 South north to Burton Dam (Figure 1). Actual measurements of SOD were performed at seven locations on the LJR (Goel and Hogsett 2009, Goel and Hogsett 2010). These measurements ranged from 0.84–3.37 g/m^2-day and generally increased with distance downstream from 2100 South. Measurements collected during the winter were higher than summer measurements at some locations. Average SOD in the LJR for all seasons and unadjusted for temperature was approximately 1.7 g/m^2-day. Measurements compare well with results from watersheds and rivers similar to the Jordan River. The final QUAL2Kw model was calibrated using measured DO levels in the LJR to prescribe SOD levels of 1–3.5 g/m^2-day.

The Phase 1 TMDL assumed that oxygen demand in the water column was primarily the result of aerobic decomposition of OM and algal respiration. Measurements of OM in the Jordan River were limited to volatile suspended solids (VSS) and respresented the suspended fraction of OM in the water column. No measurements of dissolved organic carbon (DOC) were available during the Phase 1 TMDL process and as a result, the TMDL did not include the dissolved OM fraction. Monitoring data indicated the average organic content of suspended solids in the LJR ranged from 15-25 percent. Biochemical oxygen demand (BOD) was used to define loss of oxygen in the water column due to OM decomposition. Monitoring data indicated that demand on DO from BOD between 2100 South and Burton Dam could be 0.8–1.4 mg/L, based on BOD of 3.0–5.5

mg/L and 0.85 days of travel time. These results indicate that BOD could potentially account for losing over half of the DO provided by reaeration in the LJR.

Limited information was available to define how fast decomposition in the water column was occurring. This rate is influenced by OM structure and concentrations of carbon (C) and nitrogen (N).

Measurements of chlorophyll-a (Chl-a) represent algal growth and a source of OM in the water column. Measurements of Chl-a used in the Phase 1 TMDL indicate eutrophic conditions in the LJR and that Utah Lake is a major source of algae for the Jordan River. The report also indicates that algae growth in the LJR is limited due to turbid conditions created by suspended OM and less so by nutrient concentrations.

Diel DO measurements collected from upper and lower segments were presented in the Phase 1 TMDL. Diel DO concentrations, from algal photosynthesis and respiration varied by 3–5 mg/L and demonstrated the influence of algal photosynthesis and respiration. This range generally decreased with distance downstream. A comparison of monitoring data indicated the magnitude of diel cycles was similar between all LJR sites in June. By August, the greatest diel range occurred at the 2100 South site with smaller effects further downstream at Cudahy Lane. This was considered to be due to increased suspended OM and a subsequent increase in turbidity and light-limited conditions that reduced algae growth. Nearly all diel monitoring data indicated a strong influence on DO levels by algae growth and respiration. However few calculations of stream metabolism were made in the TMDL to determine the net effect of productivity and respiration on chronic DO impairment.

The potential for reaeration was modeled in the Phase 1 TMDL using empirical equations that accounted for factors in the Jordan River such as channel shape and roughness, flow, and depth. Based on these equations, potential reaeration in the LJR was estimated at a rate of 1.9–2.3 1/day. The TMDL reported actual measurements of reaeration collected from seven segments of the Jordan River including two locations in the LJR below 2100 South. Measured reaeration ranged from 0.6–4.1 1/day. Values at the upper end of this range could be influenced by oxygen bubbles produced during the day. The lower end of the measured reaeration range is strongly dependent on depth. These data suggested that values calculated from empirical equations may understate actual reaeration by at least half in some reaches. Based on LJR travel times and the results of these studies, reaeration should generally increase DO concentrations by at least 1.7–3.4 mg/L between 2100 South and Burton Dam. However, monitoring data in the TMDL also indicated that DO concentrations decrease with distance in the LJR, indicating that factors other than reaeration rates are responsible for low DO levels.

The Jordan River QUAL2Kw model was originally calibrated to three sampling (synoptic) events, each in a different season (October 2006, February 2007, and August 2009). Model input parameters, process rates, and constants were selected based on measured data whenever possible as well as applicable values from scientific literature. The model was calibrated to an August 2009 synoptic monitoring event following extensive discussion with stakeholders and input from one of the model's authors, Dr. Steven Chapra.

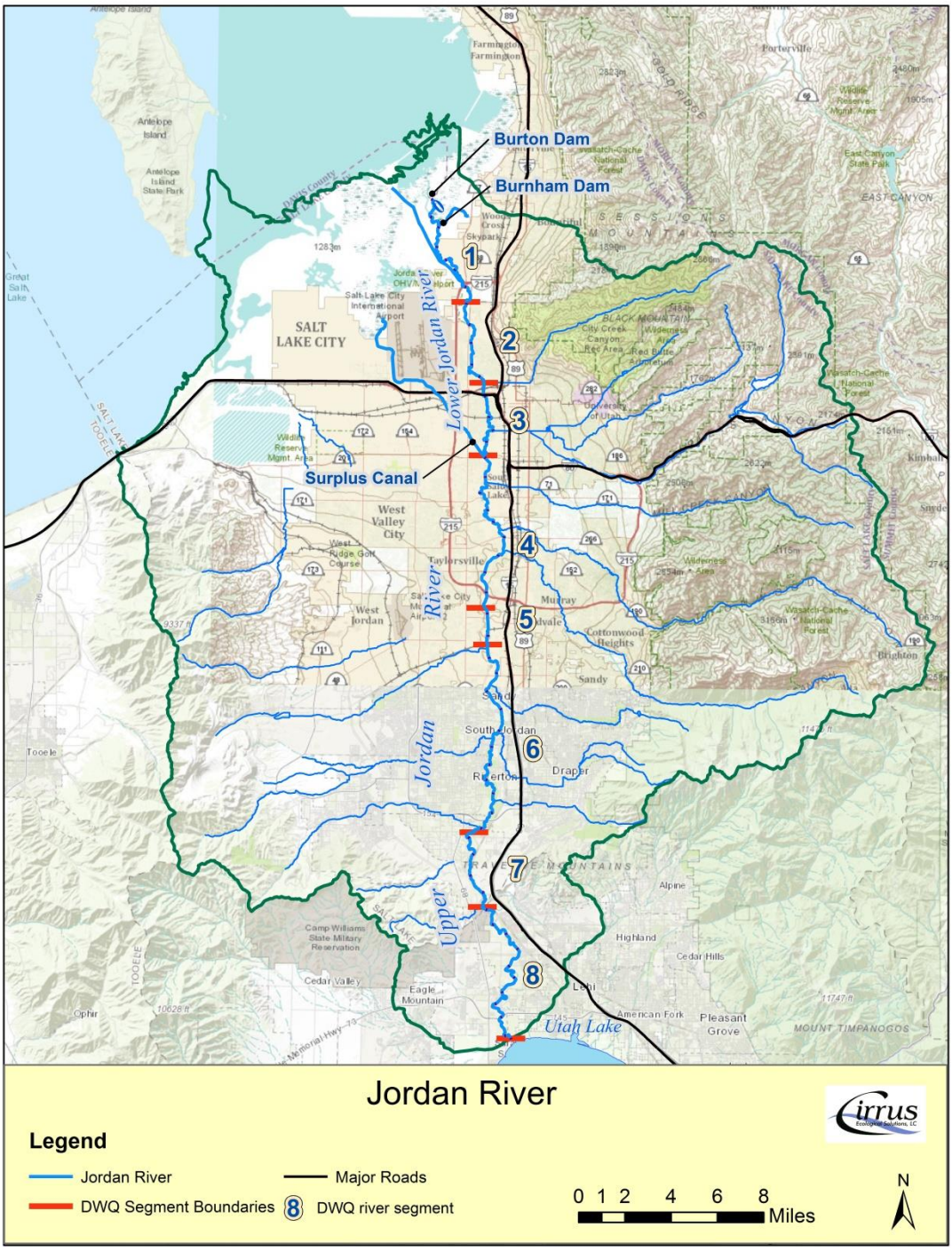

Figure 1. Location of upper and lower segments of the Jordan River. Numbers correspond to DWQ river segments.

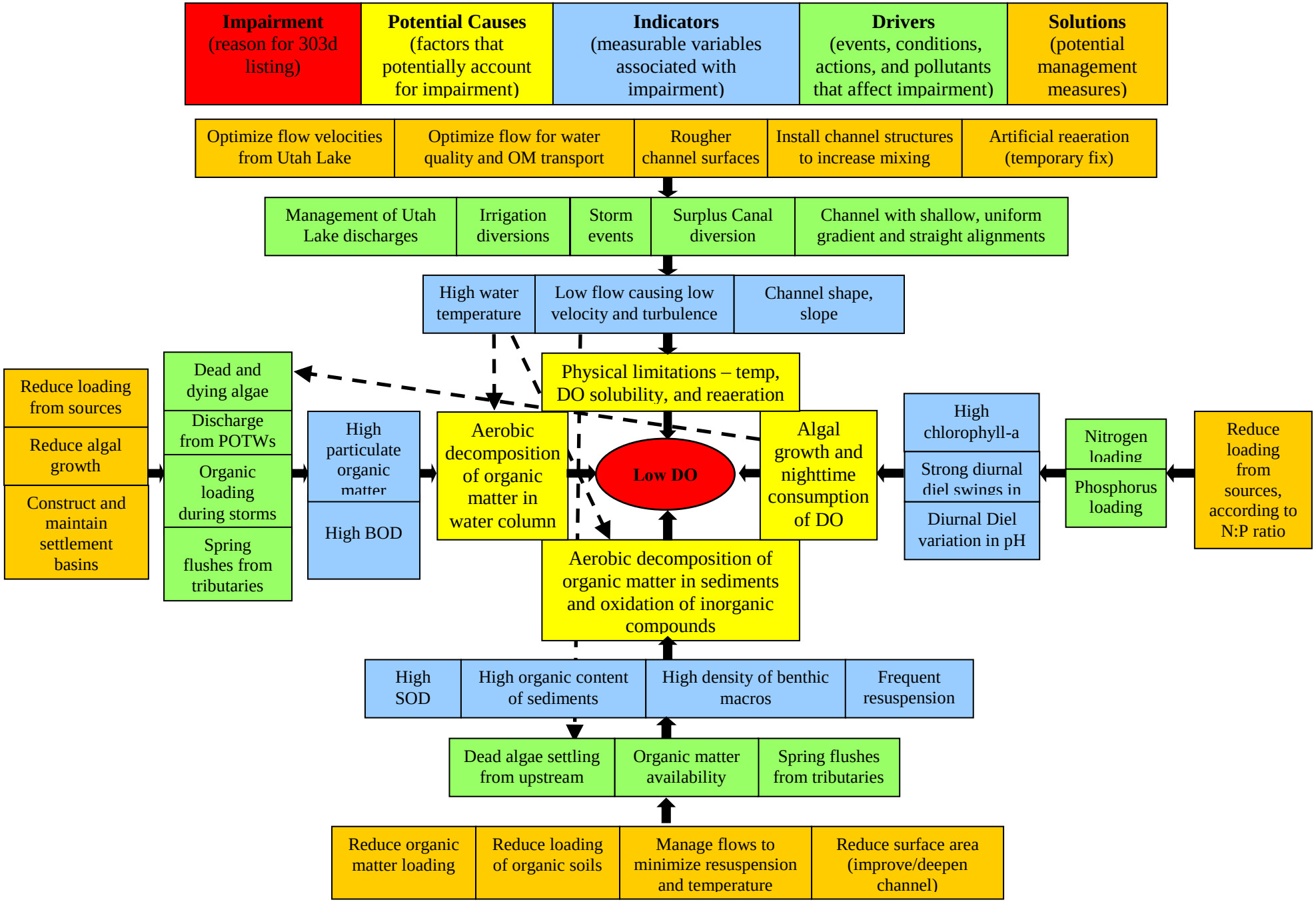

Figure 2. Factors affecting DO in the lower Jordan River. Source: Figure 2.3 Phase 1 TMDL

The QUAL2Kw model was used for several purposes in the Phase 1 TMDL. One important use was to define a *concentration* of OM derived from VSS measurements that would not violate a *target* model DO concentration during the most critical conditions of late summer. The OM concentration as derived from VSS in the model that met the target model DO concentration was used to determine the load capacity for the LJR although this did not include the DOC (dissolved organic carbon) or CPOM (coarse particulate organic matter) fraction of organic matter due to the limitations of sampling VSS. The load capacity (or target load) was then allocated among pollutant sources. An additional use of the model was to define the linkage between water quality impairment and pollutant sources and determine which processes were most influential on water quality.

The remaining sections of Chapter 2 discuss results from new research that add understanding to the linkage between water quality and chronic impairment.

2.2 Oxygen Demand in Sediment

SOD was measured at 27 locations on the Jordan River during 2009–2013 for a total of 142 measurements, including 98 measurements from the LJR (Hogsett 2015). The results of this monitoring indicate that SOD increases with downstream distance in the LJR. Seasonal average SOD fluxes below 2100 South were -1.5 g-DO/m^2/day and increased to -2.3 g-DO/m^2/day downstream from the Davis County border. This increasing trend in SOD corresponds to decreasing DO levels with distance in the LJR recorded by diel monitoring. SOD levels in the lowest segment of the Jordan River are characteristic of large rivers with shallow gradients that accumulate organic-rich sediment. Rivers with a managed flow regime can quickly accumulate this material in deposition zones. Decomposing OM will result in a loss of oxygen near the sediment-water interface and contribute to water-quality degradation.

Measurements of SOD varied between years and seasons (Hogsett 2015). SOD was less in the LJR during 2011 due to deposition of inorganic sediments. High snowpack and runoff levels were observed in the Wasatch Mountain range during the spring season of that water year (2010–2011). Measured values of SOD in the LJR show seasonal variation that sometimes corresponded with OM input such as riparian leaf litter or winter urban stormwater. Seasonal decreases in temperature were noted to decrease oxygen consumption in the water column (respiration) and sediment (methane production). In spite of these indications, SOD measurements did not show a corresponding decrease with winter temperatures. Roughly half or more of the winter SOD measurements during 2009 and 2010 from the upper Jordan River (UJR) and LJR were greater than the corresponding summer SOD measurements collected from the same locations. Reasons for this could be the result of (1) groundwater upwelling, (2) greater periphyton growth, (3) fall leaf drop and seasonal OM load, (4) bacteria and microbes that are tolerant to environmental change, and (5) diffusion of reduced chemicals being a rate-limiting parameter for SOD and not affected by temperature.

SOD was shown to have a significant influence on oxygen levels in the LJR. Ambient DO deficit was calculated for each measurement location based on SOD and water column respiration (Figure 3). This assessment showed that SOD accounted for over 50 percent of the ambient DO deficit during 84 percent of the sampling events in the LJR (N = 46) and over 75 percent of the DO deficit during 58 percent of the sampling events (N = 32). Based on seasonal average SOD values of 2, 1.8, and 1.5 g O^2/m^2-d for LJR segments SOD accounts for 54 percent of the ambient DO deficit in the LJR (Hogsett 2015).

Oxygen lost to SOD can be influenced by aerobic and anaerobic processes. Methane gas produced by anaerobic sediment metabolism contributes a substantial amount of SOD during methane oxidation under aerobic conditions. Based on laboratory tests (serum bottles), methane oxidation in surface sediments (0–2 cm) could be responsible for as much as 56 percent of measured SOD (Hogsett 2015). This scenario represents "ideal" conditions where sediments are manually disturbed when the serum bottle is shaken and trapped methane is released. When methane gas is rapidly released under natural conditions (ebullition), most of the gas exits the water column without dissolving and simply enters the atmosphere. A more significant demand occurs over the long term as methane seeps from channel sediments and contributes to chronic DO impairment (Hogsett 2015).

Laboratory measurements also indicated that surface sediments produced the most methane compared to deeper sediments (5, 10, 15, and 20 cm). Furthermore, methane production was positively correlated with surface sediment OM and indicates potential for future use in characterizing the spatial distribution of sediment methane flux oxygen demand.

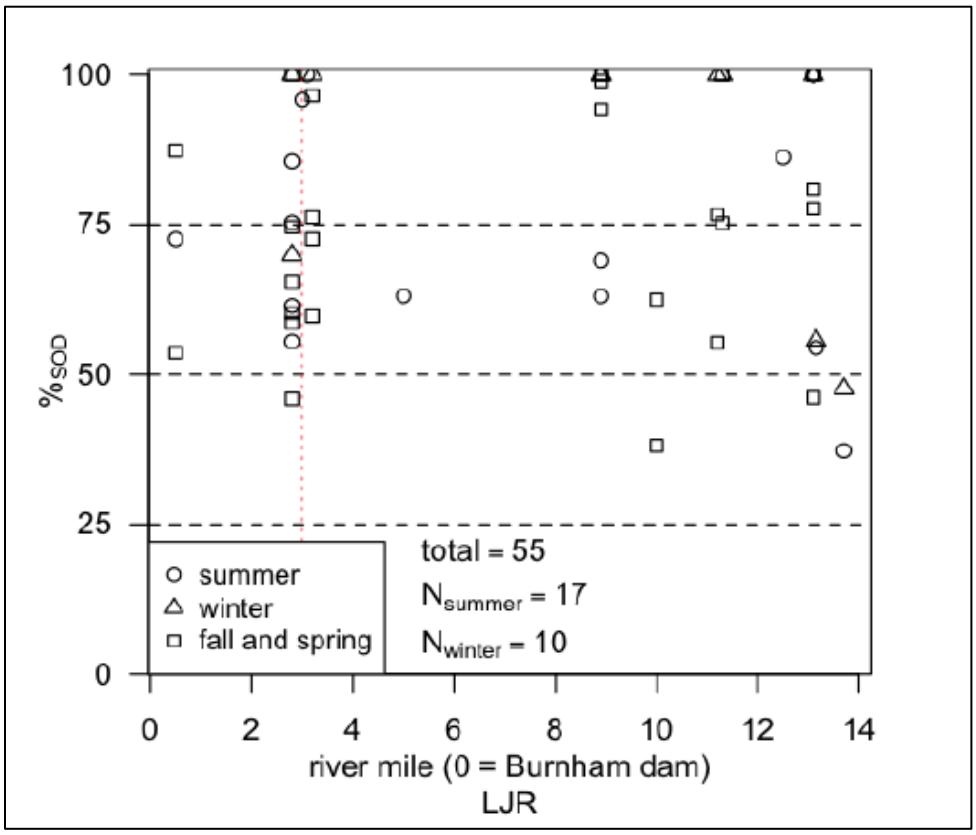

Figure 3. Percent of ambient oxygen demand associated with sediments in LJR. Dashed red line indicates location of South Davis South WRF. Source: Figure 40, Hogsett 2015.

2.3 Stream Metabolism

Algal production and respiration were measured in the Jordan River during several research efforts (DWQ 2015a, Epstein et al. 2015, Hogsett 2015). High levels of primary production are exhibited by large diel DO ranges from the Narrows down to 3300 South. Based on diel DO range, the level of productivity did not seem to be significantly influenced by discharge from Jordan Basin, South Valley, and Central Valley water reclamation facilities (WRFs). Also, the

addition of tributary input from Little Cottonwood Creek and Big Cottonwood Creek appeared to have little influence on the range of diel DO at 3300 South. Both DO minimum and the range of diel DO were relatively lower at 2100 South compared to 3300 South. Measurements of DO at 2100 South and several downstream locations on the Jordan River violated the minimum criteria (4.5 mg/L May through July) on seven consecutive days (July 23–29, 2016) including 6 days prior to and one day of a storm event (Figures 16-17 DWQ 2015a). Diel DO range at 2100 S is likely influenced by channel characteristics in this area. Downstream of 3300 South and near the confluence with Mill Creek, channel slope decreases and the river segment transitions from a transport reach to a depositional reach. The substrate consists of finer materials that are less suitable for periphyton growth, and the deposition of organic matter from the UJR results in enhanced SOD.

Diel DO measurements can be used to estimate the effects of gross primary production (GPP) and ecosystem respiration (ER) on stream metabolism (DWQ 2015a). Figure 4 shows estimates of GPP, ER, and reaeration based on diel DO data. These results show a general upward trend in GPP and ER between 12600 South and 3300 South. The lowest values for GPP and highest values for ER were found at Center Street and Burnham Dam. Both GPP and ER were lower immediately downstream from Jordan Basin, South Valley and Central Valley WRFs as compared to the most immediate upstream sites. This is likely due to dilution with effluent that is devoid of both alge and labile OM that can readily consume oxygen. Note that Figure 4 indicates UJR segments are net autotrophic (GPP > ER) and LJR segments are net heterotrophic (GPP<ER). Segments of the Jordan River are considered to have large amounts of groundwater upwelling. If these flow inputs are characterized by low DO, they could influence estimates of GPP, ER, and reaeration.

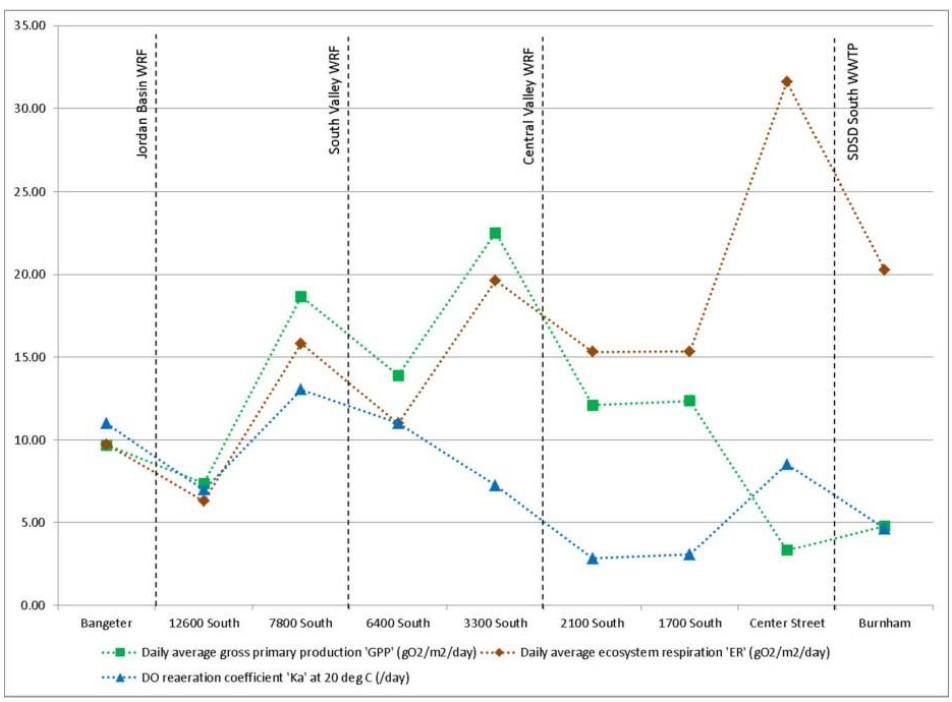

Figure 4. Model estimates of whole-stream metabolism (g O^2/m^2-day) for the Jordan River in dry periods (i.e. non-storm) during July-August 2014. Note that locations are organized from upstream (left) to downstream (right). Source: Figure 18 Utah DWQ 2015a.

Figure 5 compares direct measurements of GPP to ER shown as 24-hour community respiration (Hogsett 2015). A ratio greater than 1 indicates a net autotrophic segment and less than 1 indicates a net heterotrophic segment. In regard to OM production, a ratio greater than 1 indicates that OM is being produced faster than it is consumed, creating the potential for OM loading to downstream segments. Figure 5 shows a general decline in productivity with distance downstream with the exception of the LPN NE site. All UJR sites were autotrophic year-round. All LJR sites were heterotrophic in January, possibly due to decreased light, and 300 N was heterotrophic year-round. Although the LPN E site had very high levels of productivity, the results include some bias due to lack of access to the deepest parts of the channel where benthic production is typically low. Estimates of stream metabolism based on diel DO measurements (Figure 4) can be compared to direct measurements of stream metabolism (Figure 5). Monthly measurements of stream metabolism are not in complete agreement with model estimates, but both methods generally show that LJR sites are less productive and sometimes heterotrophic compared to UJR sites.

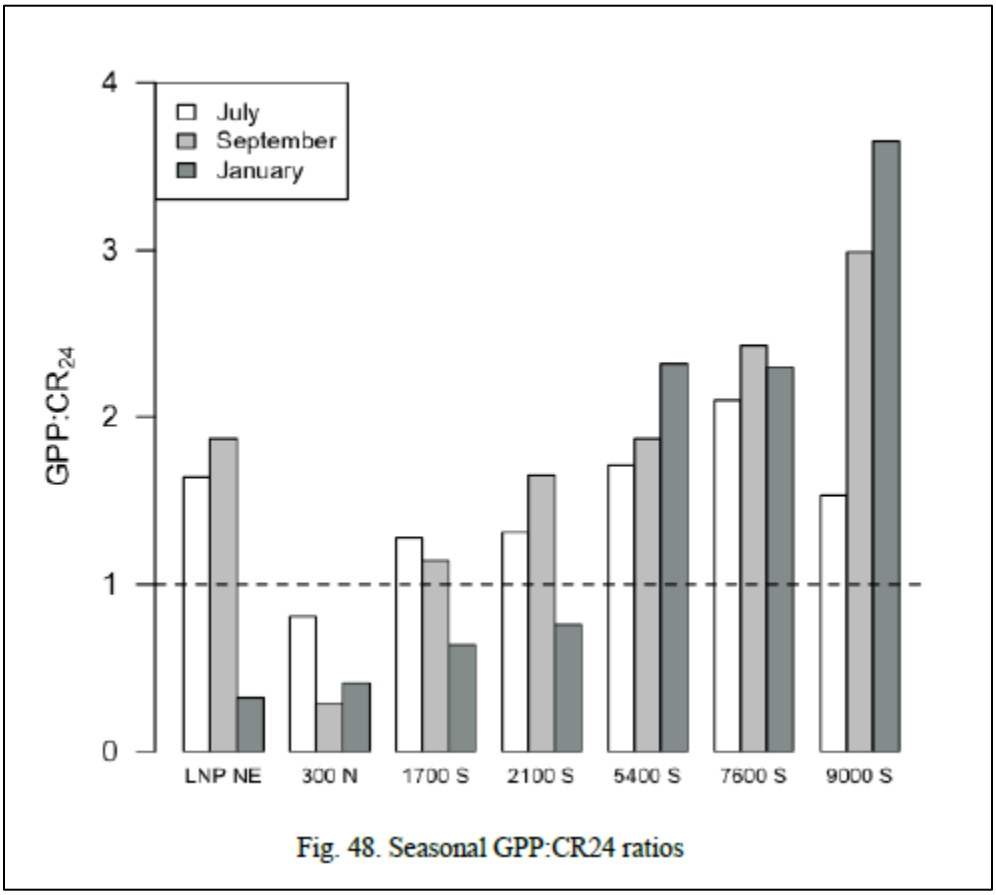

Figure 5. Seasonal ratio of measured Gross Primary Productivity (GPP) and Ecosystem Respiration (CR_{24}) from Jordan River sites in 2010-2011. Note that locations are organized from downstream (left) to upstream (right). Source: Figure 48 Hogsett 2015.

2.4 Oxygen Demand in Water Column

Oxygen demand in the water column is generated as OM particles are degraded by microorganisms and then oxidized by aerobic bacteria. OM decay and leaching rates were

measured from several types of terrestrial OM that typically enter the Jordan River (Richardson 2014). Leaching rates of dissolved organic carbon (DOC) from grass or leaves were 9–10 times greater than wood. Grass produced more total dissolved nitrogen (TDN) leachate than both leaves and wood during the same time period.

Significant differences in the amount of DOC leaching were observed during the first 6 hours between coarse particulate organic matter (CPOM) types. In regard to TDN, no significant differences were observed between CPOM types after the first hour. All types of OM included in the test indicated a rapid and significant loss of DOC and TDN from leaching in the first few hours. Loss of DOC in the first 3 hours was 87–92 percent of the total DOC measured during the analysis and loss of TDN during the same time period was 83–87 percent. After the first 3 hours, leaching of DOC and TDN continued at a much lower rate from all CPOM types throughout the remainder of the 24-hour test. These results indicate that substances leaching from CPOM during the first 3 hours are most labile and that prolonged contact with water continues to leach somewhat less biodegradable OM at a steady rate.

Leaching tests have indicated similarities between BOD and less expensive or less time-consuming water quality tests that also measure oxygen demand in the water column. For instance, DOC and chemical oxygen demand (COD) were correlated to BOD at 0.98 and 0.99, respectively (Richardson 2014). These results indicate that DOC and COD could be used to predict the BOD of a CPOM-derived dissolved OM. The cost for each test varies by laboratory , but several Utah laboratories indicate COD is a less-expensive measurement than BOD_5 The time needed to complete a DOC or COD measurement is several hours compared to the five-days needed for a BOD_5 measurement.

In regard to COD tests, measurements found no significant difference in COD from filtered and unfiltered leachate so COD is primarily attributed to mostly dissolved material rather than the particulate material. Similar to DOC, the rate of production of COD was highest during the first hour of leaching tests.

Research has compared the C:N ratio in leachate to the C:N ratio in solids to identify the nature of material leaching from OM solids (Richardson 2014). The ratio of C:N in leachate suggests that oxygen-demanding processes are primarily regulated by the content of biodegradable C and not the N content. The ratio of C to N in leachate also suggests that C compounds are more soluble than N compounds in leaves, and N compounds are more soluble than C compounds in wood. The ratio of C to N in leachate and solids is statistically the same for grass. This has implications for source allocations by emphasizing more control of substances containing biodegradable C (i.e. leaves) over wood debris. These results also justify using DOC as a monitoring parameter for water column demand in the future, as most oxygen demand is generated by biodegradable C and not nitrogen.

Measured levels of oxygen demand in the water column are greatest in the UJR (Hogsett 2015). These differences could be due to the BOD required to oxidize soluble and suspended OM in the water column or respiration by suspended living material (e.g., phytoplankton and sloughed periphyton). In general, water column oxygen demand decreased dramatically during the winter including several sampling events where demand was zero. Warm temperatures increase water column metabolism. During the winter these rates were much lower where water temperatures were not influenced by warm discharge from WRFs.

Simultaneous measurements of DO and fluorescent dissolved organic matter (fDOM) were collected from in-situ monitoring sensors installed at five locations in the LJR (DWQ 2015b). An

increased concentration of fDOM measured at these locations generally corresponded to a decrease in DO that recovered within a few days (Figure 6). The relationship between fDOM and storm events appears to be strongest during the spring season. The largest increase in fDOM occurred near the end of July in response to a series of fairly minor storm events. Larger storm events during other times of the year corresponded to a relatively lower increase in fDOM. Although Figure 6 indicates the interaction among storm events, fDOM, and DO, the general trend in DO seems to be independent of storm events.

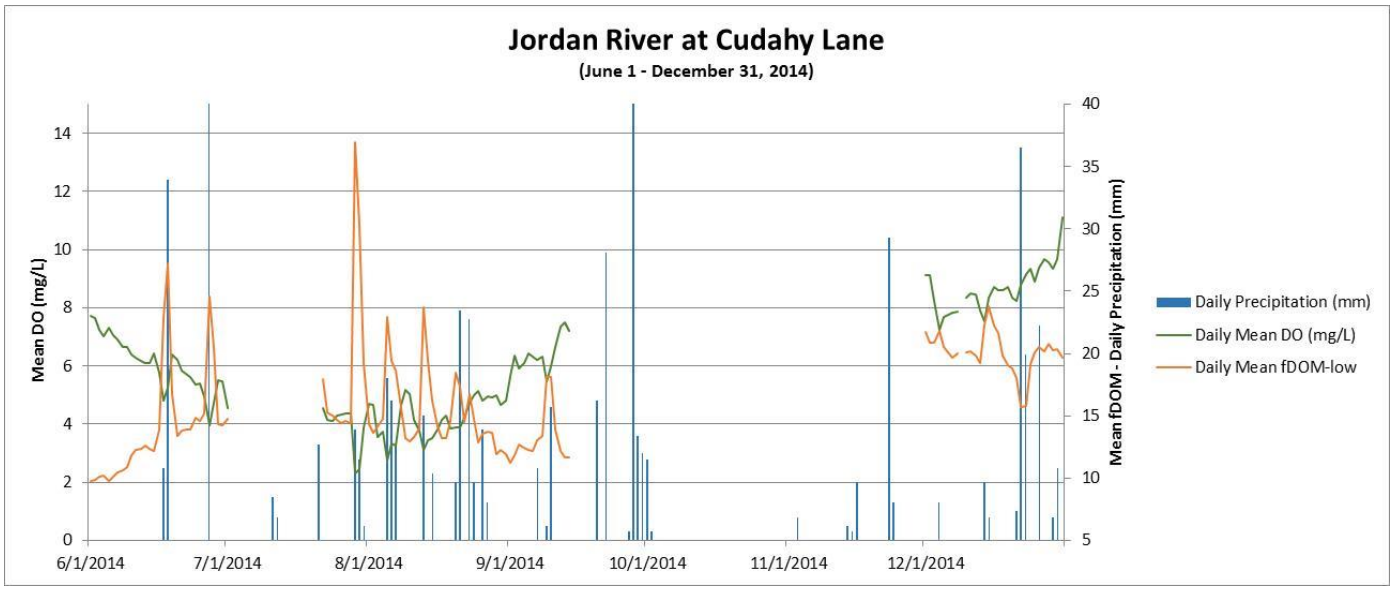

Figure 6. Daily average concentrations of DO (mg/L) and fDOM at Cudahy Lane. Source: DWQ 2015b.

2.5 REAERATION

Reaeration was modeled in the Jordan River using measurements of DO and temperature that provide an additional comparison to measured rates (Hogsett 2015). Average reaeration estimates (K d^{-1}) in the LJR ranged from 0.4 to 14 d^{-1}. They varied between sites and seasons but generally showed a reduction with distance downstream that corresponded to a reduction in channel gradient and increased stream depth. The highest estimates were made at the furthest upstream sites and lower reaeration estimates were associated with the lower river. Sites with the highest reaeration estimates were also the most autotrophic (7800 South and 5400 South). The highest reaeration and metabolism estimates were made at 5400 South, which was a highly productive stream reach with a high gradient. Lowest reaeration rates were estimated in LJR segments.

Although some measured reaeration rates were used in the Phase 1 TMDL, additional assessment and analysis of these and other measurements has been completed since that time (Hogsett 2015). Table 1 shows reaeration rates that were measured with a diffusion dome floated down the middle of the channel in all sections of the Jordan River. Measured reaeration ranged from 0.6 to 17.7 1/day. Reaeration rates were greatest in middle sections of the UJR where gradients are steepest and less in upper (near Utah Lake) and lower segments (below Cudahy Lane) where gradients are relatively flat and the river is deeper. Measured and modeled reaeration rates have similar ranges, and both methods show relatively lower values in LJR segments.

River section	Reach #	$K_{2,20}$ (1/day)	Float #
1700 N to LNP NE	1 & 2	0.6	1 & 1b
1700 S to 900 S	3	4.2	2
3300 S to 2100 S	3 & 4	7.0	3
5400 S to 4170 S	4	5.1	4
9000 S to 7800 S	5 & 6	17.7	5
12600 S to 10600 S	6	11.0	6
Lehi	8	3.4	7

Note: $K_{2,20}$ = Reaeration coefficient normalized to 20 °C
1b = reaeration coefficient measured twice

Table 1. Measured reaeration coefficients for the Jordan River. Source: Table 2 Hogsett 2015.

Width and depth-integrated measurements of DO were collected above and below the radial gates that divert water to the LJR (Salt Lake City 2015). This effort was completed to determine the effect of reaeration as water moves through the gates. Upstream of the radial gates, DO was measured to be 8.03 mg/L in the center of the channel. Downstream of the check dam that spans the full channel width of the Surplus Canal, DO was 8.15 mg/L. Average DO below the radial gates in the LJR was measured at 8.32 mg/L, resulting in an increase of approximately 0.3 mg/L DO due to reaeration as water passes through the radial gates.

2.6 Evidence of Chronic Water Quality Impairment

Water quality is continually measured in-situ at five locations on the LJR including Burnham Dam, Cudahy Lane, 300 North, 800 South, and 2100 South (DWQ 2015b). Measurements collected at each location include temperature, pH, DO, turbidity, and fDOM. Cross-sectional DO measurements were manually collected at each in-situ monitoring location to identify variations associated with depth and width and to compare to automated measurements from in-situ probes (Salt Lake City 2015). Cross-sectional measurements showed that variation is generally less than 1 percent of the profile's mean DO concentration. This well mixed condition is consistent during dry and wet weather. Based on these results, DO monitoring by in-situ probes to determine impairment is appropriate given the well mixed nature of the Jordan River.

Manual DO measurements on average were approximately 1.5 mg/L lower than measurements from adjacent in-situ probes (Salt Lake City 2015). This difference may be due to calibration issues/sensor drift or perhaps due to the influence of algae on the sensor housings. The latter hypothesis is an expected result if there were a localized increased flux of oxygen to the probes from algal photosynthesis. Field observations of in-situ probes also identified the presence of algae collected around some sensors.

Available in-situ DO monitoring data collected from four LJR sites were compared to appropriate acute and chronic standards (Table 2; DWQ 2015b). The total number of measurements at each site varied due to sensor malfunction and a screening process that eliminated measurements during periods when sensor voltage fluctuated. The remaining data set includes measurements collected during storm (wet) and non-storm (dry) periods. Measurements collected every 15

minutes were compared to the acute standard, and the 30-day moving average was compared to the chronic standard. Table 2 clearly shows extended periods of time when both DO standards are violated. This analysis identified violations of both DO standards during wet and dry periods, indicating that DO impairment in the LJR is not only in response to storm events.

Table 2. Comparison of diel DO monitoring data to acute and chronic standards for the lower Jordan River. Data are compared to the appropriate acute standard, based on measurement date (i.e. Aug-Apr=4.0 mg/L and May-Jul=4.5 mg/L). Each data set used in this comparison has been screened to remove measurements associated with voltage fluctuations Source: (DWQ 2015b).

Station	Monitoring Period	Duration below 4.0 or 4.5 mg/L DO (hrs.)	Consecutive days below 30-day moving average of 5.5 mg/L DO (days)
2100 S	Jan 1-Sept 2, 2014	hrs < 4.5 = 61.5 hrs < 4.0 = 0.25	0 days
800 S	May 12–August 13, 2014	hrs < 4.5 = 109.5 hrs < 4.0 = 121.75 Total hrs = 231.25	31 days
300 N	Jan 1 – Dec 27, 2014	hrs <4.5 = 136.25 hrs < 4.0 = 150	61 days
Cudahy Lane	Jun 1 – Dec 31, 2014	hrs < 4.5 = 242.25 hrs < 4.0 = 296	67 days

2.7 WATER QUALITY MODELING

Recent monitoring data from the Jordan River was used to validate the calibrated QUAL2Kw model used in the Phase 1 TMDL (DWQ 2015a). Results of this assessment identified areas where future improvements can be made. Model performance during the validation process was good for many parameters (e.g., temperature, specific conductivity, total suspended solids, total nitrogen, and total phosphorus). The updated model was considered suitable for use in making wasteload allocations for Jordan River WRF permit renewals scheduled for 2015 and 2016. Based on model validation results, several recommendations were made to improve future performance including:

- Revisit the calibration of selected parameters related to simulating benthic algae growth, as well as ammonia decay and plant uptake, particularly in the UJR. As with the original calibration, adjustments to the model parameterization should be conducted in consultation with the modeling workgroup associated with the TMDL.
- Evaluate potential enhancements to the model to improve simulation of SOD, including specification of decay rate parameters and tracking of organic matter in labile, refractory and inert pools. Improve understanding and simulation of scour of benthic algae from the UJR during storm events and at senescence, and subsequent deposition in the LJR.
- Explore transitioning the steady-state QUAL2Kw model to a dynamic modeling platform. The limitations of the steady-state model include an inability to explicitly 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. Evaluate coupling a watershed runoff model to the riverine water quality model in order to simulate wash-off and transport of nutrients and OM over multiple years, including wet and dry periods.

- 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.

The results of other Jordan River research has provided input parameters that can be used to populate the updated QUAL2Kw model. Field measurements of SOD, methane, ammonium, and orthophosphate sediment fluxes can be directly incorporated into the model (Hogsett 2015). The organic content of surface sediments (sediment %VS) has also been identified as a reliable surrogate to predict SOD and methane flux (Hogsett 2015). Sediment %VS is a relatively simple and cost-effective measure to define oxygen loss from these processes in future modeling efforts.

The calibrated QUAL2Kw model from the Phase 1 TMDL was used to evaluate potential improvements in DO under different flow scenarios (SWCA 2013). Figure 7 shows the model response to increasing flows. More specifically, a 25 percent flow increase to the LJR (from 123 to 188 cfs) would raise average DO concentrations above 5.5 mg/L. These results will be used by DWQ and the Jordan River Commission to guide field experiments that measure DO response from managed flow releases to the LJR.

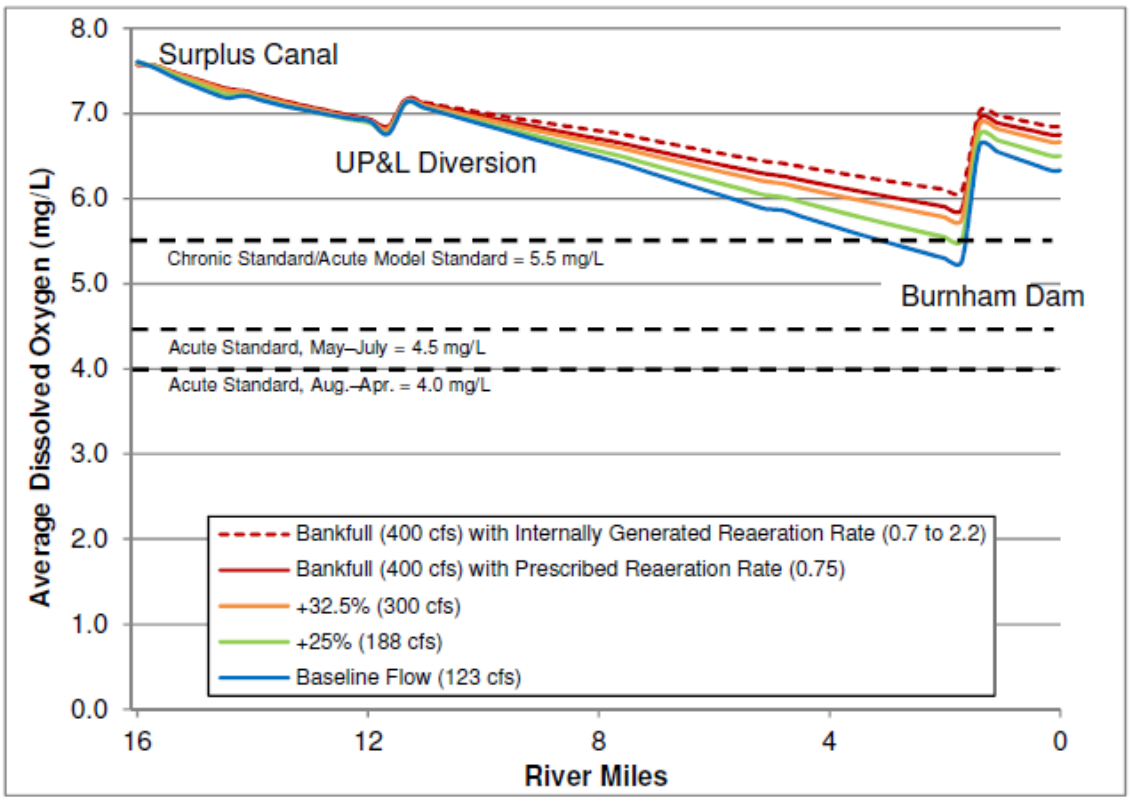

Figure 7. Sensitivity of QUAL2Kw model to changing flow conditions. Source: Figure 8 SWCA 2013.

3.0 TOTAL OM AND OM SOURCES

Organic matter in the Jordan River comes from a combination of sources located away from the channel as well as sources that create OM in the water column and sediments of the channel itself. Natural sources of OM outside of the channel are described as terrestrial sources

(allochthonous) and OM produced within the channel is defined as autochthonous. Several categories are used to characterize the size of OM produced by different sources including coarse particulate organic matter (CPOM), fine particulate organic matter (FPOM), and dissolved organic matter (DOM). In most research, the threshold between CPOM and FPOM is 1 mm and DOM is all material less than 0.45 um. In most research, DOM and DOC are used interchangeably. For consistency sake, this memo will use DOC when discussing OM measuring less than 0.45 um.

This section summarizes research results that can define OM pollutant sources and load allocations for use in the Phase 2 TMDL. This section begins with a brief summary of pollutant source information used in the Phase 1 TMDL, followed by a review of new results on total OM and OM sources. New information includes an OM budget for the Jordan River, sources of OM measured in the water column, and sources of OM in channel sediments.

3.1 PAST UNDERSTANDING

The Phase 1 TMDL defined OM in the Jordan River as a combination of living and dead material in a range of coarse and fine particles sizes. The combinations of these forms of OM can vary depending on the pollutant source and season, which has a significant effect on decomposition rates and oxygen loss. Furthermore, the rate of OM decay can vary based on the type of material exposed to decomposition. Little or no information was available to quantify how total OM loads change as they move through upper segments and into the LJR or how OM loads vary between seasons and years.

Seven pollutant sources that contribute OM to the Jordan River were identified in the Phase 1 TMDL, including Utah Lake, WWTPs, stormwater, tributaries, diffuse runoff, irrigation return flow, and natural background loads. Direct measurements of OM from each source were limited. Proxy measurements of OM, including VSS, TSS and BOD_5 were used to define OM pollutant loads for each source for current and future conditions.

The Phase 1 TMDL estimated current loads of FPOM to the LJR at 1,784,500 kg/yr. Stormwater loads of FPOM (including UJR stormwater loads) collectively contributed about 53 percent of this amount. Direct stormwater discharge between 2100 South and North Temple alone contributed about 25 percent of the total FPOM load. Stormwater loads between 2100 South and Cudahy Lane provided about 35 percent of the total FPOM load. Natural flow from tributaries contributed about 18 percent, three WRFs contributed 8 percent, and irrigation return flow and diffuse runoff accounted for the remainder of the total FPOM load.

Limited SOD measurements were available for use in the Phase 1 TMDL, and OM loads contributing to SOD were based on amounts of prescribed SOD used in the calibrated QUAL2Kw model. Levels of oxygen demand from channel sediments were converted to daily water column oxygen demand based on the stoichiometry of OM and assumptions that OM contributions to the LJR occurred year-round. Based on these assumptions, current loads of OM that contributed to SOD in the LJR were estimated at 441,022 kg/yr. About 85 percent of this amount was considered to come from nonpoint sources, and the remainder from point sources. About 68 percent of the total OM load contributing to SOD was assumed to enter the Jordan River above 2100 South.

The exact proportions of OM size categories were not known in the Phase 1 TMDL. OM particle size categories provided useful information in support of critical processes that affect movement and deposition of OM between sources and the LJR. Total OM loads were defined with a

combination of direct measurements and computer modeling. These loads were assumed to include all particle sizes and OM loads that could influence DO in the LJR. Bulk (total) loads in Table 3 show the mass of OM at the pollutant source and the resulting OM load to the LJR after accounting for diversions and processes of settling and dissolution.

Table 3. Existing bulk OM loads to the lower Jordan River used in the Phase 1 TMDL. Source: Table 3.9 Jordan River Phase 1 TMDL.

Sources		Current Loads at the Source (kg/yr)	Current Loads to Lower Jordan River (kg/yr)
Point Sources	Upstream of 2100 South	2,757,817	469,062
	Downstream of 2100 South	700,282	700,282
Nonpoint Sources	Upstream of 2100 South	6,941,909	752,429
	Downstream of 2100 South	303,749	303,749
Total		10,703,757	2,225,523

3.2 ORGANIC MATTER BUDGET

Jordan River OM transport and accumulation has been defined with an OM budget based on measurements collected during the 2013 water year (Epstein and Baker 2014, Epstein et al. 2015). These results help identify the origin of OM in the LJR and understand how and where different size classes of OM are generated. Measurements indicated the OM budget at the seven monitoring locations was dominated by DOC, which was on average an order of magnitude greater than FPOM transport and two orders of magnitude greater than CPOM transport. Figure 8 shows monthly average loads for all sites sampled in the Jordan River in regard to contributions from coarse, fine, and dissolved OM and Table 4 shows annual loads at each monitoring location.

Although discharge can be a major driving factor in the magnitude of load transport, the greatest transport of DOC and FPOM occurred during the fall and summer months, respectively, rather than during spring runoff (Figure 8). CPOM transport was greatest in May and September which correspond with growth and deposition of riparian vegetation. Loads of CPOM were typically less than 5 percent of the total OM in transport in the Jordan River (Epstein and Baker 2014). Figure 8 shows that monthly OM transport in the Jordan River was greatest during October and November , due primarily to DOC loads. Sample measurements of DOC were greatest during the fall months and fairly stable over the rest of the year. DO violations at LJR monitoring sites have occurred during most months but are greatest during July–October Dominance by DOC in the OM budget is not unique to the Jordan River. A majority of OM budget studies have reached similar conclusions in regard to DOC including those in drastically different ecosystems such as forested headwater streams.

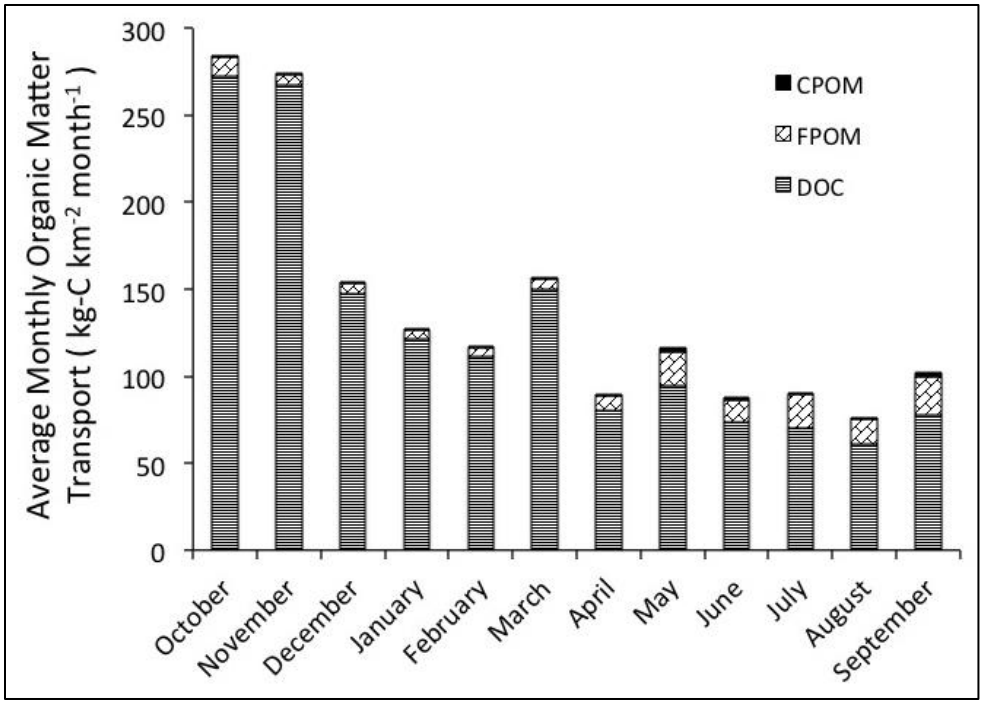

Figure 8. Average monthly OM transport in the Jordan River during the 2013 water year. OM is classified into coarse particulate OM (CPOM), fine particulate OM (FPOM), and dissolved organic carbon (DOC). Units on the y-axis are kg-C/km2/month and account for contributing watershed area. Source: Figure 3 Epstein et al. 2015.

Table 4 shows that for both DOC and FPOM, loads increased from 7800 South downstream to 2300 South. Loading between 2300 South and 1700 South was reduced by diversions to the Surplus Canal. OM transport below 1700 South was varied. The greatest increase in OM transport was found from 7800 South to 5400 South and from 3300 South to 2300 South. Some of these changes might be due to increased watershed area that contributes to each segment. To normalize this effect, OM transport "yield" was calculated by dividing gross OM transport by the contributing watershed area for each site. The yield analysis also identified river segments between 7800 South–5400 South and 3300 South–2300 South as "gaining reaches" that contribute disproportionally to the overall OM transport within the river. Transport of FPOM and DOM below the Surplus Canal was varied and transport of CPOM showed a steady increase with distance downstream in the lower Jordan River.

Table 4 indicates that OM increases to gaining reaches are primarily due to unmeasured inputs of FPOM and DOC (Epstein and Baker 2014, Epstein et al. 2015). However, other research (Peterson 2010, Miller 2015) has identified significant CPOM loading from tributaries and these results are discussed below in section 3.3.3. OM loading from gaining reaches warrants further study to quantify amounts and sources of all OM pools and their potential contribution to oxygen consumption.

	Watershed Area	Discharge	CPOM Transport	FPOM Transport	DOC Transport	FBOM Standing Stock	Litterfall
Site/reach	km^2	$m^3\ yr^{-1}$	kg-C yr^{-1}	kg-C yr^{-1}	kg-C yr^{-1}	kg-C $reach^{-1}$	kg-C $reach^{-1}$
7800S	622	7.46E+07	12,279	56,973	738,834	227	1,176
5400S	751	1.20E+08	6,785	120,986	1,324,580	429	3,251
3300S	1,088	2.19E+08	12,766	183,873	1,869,406	245	1,495
2300S	1,191	3.02E+08	27,514	298,016	3,427,084	655	184
1700S	1,243	1.22E+08	6,023	114,510	1,405,851	1,073	1,425
500N	1,606	1.69E+08	8,592	141,469	1,864,311	4,297	1,181
Cudahy	1,684	1.46E+08	14,373	123,625	1,460,248		

Table 4. Annual loads of OM size categories, standing stock, and litterfall for seven Jordan River monitoring sites included in the OM budget. Loads are based on measurements collected during the 2013 water year (August 2012–September 2013). Watershed area does not include the watershed feeding Utah Lake. Estimates of fine benthic organic material (FBOM) standing stock and litterfall represent estimates for the reach in between sampling sites. Average FBOM standing stock and litterfall measurements for each reach were multiplied by the area of the reach to generate total mass estimates. Source: Table 1 Epstein and Baker 2014.

OM budget results indicate the potential for upstream loading to downstream river segments. Table 4 identifies river segments that are either a source or sink of OM. Results of net stream metabolism calculations described above (section 2.3) also indicate loading potential from autotrophic stream segments, including 7800 South–5400 South and 3300 South–2300 South (Epstein and Baker 2014, Epstein et al. 2015). Other research indicates the majority of production and respiration in UJR segments during the late summer season occurs in the water column from phytoplankton and other suspended aquatic material (Figure 9; Hogsett 2015). Sources that contribute to an OM load that settles in the LJR must be identified along witht the timing of OM loads. Although late summer OM production in the UJR may be a potential source to the LJR, a substantial amount could also have been delivered during the spring season. Ultimately OM sources and timing of OM loads that settle in the LJR will be defined in the Phase 2 TMDL.

Measurements from Utah Lake found that water column respiration rates were greater than SOD, indicating the lake as a likely source of phytoplankton and sestonic OM to the UJR. These results, along with others indicate high productivity throughout the UJR and potential for seasonal OM contributions to the LJR. Research results that explicitly define an OM load from Utah Lake are limited. Measurements of Jordan River OM reported by Epstein et al. (2015) begin at 7800 S. and Miller (2015) was primarily focused on tributaries, LJR segments, and one OM size class. Hogsett (2015) reports OM measurements at 9000 S that reasonably approximate loading from Utah Lake. Additional monitoring data collected by DWQ will be used to supplement existing results to characterize the influence of OM loading from Utah Lake on the LJR.

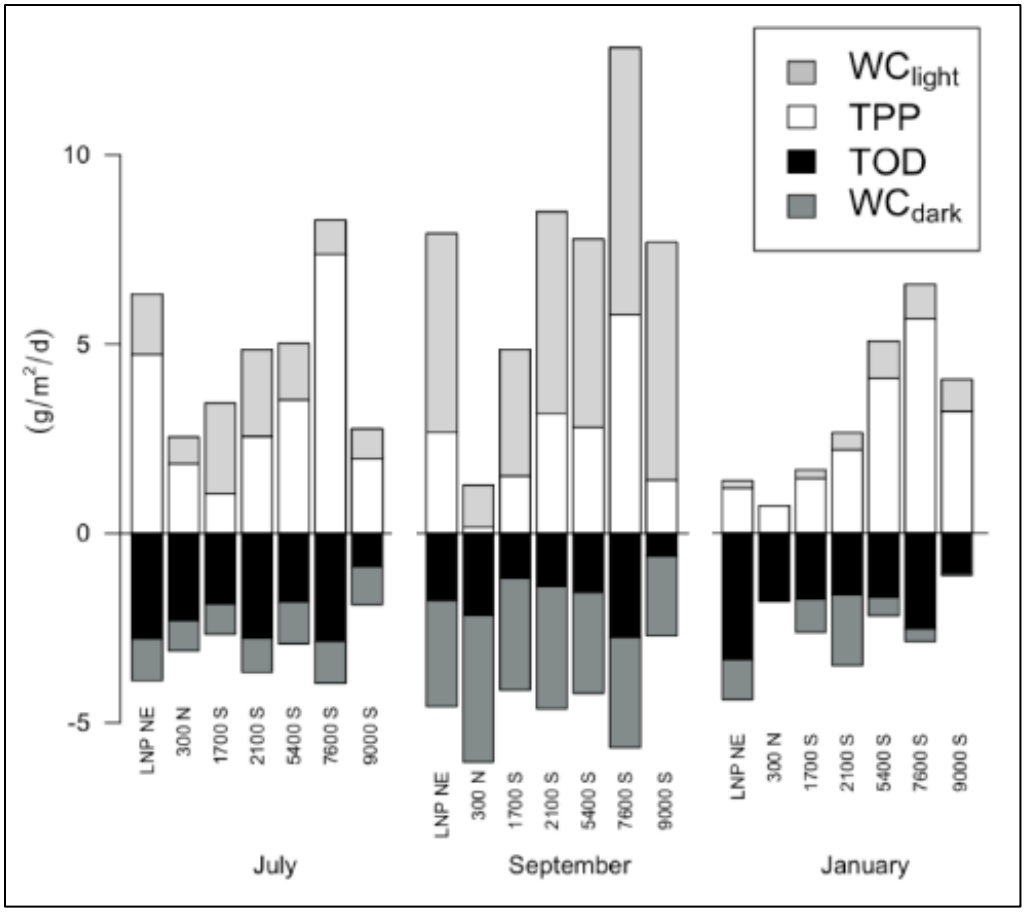

Figure 9. Gross primary productivity and respiration during July 2010, September 2010, and January 2011. Measurements include productivity from the water column (WC_{light}) and sediment (TPP), as well as respiration from the water column (WC_{dark}) and sediment (TOD). Units are g-DO/m^2-d. Source: Figure 47 Hogsett 2015.

The UJR also represents a source of OM loading to the LJR. Calculations of the autotrophic net daily metabolism in the UJR indicate this source could contribute 55 percent of the OM load estimated in the Phase 1 TMDL for the Jordan River above 2100 South (Hogsett 2015). Epstein et al. (2015) measured fine benthic OM (FBOM) standing stock in Jordan River segments and concluded that flows from Utah Lake were a primary influence on benthic OM productivity in the UJR. Epstein et al. (2015) also noted that flows from Utah Lake contain a concentrated amount of FPOM due to pelagic production and resuspension of OM deposits. Although current research does not quantify the influence of nutrients from Utah Lake on primary production in the UJR, a positive influence likely exists. Additional research should be conducted to quantify this influence.

Spiraling length and uptake velocities can be used to determine how OM molecules move through and are used in the Jordan River system (Epstein et al. 2015). Spiraling length is the downstream distance a carbon atom will travel as it cycles from dissolved to particulate form (uptake), decomposition, and transition to a dissolved form available for uptake. Estimations of spiraling length (38–68 km) for DOC indicate that loads produced at 7800 South–5400 South and 3300 South–2300 South are likely delivered to LJR segments where they contribute to the DO deficit.

Uptake velocities indicate the rate (m/d) at which carbon molecules are converted to biomass (i.e. how fast carbon molecules are pulled out of the water column). High estimated uptake velocities in the LJR indicate there is high demand for water-column nutrients and carbon from heterotrophic organisms in the river. Increased transport of OM shown in the OM budget from the upper river could explain the consumption of DO in the lower river as heterotrophs consume DO in the OM removal process (Epstein and Baker 2014, Epstein et al. 2015).

Stream metabolism index (SMI) is the ratio of measured respiration to the theoretical respiration needed to prevent accumulation of OM (i.e., process all OM entering the stream segment). An SMI less than 1 indicates no accumulation of OM and an SMI greater than 1 indicates accumulation of OM. SMI values for upper river segments (7800 South–2300 South) ranged from 0.17–0.39, indicating that OM loading was greater than respiration (Epstein et al. 2015). Estimates of SMI in the lower river ranged from 1.0–1.1 and demonstrate transport of excessive organic matter from the upper Jordan River to the lower Jordan River and not the result of lateral inputs (Epstein et al. 2015). These results are consistent with the OM budget (Epstein and Baker 2014, Epstein et al. 2015).

3.3 Organic Matter in Water Column

Organic matter in the water column provides opportunities for loss of DO as OM is consumed by bacteria. Suspended OM is either consumed, exported, or deposited on the channel bottom. Deposits of OM are resuspended and moved downstream or buried by additional material over time. This section describes sources of OM measured in the water column and new information that can be used to identify OM sources and relative contributions from each source.

3.3.1 Dissolved Organic Matter

Many studies use measurements of DOC to represent the DOM fraction. The results discussed below will refer to DOM as DOC where studies have used this measurement. The use of DOC in aquatic ecosystems is dependent on lability, and some studies consider the refractory portion of DOC to be greater than the labile portion (Epstein et al. 2015). However, research on decomposition of Jordan River OM and contributions to the DOC pool have shown a different response (Richardson 2014). These results were described above (section 2.4) and indicate the vast majority of biodegradable material is leached from OM in the form of DOC during the first 3 hours of entering the water. Furthermore, the oxygen demand generated by leached DOC is an order of magnitude higher in the first hour compared to the next 2 hours. Organic matter captured by stormwater collection systems can be rapidly decomposed prior to discharging to the Jordan River depending on the age and condition of the OM.

Instream sampling of DOC during dry (non-storm) periods identified highest concentrations during the fall months which also correspond to the highest loads from leaf litter. Measured concentrations of DOC were fairly stable in all other dry (non-storm) monitoring periods.

The level of DOC and oxygen demanding substances contained in stormwater (and other human influenced sources) can substantially decrease ambient oxygen levels as they mix with the Jordan River. OM budget numbers indicate a loss of DOC annual loads at 2300 South–1700 South and 500 North–Cudahy Lane (Table 4) and provide some indication of the extent of DOC use. However, some DOC may oxidize rapidly after entering the Jordan River, and these loads might not be captured by routine monthly sampling during dry (non-stormwater) periods (Richardson 2014).

Figure 6 indicates the periodic impact of DOM measured by in-situ probes during storm events on oxygen levels in the LJR (DWQ 2015b). Additional stormwater monitoring on Little Cottonwood Creek and Mill Creek at the Jordan River confluence showed that OM concentrations (measured as TOC, BOD, or cBOD) increased during storm events while nutrients (TP and NO3/NO2) stayed relatively constant. Comparatively, Little Cottonwood Creek had higher stormwater concentrations of OM while Mill Creek had higher concentrations of nutrients. Relatively higher OM concentrations in Little Cottonwood Creek could be due to more open space in valley areas draining to the stream. High nutrients in Mill Creek flows that enter the Jordan River are due to discharge from the Central Valley WRF which was approximately 1,000 feet upstream of the sampling location (Salt Lake City 2015).

The effects of wastewater nutrient loads on DO concentrations have also been measured (DWQ 2015a, Hogsett 2015). Water column productivity and respiration were lower t following WRF discharge at sites located at 5400 South (below South Valley WRF), 2100 South (below Central Valley WRF), and Legacy Nature Preserve NE sites (below South Davis South WRF) compared to sites upstream from WRFs (Figure 4). However, there was a general upward trend in productivity and respiration from 12600 South to 3300 South. Water quality samples collected from Mill Creek about 1,000 feet below Central Valley WRF discharge showed undetectable levels of carbonaceous BOD (cBOD), indicating the oxygen demand directly created by WRF discharge is limited to a short distance (Salt Lake City 2015). Additional research is needed to determine the influence of wastewater nutrient loads on autochthonous OM production and subsequent DO demand in the lower Jordan River.

In contrast, periodic DO monitoring at 3300 S and 2100 S has also shown a consistent decrease of 1-2 mg/L.. The only major tributary to the river between these two sites is Mill Creek indicating this tributary as a possible source of DO demanding substances (Salt Lake City 2015). However, this decrease may be due to SOD values which averaged -4.69 g DO/m^2-d just above the Surplus Canal diversion (Hogsett 2015). The amount of SOD in this reach is likely influenced by channel morphology and upstream OM sources. The Jordan River transitions from a transport to a depositional reach near 3300 South. The channel segment downstream to 2100 South accumulates organic material from upstream terrestrial and autochthonous sources. These OM deposits contribute to high SOD values in the reach. However, nutrients can also influence autochthonous OM production and more research should be conducted in regard to the influence of wastewater nutrient loads on SOD and subsequent effects on DO levels.

Isotope analysis of samples taken from known sources of DOM indicates that DOC corresponds with terrestrial sources (Figure 10a; Kelso 2015). Isotope mixing models were also used to predict the percent contribution of each source to DOM (Kelso 2015). On average, DOM was derived primarily from terrestrial sources (mean = 90 percent) and less so from autochthonous sources (mean = 10 percent, Figure 10b). Note that Figure 9b shows a relatively wide variation of potential contribution of terrestrial sources (50–100 percent) and autochthonous sources (0–40 percent).

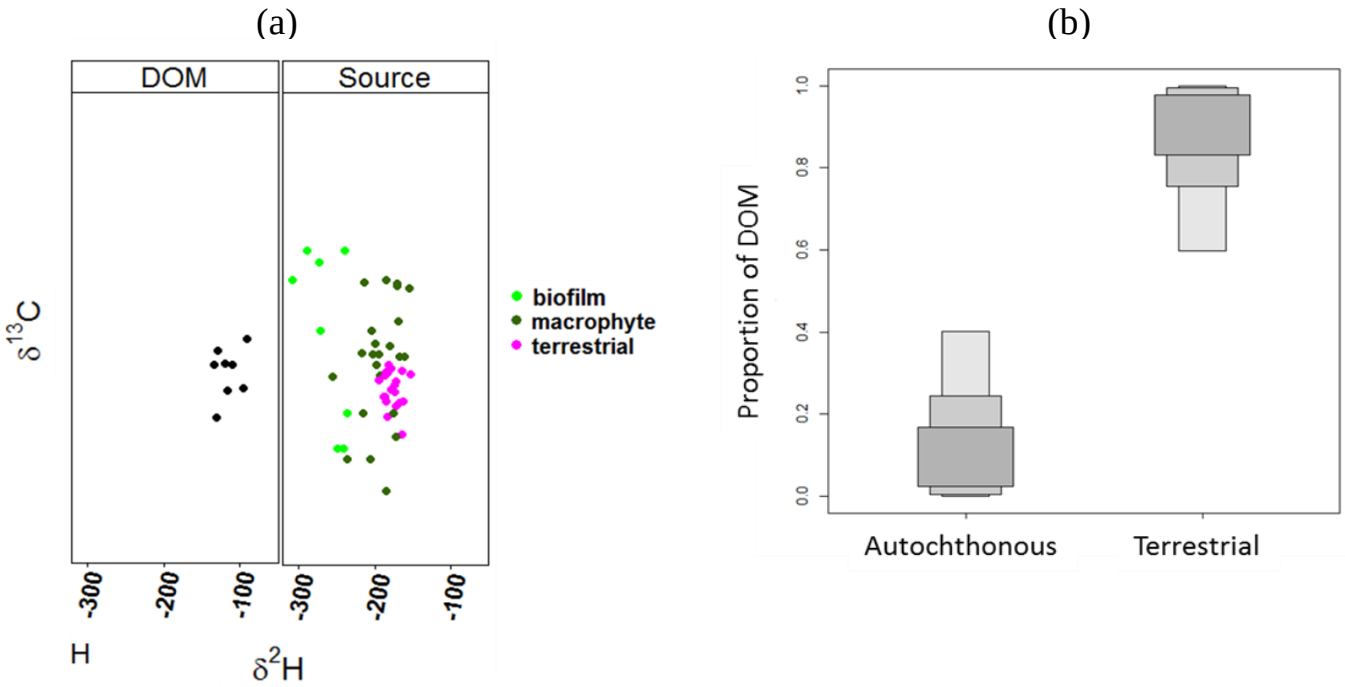

Figure 10. (a) Carbon and deuterium isotope values of DOM compared to potential sources of DOM. Potential sources of DOM are coded by color, with biofilms (all types of periphyton and algae) represented in light green, macrophytes (both senesced and alive) in dark green, and terrestrial sources (both senesced and alive) in purple. Source: Figure 2 Kelso 2015. (b) Isotope mixing model results for DOM. The DOM model was run with two isotope tracers carbon and deuterium. Source: Figure 3c Kelso 2015. Results in both figures are based on samples collected during spring, summer, and fall of 2013–2014.

Additional information has been collected regarding the potential impact of short-term disturbance on DO, during activities that involved deep and shallow disturbance in Jordan River channel sediments (Salt Lake City 2015). This research did not determine if oxygen loss was due to an influx of DOC, methane, or other substances. Measured DO levels adjacent to deep disturbance (i.e., dredging to 4-foot depths) dropped by 3.4 mg/L (from 6.3 to 2.9 mg/L) immediately after dredging started. DO levels did not return to baseline conditions for a period of about 5 minutes in backwater areas. The extent of impacts for this type of situation would depend on the magnitude (depth and length) of disturbance and local flow conditions. If disturbed sediments moved down the river, the effect would be substantial. If bulk DO went back to normal after the sediments settle, demand would be limited by diffusion of DOC out of sediments and into the water column. If sediments settled quickly, the demand would be transitory.

Measured DO levels were also recorded downstream from shallow disturbance (about 6–8 inches) at three locations in the LJR (1700 S, 800 S, and Redwood Road) during summer and fall 2015 (Salt Lake City 2015). This effort showed suspension of streambed sediments to a depth of 6–8 inches does not significantly decrease DO regardless of substrate type or location downstream from the point of disturbance.

Although initial studies indicate that small-scale suspension does not significantly affect DO, variability in results may warrant additional studies that disturb greater depths of sediment or on larger scales would be helpful to better understand DO dynamics. These results do suggest potential oxygen demand from sediments that is in addition to chronic demands produced by SOD.

3.3.2 Fine Particulate Organic Matter

Isotope analysis showed that autochthonous sources of OM (biofilms and macrophytes) have similar C13 values to FPOM and much lower C:N values than terrestrial sources (Figure 11; Kelso 2015). Lower C:N values are indicative of labile substances that are more easily decomposed. Isotope analysis of samples taken from known sources shows that FPOM corresponds more closely with autochthonous sources than with terrestrial sources (Figure 11).

Isotope mixing model estimates of FPOM predicted an equal contribution from both terrestrial and autochthonous sources (lower plot – Figure 12b). The results of Jordan River isotopic analysis agree with findings in other publications where FPOM has isotope values and C:N ratios similar to that of in-stream primary producers (Epstein et al. 2015).

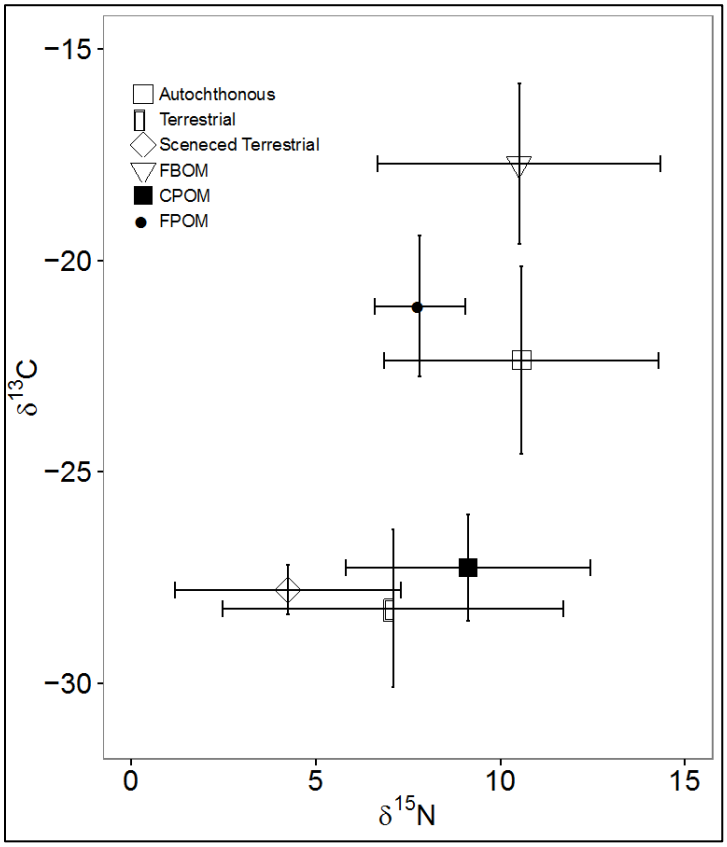

Figure 11. Stable isotope ratios ($\delta^{13}C$ and $\delta^{15}N$) for organic matter (OM) sources within the Jordan River. The OM "sources" are displayed in the frame on the right while CPOM and seston (FPOM) pools are displayed in the left and center frames, respectively. Individual points are samples taken from October 2012 to September 2013 and $\delta^{15}N$ is shown on the x-axis while $\delta^{13}C$ is shown on the y-axis. The range of $\delta^{13}C$ for DOC samples is shown within the black rectangle on the y-axis.

FPOM is typically comprised of both living and dead material. Chlorophyll *a* (Chl-a) is found in living algal cells and is a component of the FPOM pool in the Jordan River. Measured concentrations of Chl-a were much greater in UJR segments in comparison to LJR segments (Epstein et al. 2015). Concentrations were greatest at 5400 South (about 20 ug/L) and decreased down to Cudahy Lane (about 5 ug/l). On average, Chl-a comprised about 2 percent of total FPOM mass with an average concentration around 10 ug/L, while FPOM concentrations averaged 800 ug/L.

The ratio of Chl-a to FPOM varies depending on location in the Jordan River. In general, living OM (measured as Chl-a) was much greater in the UJR compared to the LJR. Visual evidence of FPOM was observed in many UJR segments as groups of filamentous algae (Epstein et al. 2015, Hogsett 2015). Concentrations of FPOM and Chl-a were relatively less in LJR segments due to greater turbidity, shading, and a smaller proportion of Utah Lake water in the river, on account of tributary inflow and groundwater contributions (Epstein et al. 2015). Note that tributaries above 2100 South include some unused irrigation return flow that is sourced from Utah Lake while LJR tributaries do not.

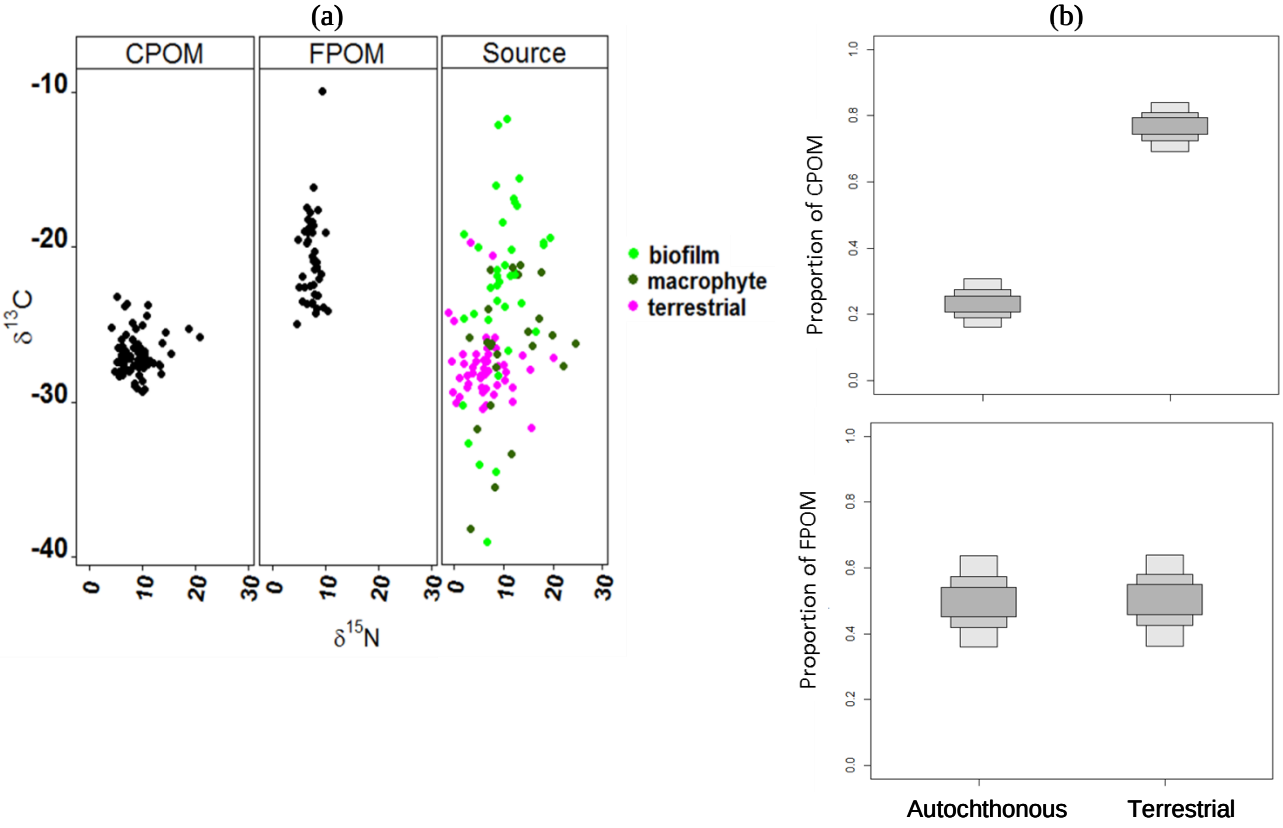

Figure 12 (a) Carbon and nitrogen stable isotope values of CPOM and FPOM compared to potential sources of CPOM and FPOM. Potential sources of OM are coded by color, with biofilms represented in light green (includes all types of periphyton and algae), macrophytes in dark green (includes both senesced and alive), and terrestrial sources in purple (includes both senesced and alive). Source: Figure 1 Kelso 2015. (b) Isotope mixing model results for CPOM and FPOM. The CPOM model was run with three isotope tracers, carbon, nitrogen and deuterium. The FPOM model was run with two isotope tracers carbon and nitrogen. Source: Figure 3a and 3b Kelso 2015.

3.3.3 Coarse Particulate Organic Matter

Isotope analysis showed that terrestrial sources of OM have similar C13 values to CPOM (Figure 11; Kelso 2015). A comparison of carbon isotopes from known sources to CPOM shows higher correlation with terrestrial sources (both living and dead) than with autochthonous sources (Figure 12a). Some overlap with autochthonous sources does exist, and it is not possible to identify individual sources. Nitrogen isotope values were much more variable than carbon isotope values and did not clearly identify differences between CPOM and FPOM. Isotope mixing model estimates predicted that CPOM was primarily composed of terrestrial OM (mean 80 percent) and a smaller contribution from autochthonous sources (mean 20 percent; upper plot Figure 12b). A comparison of molar C:N values indicated that CPOM is primarily composed of terrestrial sources, while FPOM is more similar to autochthonous sources.

Although in-stream sources of CPOM were visibly present in the Jordan River throughout the year, there was a large difference in the composition of CPOM in regard to upper and lower river segments (Epstein et al. 2015, Hogsett 2015). Samples of CPOM collected from the water column in upstream segments were comprised of mostly filamentous algae, while downstream segments yielded mostly terrestrial material (e.g., flowers, seeds, sticks, and leaves). Some differences in the type of CPOM present were likely due to increasing turbidity in lower river segments and a more expansive and mature riparian tree corridor. Results shown in Figure 9 indicate that autochthonous material (including CPOM) had the greatest influence during the critical late summer period (September), suggesting that upstream eutrophication is a potential source of OM to the LJR (Hogsett 2015). Note that high values are present at 7800 South and 9000 South, and upstream of all WRF discharges. These values suggest potential contributions from river segments above 9000 South and Utah Lake.

Inputs of terrestrial CPOM to the Jordan River may be an important source of DOM, especially in the fall months. Input from fall leaf litter during fall 2012 corresponded to maximum concentrations of DOM in the LJR. In addition, CPOM may be converted to FPOM during physical transport, but this process does not appear to be dominant due to measured loads of leaf litter in comparison to OM budget amounts of DOC and FPOM transport (Epstein et al. 2015). Isotopic signatures of CPOM (Figure 11) further indicate the primary source is terrestrial (Kelso 2015).

Monthly variation in carbon loading estimates was fairly small for DOC and FPOM but extremely high for CPOM (Coefficient of Variation=80 percent). This agrees with CPOM field surveys collected on tributaries to the Jordan River (Epstein et al. 2015, Miller 2015).

Terrestrial CPOM loads to LJR segments can be significant in some locations and during some months of the year, accounting for nearly half of CPOM transport at some sites. In comparison to the dry 2013 water year however, the total OM budget for the Jordan River indicates that CPOM contributed less than 1 percent of total OM transport (Epstein et al. 2015).

Other longer-term studies focusing specifically on CPOM loading have identified substantial OM loads that may not be reflected in Total OM budget results. Measurements of CPOM were collected on a monthly basis from the mainstem Jordan River and major tributaries to the river during April–November 2010 and throughout 2011 and 2012 (Miller 2015). During high flow periods in the spring and during periods of heavy leaf fall September–November, samples were collected every 2 weeks to more accurately account for higher CPOM delivery. Measurements were collected from tributaries at the valley edge, below debris basins, and near the Jordan River

confluence. Mainstem Jordan River sites included 1700 South, 300 North, Legacy Nature Preserve, and Burnham Dam.

Tributary measurements of CPOM indicated that debris basins had varying levels of efficiency that ranged from approximately 50–95 percent removal of the CPOM load as streams move into the Salt Lake Valley. Removal efficiency appeared to depend on basin maintenance and flow residence time (which provides opportunities for CPOM to settle). Most tributaries showed a large increase in CPOM loading contributed from urban areas in the valley, sometimes exceeding the peak monthly CPOM loads carried by each stream as it entered the valley (i.e., CPOM loads contributed by urban watersheds exceeded those from canyon watersheds). Tributary CPOM loading varied greatly between years based on annual rainfall and snowpack amounts. Peak monthly loads (typically May–June) from tributaries ranged from 1,000 to 70,000 kg CPOM depending on magnitude of flow.

Loads of CPOM measured at Jordan River sites also varied greatly between months, years, and flows (Miller 2015). Similar to tributaries, peak loads of CPOM were associated with spring flows. Monthly loads of CPOM showed a bi-modal distribution at Jordan River sites. Peak monthly loads corresponded to spring runoff and fall leaf drop, ranging from 70,000 to 6,500 kg CPOM.

The bottom discharge of the diversion dam from the Surplus Canal is considered to carry a disproportionate load of CPOM relative to actual flow. This represents CPOM loads transported as bedload which are more easily diverted to the bottom release of the gate leading to the river channel instead of over the top of the weir which is about 6 feet above the channel floor.

Based on the magnitude of flows observed during spring runoff and autumn rain events, the total annual CPOM load delivered to and carried by the Jordan River was estimated to exceed 200,000 kg/year. A combined annual CPOM load for Jordan River tributaries was also estimated at 200,000 kg/year during normal to high runoff years. Tributary loads during low runoff years were estimated to be half or less than this amount.

Differences in CPOM loading may be due to annual flows and the methods used to measure flow, collect CPOM, and process CPOM samples. Tributary loads are considered preliminary at this time, and additional documentation is needed to make an accurate comparison to OM budget research. Measurements of CPOM samples collected during both research studies were noted to have a high amount of variability between monitoring dates (Epstein et al. 2015, Miller 2015). Consequently there is potential for high variability among samples, sampling methods, and years.

3.4 Organic Matter on Channel Floor and in Sediment

Growth of OM on the channel bottom (sediment benthos) accounted for the majority of primary production in the UJR during early summer (Figure 9; Hogsett 2015). Field observations of benthic colonization were noted to be particularly high during the winter season in UJR segments relative to LJR sites. Seasonal site average percent of gross primary productivity from benthos was 65 percent for entire Jordan River.

OM research has shown that in-stream primary production from UJR segments can generate a significant amount of OM ranging from 30 to 57 percent of the OM load for the UJR estimated by the TMDL (Hogsett 2015). OM production in the UJR (water column and benthos) during the 9-month base-flow period can account for 17 percent of the annual 1.2 M kg/yr OM load estimated by the TMDL to enter the LJR.

In regard to OM loading to the LJR, the diversion at 2100 South has an underflow dam design. This design directs additional flow produced by storm events and spring runoff down the Surplus Canal. This design could potentially divert bedload CPOM (e.g. detached OM growth moving along the channel floor) from the UJR to the LJR (Hogsett 2015, Miller 2015).

A survey of benthic substrate identified dramatic changes along the length of the Jordan River from 7800 South downstream to Cudahy Lane (Epstein and Baker 2014). Channel substrate changed along a gradient from mostly cobble and rock to fine sediments (Figure 13). Finer sediments contain more OM than coarse sediment and therefore benthic biomass measured as FBOM also increased with distance downstream (Figure 14).

The OM content in sediment was observed to vary depending on runoff conditions (Hogsett 2015). Surface sediments had consistent and relatively low OM content throughout the LJR following high amounts of snowmelt in 2011 that delivered inorganic sediment. This observation corresponded to relatively lower SOD readings during that year throughout the LJR.

Surface sediments were measured for OM standing stock in 2012–2013 (Epstein and Baker 2014). These measurements indicated that 500 North–Cudahy Lane had the greatest amount (Table 4). Mean OM standing stock from 1700 South to Cudahy Lane was 5,370 kg-C (Table 4) from August 2012 through September 2013. Other measurements collected in spring 2013 identified 12,440 kg-dry OM (Table 5) in surface sediments (0-2 cm) in the reach between 1700 South and Cudahy Lane(Hogsett 2015). This mass of OM can be converted to 6,220 kg-C based on the assumption of 0.5 g C/g OM. Variance in standing stock (kg-C) between these studies could be due to seasonal differences, sample methods, or calculations used to determine area of total benthic cover. However, results from both studies can be used to characterize the mass of OM in surface sediments that contribute to SOD.

The organic content in sediment at depth steadily increased with distance downstream in the LJR (Hogsett 2015). The mass of total OM in the top 10 cm of sediment doubled between 700 South and the LNP NE site (Table 5), which is consistent with observed ambient DO deficits and measured values of SOD. Overall, the sediment column OM standing stocks increased with distance downstream in the LJR. Organic matter at greater sediment depths in the Jordan River segments downstream of the Davis County line accounted for more than 60 percent of OM in the entire LJR (Table 6).

Surface OM content (0–2 cm) in LJR segments was found to be very similar when segment totals were normalized for channel area. This consistent surface sediment layer was attributed to upstream erosion associated with the large snowmelt in 2011 that decreased SOD and %VS throughout the LJR due to an influx of silt and sand prior to the 2012 sampling event. The normalized results also showed that the subsurface sediments in the Jordan River downstream of Davis County line were more organically enriched compared to upstream reaches. The downstream State Canal had the highest SOD fluxes measured (-6 to -8 g-DO/m2/d), implying that the sediments downstream of the DO-impaired LJR are increasingly enriched with OM along a decreasing elevational gradient.

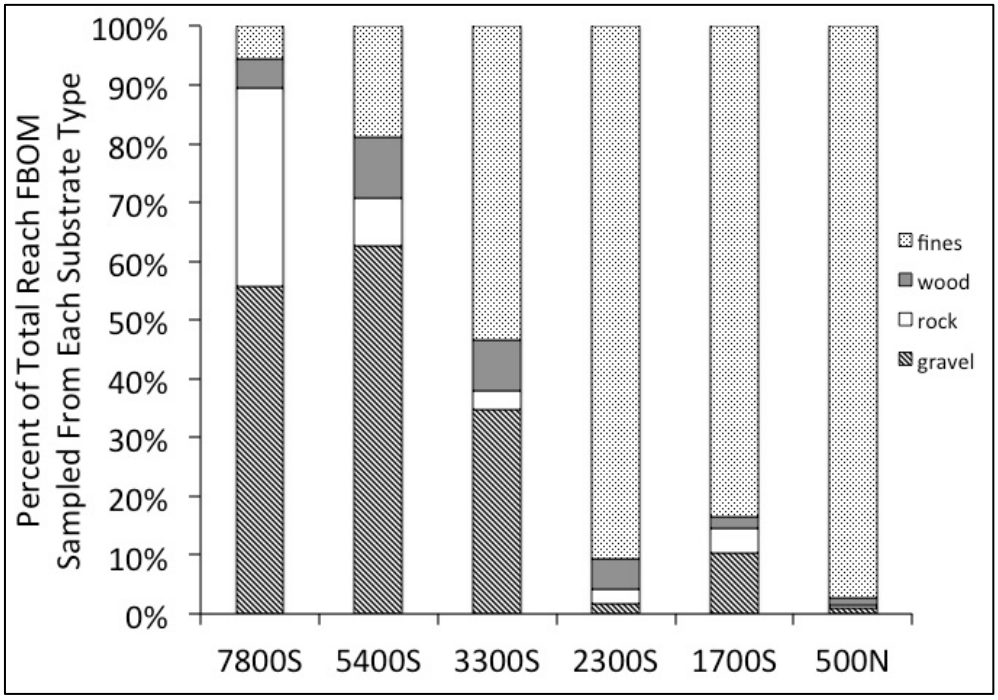

Figure 13. Proportion of each substrate type contributing to the total fine benthic organic carbon (FBOM) estimated in each reach. Source: Figure 8 Epstein and Baker 2014.

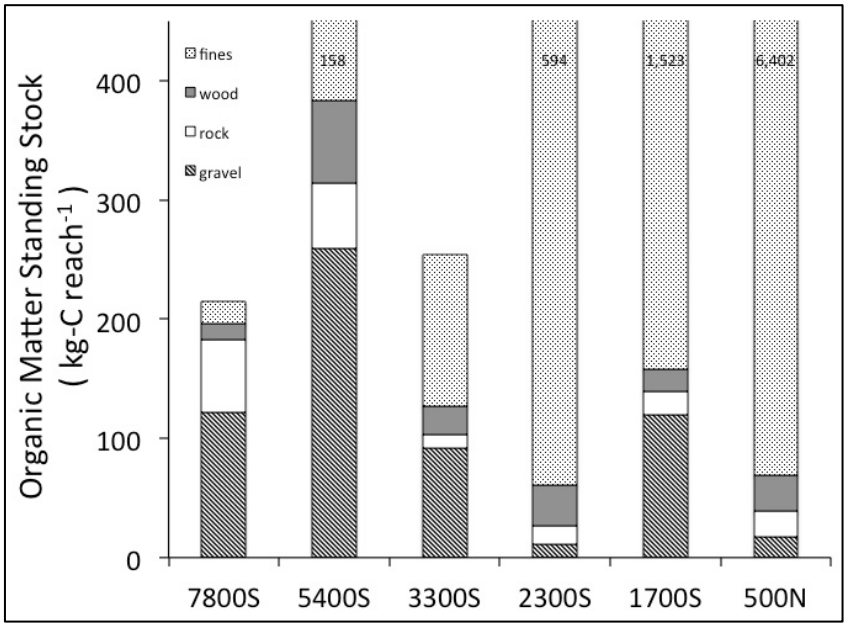

Figure 14. Standing stock estimates of fine benthic organic matter (FBOM; kg-C/reach) from biomass sampling in each of six reaches. Source: Figure 9 Epstein and Baker 2014.

Table 5. Site and river stretch sediment OM standing stocks. Values are cumulative with depth. Source: Table 37 Hogsett 2015.

	Depth (cm)	$OM_{aerial,sum}$ (g OM/m^2)	$OM_{aer,stretch,sum}$ (kg dry OM/river stretch)	$CPOM_{aer,stretch,sum}$ (kg dry OM/river stretch)
Burnham				
	0–2	71	3,953	133
	5	338	18,832	1,304
	10	576	32,118	1,857
LNP NE				
	0–2	42	1,902	216
	5	324	14,757	2,572
	10	580	26,474	5,580
Cudahy				
	0–2	66	5,016	1,256
	5	263	19,895	3,904
	10	470	35,535	6,568
300 N				
	0–2	61	5,245	2,182
	5	190	16,217	4,176
	10	314	26,776	5,963
700 S				
	0–2	43	2,179	885
	5	140	7,157	2,953
	10	271	13,815	4,587
1700 S	0–2	63	2,410	818

$OM_{aerial,sum}$ = g-OM/m2/summed depth
$OM_{aer,stretch,sum}$ = Kg OM/river stretch/summed depth
$CPOM_{aer,stretch,sum}$ = Kg CPOM/river stretch/summed depth

Table 6. Reach-based sediment OM standing stocks (kg dry OM, depth summed). Source: modified from Table 38 Hogsett.

Depth	Burton Dam – Davis Co line	Davis Co Line – North Temple	North Temple – 2100 South	LJR total OM
0-2	107,378	59,917	59,229	226,525
5	554,725	185,273	157,817	897,814
10	976,009	305,905	304,609	1,586,523

Terrestrial OM input to the LJR was estimated at 19,530 kg OM/yr (or 9,765 kg C/yr), based on aerial vegetation cover and literature values for leaf drop (Hogsett 2015). These estimates are equal to 9 percent of the 0–2 cm standing stock of OM measured in spring 2012. Note that measured loads of leaf litter (collected 2012–2013) are also shown in Table 4 for UJR and LJR segments (Epstein and Baker 2014). The measured load of litter between 1700 South and Cudahy Lane was 2,606 kg C/yr (Table 4), and if adjusted for length of the entire LJR, would be less than the estimated load from Hogsett (2015) and Miller (2015). This difference is likely due to methods used to calculate riparian cover and leaf production or large variations in runoff.

The number of days required to completely oxidize 19,530 kg OM in sediment was calculated to determine how long the load from annual leaf drop might impact DO levels in the LJR (Hogsett 2015). When the full load is evenly distributed in the LJR, the sediments cycle the carbon in 37 days, emphasizing the need for upstream OM loads to produce levels of measured SOD flux in the LJR.

These estimates of riparian litter are considered to be conservative, based on the refractory nature of some organics that take years to breakdown and some that may never contribute to oxygen demand. A comparison of cumulative sediment OM at depth and years required to oxidize this OM identified a 1:1 relationship (e.g. cumulative sediment OM at 10 cm would require 10 years to completely oxidize). This relationship indicates an annual cycle and suggests that any reductions in OM loads to the LJR will improve water quality by reducing SOD. This trend is evident in spite of LJR reaches having very different wet sediment densities, OM content, and SOD fluxes (Hogsett 2015). This finding supports an assumption made in the TMDL between OM load reductions to the LJR and improvements in water quality and SOD (i.e., reducing OM loads to the LJR would produce an equal SOD reduction over time).

Roughly one-third of surface sediments were comprised of CPOM in the LJR between 2100 South and the Davis County line (Table 5). Overall, the percent contribution of CPOM to sediment column %VS decreased with distance downstream as the concentration of OM in sediments increased. This is suspected to result from CPOM conditioning and less riparian bank cover in the lowest Jordan River segment. Mean sediment column %VS as CPOM in the LJR was 19 percent.

CPOM concentrations vary across the width of the river, and the highest concentrations of CPOM are found in the thalweg. This was particularly evident at sites beginning at Cudahy Lane and continuing upstream where over half of sediment column %VS was present as CPOM. Burnham Dam (below Cudahy Lane) had little CPOM and OM in the thalweg was mostly comprised of FPOM. The amount of CPOM decreased with depth in the thalweg, likely due to biological processing to FPOM over time.

It is anticipated that bacteria and fungi are responsible for most CPOM conditioning in the LJR. The level of CPOM in sediment is influenced by inflows to the Jordan River (Hogsett 2015, Miller 2015). Sites located downstream of tributaries and stormwater outfalls had higher CPOM:FPOM ratios (Table 5), possibly due to CPOM loading.

Macronutrients nitrogen and phosphorus appear to be influencing SOD (Hogsett 2015). The abundance of macronutrients may be contributing to the eutrophication of the Jordan River, resulting in an indirect OM load via primary production in the water column and benthos. During six of seven sampling events, SOD measurements collected in segments with low nutrient

conditions accounted for less than 50 percent of ambient oxygen demand during summertime conditions. SOD measurements during summertime in segments with relatively higher nutrient conditions accounted for more than 50 percent ambient oxygen demand. Nutrients can also influence the rate of OM decomposition in channel sediments. More research should be conducted in regard to the influence of nutrient loading on SOD and subsequent effects on DO levels.

Nutrients can be an indirect source of OM by contributing to growth of autochthonous OM in the water column and benthos (Hogsett 2015). Measurements of sediment nutrient flux indicated contributions of ammonia and phosphorus to the water column from most sites (Table 7). Based on these measurements, nutrient loads from sediment will continue to occur for some time, due to decay of OM in sediments. Comparing nutrient loads produced by sediments in the LJR to annual nutrient loads from sources indicates that sediment loads of NH4-N and PO4-P are equal to 5 percent and 1 percent, respectively, of the source nutrient load that enters the LJR.

Table 7. Average sediment nutrient fluxes (g/m^2-d) in the lower Jordan River. Data collected during 2010 and 2012-13. Source: Table 22 and Table 23 Hogsett 2015.

Site	NH4-N	NO3-N	TIN	PO4-P	Sample size
Burnham	0.03	-0.69	-0.66	-0.08	2
LNP NE	0.04	-0.11	-0.09	0.06	4
Cudahy Ln	0.22	-0.28	-0.13	0.07	3
DWQ (300 N)	0.04	-0.03	0	0.05	3
700 S	0.07	-0.27	-0.2	0.06	2
1700 S-N	0.14	-0.14	-0.04	0.11	3

4.0 SUMMARY AND CONCLUSIONS

4.1 LINKAGE

Our understanding of the linkage between water quality and DO impairment has improved based on the following conclusions of the reviewed research and monitoring data:

1. Calculations of production and respiration indicate that UJR segments are net autotrophic and LJR segments are net heterotrophic. See section 2.3 figure 4 or DWQ (2015a p.22) and Epstein et al. (2015 pg.17). Note that measurements of stream metabolism (water column only) and whole-stream metabolism (water column and benthos) are in agreement with regard to these results in the UJR and LJR. See section 2.3 figure 5 or Hogsett (2015, p.142).

2. Most organic compounds (80–90 percent) are leached from terrestrial OM within the first 3 hours of entering the water column. See sections 2.4 p. 8 and section 3.3.1 p. 18 or Richardson (2014 p. 37). The rate is affected by the type of OM and solubility of organic carbon in the OM. See section 2.4 p. 9 or Richardson (2014 Table 19, pp. 20–21, and pp. 36–37). This suggests that the majority of CPOM contained in stormwater is likely processed before reaching the LJR, removing the most labile portions of OM. If this is true, the CPOM from storm drains entering the LJR would be mostly comprised of cell-

wall material and other lignin or cellulose-based OM requiring long-term decomposition by fungus and some bacteria. This type of decomposition could include both aerobic as well as anaerobic processes (and subsequent methane production). Contributions to SOD from this slow-decomposing source are uncertain at this time. Additional monitoring data from storm drains is being collected and could validate this conclusion.

3. Annual average SOD measurements can account for 54 percent of the ambient DO deficit in the LJR. SOD measurements account for higher amounts of the ambient DO deficit in some LJR locations and at some measurement dates. See section 2.2 p. 5 or Hogsett (2015 pp. 125–126).

4. SOD increases with distance downstream in the LJR, and these values can change between years based on spring runoff. See section 2.2 p. 5 or Hogsett (2015 pp. 119–122 and p. 207).

5. SOD values increase during the winter season, the opposite of what is expected due to colder water temperatures. The increase could be due to (1) groundwater upwelling – particularly in UJR segments, (2) greater periphyton growth and respiration due to improved water clarity, (3) fall leaf drop and seasonal OM load, (4) bacteria and microbes that are tolerant to environmental change, and (5) diffusion of reduced chemicals that are rate-limiting parameters for SOD and not affected by temperature. See section 2.2 p. 5 or Hogsett (2015 pp. 128–130).

6. SOD consists of methane oxidation and aerobic metabolism at the sediment-water interface. Methane production from sediments contributes 56 percent of total SOD. See section 2.2 p. 5 or Hogsett (2015 pp. 185–186).

7. The life-cycle of sediment OM indicates that any surface OM under aerobic conditions is likely removed within a year of deposition, particularly if channel sediments are not disturbed. The life cycle of sediment OM under anaerobic conditions ranges from 2.5 to 4.8 years. In addition to aerobic/anaerobic conditions, the rate of OM decomposition (and subsequent contribution to SOD) is dependent on the labile or refractory nature of the material, Due to this extended life cycle and incoming annual loads, OM is steadily accumulating in the LJR under anaerobic conditions. See section 3.4 p. 28 or Hogsett (2015 pp. 166–167 and p. 186).

8. Based on DO monitoring during dredging, oxygen demand can be enormous if sediment is disturbed at depth but insignificant at shallow depths on small scales. See section 3.3.1 pp. 20–21 or Salt Lake City (2015 Dredging Event 1 p. 6) or Salt Lake City (2015 Sediment Event 1 pp. 3–4) or Salt Lake City (2015 Sediment Event 2 pp. 3–4). Based on these assumptions and under anaerobic conditions, the life cycle of OM is limited by oxygen transfer rates and could potentially be shortened if sediments were disturbed.

4.2 OM Characteristics and Source

Our understanding of total organic matter and organic matter sources has improved based on the following conclusions:

1. The OM budget for the Jordan River indicates that DOM is the major component of OM, followed by FPOM, then CPOM. Based on monitoring completed in 2012–2013 on the

main stem Jordan River, CPOM contributes roughly 5 percent of Total OM. See section 3.2 p. 16 or Epstein et al. (2015 pp. 15, 20–21) and Epstein and Baker (2014 p. 8). However, CPOM data collected from 2010–2012 indicates substantial CPOM loading from tributaries during high runoff years in LJR segments that may not be reflected in OM budget results. See section 3.3.3 pp. 23–24 or Miller (2015 pp. 7–21). Measurements of CPOM samples collected during both research studies were noted to have a high amount of variability between monitoring dates. See section 3.3.3 p. 24 or Epstein et al. (2015 p. 15) and section 3.3.3 p. 24 or Miller (2015 p. 30–31). There is potential for high variability among samples, sampling methods, and runoff between years that could explain some of the discrepancy between the two studies' findings regarding CPOM mass in the Jordan River. Additional documentation is needed describing methods and data analyses to allow DWQ to resolve these discrepancies. Review of raw data may be necessary.

2. Monthly stream monitoring indicated the highest concentrations of DOC during the fall season which corresponds to leaf drop. See section 3.2 p. 16 or Epstein et al. (2015 p. 19). Loads of litter to the LJR were estimated and found to equal about 9 percent of the OM standing stock in surface sediments. See section 3.4 p. 28 or Hogsett (2015 p. 98). Based on estimates of carbon life cycle, the sediment should completely cycle this amount in 37 days, indicating the significance of upstream loads that maintain measured SOD levels in the LJR. See section 3.4 p. 28 or Hogsett (2015 p. 198).

3. River segments with greatest annual OM pools include UJR segments 7800 South–5400 South and 3300 South–2300 South. Increases in these segments are not due to CPOM but to unmeasured inputs of FPOM and DOC. See section 3.2 pp. 16-17 or Epstein et al. (2015 pp. 15–16). When accounting for watershed area, net OM transport decreased or was close to zero in most reaches except for UJR segments 7800 South–5400 South and 3300 South–2300 South. See section 3.2 p. 16 or Epstein et al. (2015 p. 16 and Figure 6b).

4. UJR segments have high levels of primary production, both in the water column and from the benthos. OM loads to the LJR based on estimates of primary productivity can account for 30–57 percent of the Total OM load for the UJR that was calculated in the Phase 1 TMDL. See section 3.4 p. 24 or Hogsett (2015 p. 203). Although these estimates vary, the UJR is a significant source of OM to the LJR as a result of eutrophication. Research indicates that autotrophic net daily metabolism for the UJR may contribute 55 percent of the OM load estimate in the Phase 1 TMDL for this reach. See section 3.2 p. 17 or Hogsett (2015 p. 205).

5. Isotope analysis of OM from known sources and OM size categories (i.e., DOM, FPOM, and CPOM) indicate the percent contribution from terrestrial and autochthonous sources. An isotope mixing model (SIAR) was used to predict the percent composition of OM sources in each size category. Based on isotope analysis, DOM was derived primarily (90 percent) from terrestrial sources although the SIAR model showed much greater variation between terrestrial and autochthonous sources. See section 3.3.1 p. 19 and Figure 10 or Kelso (2015 pp. 2–3). Isotope analysis of FPOM indicated similar concentrations of C13 to autochthonous material, while model results indicated FPOM was comprised of equal proportions of terrestrial and autochthonous sources. See section 3.3.2 p. 21 and Figure 12 or Kelso (2015 pp. 2–3). Both isotope analysis and model predictions indicated CPOM was comprised primarily of terrestrial sources. See section 3.3.3 p. 23 and Figure 12 or Kelso (2015 pp. 2–3).

6. C:N ratios more clearly indicated differences between autochthonous and terrestrial OM sources. C:N ratios for FPOM were similar to autochthonous sources while C:N ratios for CPOM were similar to terrestrial sources. See section 3.3.2 p. 21 and Figure 11 or Epstein et al. (2015 p. 18 and Figure 10).

7. Episodic releases of highly degradable DOC from storm events flushing the stormwater conveyance system could be related to DO depletion events in the LJR. See section 3.3.1 p. 19 and Figure 6 or Richardson (2014 pp. 41–43). The remaining particulate OM in stormwater could settle to the channel bottom and contribute to SOD. Estimates of leaf drop from LJR riparian zones indicate the OM load from this source could be processed in as little as 37 days in channel sediments. See section 3.4 p. 28 or Hogsett (2015 p. 198). The deposition of residual, more recalcitrant particulate organic matter from stormwater flushing and fall leaf drop could contribute OM to SOD, but the year-round SOD is likely related to a variety of OM sources.

4.3 VALUES AND ASSUMPTIONS – LOAD ALLOCATIONS

The focus of the updated TMDL will be on defining information and processes that can be used to allocate OM loads to pollutant sources. Figure 15 shows a modified version of the original Figure 1 from the Phase I TMDL which reflects critical pieces that need to be addressed in the Phase 2 TMDL. Results provided by recent Jordan River OM research that meet some of these needs are described in the remainder of this section. However, these studies do not meet all TMDL needs. Additional data that should be collected for the updated TMDL is described in section 4.4.

<u>Total OM Load to the LJR</u>
The Phase 2 TMDL report will use data that characterizes all OM sources contributing to the LJR. Research results can provide a basis for characterizing and distributing this load.

1. The mass of OM needed to produce measured levels of oxygen demand can be calculated using DO as a surrogate. See section 2.7 p. 12. Total oxygen demand can be calculated from seasonal average respiration and SOD values. Mass of OM needed to produce the measured oxygen demand can be calculated based on glucose equivalents or stoichiometric ratio of OM in the sediments and water column.

2. OM totals shown in Table 4 can also be used to indicate mass of total OM transport to and through the LJR.

3. OM loads that directly enter the LJR will require monitoring data to characterize stormwater, tributary flow (Parleys, Emigration, Red Butte, and City Creek), irrigation return flow, and discharge from South Davis South WRF. These data are currently being collected and should include the fraction that settles and contributes to SOD.

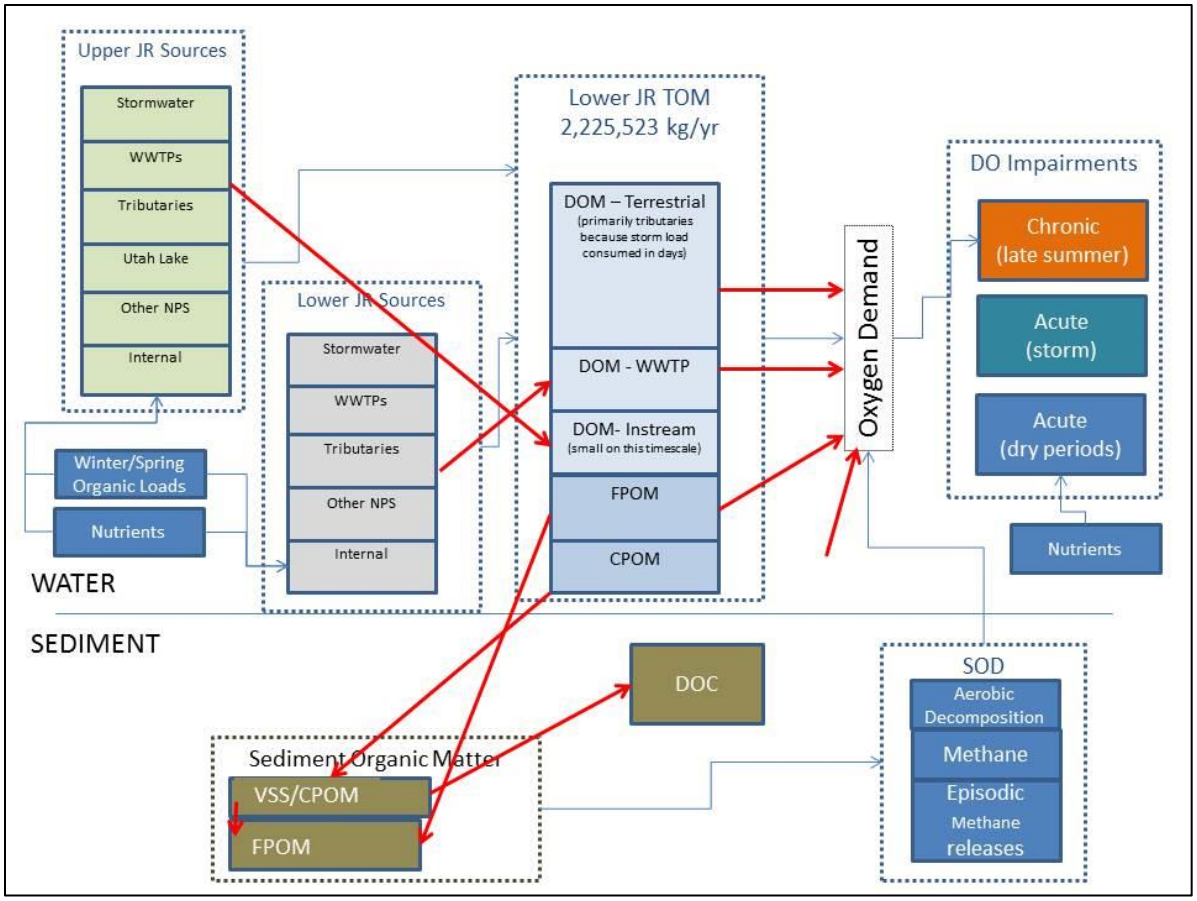

Figure 15. Jordan River Total Organic Matter (TOM) and DO linkages based on current understanding and regulatory needs of the updated TMDL.

<u>Upper Jordan River OM Load</u>

The OM load upstream of 2100 South delivered to the LJR will be calculated based on a monitoring data set accounting for long-term seasonal and annual variability. Research results that can be used to characterize the total OM load from the UJR include:

1. OM budget results shown in Table 4 can be used to partition a total load into size categories (DOM, FPOM, and CPOM) based on percent contributions.

2. Results of the isotope analysis can be used to categorize OM size categories into terrestrial and autochthonous source (e.g., DOM loads are 90 percent terrestrial and 10 percent autochthonous, FPOM loads are 50 percent terrestrial, etc.).

3. The Phase 1 TMDL did not include an OM load from instream production in the UJR below Utah Lake. Values of primary production from benthos and water column measured from the UJR indicate potential OM loading to downstream segments. The OM budget (Table 4) shows percent composition of OM size categories in water column at 2300 South. Isotope analysis indicates composition of OM size categories by source including terrestrial vs. autochthonous. See sections 3.3.1 p. 19, 3.3.2 p. 21, 3.3.3 p. 23 and Figures 10b and 12b. Assuming the OM load from the UJR to the LJR is generated by a similar composition of OM sources and weighted according to OM budget size

categories, this method can partition the UJR load into terrestrial and autochthonous sources.

OM Load Contributing to SOD

Many processes influence OM as it moves from the source, through the water column, and becomes incorporated into channel sediments. These processes will need to be accounted for in the Phase 2 TMDL. Ultimately the OM load that contributes to SOD in the LJR will need to be partitioned and allocated to pollutant sources. Research results that can be used to characterize OM contributions to SOD in the LJR include:

1. The OM load required to produce measured levels of SOD can be calculated using DO as a surrogate (see above).

2. Standing stock measurements in the LJR (Tables 5 and 6), and FBOM estimates (Figure 15) can also be used to quantify existing levels of OM in surface sediments.

3. Measurements of CPOM in channel sediments have been collected (Table 5), as well as information describing the percent composition of channel sediment size (Figure 14).

4. The OM loads contributing to SOD should be examined in regard to seasonal variations in SOD that could be a response to input from each source. See sections 2.2 p. 15 and 3.4 p. 28. Research shows that more than 80 percent of oxygen demanding OM could be is leached from CPOM in the first 3 hours after entering the water. These results should be accounted for when determining the contribution of terrestrial CPOM to SOD.

5. Isotope mixing models indicate percent composition by source for all OM categories sampled from the water column (e.g., DOM is 90 percent terrestrial and 10 percent autochthonous, FPOM is 50 percent terrestrial, etc.). Results of the OM budget indicate percent composition of all size categories (Table 4) contributing to OM transport in the LJR. Assume the OM load contributing to SOD is generated by a similar composition of OM sources and weighted according to OM budget size categories averaged across the length of the LJR. This method could partition the OM load contributing to SOD to terrestrial and autochthonous sources.

Other Information

Results of the reviewed research support assumptions that could be used in the TMDL to help characterize pollutant sources and processes that influence OM loading and oxygen demand. Some of these results include:

1. Approximately 50 percent of SOD is from methane gas production (2–5 cm or deeper) and the remainder is from aerobic respiration at the sediment-water interface. Methane production is a chronic impairment that typically consumes oxygen as methane is diffused through the sediments and into the water column at a continuous, slow rate. Rapid release of methane (ebullition) was visually observed in the LJR when sediments with %VS greater than 5 percent were disturbed. Sediments with %VS greater than 10 percent were accompanied by sporadic gas ebullition from undisturbed sediments. Average %VS in the LJR was typically less than 5 percent and ranged from 4 to 7 %VS in the LJR downstream from the Davis County line.

2. The influence of DOC leaching from instream CPOM can be determined by comparing the DOC production rate from degradation of CPOM with whole stream respiration rate.

If the production rate is some proportion of whole-stream respiration rate (water column and benthos) then attribute the remainder of respiration to autotrophic community.

3. DO demand to the LJR produced by CPOM carried in tributary loads can be estimated from CPOM leaching studies and travel time. CPOM leaching studies quantify DOC production over time and the corresponding ultimate oxygen demand.

4. The influence of nutrients on autochthonous OM production and SOD is apparent, based on measured values. This indirect influence on OM should be accounted for in load allocations. Additional research should be conducted to determine nutrient limitation of SOD components.

Water Quality Modeling

1. Surface sediment % VS (0-2 cm) is a practical surrogate for estimating SOD without chambers in silty sediments of the LJR (SOD = 0.34 * %VS + 0.68). The SOD:VS relationship for the Jordan River can be utilized to estimate SOD in silty sediments using standard methods for modeling purposes. This relationship can also be used to set goals for the reduction of surface sediment OM (and SOD) in the LJR.

2. Estimates of surface sediment oxygen demand due to methane flux can use sediment %VS as a surrogate. Correlations defined by research results can be used to help populate the Jordan River QUAL2Kw model.

3. Measured rates of OM decomposition, methane production, and nutrient transformation in the sediments can support model parameterization of SOD.

4.4 ADDITIONAL RESEARCH

1. Research and data used by DWQ in the TMDL process must meet agency QA/QC standards and pass professional review by agency scientists. Any results used in the TMDL must be clearly documented to provide a basis for valid comparison to other research.

2. The Jordan River segments Bangeter Highway–7800 South, 7800 South–5400 South and 3300 South–2300 South show significant OM loading and should be targeted for reduction of OM sources to the river. Increased OM transport in these segments appears to be due to inputs of FPOM and DOC and not CPOM. Further study of these reaches is warranted to quantify amounts and sources of all OM pools and their potential contribution to oxygen consumption.

3. Quantify differences between OM budget results and CPOM tributary monitoring and identify potential reasons for these differences. Determine if additional research is needed to identify effect of CPOM loading from tributaries on SOD levels in LJR.

4. Complete OM budget study during a water year with greater flow and snowmelt runoff than the 2012–2013 water year. This may or may not be needed depending on the conclusions of point 2 above.

5. Define the proportion of the DOC load entering the LJR that consumes oxygen before passing out of the system (e.g., labile vs. refractory). Results of Jordan River research indicate that DOC leached from terrestrial CPOM is highly labile while some published literature indicates a majority of DOC is refractory.

6. Characterize the linkage between DO demand and CPOM-FBOM-methane production and other sources of oxidizable small chain fatty acids.

7. Research has shown that SOD contributes approximately half of the ambient DO deficit in the LJR and assumptions can be made regarding the load of OM needed to create this demand. Isotope analysis results can identify terrestrial and autochthonous OM sources based on particle size, but processes in channel sediments influence particle size. Additional research will be needed to determine what sources of OM contribute to SOD. Initial efforts should characterize OM settling from UJR and LJR loads during monthly flows and velocities. Isotope analysis of OM in channel sediments could also help to answer this question.

8. Quantify the DOC load from WRFs with routine bi-weekly or monthly monitoring and determine if DOC is correlated with BOD and CBOD Include these parameters in WRF discharge permits.

9. Quantify the influence of nutrients on total SOD and rate of OM decomposition in the sediments.

10. Monitor OM contributions from Utah Lake, stormwater, tributaries to the LJR and irrigation return flows in order to determine seasonal loading patterns and contributions from OM size categories (e.g., CPOM, FPOM, and DOC).

11. Quantify the influence of releases from Utah Lake on changes in water clarity, autochthonous OM production, and SOD. Quantify the load of OM from Utah Lake that reaches the LJR, and the contribution of phytoplankton and nutrients from Utah Lake on primary production in the UJR.

12. Investigate the effect of channel sediment temperature on SOD. Given the potential influence of groundwater on SOD in some locations and the constant temperature of groundwater, temperatures in sediment are likely stable throughout the year. Sediment temperature could be more important for understanding seasonal SOD dynamics than the water temperature above the sediment layer.

13. Continue in-situ diel DO monitoring with routine maintenance and calibration of sensors to minimize data gaps and improve sensor accuracy. Calibration efforts could include manual field DO measurements near each probe.

14. Utilize DOC measurements in future monitoring as a cost and time-effective measure of BOD. Utilize sediment %VS as a surrogate measurement for SOD in silty sediments of the LJR and to track progress in reducing SOD.

15. Discuss and develop water quality models in preparation for use in the Phase 2 TMDL.

16. Verify size categories of OM primary production loads to the LJR (i.e., bedload CPOM or suspended OM) during peak runoff. Table 4 indicates the annual CPOM load is a

minor percentage of total OM transport at 1700 South monitoring site. However benthos production in UJR segments indicate a high potential for bedload CPOM during peak flows.

17. Determine the potential for delivery of bedload CPOM through the 2100 South diversion gate during peak flows.

18. Develop an SOP for sampling and analyzing %VS in surface sediments.

19. Conduct a basic literature review of the importance of benthic macroinvertebrates to OM and DO spiraling, particularly the invasive Asian clam, Corbicula and snail Potamopyrgus. Incorporate these findings into models.