Jordan River Total Maximum Daily Load Water Quality Study - Phase 1

Prepared for:

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Jordan River TMDL

Waterbody ID	Jordan River – 1 (UT16020204-001) Jordan River – 2 (UT16020204-002) Jordan River – 3 (UT16020204-003)
Parameter of Concern	Dissolved Oxygen
Pollutant of Concern	Total Organic Matter
Impaired Beneficial Use	Class 3B Protected for warm water species of game fish and aquatic life, including the necessary aquatic organisms in their food chain.
Loading Assessment	
Current Load	2,225,523 kg/yr Total Organic Matter
Loading Capacity	1,373,630 kg/yr or 3,763 kg/day Total Organic Matter (38% reduction)
Margin of Safety	Load capacity based on OM concentrations that result in DO model endpoint of 5.5 mg/L, including 1.0 mg/L implicit MOS added to the instantaneous DO water quality standard of 4.5 mg/L.
Bulk Load Allocation	684,586 kg/yr Total Organic Matter (35% reduction)
Bulk Waste Load Allocation	689,044 kg/yr Total Organic Matter (41% reduction)
Defined Targets/Endpoints	Total OM load to lower Jordan River (kg/yr) <= 1,373,630 kg/yr Dissolved Oxygen => 4.5 mg/L
Nonpoint Pollutant Sources	Utah Lake, Tributaries, Diffuse Runoff, Irrigation Return Flow, Groundwater
Regulated Point Source Pollutants	**Wastewater** Jordan Basin WRF (UT0025852) South Valley WRF (UT0024384) Central Valley WRF (UT0024392) South Davis WTP (UT0021628) **Stormwater** **Phase I Permit** Salt Lake County Salt Lake City UDOT **Phase II Permit** Bluffdale, Draper, Herriman, Holladay, Lehi, Midvale, Murray, Riverton, Sandy, South Jordan, South Salt Lake, Taylorsville, West Jordan, West Valley
TMDL Strategy	**Phased TMDL** Phase II (2012–2018): Characterization of OM and WQ Response; BMP Implementation Phase III (2018–2023): BAT Design; Implementation of Stormwater Capital Improvements; Begin implementation strategy in revised TMDL. Phase IV (2023-2028): Construction upgrades for point sources to meet WLAs, meet all DO water quality standards.

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EXECUTIVE SUMMARY

This water quality study for the Jordan River establishes the Total Maximum Daily Load (TMDL) for Total Organic Matter (OM) of 3,983 kg/day that will achieve the model endpoint for Dissolved Oxygen (DO). This target concentration is defined in a water quality model (QUAL2Kw) which is being used as a decision support tool for restoring beneficial use to the lower Jordan River. Additional testing was conducted to quantify uncertainty of input parameters and rates used in the calibrated model. Based on these results and additional information reviewed during the TMDL process, a 1.0 mg/L implicit Margin of Safety (MOS) was added to the Jordan River instantaneous DO standard of 4.5 mg/L. Input concentrations of Total OM that resulted in meeting the model endpoint of 5.5 mg/L DO were used to define permissible loads to the lower Jordan River. This model endpoint and the resulting permissible loads account for levels of uncertainty that exist in the TMDL process at this time and are designed to maintain DO levels in the lower Jordan River above the instantaneous DO standard.

The five chapters in this report meet EPA requirements for a TMDL water quality study.

Chapter 1 describes the justification for this TMDL water quality study and the physical and social conditions in the Jordan River watershed that influence existing and future water quality conditions.

The Jordan River is a relatively short river, approximately 51 miles long, originating at Utah Lake and flowing north to terminate in wetlands that eventually discharge to the Great Salt Lake. The topography within the Jordan River watershed contributes to a very complex precipitation pattern with great variability in amounts and timing of flows. Although Utah Lake is the single largest source of flows to the Jordan River, much of this water is diverted within a few miles for agricultural and municipal use. Other tributaries flow into the Jordan River from both east and west, but these, too, are subject to a complex network of diversions, return flows from canals, stormwater discharge, and exchange agreements between culinary and agricultural users. The lower Jordan River begins downstream of the largest diversion, the Surplus Canal, which redirects up to 90 percent of the flow from the Jordan River directly to the Great Salt Lake to protect neighborhoods and developments from flooding.

Designated beneficial uses for the various segments of the Jordan River include domestic uses (with prior treatment), secondary contact recreation (boating, wading, fishing, etc.), cold and warm water fisheries, other wildlife that depend on an aquatic environment (waterfowl, shorebirds, and the aquatic organisms in their food chains), and agricultural irrigation. These uses are protected by a variety of water quality standards, but every segment of the Jordan River has been found to be non-supporting of one or more beneficial uses (i.e., impaired) due to exceeding one or more of these water quality standards.

Violations of two of the water quality standards, temperature and Total Dissolved Solids (TDS), are largely due to natural causes, including shallow water, hot summer air temperatures, and ground water high in natural thermal discharges and TDS. A separate analysis of these factors is being undertaken that may include proposals for site-specific criteria.

Only the lower Jordan River downstream of the Surplus Canal (north of 2100 South in Salt Lake City) is listed as impaired for Dissolved Oxygen (DO), a critical condition for many aquatic species. The pollutant of concern, linkages between that pollutant and DO, sources of loading, and a load allocation that will resolve the DO impairment, are the subject of this TMDL study.

Chapter 2 reviews the available water quality data to show that DO impairments exist in the lower Jordan River under critical, late summer conditions, although not in all years. It also establishes the linkage between low DO and the DO demand of aerobic and anaerobic decomposition of particulate OM, both in the water column measured as Biochemical Oxygen Demand (BOD) and at the sediment interface measured as Sediment Oxygen Demand (SOD).

Data show that DO deficits (difference between theoretically saturated and actual measured concentrations) occur year round in the lower Jordan River, but are greatest in late summer and early fall, corresponding with instances of violations of DO water quality standards. Four processes affect DO in the water column: physical factors, including water temperature and channel characteristics that influence reaeration from the atmosphere; aerobic decomposition of Organic Matter (OM) and inorganic nitrification of ammonium in the water column, measurable as bio-chemical oxygen demand, or BOD; aerobic decomposition of OM and inorganic oxidation at the sediment-water interface, measurable as sediment oxygen demand, or SOD; and algal growth generating a net increase in DO during daylight hours and net consumption of DO associated with respiration during the night. These processes are analyzed in detail in Appendix D.

The critical condition for low DO in the lower Jordan River was determined from the theoretical assessment of the four processes and from the timing and distribution of historical DO data. The critical conditions are typically in late summer, when flows are lowest, air temperatures are high, and solar radiation is still intense. The most critical conditions do not occur every year, however.

A water quality model (QUAL2Kw) was used to integrate and assess the effects of the four processes on DO in the lower Jordan River. The model was calibrated for the time of year when critical conditions occur, although the data used for calibration was from a year when conditions did not result in extensive DO water quality violations. Nevertheless, the model did reveal that reductions in nutrients, a pollutant commonly associated with low DO in other systems, would not result in significant improvement in DO. This is probably due to the short distance of the Jordan River that does not allow enough time for algae to take full advantage of these nutrients.

Instead, the model showed a strong relationship between OM and DO. It also helped to determine the maximum concentration of OM that could be tolerated and still achieve a target DO endpoint. This target DO endpoint included an implicit margin of safety based on recognized uncertainties, some of which were inherent in the model itself.

QUAL2Kw only accounts for the smallest particles of OM, ignoring larger particles. Because it was necessary to prescribe additional SOD to calibrate the model, it is assumed that this other OM is part of the total OM that accounts for the extra prescribed SOD necessary to calibrate the model. Additional detail and discussion on how all size fractions of total OM were accounted for in load calculations and load reductions are found in Chapter 3 and Chapter 4.

Chapter 3 characterizes the sources of OM loading and presents calculations of monthly loading of Fine Particulate OM (FPOM) and Other OM (i.e. OM not captured by FPOM measurements) that contribute to SOD. This was accomplished with models that estimate present and future OM loads based on correlations with measurements of Total Suspended Solids (TSS), BOD, and assumptions regarding the amount of OM required to account for the prescribed SOD in the QUAL2Kw model.

The sources examined included:

- Point Sources:
  - WWTPs
  - Stormwater
- Nonpoint sources:
  - Utah Lake
  - Tributaries
  - Diffuse Runoff
  - Return Flows from Irrigation Canals
  - Natural Background

A separate spreadsheet model was developed to calculate the monthly loading of FPOM from each source and estimate the residual loading to the lower Jordan River after the diversions of flow and the settlement and dissolution that reduce FPOM concentrations. Future loads were calculated based largely on predictions of population growth and changes in diversions and water supplies provided by the Salt Lake County Water Quality Stewardship Plan (WaQSP, Salt Lake County 2009). Other OM was based on the amount of DO consumed by bacteria for each unit of OM, and the total DO consumed in the lower Jordan River each day based on SOD rates ($g/m^2/day$). Table 3.9 summarizes total OM loads (including FPOM and Other OM) to the lower Jordan River based on the methods outlined above. Point sources (including stormwater) account for 53 percent of the OM load to the lower Jordan River, versus 47 percent for nonpoint sources. Sources upstream of 2100 South account for 55 percent of the OM load, versus 45 percent from downstream sources. These load estimates represent the best information currently available and could change during future phases of the TMDL study as additional data is collected and analyzed.

Calculations of future loads of FPOM revealed substantial increases from both stormwater, as more of the developed areas are serviced by stormwater catchments, and WWTPs, as the population grows and a new WWTP comes on line. Future loads of Other OM were not possible to calculate because it was impossible to reasonably estimate the future SOD in the lower Jordan River, upon which estimates of Other OM loading are based.

Chapter 4 provides the permissible load of OM, or the maximum amount of **Total OM** (including FPOM and Other OM) the lower Jordan River can receive and still maintain DO levels that fully support designated beneficial uses. This chapter also includes bulk load allocations of **Total OM** for point and nonpoint sources to the lower Jordan River.

The spreadsheet model was used to estimate load reductions necessary to achieve the target DO endpoint, based on a maximum permissible concentration of OM derived from the QUAL2Kw model. Load reductions needed from sources of Other OM used the same percent reduction in loading required from sources of FPOM. Table 4.1 summarizes the results of load reductions from FPOM and Other OM and Appendix G (Tables G.1-G.3) provides additional detail. Based on this model and its assumptions, point sources upstream and downstream of 2100 South will have to reduce their loads by 39 and 42 percent respectively. Nonpoint sources upstream and downstream of 2100 South will have to reduce their loads by 27 and 54 percent respectively (Table 4.1).

Chapter 5 outlines a phased TMDL approach to meet the permissible load and specific activities associated with each phase.

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 next phase in the TMDL process, Phase II, will be focused on gathering additional data to support a more accurate assessment of OM loading, both temporally and spatially. Even in the face of the uncertainty in OM loading, however, some reduction in OM is still possible and reasonable to expect. In particular, actions that do not involve long term commitments to substantial capital investment – typically changes in behavior or procedures, on the part of individuals and facilities – may significantly improve water quality. Phase III can then take advantage of the new knowledge gained in Phase II to develop better designs in point source controls. Phase IV involves the construction of capital facilities which should then carry a high degree of assurance in reducing OM loading and securing acceptable levels of DO in the lower Jordan River.

There will be roles for the public, scientists, private businesses, and public facilities. It is even possible that mechanical reaeration could restore some measure of adequate DO in the lower Jordan River until implementation of new programs and capital improvements are complete. Completion of these activities will ultimately restore full support of beneficial use to the lower Jordan River.

Eight appendices to this document provide additional details that support conclusions made in the main body of the report.

1.0 INTRODUCTION AND STATE OF THE JORDAN RIVER

This water quality study for the Jordan River, referred to as a Total Maximum Daily Load (TMDL) determination was initiated because levels of Dissolved Oxygen (DO), Total Dissolved Solids (TDS), *Escherichia coliform* (*E. coli*), and water temperature (Temperature) have violated Utah water quality standards associated with several of its designated beneficial uses. Under current Utah water quality regulations, these violations resulted in the river being listed as impaired on the State's 303(d) list of impaired waters. The Federal Clean Water Act requires States to determine the maximum amount of pollutants that an impaired waterbody can receive and still safely meet water quality standards.

Investigations of the Jordan River began in 1996 and have been ongoing since that time. The lower Jordan River was first listed as impaired in the 2004 303(d) list. Upper Jordan River segments and additional pollutants of concern were added in the 2006 303(d) list. These additional listings required the entire river to be considered in this study beginning at the headwater source (Utah Lake) to the river's end at Burton Dam. Results of this study coupled with predictive water quality modeling conclude that excess loads of Organic Matter (OM) are the primary cause for low DO concentrations in the lower Jordan River, impairing its warm water aquatic life beneficial use. Impairment by other pollutants of concern (TDS, E. coli, and Temperature) has also been addressed and is discussed briefly in this report. However, this report does not include a TMDL for TDS, E. coli, or temperature. A list of acronyms and abbreviations commonly used in the TMDL process are included in Appendix A. A synopsis of all documents produced as part of the Jordan River TMDL study from 2005 through 2010 is included in Appendix B.

1.1 THE TMDL PROCESS

1.1.1 FEDERAL REQUIREMENTS OF CLEAN WATER ACT

Amendments to the Federal Water Pollution Control Act in 1972 and again in 1977 produced what is commonly known as the Clean Water Act (CWA). Important provisions of the 1977 amendments include regulations on point source pollutant discharges into waters of the United States, legal authority to EPA for defining industry standards for wastewater, and identification of critical nonpoint source pollution problems. Additional amendments to the CWA in 1981 and 1987 provided the necessary guidance for states to begin assessing waterbodies for inclusion on annual 303(d) lists.

TMDL regulations were issued in 1992 in Title 40 of the Code of Federal Regulations Section 130.7. These regulations established specific requirements for addressing water quality impairment to 303(d) listed water bodies that include:

1. More stringent water quality-based controls when technology-based controls do not achieve State water quality standards.

2. Increased opportunity for public involvement.

3. A process to expedite NPDES permitting.

4. Technically sound and legally defensible decisions that result in achieving water quality standards.

5. A means to integrate management of point and nonpoint source pollutants that contribute to impairment.

1.1.2 TMDL GUIDELINES

This TMDL study for the Jordan River defines the relationship between pollutant sources and in-stream water quality conditions. Based on this relationship, a permissible load is defined that will result in meeting state water quality standards and restore aquatic life beneficial use support for impaired segments of the Jordan River.

The Jordan River TMDL defines the permissible load in terms of a Wasteload Allocation (WLA) assigned to point sources and a Load Allocation (LA) assigned to nonpoint sources. Point sources include all discharges regulated under the National Pollutant Discharge Elimination System (NPDES) program while nonpoint sources incorporate all remaining pollutant sources including anthropogenic sources and natural background. This TMDL also accounts for seasonal variation in water quality and includes a Margin of Safety (MOS) that accounts for the uncertainty in the relationship between pollutant load reductions and the response in the Jordan River's water quality.

The geographic extent of the Jordan River TMDL is focused on pollutant sources that exist within the Jordan River watershed between the outlet of Utah Lake and the end of the Jordan River at Burton Dam. Future efforts will focus on water quality issues upstream and downstream of this area and will be accounted for in updated versions of the Jordan River TMDL. Additional details describing timing and implementation of the Jordan River TMDL are discussed later in this report.

The Jordan TMDL will employ a phased approach that promotes water quality improvements while addressing scientific uncertainty through ongoing research. The phased approach to TMDL development is appropriate when it is expected that the loading capacity and pollutant allocations will be adjusted based on the collection of additional data (Best-Wong 2006). The outcome of a phased TMDL must still result in meeting water quality standards (EPA 1991, United States District Court 2005).

1.1.3 UTAH WATER QUALITY STANDARDS AND JORDAN RIVER BENEFICIAL USES

Jordan River water quality is defined by numeric standards and narrative criteria adopted by the state to safeguard public health and protect its designated beneficial uses including domestic use, recreation, aquatic life and agricultural uses. Beneficial use classifications applicable to the Jordan River include:

Class 1C: Protected for domestic purposes with prior treatment by treatment processes as required by the Utah Division of Drinking Water.

Class 2B: Protected for secondary contact recreation such as boating, wading, or similar uses.

Class 3A: Protected for cold water species of game fish and other cold water aquatic life, including the necessary aquatic organisms in their food chain.

Class 3B: Protected for warm water species of game fish and other warm water aquatic life, including the necessary aquatic organisms in their food chain.

Class 3D: Protected for waterfowl, shore birds and other water-oriented wildlife not included in classes 3A, 3B, or 3C, including the necessary aquatic organisms in their food chain.

Class 4: Protected for agricultural uses including irrigation of crops and stock watering.

Based on current Utah water quality standards, the 2008 303(d) list identifies seven segments of the Jordan River as impaired (Utah DWQ 2008a). The impaired beneficial uses, parameters of concern, and standards associated with these parameters are identified in Table 1.1 and Figure 1.1. This TMDL study will examine both 303(d) listed parameters and other related water quality constituents.

Site-specific DO standards for the Jordan River include standards that are imposed from May through July or August through April. Standards applicable for May through July include a 7-day DO average of 5.5 mg/L, a 30-day DO average of 5.5 mg/L, and an instantaneous minimum of 4.5 mg/L (UAC 2010). Site-specific DO standards enforced August through April include a 30-day DO average of 5.5 mg/l and an instantaneous minimum of 4.0 mg/L. As noted in Table 1.1, Class 3A temperature standards only apply to the Jordan River above the confluence with Little Cottonwood Creek upstream to the boundary between Segments 7 and 8 (Jordan River at Turner Dam).

1.1.4 Status of Current Impairments and Phased Approach

Since the beginning of this TMDL study in 2005, new information has been collected supporting the need for site-specific criteria and changes to beneficial use classifications in regards to TDS and Temperature in Segments 5–8 (Cirrus 2010b). A detailed discussion of existing TDS and Temperature data, pollutant loads, permissible loads and recommended endpoints are included in documentation completed prior to this report (Cirrus 2010a, Cirrus 2010b, Cirrus 2010c). Separate documentation is required by EPA to justify site specific criteria recommendations for Jordan River segments impaired by Temperature and TDS. Additional *E. coli* measurements are currently being collected throughout the Jordan River watershed to support a future TMDL study for this pollutant.

The purpose of this TMDL study is to define water quality endpoints that will restore the aquatic life beneficial use to segments impaired by OM and resultant low DO based upon the best information available. These endpoints are established following a thorough scientific analysis detailed in Chapters 2 through 5. However, future studies are needed to help refine our understanding of OM sources, loading and habitat limitations to the Jordan River. Therefore, a phased approach is appropriate for updating this TMDL, including specific recommendations and a timeline as described in Chapter 5.

Table 1.1. DWQ segments of the Jordan River included on the Utah 2008 303(d) List (Utah DWQ 2008a).

DWQ Segment	Beneficial Use and Support Status [1]							(Beneficial Use) Pollutant of Concern	Standard or Pollution Indicator Level [2] for Pollutant of Concern
	River Mileage	1C	2B	3A	3B	3C	4		
1	0–6.9				NS	NS		**(3B)** Benthic Macro Impairment[2] **(3B)** Organic Enrichment/Low DO (**3C**) Organic Enrichment/Low DO	**(3B)** O/E ratio[3] >0.74 or >0.54 per sample size **(3B)** Min: Aug–Apr = 4 mg/L, May–Jul = 4.5 mg/L (**3C**) 30-day avg DO = 5 mg/L
2	6.9–11.4		NS		NS			**(2B)** *E. coli* **(3B)** Benthic Macro Impairment **(3B)** Organic Enrichment/Low DO	**(2B)** Max=940 col/100 mL, Geo. Mean=206 col/100 mL **(3B)** O/E ratio >0.74 or >0.54 per sample size **(3B)** Aug–Apr = 4 mg/L, May–Jul = 4.5 mg/L
3	11.4–15.9		NS		NS			**(2B)** *E. coli* **(3B)** Organic Enrichment/Low DO **(3B)** Total Phosphorus	**(2B)** Max=940 col/100 mL, Geo. Mean=206 col/100 mL **(3B)** Aug–Apr = 4 mg/L, May–Jul = 4.5 mg/L **(3B)** 0.05 mg/L (pollutant indicator level)
4	15.9–24.7			[4]			NS	**(4)** Salinity/TDS/Chlorides	**(4)** 1,200 mg/L
5	24.7–26.4		NS	NS			NS	**(2B)** *E. coli* **(3A)** Temperature **(4)** Salinity/TDS/Chlorides	**(2B)** Max=940 col/100 mL, Geo. Mean=206 col/100 mL **(3A)** Max = 20°C **(4)** 1,200 mg/L
6	26.4–37.6			NS				**(3A)** Benthic Macro Impairment **(3A)** Temperature	**(3A)** O/E ratio >0.74 or >0.54 per sample size **(3A)** Max = 20°C
7	37.6–41.8			NS			NS	**(3A)** Benthic Macro Impairment **(3A)** Temperature **(4)** Salinity/TDS/Chlorides	**(3A)** O/E ratio >0.74 or >0.54 per sample size **(3A)** Max = 20°C **(4)** 1,200 mg/L
8	41.8–51.4	[1]		NS			NS	**(3A)** Benthic Macro Impairment **(3A)** Temperature **(4)** Salinity/TDS/Chlorides	**(3A)** O/E ratio >0.74 or >0.54 per sample size **(3A)** Max = 20°C **(4)** 1,200 mg/L

[1] Shaded cells indicate beneficial uses assigned to each DWQ segment. NS indicates non-support of the assigned beneficial use.
[2] Benthic macroinvertebrate impairment is based on pollution indicator values.
[3] O/E ratio – the measured ratio of observed macroinvertebrate species to expected macroinvertebrate species (Utah DWQ 2008b).
[4] Beneficial use class 3A applies to DWQ Segment 4 above the confluence with Little Cottonwood Creek.

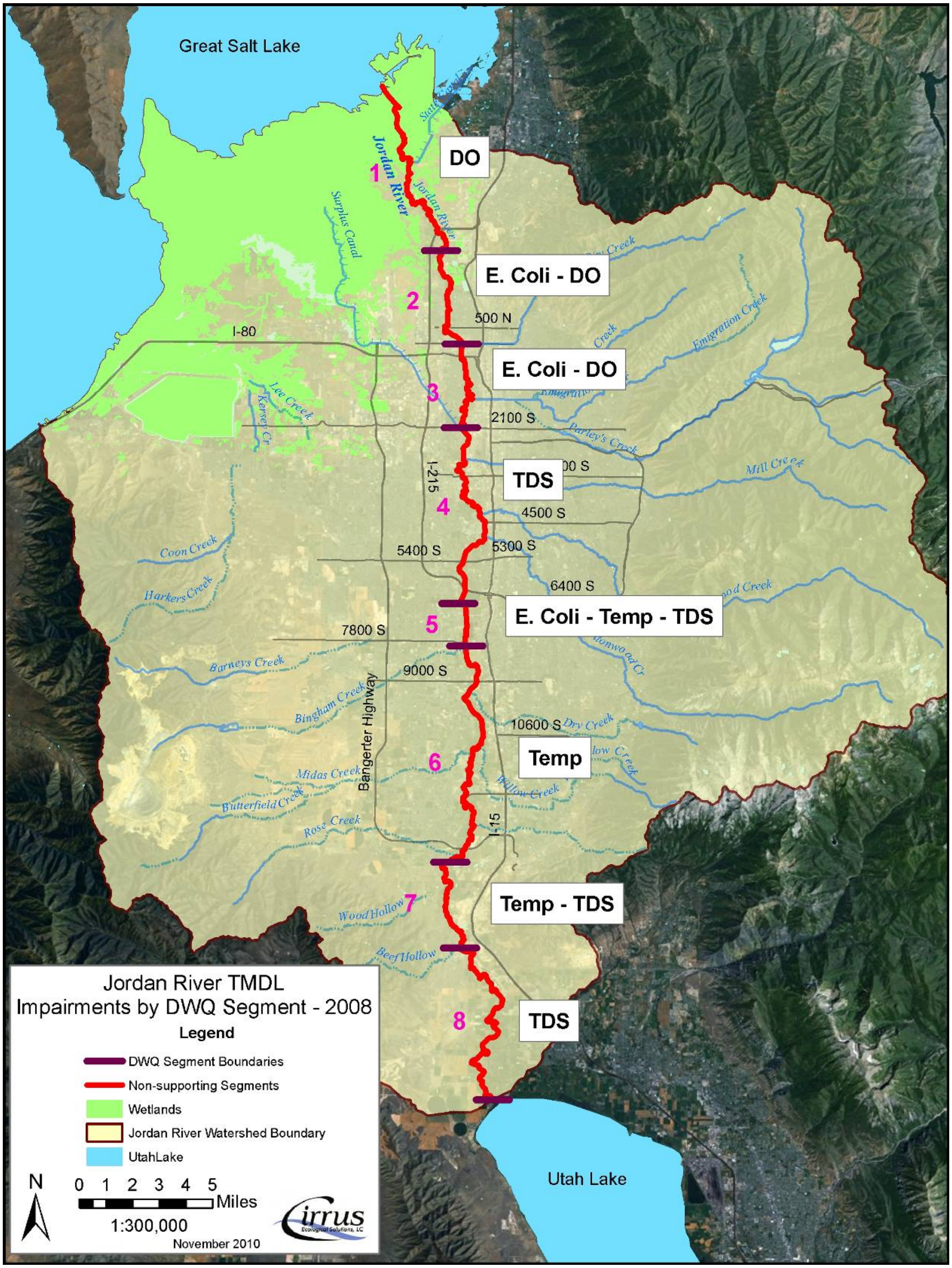


Figure 1.1. DWQ-designated segments and water quality impairments on the Jordan River.

1.2 WATERSHED DESCRIPTION

The Jordan River watershed is a part of the Great Salt Lake Basin which incorporates much of northern and western Utah as well as portions of Idaho, Wyoming, and Nevada (Figure 1.2). The total area of the Great Salt Lake Basin is about 35,000 mi^2 including about 14,000 mi^2 that do not contribute flow to the Great Salt Lake (Arnow and Stephens 1990). This latter area is referred to as the West Desert and extends several hundred miles south of the Great Salt Lake along the border between Nevada and Utah.

The Jordan River watershed comprises the downstream end of the Provo/Jordan River Basin and is one of three river basins that contribute 92 percent of inflow to the Great Salt Lake (Arnow and Stephens 1990). The other two basins are the Bear River Basin and the Weber River Basin (Figure 1.2). The Bear River and the Weber River discharge to Bear River Bay and Ogden Bay, respectively. Flows of the Jordan River ultimately enter Farmington Bay after it is distributed through a series of canals, ponds, and wetlands. The Jordan River contributes approximately 13 percent of the total inflow to the Great Salt Lake (Arnow and Stephens 1990). However, most of that flow enters via the Surplus Canal and Gilbert Bay. Total Jordan River flows rank as the third largest contribution to the Great Salt Lake behind the Bear River and the Weber River.

The Jordan River originates at the outlet of Utah Lake and flows 51 miles to the north where it terminates at Burton Dam. The Jordan River watershed incorporates all of Salt Lake County and some of the most densely populated areas of Utah.

1.2.1 TOPOGRAPHY

The topographic boundary of the Jordan River watershed is defined on the east, west, and south by mountain ranges and on the north by the Great Salt Lake. The Wasatch Mountain range is located on the east side of the basin and rises from about 4,300 feet at the valley floor to more than 11,000 feet. These mountains are part of the greater Rocky Mountain Range that extends from Canada south to New Mexico. The Oquirrh Mountain range is located on the west side of the basin and includes peaks that reach 10,000 feet. The Traverse Mountains define the southern boundary of the watershed and meet the Oquirrh Mountains on the west at the Jordan River Narrows. The topographic restriction created by the Traverse Mountains at the Narrows defines the boundary between DWQ Segments 7 and 8 but does not capture the entire Jordan River watershed to its headwater source. Therefore, the watershed boundary considered in this report extends south of the Narrows to Utah Lake's outlet. Figure 1.3 shows the topographic boundary for the Jordan River TMDL project area including areas south of the Narrows.

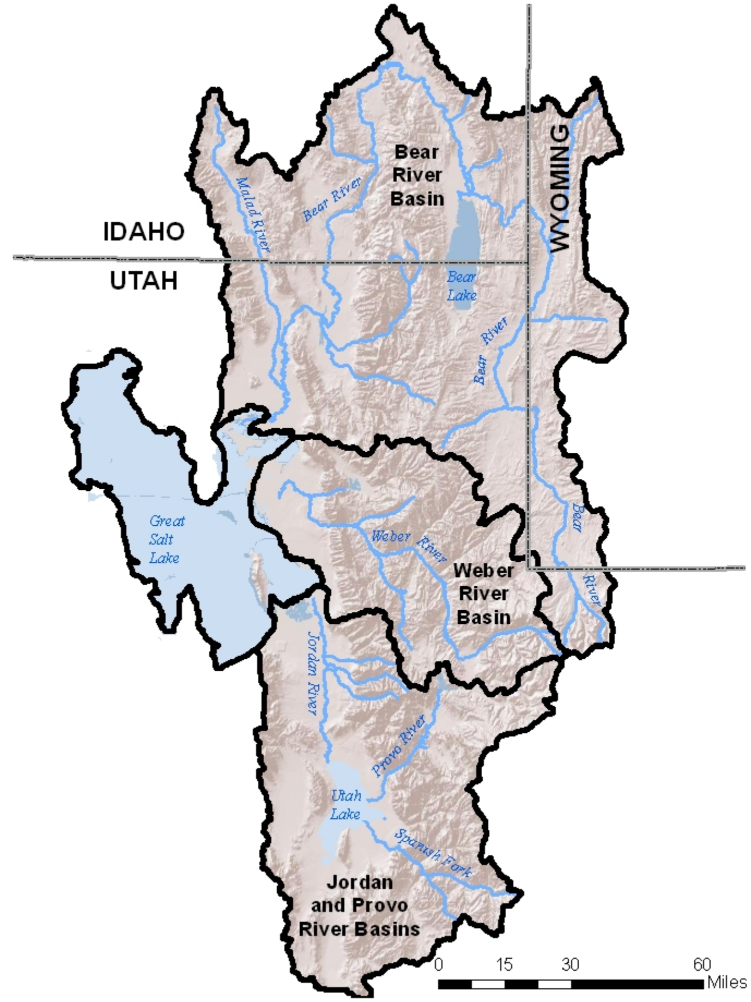


Figure 1.2. Great Salt Lake Basin (left) and perennial tributaries to the Great Salt Lake (right).

Figure 1.3. Jordan River TMDL tributaries to Jordan River.

1.2.2 Geology/Soils

The Jordan River watershed is part of the Basin and Range Province found throughout Utah. The Wasatch Mountains that define the eastern watershed boundary are fault block mountains produced during historic periods of uplift and subsidence along the Wasatch Fault. Ancient Lake Bonneville covered most of Utah at one time to depths of 1,000 feet or more above the existing elevation of the Great Salt Lake. As Lake Bonneville drained, large deposits of sand and gravel were left on historic shorelines that appear as terraces along many mountain ranges in northwest Utah. Cobble, gravel, and sand deposits are found in alluvial fans located near canyon mouths along the east and west boundaries of the watershed. Finer materials are generally found in valley bottoms. Multiple periods of deposition corresponding with historic lake elevation changes have contributed to soil formation in the watershed. As a result, soil profiles are highly stratified.

1.2.3 Precipitation

Precipitation in the form of rain and snow varies widely across the Jordan River basin due to the effect of topography on regional and local weather patterns. Weather patterns in the Jordan River Basin are typical of the Intermountain West and are characterized by four distinct seasons. Much of the annual precipitation falls as snow in the Wasatch Mountains and contributes high runoff and streamflow during the spring thaw. Annual precipitation levels range from 12 to 16 inches on the valley floor to over 60 inches near mountain peaks (Utah DWRe 2010).

1.2.4 Hydrology

The Jordan River is highly managed due to regulation of discharge from Utah Lake, tributary flows, irrigation diversions, stormwater contributions and flood control. Numerous studies of inflows and outflows to the Jordan River watershed have previously been completed to address interactions between these water developments (Coon 1982, Utah DWRe 1997, Borup and Haws 1999, CH2M Hill 2005). A separate assessment of inflows and outflows was previously completed to address the specific needs of this TMDL study (Cirrus 2009b).

Following a review of published literature, discussions with stakeholders, and an assessment of available flow monitoring data, the following sources of flow to the Jordan River were identified:

- Utah Lake – the existing outlet from the lake is the original surface water source for the Jordan River.
- Tributaries – gaged and ungaged.
- Permitted Discharges – effluent from wastewater treatment plants.
- Stormwater – surface runoff from collection systems that discharge via direct outfalls or larger storm drains and tributaries that receive stormwater and eventually enter the Jordan River.
- Diffuse Runoff – surface runoff outside of stormwater catchments that contribute sheet flow into the Jordan River.
- Irrigation Diversions and Return Flows – flows diverted to irrigation canals and the return of unused irrigation water discharging from canals to the Jordan River.
- Groundwater.

A description of each source of flow is included in Appendix C to this report and discussed in detail in previous reports (Cirrus 2009b). Flows are significant to load calculations and are defined in this TMDL study as accurately as possible. The water budget quantifies flows from each pollutant source in context with others.

The Jordan River water budget utilized historical flow data from 1980 through 2005 in order to incorporate a hydrologic period that is common to all flow data sources and utilizes modern collection procedures (i.e. automated flow gages). The 26 years within this period also incorporate wet and dry climatic cycles that significantly influence average flow calculations in the western United States. Sources of inflow and outflow were defined using data from several sources. Where available, monthly averages of available flow gage data were used in the water budget. For other inflows and outflows such as Utah Lake, ungaged tributaries, stormwater, diffuse runoff, irrigation return flows, and groundwater, gage data was used in combination with other flow information to estimate flows and to check results through water budget calculations.

An annual water budget for the Jordan River is summarized in Figure 1.4. Differences between predicted and measured flow for each segment are also shown below the graphics defining inflows and outflows. Note that no flow measurements are available for the Brighton canal. This canal diverts water from the Jordan River just downstream from the confluence of Little Cottonwood Creek. Estimates of average diversions by the Brighton canal used in previous studies range from 20 cfs (Borup and Haws 1999) up to 70 cfs (CH2M Hill 2005). The end of the lower Jordan River at Burton Dam does not have a continuous measurement record. Therefore, measurements at the closest upstream site (Cudahy Lane) were used to define the difference between predicted and measured flows. A more detailed version of the water budget in tabular form is included in Appendix C.

1.3 STAKEHOLDERS AND THE TMDL PROCESS

The TMDL process is defined and guided by the EPA and Utah DWQ. However, the Jordan River's water quality is determined in large part by the authorities, management directives, and jurisdictional boundaries of other governmental agencies and districts. Therefore, other federal, state, and local agencies were included in determining the most reasonable and effective means to achieve water quality improvements and restore the Jordan River's beneficial uses. A detailed discussion of governing entities in Salt Lake County is provided in the *Salt Lake County Water Quality Stewardship Plan* (Salt Lake County 2009). A brief discussion of political entities that are important to the TMDL process is included below.

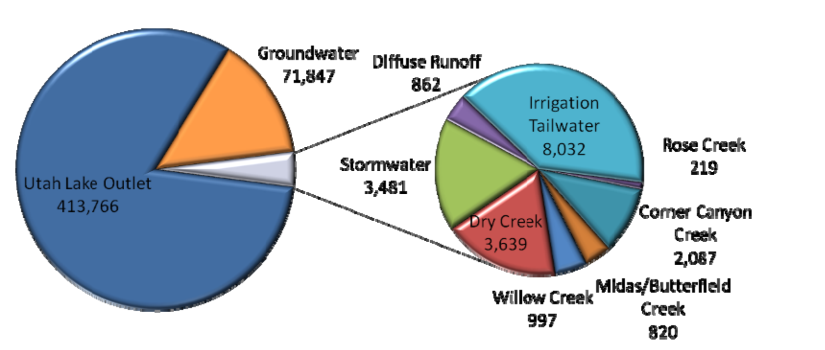
1.3.1 FEDERAL, STATE, AND MUNICIPAL AUTHORITY

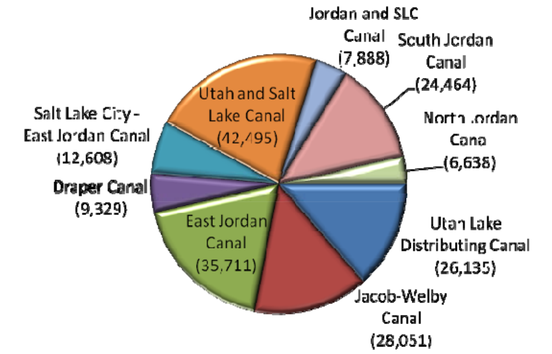
Several government agencies have been assigned specific authority to protect water quality in the Jordan River watershed. The U.S. Forest Service manages the greatest amount of federally administered land in the watershed under the guidance provided in the latest resource management plan for the Wasatch-Cache National Forest (USFS 2003). The Forest has been charged to manage and protect watersheds used as a municipal water source in cooperation with Salt Lake City. State agencies responsible for water quality protection include the Department of Environmental Quality Division of Drinking Water and the Division of Water Quality. Specific responsibilities include administering the TMDL, UPDES permitting, and source water protection programs.

Figure 1.4. Water budget for Jordan River from Utah Lake to Burton Dam (1980–2005).

	Inflow (ac-ft)	Outflow (ac-ft)

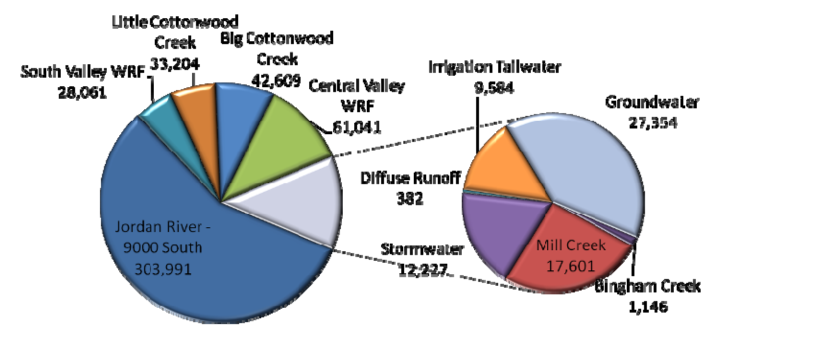
Utah Lake – 9000 South

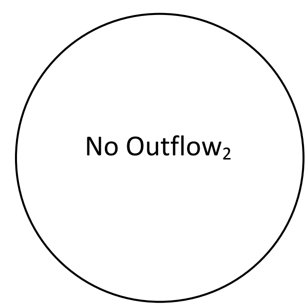




Total Flow (ac-ft/yr)	505,750	193,320
Predicted Flow (ac-ft/yr)	312,430	
Measured Flow₁ (ac-ft/yr)	303,991	
Difference (%)	2.8	

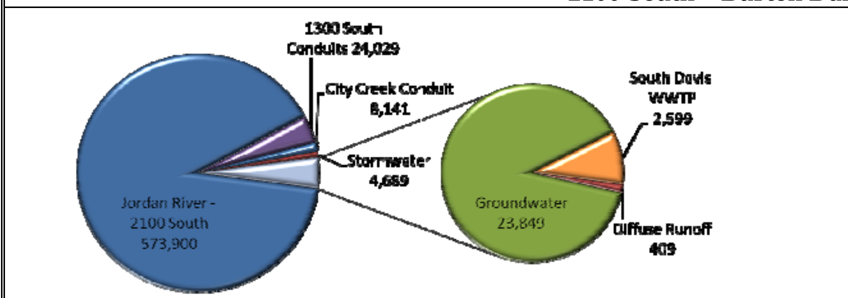
9000 South – 2100 South

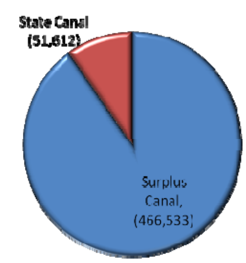




Total Flow (ac-ft/yr)	537,200	0
Predicted Flow (ac-ft/yr)	537,200	
Measured Flow₃ (ac-ft/yr)	573,900	
Difference (%)	(6.4)	

2100 South – Burton Dam





Total Flow (ac-ft/yr)	637,615	518,145
Predicted Flow Burton Dam (ac-ft/yr)	119,470	
Measured Flow Burton Dam (ac-ft/yr)	NA	
Total Cudahy Lane (ac-ft/yr)	164,778	
Predicted Flow Cudahy Lane (ac-ft/yr)	164,778	
Measured Flow Cudahy Lane₄ (ac-ft/yr)	164,097	
Difference (%)	0.4	

[1] USGS Station 10167230 [2] No flow measurements available for Brighton Canal [3] 10170490 – Combined Flow Jordan River & Surplus Canal at Salt Lake City, UT - 2100 S [4] DWR-Cudahy Lane

The majority of the Jordan River watershed is within Salt Lake County (Figure 1.5). Salt Lake County includes 16 incorporated municipalities, with the largest population found in Salt Lake City. Small portions of Davis County and Utah County flow to Jordan River Segments 1 and 8, respectively. No incorporated municipalities are found in the Davis County portion of the study area. The city of Lehi is located in Utah County adjacent to the east side of Jordan River Segment 8. Significant population growth is expected throughout the watershed during the next 20 years (GOPB 2008). The planning process used by each municipality to accommodate this growth must recognize potential impacts to water quality and include management practices that minimize pollutant loads.

Local municipalities also have authority over land uses within the watershed (Utah Constitution Article X1, Section 5). Cities have the authority and responsibility to provide stormwater management services as well as promote and enforce programs that protect source water. Moreover, Salt Lake City and Sandy City have been assigned First Class City status by state legislation. This ranking grants authority to manage land and water resources in Wasatch Mountain watersheds that provide culinary water to these cities (Utah Administrative Code 10-8-15). Included in this authority is the right to regulate development and other activities outside of city boundaries. Specific restrictions are included in the FCOZ that incorporates all Wasatch Mountain streams in Salt Lake County (Salt Lake County 2010).

1.3.2 MUNICIPAL WATER DEMAND

Culinary water is delivered to municipalities in Salt Lake County by multiple water providers, including Salt Lake City Department of Public Utilities (SLCPU), Metropolitan Water District of Salt Lake and Sandy (MWDSLS), Jordan Valley Water Conservancy District (JVWCD) and other municipal water providers. These facilities treat groundwater, surface water diverted from tributaries, and water imported from outside the Jordan River watershed. Treated water from Wasatch Mountain streams provides 60 percent of the potable water used by Salt Lake City, and other municipalities (Salt Lake County 2009). At present, there are nine water treatment plants responsible for drinking water treatment and supply. Eight of these plants treat surface water and one plant also treats groundwater.

Future potable water demand is projected to increase 67 percent from 2005 through 2100 for Salt Lake County (Bowen Collins 2007), and demonstrates a need to continue developing and preserving high levels of water quality in the Jordan River watershed. Water sources and strategies that are being considered to meet the future demand for potable water include continuing development of groundwater resources, using additional Wasatch Mountain stream sources, importing water, reuse of treated wastewater for landscape irrigation, and conservation (Salt Lake County 2009). One of the current water developments is the Southwest Jordan Valley Groundwater Project, which will pump groundwater from aquifers west of the Jordan River. In cooperation with Kennecott Utah Copper Corp., JVWCD has constructed a reverse osmosis plant as part of remediation efforts to treat contaminated groundwater from the Bingham Canyon area. The plant will provide up to 7 million gallons per day for municipal use by 2012 (JVWCD 2010).

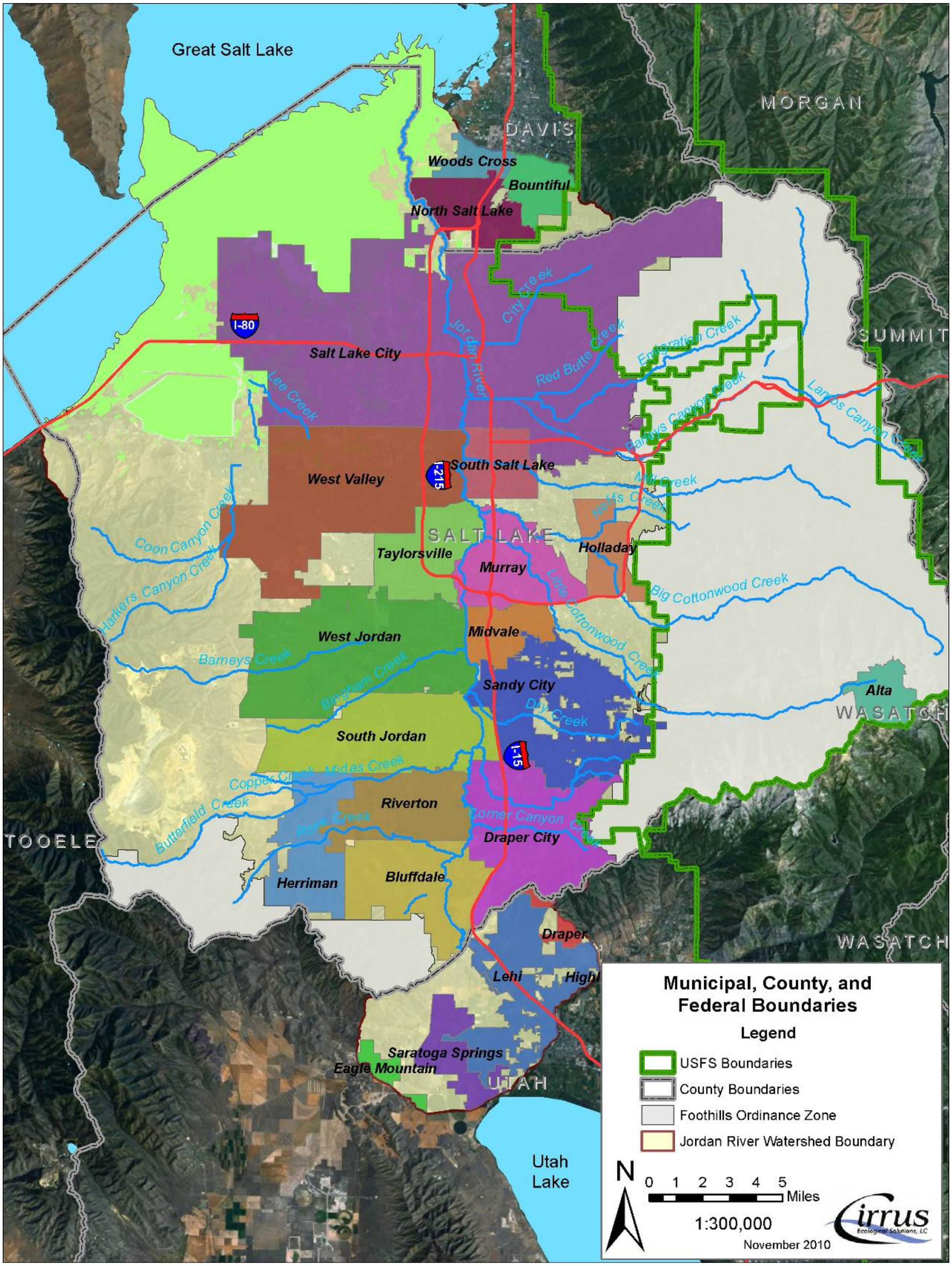


Figure 1.5. Municipal, county, and federal boundaries including Lehi, FCOZ boundary, and Forest boundary.

1.3.3 FLOOD CONTROL

Past management of the Jordan River has focused on water development and flood control programs. A discussion of the influence of water rights on sources of Jordan River flow is included in Appendix C. Flood control is the responsibility of Salt Lake County as defined in Section 17 of the Salt Lake County Code of Ordinances. Flood control facilities used by the county include drainage pipes, open canals, and natural stream and river channels. Irrigation canals play a significant role in flood control by transferring infrequent stormwater flows to stream channels or drains which have the capacity to safely move water to the Great Salt Lake. The Surplus Canal is a major flood control feature that can convey all the flow in the Jordan River above 2100 South directly to the Great Salt Lake. The gate on the canal that feeds the lower Jordan River is operated to satisfy downstream water rights in the lower Jordan River while maintaining the reserve capacity to receive tributary storm flows. Tributary storm flows in the lower Jordan are delivered by City Creek, Red Butte Creek, Emigration Creek, and Parleys Creek.

Options for improving Jordan River water quality through increased flow are limited. Managing flows in the lower Jordan River for the benefit of water quality must also satisfy established water rights and meet the objectives of county and municipal flood control programs. This TMDL study considers the effect of low flow on water quality in an analysis of critical conditions within Chapter 2. The load allocation analysis in Chapter 4 shows that DO can be restored through pollutant load reduction and does not require flow modification. However flow modification may improve DO concentrations and will be explored in future phases of the TMDL.

1.4 WATER QUALITY

The purpose of this section is to review DO water quality data used for Utah 303(d) listing collected from main-stem Jordan River stations. A more comprehensive review of water quality data related to all impaired segments of the Jordan River is found in *Lower Jordan River TMDL: Work Element 1 – Evaluation of Existing Information* (Cirrus 2007). A thorough review of water quality parameters and processes that could potentially influence low DO levels in the lower Jordan River is included in Chapter 2.

1.4.1 DATA COLLECTION

Over 1,300 well, spring, and stream water quality monitoring stations in the Jordan River Basin have been identified and all available data compiled into a database (Cirrus 2007). The locations of the primary water quality monitoring stations used in the TMDL study are shown in Figure 1.6. In general, water quality samples from streams have been collected from early spring to early fall. A limited number of stations have been visited on a monthly basis during some years. Although this assessment of surface water quality relies heavily on monitoring conducted by DWQ, water quality data collected by other agencies has also been reviewed and used where appropriate throughout this study. The DWQ has collected the majority of surface water quality samples in the study area, extending back to the early 1970s. Other entities that have collected water quality and flow monitoring data include various state, county, and city agencies as well as several stakeholder groups operating in the Jordan River Basin. The intent of the phased TMDL will be to enhance the quality and quantity of data to assure that the appropriate identification of impairment and remediation is identified.

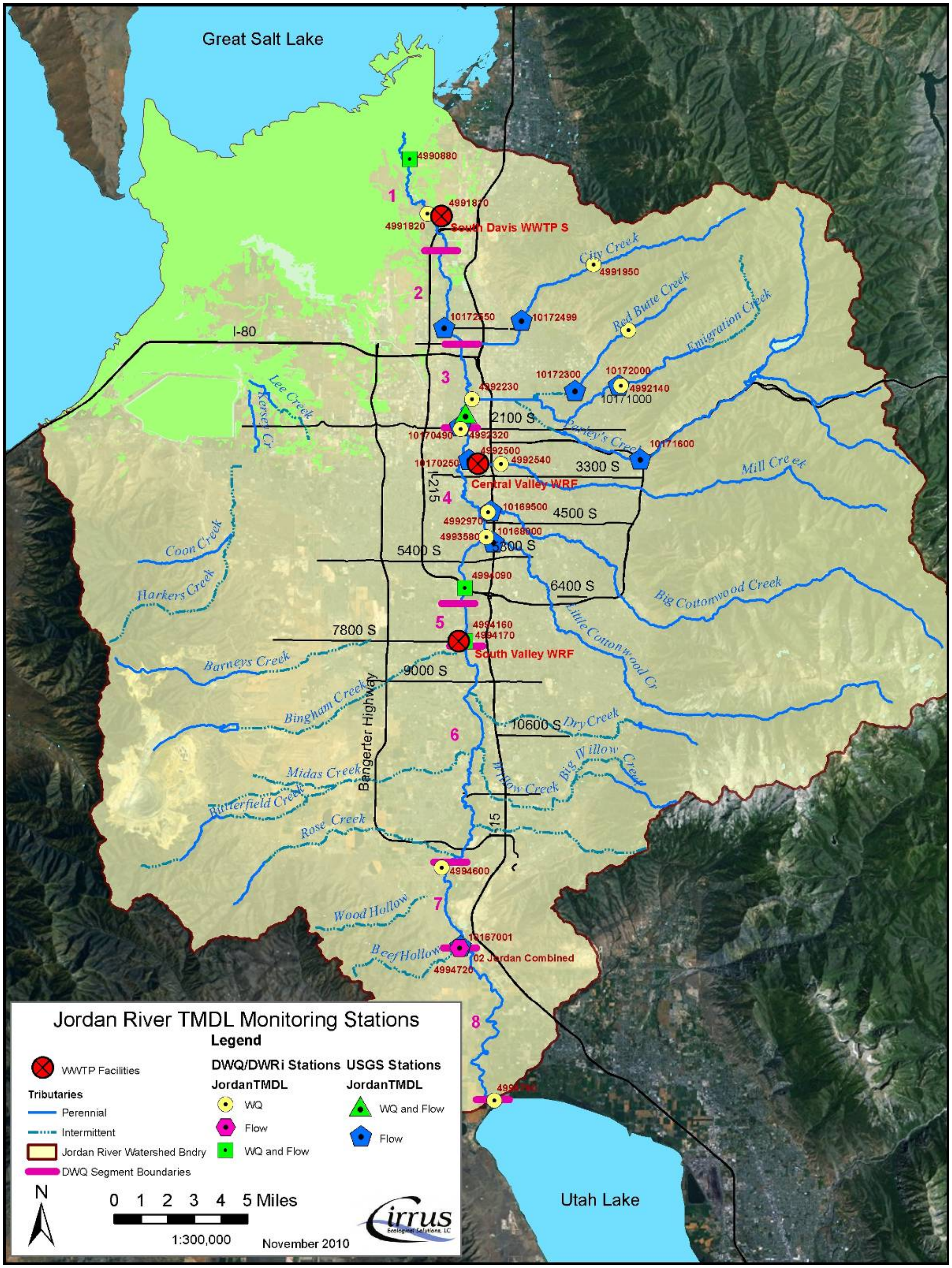


Figure 1.6. Jordan River TMDL monitoring stations.

The DWQ relies on multiple monitoring stations and long term and intensive monitoring frequencies to assess beneficial use support for a given waterbody. Some stations are designated for routine, long-term monitoring and are visited every 4–6 weeks. DWQ also conducts intensive monitoring efforts on a 5-year rotating cycle that includes both long-term monitoring stations and additional stations that provide a basis for assessment and TMDL studies. Intensive monitoring was conducted in 1999–2000 and 2004–2005 within the Jordan River watershed. A smaller set of stations associated with the mainstem Jordan River were also selected for intensive monitoring during 2008 in an effort to fill data gaps. Data collection of this type includes instantaneous grab sample measurements as well as automated measurements to measure diurnal fluctuations for some constituents.

One of the methods used to determine water quality impairment is based on the percent of samples exceeding numeric standards. DWQ recommends that a minimum of 10 grab sample measurements be collected from monitoring sites within 1 year in order to incorporate seasonality into the data set. If more than 10 percent of measurements exceed numeric standards, the associated waterbody is considered impaired for that parameter.

In contrast to the extensive database of conventional water quality parameters assembled in support of the TMDL, there are far fewer data to fully characterize OM. Focused monitoring of OM will continue throughout the steps recommended for achieving a phased Jordan River TMDL. Load calculations described in Chapter 3 rely upon a combination of direct measurements, computer modeling, and scientifically based assumptions that together attempt to quantify total OM. All assumptions used in load calculations and other areas of the pollutant source assessment have been clearly defined as they are used, including assumptions used to estimate OM loads not captured with existing water quality monitoring data.

1.4.2 Existing Water Quality Conditions

Current water quality is characterized in this report based on monitoring data collected from 1995 through 2008. Since 1995 was the first year for Phase I Stormwater permitting, it is anticipated that some improvements in the water quality of the Jordan River would continue with the implementation and refinement of stormwater BMPs. Best efforts have been made to incorporate data into the TMDL report that clearly identify existing conditions in the Jordan River. However, water quality conditions may be changing, and the impairments identified using existing data sets may be superseded by enhanced monitoring being conducted in the phased TMDL. Every effort is being made to assure the long term water quality of the Jordan River and additional data will support these efforts.

Support or impairment of surface waters is initially determined by comparing monitoring data to numeric criteria and indicator values. Table 1.1 lists the numeric criteria and indicator values used in the water quality assessment of DO concentrations in the Jordan River TMDL. Biological metrics have been developed and were also used to determine DO impairment for the 2008 303(d) list (Utah DWQ 2008b).

Guidelines used for assessing existing water quality conditions and determining beneficial use support are included in the *2008 Utah 303(d)/305(b) Integrated Report*. Some of the significant guidelines applicable to DO impairment include (Utah DWQ 2008c):

- A minimum of ten data points at individual sites. If less than 10 samples are collected additional considerations will be needed to determine impairment.

- It is preferred that data used for an impairment assessment be collected within a single year and that seasonality is incorporated into collection of the data.

- Analysis of data will focus on data not older than 5 years. Data as old as 10 years may be used if information is available to validate that there has not been a significant disturbance in the watershed during this time that would significantly change the results of the assessment.

- The impact of naturally occurring or severe environmental conditions not reflective of a normal hydrological regime during the monitoring period must be considered.

- Instantaneous measurements of DO should be compared to the 30-day conservative standard (5.5 mg/L).

- A waterbody is included on the 303(d) list if two or more samples violate the 30-day standard and if the standard is violated in more than 10 percent of the samples.

- Additional studies based on diurnal DO measurements may be used to further determine support of beneficial use, or delisting if necessary.

- The final decision to include or to leave a waterbody on the 303(d) list is based on the discretion of Utah DWQ that goes beyond criteria listed above and can include other types of information and best professional judgment.

The DO assessment and this document consider data up to 2009, and does not consider 2010 data in the assessment process. DWQ realizes that more data has become available since the distribution of this report. The next phase of the TMDL will consider data collected after 2009 to assess and validate the 303(d) impairment listing. It is noted, however, that the 2010 grab sample data collected by DWQ showed a limited number of exceedances of the 30 day standard, as would be expected in a high flow year. As such, there is a desire in the next phase to install continuous DO monitoring stations to insure adequate data either validating the 303(d) impairment listing or justifying delisting. The installation of these monitoring stations will be negotiated with the POTW and stormwater dischargers.

Figure 1.7 shows DO measurements collected from segments 1 through 3. The lower plot in Figure 1.7 shows all DO concentrations measured in 2004 through 2008 and identifies two critical periods when violations occurred. The upper and middle plots show only data collected during 2008 and 2004, respectively, and identify several measurements ranging from 3 to 4 mg/L. These values are well below the 4.5 mg/L site-specific standard for the Jordan River applicable in May through July and are slightly below the 4.0 mg/L standard applicable in August through April.

The months during which data were collected from most stations are May through September and define a critical period for DO levels. The longer term record for DO at Cudahy Lane is shown in the upper plot of Figure 1.7 and indicates that low DO does not occur during other times of the year.

Table 1.2 shows the number and percent of DO samples violating the 30-day average DO standard (5.5 mg/L) and the instantaneous site-specific standards (minimum acceptable DO levels) applicable to the Jordan River of 4.0 mg/L from August through April and 4.5 mg/L from

May through July. Results for site specific DO criteria were determined from samples collected during months associated with the respective standard. The total samples compared to either the 4.5 mg/L or 4.0 mg/L standard are provided for each station. Note that the total number of samples compared to the 5.5 mg/L standard is equal to the total samples compared to the 4.5 mg/L and 4.0 mg/L DO standard for each row in the table. The percent of samples violating the 30-day average DO standard of 5.5 mg/L ranges from approximately 20 to 80 percent during most summer months and clearly exceeds the 10 percent threshold and the minimum number of samples used to determine inclusion on the 303(d) list. Although the total number of samples for several stations is less than 10, the group of stations together provides clear indication of a seasonal period when low DO levels occur. As the TMDL progresses, DWQ will continue to monitor, validate and further refine the nature and extent of the DO impairment.

The average time of day when DO violations occur is also provided in Table 1.2. DO violations for the 4.0 mg/L and 4.5 mg/L instantaneous standard were collected before noon when the diurnal cycle is moving away from the minimum daily value that occurs near sunrise before algae begin producing oxygen through photosynthesis. However, several violations of instantaneous standards were also measured in the early to late afternoon hours when the diurnal cycle is approaching peak DO concentrations. Based on diurnal cycles measured during synoptic monitoring, the minimum DO level can be 2 to 4 mg/L below the peak concentration depending on location and time of year.

Diurnal DO measurements were collected from lower Jordan River segments starting in 2004 by DWQ and other stakeholder groups. Diurnal measurements are collected by placing a DO meter in the river channel for several days and programming it to measure and record DO levels at a pre-determined interval such as every half hour. Many of these measurements show a strong diurnal pattern above and below 2100 South during most seasons of the year. Many of the diurnal measurements remained above 4.0 mg/L or 4.5 mg/L. One sample period in September, 2007 measured diurnal DO values below 4.0 mg/L at three stations including Burnham Dam, Cudahy Lane, and 500 North for an extended period of 16 to 32 hours (Figure 1.8). The low DO levels were consistent at all three sites in terms of magnitude while the timing of this period was coincident to all four sites measured on the lower Jordan River.

1.5 SUMMARY AND DISCUSSION

Segments of the lower Jordan River are currently impaired due to low levels of DO, organic enrichment, TDS, high water temperatures, and *E. coli* (Table 1.1). Once a waterbody is included on a 303(d) list, additional review and investigation of data is required to confirm the assessment and what further actions may be needed. The investigation of pollutant sources, processes, and conditions that lead to low DO levels in the lower Jordan River has continued from 2005 to the present. A list of reports that document this effort is included in Appendix B. Results have indicated that natural pollutant sources justify a site-specific criterion for TDS and temperature in upper Jordan River segments (Cirrus 2010c) and that a TMDL determination is required to support the lower Jordan River's aquatic life beneficial use (Cirrus 2010c).

The data used to assess impairment for the 2004 303(d) list are presented in Figure 1.7 and in Table 1.2. Based on data guidelines and requirements included in the 2008 integrated report (Utah DWQ 2008c), listing of lower Jordan River segments is justified. Chapter 2 describes the linkage between Jordan River pollutant sources and water chemistry in the lower Jordan River.

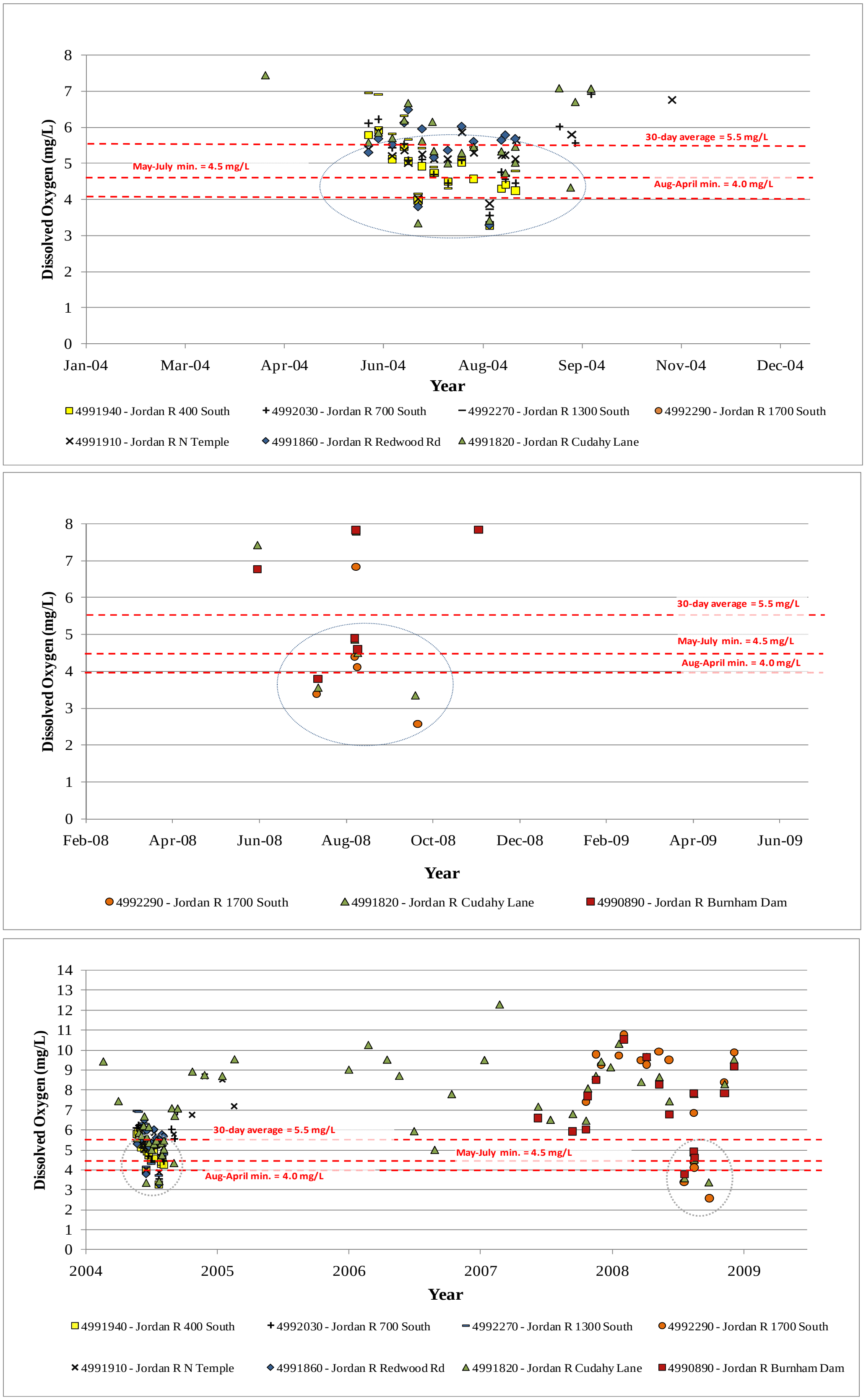


Figure 1.7. Dissolved oxygen concentrations measured from lower Jordan River segments. [Circled measurements indicate periods of violations of Jordan River DO water quality standards.]

Table 1.2. DO exceedances for selected stations on the lower Jordan River.

Station	Jordan River Location	5.5 mg/L (Year round) Total Samples	Violations	% Exceedance	Average Time (hr:min)	4.5 mg/L (May-July) Total Samples	Violations	% Exceedance	Average Time (hr:min)	4.0 mg/L (Aug-Apr) Total Samples	Violations	% Exceedance	Average Time (hr:min)
1995 – 2008													
4990890	Burnham Dam	16	3	19	16:01	4	1	25	10:45	12	0	0	NA
4991800	1000 ft below SDWTP	6	2	33	11:32	3	1	33	9:49	3	1	33	13:14
4991820	Cudahy Lane	129	23	18	11:58	38	5	13	11:58	91	2	2	11:57
4991830	2600 North	14	4	29	14:57	3	1	33	10:02	11	1	9	13:33
4991860	Redwood Road	15	5	33	10:12	11	1	9	10:20	4	1	25	10:10
4991880	900 North	3	0	0	NA	0	0	NA	NA	3	0	0	NA
4991890	500 North	12	4	33	15:02	3	1	33	8:54	9	2	22	16:50
4991910	North Temple	24	13	54	10:10	11	1	9	10:00	13	1	8	9:55
4991940	400 South	15	13	87	9:51	11	1	9	9:50	4	1	25	9:40
4992030	700 South	18	12	67	9:35	11	2	18	9:32	7	1	14	9:15
4992270	1300 South	14	9	64	9:14	11	2	18	9:17	3	1	33	9:00
4992290	1700 South	16	4	25	14:05	3	1	33	12:47	13	1	8	10:09
2004 intensive monitoring													
4990890	Burnham Dam	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
4991800	1000 ft below SDWTP	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
4991820	Cudahy Lane	26	11	42	10:27	12	1	8	10:30	14	1	7	10:25
4991830	2600 North	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
4991860	Redwood Road	15	5	33	10:12	11	1	9	10:20	4	1	25	10:10
4991880	900 North	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
4991890	500 North	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
4991910	North Temple	19	13	68	10:10	11	1	9	10:00	8	1	13	9:55
4991940	400 South	15	13	87	9:51	11	1	9	9:50	4	1	25	9:40
4992030	700 South	18	12	67	9:35	11	2	18	9:32	7	1	14	9:15
4992270	1300 South	14	9	64	9:14	11	2	18	9:17	3	1	33	9:00
4992290	1700 South	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
2008 intensive monitoring													
4990890	Burnham Dam	10	3	30	16:01	3	1	33	10:45	7	0	0	NA
4991800	1000 ft below SDWTP	6	2	33	11:32	3	1	33	9:49	3	1	33	13:14
4991820	Cudahy Lane	14	4	29	14:54	3	1	33	9:59	11	1	9	13:29
4991830	2600 North	14	4	29	14:57	3	1	33	10:02	11	1	9	13:33
4991860	Redwood Road	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
4991880	900 North	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
4991890	500 North	12	4	33	15:02	3	1	33	8:54	9	2	22	16:50
4991910	North Temple	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
4991940	400 South	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
4992030	700 South	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
4992270	1300 South	0	0	NA	NA	0	0	NA	NA	0	0	NA	NA
4992290	1700 South	13	4	31	14:05	3	1	33	12:47	10	1	10	10:09

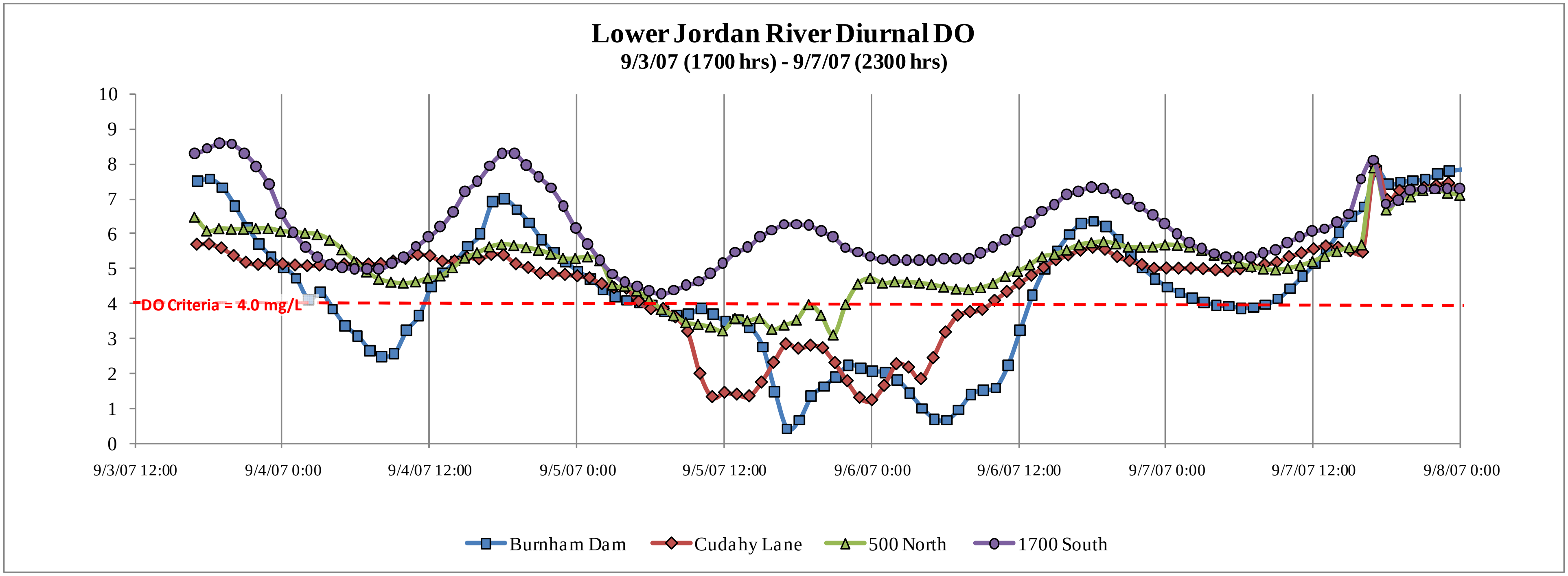


Figure 1.8. Lower Jordan diurnal DO measurements September 2007. [Note that probes were retrieved at approximately 1400 hrs (2:00 p.m.) on September 7, 2007.]

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2.0 WATER QUALITY LINKAGE IN THE LOWER JORDAN RIVER

2.1 INTRODUCTION

Water quality linkage is the connection between a water quality impairment and the pollutants and processes that cause it. Demonstrating that connection with data and calibrated models is essential to successfully addressing the impairment and restoring a water's beneficial use.

This chapter begins with a review of evidence that low DO impairs the aquatic life beneficial use in the lower Jordan River. Four processes that affect DO are described including: physical processes such as reaeration; organic and inorganic processes that consume DO in the water column; organic and inorganic processes that consume DO at the water-sediment interface; and processes related to algal growth. Additional information regarding these four processes is included in Appendix D. Based on the evidence presented in that appendix, the pattern of DO impairments is assessed to determine the critical conditions for controlling these processes.

A calibrated water quality model, QUAL2Kw was utilized to evaluate water quality responses to various processes. This model was used to identify which pollutants are primarily responsible for DO impairment and how much reduction is required to achieve the water quality endpoint. The model demonstrates that Organic Matter (OM) at this time is the most significant pollutant affecting DO in the lower Jordan River. A more detailed assessment of OM in the Jordan River follows, distinguishing between measured Fine Particulate OM (FPOM) and other OM (including coarse OM) that ultimately decomposes and results in Sediment Oxygen Demand (SOD). Subsequent chapters evaluate the sources of pollutants in more detail and describe models to provide a bulk allocation of OM, taking into account the proximity of point and nonpoint sources to the impaired reaches of the lower Jordan River.

2.2 EVIDENCE OF DO IMPAIRMENT IN THE LOWER JORDAN RIVER

2.2.1 WATER QUALITY STATIONS ON THE LOWER JORDAN RIVER

The three contiguous segments impaired for DO span 16 river miles of the lower Jordan River from the 2100 South road crossing to Burnham Dam. Several water quality monitoring stations, diversions, and inflows exist along the lower Jordan River (Table 2.1). The average annual flow in the Jordan River between 1980–2003 was 573,900 ac-ft at 2100 South (USGS gage 10170490), but only 106,145 ac-ft at 1700 South (USGS gage 10171000), revealing that the lower Jordan River receives less than 20 percent of the total flow upstream of the Surplus Canal, with monthly mean flows to the lower Jordan River relatively constant at 190 to 320 cfs. Details of the range of flows observed in lower Jordan River segments are discussed in Chapter 1 and Appendix C.

Table 2.1. Major water quality monitoring stations, diversions, and inflows in lower Jordan River (DWQ Segments 1, 2, and 3).

River Mile	Water Quality Monitoring Station (DWQ or USGS Station Number)	Diversion	Significant Inflows
16.1	2100 South (4992320)		
16.0		Surplus Canal diversion	
15	1700 South (10171000)		
14.2			1300 South Conduit (Parleys Creek, Emigration Creek, Red Butte Creek)
11.6			North Temple Conduit (includes City Creek)
10.3	500 North (4991890)		
5.2	Cudahy Lane (4991820)		
5.1			South Davis South Wastewater Treatment Plant
1.6		State Canal	
1.5	Burnham Dam		
0		Burton Dam, Great Salt Lake	

2.2.2 Seasonal Patterns in DO Measurements and Violations

Mean monthly DO concentrations from samples collected at four sites on the lower Jordan River from 1995 to 2008 are shown in Figure 2.1. Also shown are the percent of these samples that violate the 30-day average standard of 5.5 mg/L of DO. At all monitoring stations, monthly average DO is 3 to 4 mg/L lower and percent violations are higher in late summer than in mid-winter. All violations of the standard occur in June, July, and August at the lower Jordan River stations. However, these statistics likely understate the frequency of violations because 52 percent of DO measurements taken during 1995-2008 at Cudahy Lane, and 2100 South were made after 12:00 noon when algal photosynthesis is making significant contributions to DO concentration. Had DO been measured prior to when photosynthesis begins, concentrations of DO would have been lower and the number of violations higher.

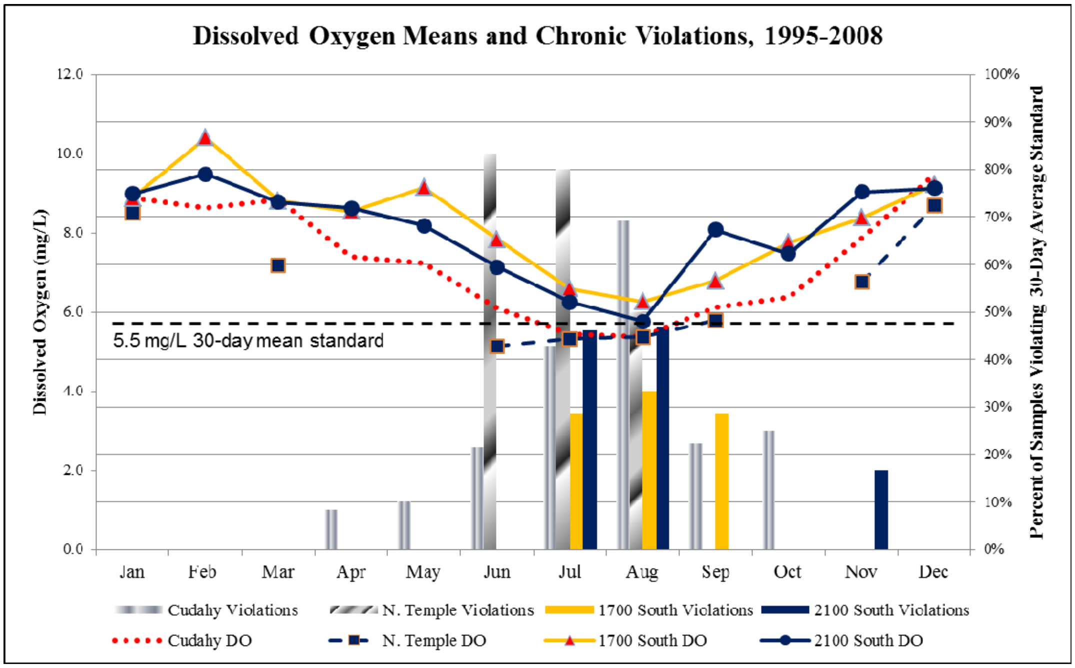

Figure 2.1. Mean monthly DO (lines, plotted on left axis) and percent of samples violating the 30-day average standard (bars, plotted on right axis).

Low DO in the lower Jordan River appears to be influenced by both physical and biological processes. No violations of the DO standard were identified in the Surplus Canal from data records used for this TMDL report. The Surplus Canal, which is also assigned a 3B warm water fishery beneficial use, and is monitored at two Utah DWQ monitoring stations: 4991310-Surplus Canal at I-80 Crossing, and 4991290-Surplus Canal Northwest of Airport. Different physical characteristics that may help to explain the lack of violations of the DO standard in the Surplus Canal include:

1. The Surplus Canal has higher reaeration rates.
2. Higher flows and greater depth of the Surplus Canal resulting in lower water temperatures which would increase DO solubility.

2.2.3 DO Deficits

A DO deficit occurs when measured DO concentrations in the water column are below saturated concentrations. The saturated DO concentration is a physical variable based primarily on water temperature and altitude. A detailed discussion of methods used to calculate DO deficit can be found in Chapra (Chapra and Pelletier 2003).

Figure 2.2 shows DO deficits for the lower Jordan River, based on comparing observed mean monthly DO concentrations and temperatures and calculated saturation values for several stations using formulas from the QUAL2Kw water quality model. A DO deficit exists in the lower Jordan River in all seasons of the year and in nearly every month, and it increases downstream from 1700 South to Cudahy Lane. The average monthly deficit for these three stations ranges from 0.8 to 1.7 mg/L.

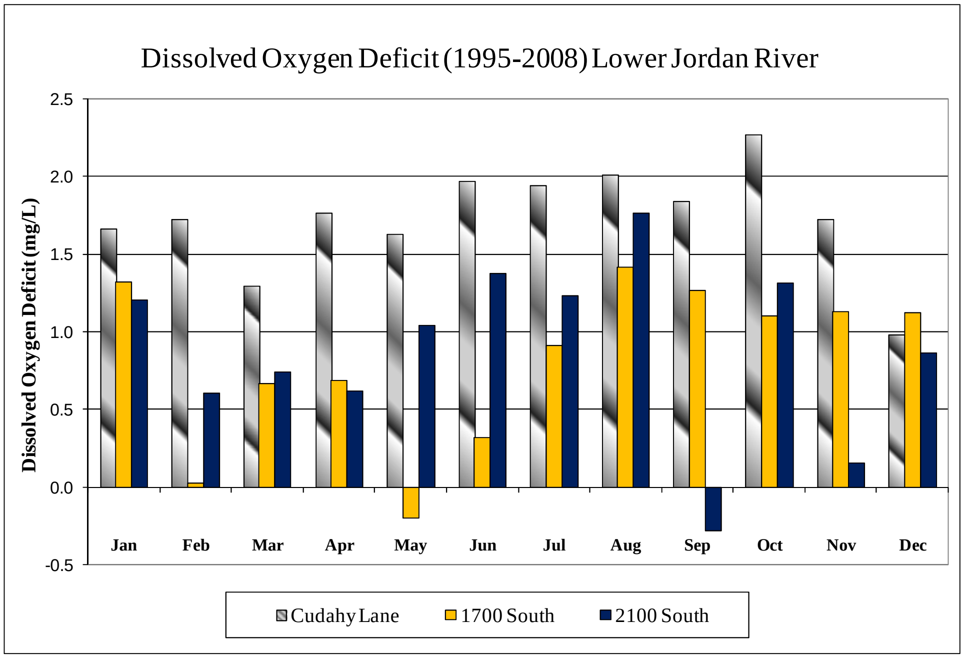

Figure 2.2. Monthly DO deficit in the lower Jordan River

2.3 PROCESSES AFFECTING DO IN STREAMS AND RIVERS

The linkage between physical and biological factors and their effects on DO in the Jordan River involve complex processes which are driven at different rates and directions. For example, warmer water temperatures reduce DO solubility and also increase rates of aerobic decomposition, which further reduces DO. On the other hand, warmer water temperatures can also increase the rate of algal photosynthesis, which increases daytime DO concentrations. But high rates of photosynthesis also mean increased algal respiration that can result in low levels of DO at night when algal photosynthesis has stopped. This increased algal biomass will then eventually die, resulting in yet more DO demand during bacterial decomposition.

This complexity can be distilled into four major factors that influence the concentration of DO in the lower Jordan River (EPA 2000). These factors, illustrated in Figure 2.3 with indicators, drivers, and possible solutions, include:

1. Physical factors, including water temperature and channel characteristics that influence reaeration from the atmosphere.
2. Aerobic decomposition of OM and inorganic nitrification of ammonium in the water column measurable as bio-chemical oxygen demand, or BOD.
3. Aerobic decomposition of OM and inorganic oxidation at the sediment-water interface measurable as sediment oxygen demand, or SOD.
4. Algal growth generating a net increase in DO during daylight hours and net consumption of DO associated with respiration during the night.

A more detailed discussion of each process is included in Cirrus (2009a), Cirrus (2010d) and Appendix D of this report.

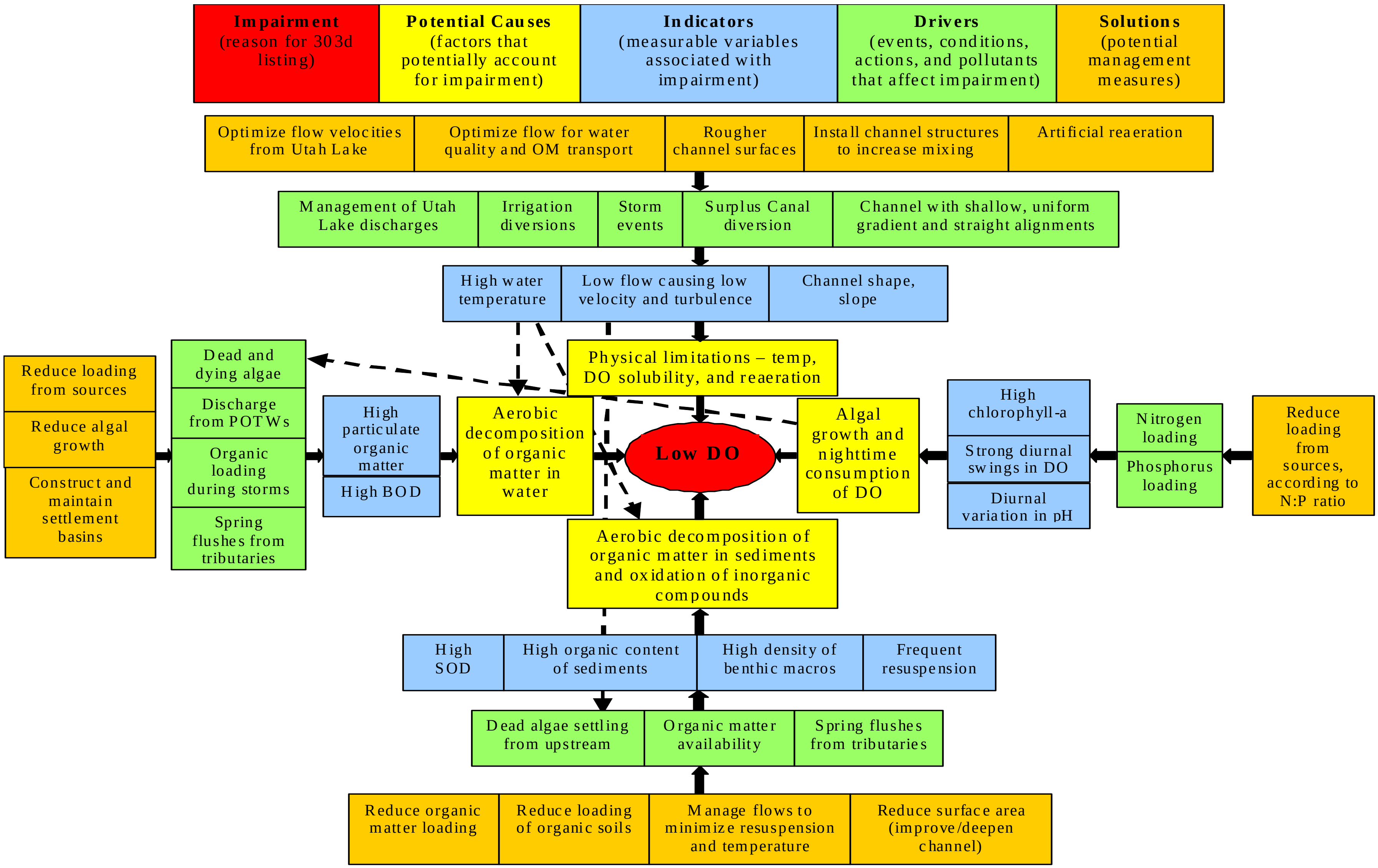

Figure 2.3. Factors affecting DO in the lower Jordan River.

2.4 CRITICAL CONDITION

2.4.1 DEFINITION

The critical condition is the combination of environmental factors such as flow, temperature, and season under which the water quality criteria are most likely to be exceeded. If water quality end points are achieved under the critical condition, they will be maintained under all conditions.

The critical condition should be represented by field data for the water quality model to accurately predict conditions leading to exceedences of water quality criteria. A well calibrated model will perform well under a wide range of conditions but it is especially important under the critical condition.

Three approaches commonly used to define the critical condition are identified and evaluated in Table 2.2 (Zhang and Yu 2006). Variations on these three approaches have been adapted for special circumstances where impairment is solely the result of either point or nonpoint source pollution or dominated by one type of pollutant source (e.g., storm events). The low-flow-analysis/steady-state-model method typically relies on a design low-flow condition. This method is appropriate where water quality conditions are primarily influenced by point source discharges. The use of dynamic models that continuously simulate stream systems can quantify the impact of processes over short periods of time. The load duration curve method characterizes pollutant loadings over the full range of measured flows and can provide a general characterization of pollutant sources with regard to point source or nonpoint source loading. Although load duration curves have been used to characterize pollutant loading from nutrients and sediment, insufficient measurements of OM are not available to support this type of assessment.

Table 2.2. Comparison of available methods in defining critical condition in TMDL (Zhang and Yu 2006).

Method	Advantage/Benefit	Disadvantage/Shortcoming
1. Low flow analysis using steady state models.	Simple, well established.	(1) Steady state approach. Only acceptable for point source dominated situations. (2) May reduce the level of protectiveness provided by the critical condition assumptions of the steady state model approach.
2. Continuous simulation using dynamic models.	(1) Allows for analysis of long term source loading and instream conditions, if data available. (2) Further, continuous modeling approach can generate multiple data points, which are essential for certain water quality criteria (e.g., 30-day geometric mean for fecal coliform).	(1) There is no guarantee that a reasonable limiting condition will be included during the specified time period, which normally corresponds to a short period of time, i.e. a couple of years. (2) The risk/reliability (e.g., return period of management scenarios) associated with continuous simulation cannot be estimated. (3) Generally very data intensive.
3. Flow-based load duration curve method.	(1) Simple, a good tool for problem characterization. (2) TMDL load is expressed as a function of flow conditions (covering all flow conditions, including critical flow condition).	(1) Difficult to evaluate influencing factors on critical condition and derive explicit percentage reduction of source categories in TMDL allocation. (2) Some watershed managers do not prefer an average TMDL based on all flow conditions.

2.4.2 APPLICATION TO THE LOWER JORDAN RIVER

2.4.2.1 Process Used to Identify Critical Condition for DO

Identifying the critical condition must take into account the variation in climate and flow between years and protect for the year when the most critical combination of factors might occur. Similarly, DO concentrations can swing 4 mg/L or more in a single day so basing an assessment of DO on an average of measurements taken during daylight hours will not capture the lowest, and most critical, DO conditions. A buffer above the minimum standard is necessary to ensure that DO does not fall below the water quality standard at any time.

Data from routine monitoring programs, synoptic events, and hourly diurnal monitoring were examined in relation to instances of low DO. Identifying the critical condition began with a seasonal assessment of measurements that violated numeric DO criteria, a review of paired flow and water quality measurements to determine if water quality exceedences were associated with certain flow conditions, and finally an assessment of the four dynamic processes influencing DO including reaeration, BOD, SOD, and nighttime respiration.

The results of initial QUAL2Kw modeling were also used in defining the critical period. The model used a combination of Methods 1 and 2, low-flow analysis and continuous simulation, shown in Table 2.2 that provided a means to quantify the four dynamic processes known to influence DO in the Jordan River.

2.4.2.2 Findings Relating to Critical Condition

Figure 2.1 shows that mean monthly DO is lowest in August and exceeds the water quality standard most frequently in either July or August, depending on the site. Instances of low DO are not limited to very low or very high flow conditions. Tables D.3 and D.4 in Appendix D show that the highest percentages of violations of the acute criterion (4.5 mg/L between May and July and 4.0 mg/L in other months) occur at flows in the 40–60 percentile ranges and the highest percentages of violations of the chronic criterion (30-day average of 5.5 mg/L) occur over the 20–80 percentile ranges.

Low DO in late summer is partly related to physical processes. Higher water temperatures result in lower saturated DO concentrations, making it more difficult for reaeration processes to maintain high DO levels, specifically at 2100 South and 1700 South. The higher and more broadly distributed DO deficits at Cudahy Lane may be a result of greater turbidity, which limits light penetration and reduces the DO contributions of algal photosynthesis, as suggested by Baker (2010a).

Water quality modeling (Section 2.7) shows that the largest impacts on DO are attributable to increased respiration rates associated with OM decomposition, especially at the sediment interface (SOD). Nitrification of NH_4 may also contribute a significant oxygen demand from the sediments that is captured as part of the SOD measurements, as the conversion of NH_4 to NO_3 consumes three atoms of oxygen for every molecule of NH_4.

BOD is a direct measure of the combined demand for DO by bacterial decomposition of OM and nitrification occurring in the water column. Figure D.4 in Appendix D shows that the maximum frequency of DO violations at Cudahy Lane and 2100 South occurs at the same time as the late summer peak in BOD. Fewer violations occur during the earlier spring peak in BOD due to the higher DO saturation of cold water.

Not every year is equally critical. Figure 2.4 shows that, while August may be the most critical month, DO measurements in August 2009 are higher than the long-term average at most sites except Burnham Dam. Chlorophyll-a concentrations were also very low in 2009 as shown in Figure 2.5.

The quality of Utah Lake water may also play an important role for the Jordan River. During years of low water levels in Utah Lake, the gates at the outlet may never be opened, and water is pumped from the lake into the Jordan River to satisfy downstream water rights. Table 2.3 shows when the gates were opened or pumping started, and when they were closed. The DO violations recorded during 2004 correspond with low lake levels of that year including above average water temperatures and concentrations of pollutants that influence DO. Water discharged to the Jordan River under such conditions could have higher than normal levels of algae. Note also that the gates were never opened in 2004, and that was the earliest date of pumping within the last decade. In contrast, in 2009, the gates were opened on the latest date and it was never necessary to pump since 2009 was a relatively wet year. This would again indicate the necessity of including Utah Lake in future analyses of the Jordan River for any water quality impairment.

Appendix D discusses the effect of algae and other primary producers on diurnal DO, increasing DO during daylight hours and decreasing DO at night due to photosynthesis and respiration. The diurnal DO patterns shown in Figure D.12 in Appendix D measured at 1700 South, Cudahy Lane, and Burnham Dam in August 2009 are similar to the diurnal swings in DO recorded in 2006 (Figure D.11 in Appendix D). Table 2.4 compares the averages, maximums, and minimums for these two periods for these three stations. The “sag-below-average” is the difference between the average and the minimum DO concentrations. The August 2006 data show a sag-below-average of over 2.0 mg/L. Thus, grab samples taken during daylight hours may miss the instantaneous minimum by 2 mg/L and may unduly bias the calculation of average DO.

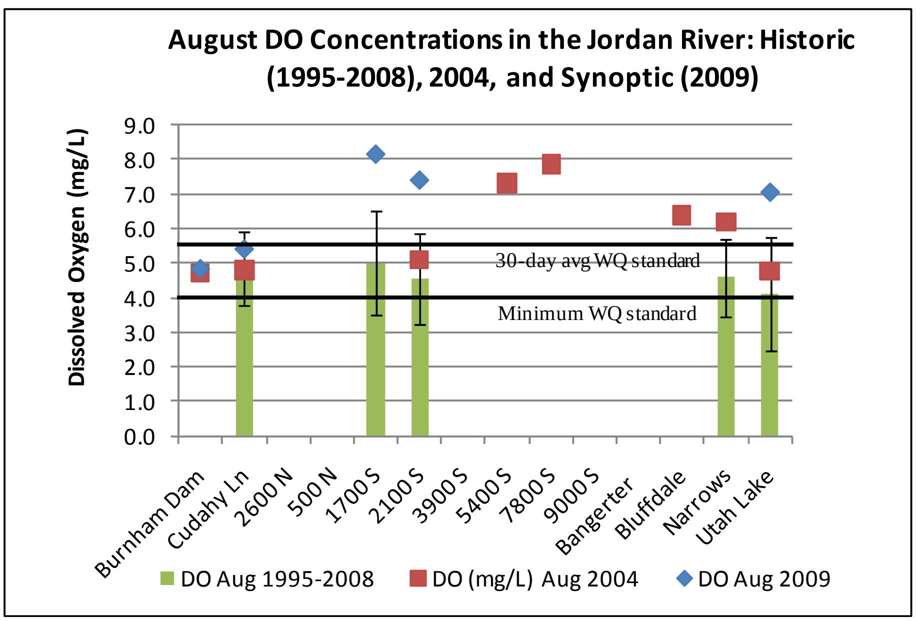

Figure 2.4. August DO concentrations in the Jordan River.

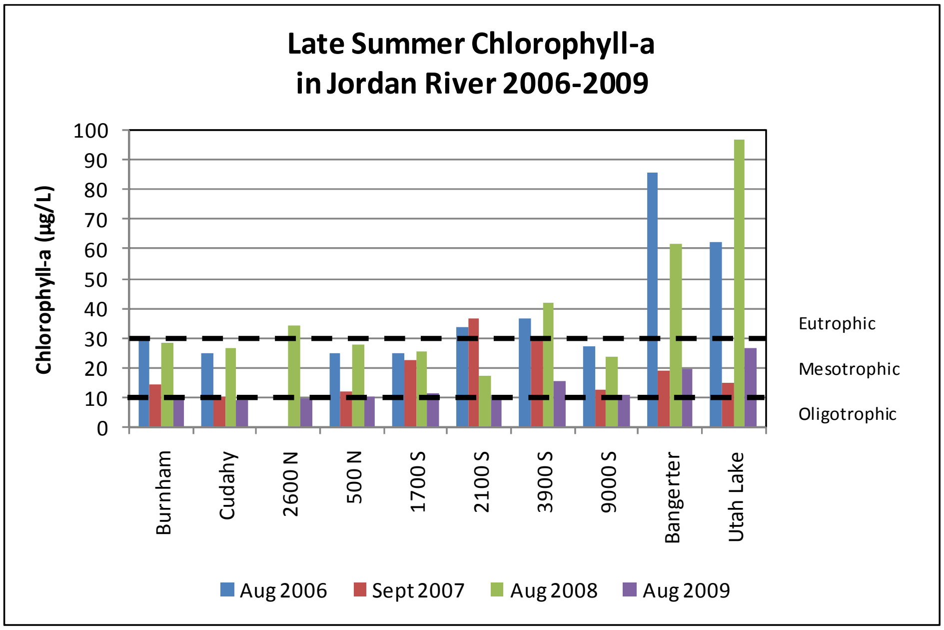

Figure 2.5. Late summer chlorophyll-a concentrations in recent years in the Jordan River from the Utah Lake outlet to Burnham Dam and State Canal. [Trophic levels determined per Dodds et al. (1998).]

Table 2.3. Gate opening and pump use history at pump station at Utah Lake.

Year	Utah Lake Gates Opened	Pumps Operating	Utah Lake Gates Closed or Pumping Ceased
2009	4/28	n/o	10/15
2008	3/28	7/11	10/15
2007	2/5	n/o	10/15
2006	3/18	n/o	10/15
2005	4/14	5/23	10/15
2004	n/o	4/15	9/30
2003	n/o	4/25	10/15
2002	4/1	4/23	10/15
2001	4/15	5/3	10/15
2000	2/13	6/9	10/15

Notes: n/o = not operational. Source: (Larsen 2010a).

Table 2.4. Diurnal patterns in DO at Burnham Dam, Cudahy Lane, and 1700 South on the lower Jordan River, August 2006 and 2009 (mg/L).

	August 2006			August 2009		
	Burnham Dam	Cudahy Lane	1700 South	Burnham Dam	Cudahy Lane	1700 South
Average	6.2	6.0	7.4	5.0	5.4	6.7
Maximum	8.8	7.9	10.2	5.5	6.2	8.8
Minimum	4.4	4.1	5.3	4.5	4.6	5.2
Range	4.3	3.8	4.9	1.0	1.6	3.5
Sag Below Average	1.8	1.9	2.1	0.4	0.8	1.5

Source: 2009 data for Cudahy Lane and Burnham Dam provided by Miller (2010a); all other data provided by DWQ.

2.4.2.3 Critical Condition for DO in the Lower Jordan River

Based on this review, the early morning hours of August 2004 represent the critical condition for DO on the lower Jordan River. Violations of the 5.5 mg/L DO standard occurred in the lower Jordan River at this time as well as violations of the acute 4.5 mg/L standard (Table 1.2). Based on available data however the model was calibrated using the August 2009 synoptic monitoring event. In comparing 2004 to 2009, the key variables of time of year and temperature match but the Utah Lake discharge scenario does not. The 15-min diurnal data from 2009 does show a minimum DO of 4.6 mg/L on one day at 4:55 a.m. at Cudahy Lane and 4.5 mg/L on another day at 4:00 a.m. at Burnham Dam, below the 5.5 mg/L standard used to assess routine monitoring data.

Given that several key variables are similar between 2004 and 2009, that the differences between the two periods are known, and that the model calibration was successful, the critical condition has been appropriately defined and carried forward into this TMDL analysis.

The QUAL2Kw model calibrated for the lower Jordan River was used to explore the effects of changing input variables on DO. The model is based on data collected during synoptic monitoring conducted in October 2006 and February through March 2007 and was calibrated to another synoptic monitoring event conducted in August 2009. The model was revised in December 2009 based on stakeholder review and comments made during an open calibration meeting and then later validated with a separate synoptic event from September 2007 (Stantec 2010a). The model was recalibrated a second time in July 2010 based on concerns expressed by the WWTP stakeholder group. Dr. Steve Chapra provided expert technical review and suggestions for selection of rate parameters during this process (Chapra 2010). Complete documentation of model development is provided in Stantec (2006a) and Stantec (2010a). Final model calibration that took place following the July 2010 meeting is included in Utah DWQ (2010).

2.5 MODELING WATER QUALITY RESPONSES TO POLLUTANT LOADING IN LOWER JORDAN RIVER – APPLICATION OF THE QUAL2KW WATER QUALITY MODEL

2.5.1 MODEL DESCRIPTION

The QUAL2Kw model was used to explore the effects of changing different inputs on DO for several reasons: it is a one-dimensional water quality model suitable for riverine conditions; it simulates many water quality processes; and it is capable of predicting water quality response over several days. It evolved from the QUAL2K model developed by Chapra and Pelletier, which was itself an update to the QUAL2E model developed by Brown and Barnwell (1987). Some of the important enhancements to QUAL2Kw relevant for the Jordan River include (Chapra and Pelletier 2008):

- QUAL2Kw allows for unequally-spaced reaches. In addition, multiple loadings and abstractions can be input to any reach.

- QUAL2Kw can use two forms of carbonaceous BOD to represent organic carbon. These forms are a slowly oxidizing form (slow CBOD) and a rapidly oxidizing form (fast CBOD).

- Denitrification is modeled.

- Sediment-water fluxes of dissolved oxygen and nutrients are simulated internally rather than being prescribed.
- The model simulates attached bottom algae.
- Light extinction is calculated as a function of algae, detritus and inorganic solids.
- Both alkalinity and total inorganic carbon are simulated. The river's pH is then simulated based on these two quantities.
- Automatic calibration. A genetic algorithm is included to determine the optimum values for the kinetic rate parameters to maximize the goodness of fit of the model compared with measured data.

In addition, the model is distributed in the form of a Microsoft Excel spreadsheet, enabling people with knowledge of Excel and water quality, but without extensive modeling experience, to explore various scenarios. Finally, a Monte Carlo sensitivity analysis is available as an add-in to test the significance of input parameters (Appendix E).

QUAL2Kw was configured to calculate WQ and flow at intervals of 11 minutes 15 seconds over the course of 6 days. The Jordan River was divided into 166 reaches, each 0.5 km long. Each reach was characterized in terms of elevation, channel shape and slope, percent coverage of bottom algae, and bottom sediment characteristics. Headwater and pollutant source conditions for the model included:

- Temperature (hourly)
- Conductivity
- Inorganic Solids
- Dissolved Oxygen
- CBOD slow
- Organic Nitrogen
- NH_4-Nitrogen
- NO_3-Nitrogen
- Organic Phosphorus
- Inorganic Phosphorus
- Phytoplankton
- Detritus (POM)
- Alkalinity
- pH

River-wide inputs included hourly meteorological values, such as air temperature, wind speed, cloud cover, shading, and solar radiation. Inputs from pollutant sources included three WWTPs, five tributary inputs (draining eight tributaries), and two major storm drains. Nonpoint diffuse sources included groundwater and instream erosion. Diversions to nine major canals were accounted for.

Equations from scientific literature were used to model processes affecting water quality, including light and heat; settling velocity for organic and inorganic material; reaeration; oxidation; hydrolysis; nitrification; phytoplankton and bottom plant growth, respiration, and death rates; detritus dissolution and settling rates; and hyporheic flow and metabolism.

Outputs from the model for each segment, with maximums and minimums, included flows, temperature, and water quality parameters such as DO, conductivity, TSS – Inorganic Suspended Solids (ISS) and VSS, cBOD, N in various forms, P in various forms, phytoplankton, alkalinity, pH, bottom algae, SOD, and sediment fluxes.

2.5.2 Calibration

A thorough description of the calibration process for the Jordan River TMDL QUAL2Kw model was provided by Stantec (2010a). A general description follows.

Models such as QUAL2Kw use equations to process data to predict a response. The equations are typically taken from the scientific literature, but often, as with QUAL2Kw, there are choices about what coefficients and exponents to use. These are typically presented as a choice of rates and constants. The objective is to choose rates and constants appropriate for that waterbody and which also result in model output similar to observed conditions. There must also be sound rationale and theory behind the choice of parameter values.

The Jordan River QUAL2Kw model was initially calibrated to three synoptic events, each in a different season (October 2006, February 2007, and August 2009). Each synoptic monitoring event typically provided 3 days of data collected over the length of the river. In addition, some parameters such as temperature, conductivity, DO, and pH were monitored at 15 minute intervals over the course of several days overlapping the synoptic monitoring period, providing a diurnal dataset of conditions at selected sites.

A meeting in December 2009 included interested stakeholders in a discussion on alternative calibration parameter values. This meeting was followed by a 2-day consultation on June 15 and 16, 2010, with Dr. Steve Chapra, one of the model's authors, which resulted in adjusting some parameters. One of the outcomes of this meeting was a list of recommended structural changes and refinements to the model which included refining the calibration to the critical time period of late summer and running the model with settlement rates, prescribed SOD, and other parameters calibrated only to August-September.

Subsequent meetings were held with stakeholders having modeling experience on July 19 and 26, 2010, to review the adjustments proposed in the meeting with Dr. Chapra and refine the assumptions needed to calibrate the model to match the August 2009 synoptic data (see Section 2.5). In particular, the final calibration required a prescribed SOD over the entire river, varying from 1.0 to 3.5 mg/m^2/day, and increasing downstream from Utah Lake. The final step in matching the last 0.1 mg/L of measured DO values in the lower Jordan River required prescribing an unknown oxygen demand between SVWRF and 2100 South possibly from hyporheic exchange across bends in the river or in eddies, backwaters, or quiet pools above diversions.

2.6 DO ENDPOINT FOR THE LOWER JORDAN RIVER

2.6.1 DEFINITION AND USE OF ENDPOINTS IN THE TMDL

EPA (2009) defines an endpoint as, "an observable or measurable biological event or chemical concentration (e.g., metabolite concentration in a target tissue) used as an index of an effect of a chemical exposure." Endpoints can also be classified as either assessment or measurement endpoints (EPA 1999). An assessment endpoint is a valued environmental characteristic with societal relevance. For the purposes of this TMDL, assessment endpoints are beneficial uses that are fully supported by appropriate water quality conditions. A measurement endpoint is defined as an observed or measured response to a stress or disturbance. Numeric criteria that define state water quality standards are examples of measurement endpoints. Hickey et al. (2002) recommends that water quality endpoints be: "(1) enforceable by law; (2) indicative of ambient water quality; (3) of ecological or anthropogenic significance; (4) measurable in the field; (5) predictable using a water quality model; and (6) of stakeholder concern."

2.6.2 MARGINS OF SAFETY IN ESTABLISHING AN ENDPOINT

A Margin of Safety (MOS) is used in TMDLs to protect against uncertainty in calculating pollutant loading and water quality response. It is important to articulate each uncertainty and protect against it in setting endpoints and allocating pollutant loads. If water quality models are used in developing a TMDL, the level of uncertainty that is inherent in model predictions should be defined. The TMDL process requires that an MOS be included in the final load allocation. An MOS can be defined through an explicit or implicit calculation. Some TMDLs utilize both methods in order to capture high levels of uncertainty. An explicit MOS can be defined by simply not allocating a portion of the available loading capacity and reserving it for the MOS. Some of the approaches used to define an implicit MOS could include using conservative assumptions in deriving numeric endpoints, pollutant loadings, or pollutant transport rates (EPA 1999). Both methods result in decreasing the loading capacity and increasing load reductions from pollutant sources. Therefore, an MOS must be selected carefully to account for uncertainties that result in consistent water quality violations, but also avoid project costs that produce limited or no benefit to impaired water bodies. Some of the uncertainties faced in the Jordan River TMDL, and the associated contribution to the MOS, are summarized in Table 2.5.

Based on these uncertainties, a 1.0 mg/L MOS, or a DO model endpoint of 5.5 mg/L, is reasonable to use at this point in the TMDL process. This implicit MOS is considered to represent uncertainty levels that exist in modeling and current data sets, however, the addition of a DO requirement above the water quality standard in a final load allocation may result in significantly higher costs for no additional benefit. The phased TMDL approach that is described in Chapter 5 will provide a means to understand and characterize OM pollutant sources and processes before making significant capital investments. Thus, adopting 1.0 mg/L as an implicit MOS will not constrain capital investments by known OM sources, nor will it preclude an adjustment in the DO model endpoint if deemed necessary.

<table>
<tr><th colspan="3">Table 2.5. Factors contributing to an implicit Margin of Safety for the DO endpoint.</th></tr>
<tr><td colspan="2">Instantaneous Minimum DO WQS during July for protection of young fish as a biological resource.</td><td>4.5 mg/L</td></tr>
<tr><td>An unknown source of oxygen demand of 0.1 mg/L was necessary above 2100 South to calibrate QUAL2Kw to measured values in the lower Jordan River.</td><td>0.1</td><td rowspan="7">1.0 mg/L</td></tr>
<tr><td>The Monte Carlo uncertainty analysis estimated approximately 0.7 mg/L of uncertainty between the lowest and average values of minimum DO predicted at Burnham Dam within a 90% confidence interval, based on 2,000 iterations and sensitivity analyses of 47 parameters and inputs. (See Appendix E for report on the Monte Carlo uncertainty analysis).</td><td>0.6</td></tr>
<tr><td colspan="2">Other uncertainties:</td></tr>
<tr><td>• Few instances of synoptic and diurnal monitoring are available, and none during recent years worst for DO (e.g., 2004 and 2008). QUAL2Kw was calibrated to DO; variations in DO data for calibration were not part of the Monte Carlo uncertainty analysis.</td><td rowspan="4">0.3</td></tr>
<tr><td>• 52 percent of DO measurements in the lower Jordan River between 1995-2008 (44 percent 2004-2008) were made after noon, perhaps missing lowest DO conditions near dawn and additional DO violations..</td></tr>
<tr><td>• Few actual measurements of reaeration that do exist do not correspond well with values expected from established reaeration equations. QUAL2Kw was calibrated, in part, to measured reaeration values; did not allow reaeration to vary in Monte Carlo uncertainty analysis.</td></tr>
<tr><td>• The state may be successful in enforcing pollutant limits on point sources, and various communities may be successful in curbing many nonpoint sources of OM. However, given the vagaries of weather and climate along the margins of the Jordan River watershed, a “perfect storm” of runoff conditions is entirely likely with a frequency which will result in significant, uncontrollable loading to the Jordan River.</td></tr>
<tr><td colspan="2">Total recommended target endpoint for calculating OM Loads</td><td>5.5 mg/L</td></tr>
</table>

DWQ recognizes there are alternative methods to establish the MOS~~,~~ In the next phase of the TMDL, DWQ will consider exploring other means of establishing the MOS. For example, Table 2.6 shows the results of how load reductions and permissible loads would change with different implicit and explicit MOS. Line B, C, D, K, L, & M show the use of an implicit margin of safety which is added to the standard (either 0.0, 1.0 or 1.5 mg/L DO) as currently included in this report. Lines E–J and N-Y show various explicit margins of safety that could be used in the TMDL. As can be seen, lines L and X demonstrate that a 1.0 mg/L implicit margin of safety is the same as a 19% explicit margin of safety. As additional data is collected and uncertainty is reduced, a lower implicit or explicit MOS most likely would be applied. Changes to the MOS must be supported by a scientific basis and show that minimum DO standards will not be violated.

Table 2.6. Pollutant OM load reductions to the lower Jordan River (kg/yr) and percentages of total reductions required under different MOS scenarios. All scenarios are based on a 4.5 mg/L DO endpoint.

	Scenario		**Point Sources**		**Non-point Sources**		**Total**
			Above 2100 South	**Below 2100 South**	**Above 2100 South**	**Below 2100 South**	
	Existing Loads into lower Jordan River (all implicit MOS scenarios)						
A[1]	Implicit MOS	0 mg/L	469,062	700,282	752,429	303,749	2,225,523
	Load Reduction into the Lower Jordan River with % total reduction						
B	Implicit MOS	0 mg/L (4.5 mg/L endpoint)	107,566 (21%)	174,196 (33%)	131,399 (25%)	111,329 (21%)	524,490
C	Implicit MOS	1.0 mg/L (5.5 mg/L endpoint)	185,877 (22%)	294,424 (35%)	206,897 (24%)	164,694 (19%)	851,892
D	Implicit MOS	1.5 mg/L (6.0 mg/L endpoint)	246,489 (23%)	382,577 (35%)	255,957 (24%)	196,019 (18%)	1,081,042
	Scenarios associated with a 0 mg/L implicit MOS.						
E[2]	Explicit MOS	0%	107,566 (21%)	174,196 (33%)	131,399 (25%)	111,329 (21%)	524,490
F[3]	Explicit MOS	5%	125,641 (21%)	200,500 (33%)	162,451 (27%)	120,950 (20%)	609,542
G	Explicit MOS	10%	143,716 (21%)	226,805 (33%)	193,502 (28%)	130,571 (19%)	694,593
H	Explicit MOS	15%	161,790 (21%)	253,109 (32%)	224,554 (29%)	140,192 (18%)	779,645
I	Explicit MOS	19%	177,044 (21%)	275,308 (32%)	250,759 (29%)	148,311 (17%)	851,422
J	Explicit MOS	33%	225,747 (21%)	346,185 (32%)	334,427 (31%)	174,235 (16%)	1,080,594
	Permissible Loads into lower Jordan River						
K	Implicit MOS	0 mg/L	361,496	526,086	621,030	192,420	1,701,032
L	Implicit MOS	1.0 mg/L	283,185	405,858	545,532	139,055	1,373,630
M	Implicit MOS	1.5 mg/L	222,573	317,705	496,472	107,730	1,144,480
	Load Reductions into Jordan River Equivalent to MOS						
N	Explicit MOS	0%	0	0	0	0	0
O	Explicit MOS	5%	18,075	26,304	31,052	9,621	85,052
P	Explicit MOS	10%	36,150	52,609	62,103	19,242	170,103
Q	Explicit MOS	15%	54,224	78,913	93,155	28,863	255,155
R	Explicit MOS	19%	69,478	101,112	119,360	36,982	326,932
S	Explicit MOS	33%	118,181	171,989	203,028	62,906	556,104
	Permissible Loads into lower Jordan River allocated to sources						
T[4]	Explicit MOS	0%	361,496	526,086	621,030	192,420	1,701,032
U	Explicit MOS	5%	343,421	499,782	589,979	182,799	1,615,980
V	Explicit MOS	10%	325,346	473,477	558,927	173,178	1,530,929
W	Explicit MOS	15%	307,272	447,173	527,876	163,557	1,445,877
X	Explicit MOS	19%	292,018	424,974	501,670	155,438	1,374,100
Y	Explicit MOS	33%	243,315	354,097	418,002	129,514	1,144,928

Footnotes:

[1] To calculate Row A 2,225,522 (Existing Load) = Row K 1,701,032 (Permissible Load) + Row E 524,490 (Load Reduction).

[2] To calculate Row E 524,490 (Load Reduction Scenarios associated with a 0 mg/L implicit MOS) = Row A 2,225,522 (Existing Load) - Row K 1,701,032 (Permissible Load) .

[3] To calculate Row F 639,867 (Load Reduction Scenarios associated with a 5% Explicit MOS of Permissible Load, Row K 1,701,032) = 0.05 x 1,701,032 = Row O 85,052 (Load Reduction into Jordan River Equivalent to MOS) + Row E 524,490 (Pollutant Load Reduction into the lower Jordan River with 0% MOS).

[4] To calculate Row T 1,701,032 (Permissible Loads into lower Jordan River allocated to sources) = Row O 85,052 (Load Reduction into Jordan River Equivalent to MOS) + Row U 1,615,980 (Equivalent MOS Permissible Load).

2.7 POLLUTANT OF CONCERN AND PERMISSIBLE LOADS (WATER QUALITY RESPONSES TO POLLUTANTS FROM QUAL2KW MODEL)

2.7.1 EFFECT OF REDUCING NUTRIENTS ON DO IN THE LOWER JORDAN RIVER

The calibrated QUAL2Kw model was used to explore options for increasing DO in the lower Jordan River by reducing various pollutants. Table 2.7 shows the predicted results of reducing nutrients in various forms and amounts on DO at compliance points at Cudahy Lane and at Burnham Dam. Even drastic reductions in nutrient concentrations offer little or no improvement in DO. The QUAL2Kw model was later recalibrated in July 2010, but the resulting changes would not be expected to alter the main conclusion of this exercise that reducing nutrients alone at 2100 South would have little or no effect on DO in the lower Jordan River. Details of the model effort associated with nutrient reductions are found in Cirrus (2010c).

Table 2.7. Mean and minimum DO at Cudahy Lane and Burnham Dam modeled in QUAL2Kw under alternative nutrient reduction scenarios.

		Average DO (mg/L)		Minimum DO (mg/L)	
Scenario	**Description**	**Cudahy Lane**	**Burnham Dam**	**Cudahy Lane**	**Burnham Dam**
August 2009 Synoptic Period	**Measured values during the August 2009 diurnal monitoring.[1]**	**5.4**	**5.0**	**4.6**	**4.5**
1. Baseline	Output generated by calibrated August 2009 model. Represents the starting conditions found during the most recent synoptic monitoring.	5.3	4.6	4.3	3.8
2. TP = 0	Reduce TP at 2100 South to 0 mg/L. Reduces all forms of P to zero.	4.1	3.5	4.0	2.9
3. TP = 50%	Reduce all forms of P at 2100 South by the same ratio of 50%.	5.3	4.6	4.3	3.8
4. TP = 0.05 mg/L	Reduce all forms of P at 2100 South by the same ratio to achieve TP = 0.05 mg/L.	5.2	4.4	4.3	3.8
5. TP = 0.05 mg/L and NO_3-N = 4 mg/L	Starting from baseline, reduce all forms of N at 2100 South by same ratio to achieve NO_3-N of 4 mg/L and reduce all forms of P by same ratio to achieve TP of 0.05 mg/L.	5.5	4.8	4.5	4.0
6. NO_3 = 4 mg/L	Starting from baseline, reduce all forms of N at 2100 South by same ratio to achieve NO_3-N of 4 mg/L.	5.4	4.6	4.5	4.0
7. NH_4-N = 0.08 mg/L	Starting from baseline, reduce NH_4-N (only) at 2100 South to 0.08 mg/L.	5.6	4.8	4.5	4.0
8. Pollution Indicator Condition w/ NH_4 Limit	Starting from baseline, reduce N03-N to 4.0 mg/L, NH_4-N to 0.08 mg/L, and all P sources by same ratio at 2100 South to achieve TP of 0.05 mg/L.	5.5	4.6	4.5	3.9

[1] Model used data from August 18–20, 2009. Measured values at Cudahy Lane and Burnham Dam collected slightly later, from August 21–28, 2009.

2.7.2 Effect of Reducing Organic Matter on DO in the lower Jordan River

Once it became apparent that reducing nutrients would not achieve the DO water quality standard in the lower Jordan River, the focus shifted to assessing another major pollutant, OM. The calibrated QUAL2Kw model was next used to evaluate the effect of reducing OM from all upstream point and nonpoint sources and from all sources discharging directly to the lower Jordan River.

From the discussions in Section 2.3 and the detailed review of linkage processes in Appendix D, it was clear that SOD places a major demand on DO. The QUAL2Kw model accounts for SOD in the lower Jordan River resulting from settling detritus generated during the six day model run and from prescribed SOD attributed to OM that enters the Jordan River in the preceding weeks and months. The prescribed SOD reflects measured rates and allows for a more accurate model calibration.

A limitation of the QUAL2Kw model is that it incorporates OM only as VSS, typically particles smaller than 1.0 mm analyzed in the laboratory by standard VSS methods. OM not captured in VSS measurements must be represented in QUAL2Kw indirectly via prescribed SOD. The need to prescribe 6 to 20 times as much SOD as is generated by the six-day model run indicates a significant but unmeasured load of OM to the Jordan River. This unmeasured load is likely associated with episodic storm and seasonal runoff events that transport leaf fall and accumulated organic debris from the watershed into the Jordan River. Development of appropriate sampling methods to measure these shorter duration, high intensity OM loading events will be required to quantify total OM loading and effectiveness of future control efforts.

VSS in QUAL2Kw is a combination of detritus (dead OM) and phytoplankton, represented by chlorophyll-a. The headwater conditions, inputs, and calibration values also come from measurements of VSS. For the model, detritus was calculated as the mass of VSS remaining after subtracting living phytoplankton, estimated based on the stoichiometric ratio of 1:100 for the concentration of chlorophyll-a to phytoplankton (an equation from QUAL2Kw). For the initial run, no changes were made to water quality of the outflow from Utah Lake.

Table 2.8 shows the predicted DO response for the compliance points at Cudahy Lane and Burnham Dam to reductions in VSS (detritus and chlorophyll-a) and an equal percentage reduction in prescribed SOD in the lower Jordan River for the QUAL2Kw model calibrated for August 2009. An equal reduction of VSS and prescribed SOD in QUAL2Kw model scenarios is not meant to imply that desired DO levels can be achieved merely by reducing VSS. This scenario assumes that actions taken to reduce VSS would also reduce other components of Total OM, not captured in a VSS sample, that contribute to prescribed SOD. No information is available at this time to accurately quantify the cause and effect relationship between VSS reductions and SOD. Based on current knowledge, it is reasonable to assume that over time, a reduction of Total OM (including VSS) would result in an equal reduction of SOD.

QUAL2Kw model results show that a 30% reduction in VSS with an equal reduction in prescribed SOD in the lower Jordan River would meet the recommended DO endpoint of 5.5 mg/L at Burnham Dam, which includes a 1.0 mg/L MOS. The equal reduction in prescribed SOD is critical to achieve this endpoint, indicating that the loading reduction required will be from all forms of OM to meet the endpoint, and not just VSS. In particular, OM prone to settle to the bottom as well as the effect of buried legacy OM will also need to be considered in loading reductions.

An additional set of DO responses was modeled assuming equal reductions in VSS from Utah Lake. Comparing Table 2.8 and Table 2.9 shows that reducing Utah Lake loads has little added effect on DO in the lower Jordan River, in part because much of the flow from Utah Lake is diverted either at the Narrows or at the Surplus Canal. The model actually predicts that a slightly smaller reduction of VSS and prescribed SOD would be necessary to achieve the same DO endpoint if Utah Lake VSS loads were reduced. This small difference may be due to DO contributions by algal photosynthesis or inherent in the variance of the model. An additional issue is the return of Utah Lake irrigation water to the Jordan River. This return flow occurs throughout the summer months, and may be a higher percentage of the flow during dry/drought weather.

Table 2.8. QUAL2Kw model scenarios to increase DO concentrations in the lower Jordan River by reducing both VSS[1] and prescribed SOD, assuming NO reduction to headwater detritus and chlorophyll-a from Utah Lake.[2]

Percent Reductions		Min DO (mg/L)	
VSS	**Prescribed SOD**	**Cudahy Lane**	**Burnham Dam**
0%	0%	5.2	4.8
10%	10%	5.4	5.0
20%	20%	5.6	5.3
30%	**30**%	**5.8**	**5.5**
40%	40%	6.0	5.7
50%	50%	6.2	6.0
60%	60%	6.4	6.2
70%	70%	6.6	6.4
80%	80%	6.7	6.7
90%	90%	6.9	6.9

[1] VSS is represented in the QUAL2Kw model by detritus and chlorophyll-a.
[2] Bold text indicates final target concentrations to achieve model DO endpoint.

Table 2.9. QUAL2Kw model scenarios to increase DO concentrations in the lower Jordan River by reducing both VSS[1] and prescribed SOD, assuming EQUAL reduction to headwater detritus and chlorophyll-a from Utah Lake.[2]

Percent Reductions		Min DO (mg/L)	
VSS	**Prescribed SOD**	**Cudahy Lane**	**Burnham Dam**
0%	0%	5.2	4.8
10%	10%	5.4	5.0
20%	20%	5.6	5.3
30%	**30**%	**5.8**	**5.5**
40%	40%	6.0	5.7
50%	50%	6.2	6.0
60%	60%	6.4	6.2
70%	70%	6.6	6.4
80%	80%	6.8	6.6
90%	90%	7.0	6.9

[1] VSS is represented in the QUAL2Kw model by detritus and chlorophyll-a.
[2] Bold text indicates final target concentrations to achieve model DO endpoint.

2.7.3 Nature of OM in the Jordan River

Attaining DO water quality standards is possible through reducing OM loading that enters the lower Jordan River as suspended detritus and phytoplankton, which together constitute the VSS component of TSS, combined with reductions of other OM that occurs throughout the year. With a MOS of 1.0 mg/L DO and a minimum instantaneous DO endpoint of 5.5 mg/L, a modeled reduction of approximately 30% of VSS and prescribed SOD would be required for the calibrated period in August 2009. However, a reduction of Total OM is necessary year round because OM is constantly settling in the slower moving waters of the lower Jordan River where it decomposes over time. Furthermore, conditions that influence OM pollutant loading change between years, indicating that historic data is needed to account for this variation.

The QUAL2Kw model is limited, however, by directly considering only one form of OM, the smaller particles analyzed in the laboratory by standard VSS methods, and a calibration period that represents critical conditions (August). VSS does not include larger forms of OM, such as leaves, twigs, or algal mats, or material that stays on the channel bottom. Total OM is composed of both VSS and coarser particulate OM. Preliminary measurements suggest that substantial loads of larger material are being transported to the system, and seasonally in large quantities, such as during spring runoff and autumn leaf fall. No regular measurements of this larger material are available, but it certainly does contribute to SOD. Figure 2.6 illustrates how larger material (coarse particulate OM, or CPOM) and the fine particulate organic matter (VSS, or FPOM) may both be present in the water column. CPOM eventually breaks down into FPOM, which in turn breaks down into dissolved OM, or DOM. A portion of both FPOM and CPOM settle to the bottom to contribute to SOD as they are decomposed by benthic aerobic and anaerobic bacteria.

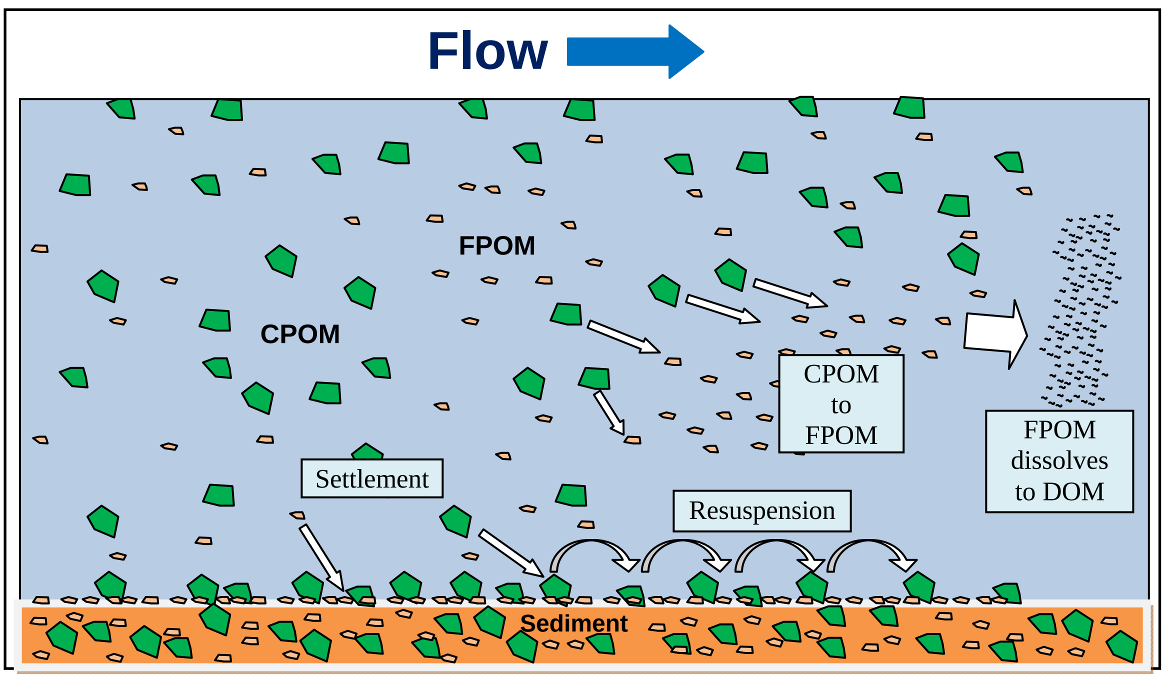

Figure 2.6. Conceptual diagram of OM in the water column and contribution to sediment.

Natural processes affect FPOM and CPOM differently. Living phytoplankton may exist as single cells or small masses less than 1.0 mm, or it may coalesce into larger mats. CPOM and FPOM have different densities, and are made up of different components, so they settle and dissolve at different rates. Storms and runoff events deliver FPOM and CPOM at different rates, and diversions and exchange flows affect them differently. Although CPOM is observable, it is difficult to measure because of its intermittent nature. Hence, there is little data on its characteristics, mass, or spatial and temporal distribution at this time, although Phase 2 of the TMDL work will achieve a better understanding of OM.

To estimate permissible Other OM (including CPOM) loads to the lower Jordan River the following steps are involved:

a. Using QUAL2Kw, calculate maximum permissible daily load of OM.
b. Assume the prescribed SOD (g O_2/m^2/day) results from decomposing OM entering lower Jordan River outside of model period, or “Other OM.”
c. Calculate permissible incoming Other OM in g/day:
    i. QUAL2Kw uses a stoichiometric ratio of 1 g C per 2.69 g DO demand because nearly all C is converted to CO_2 in decomposition processes.
    ii. QUAL2Kw uses a stoichiometric ratio of 0.4 g C per 1 g OM.
    iii. Therefore, for each g O_2/m^2/day of SOD an average load of 0.9293 g OM/m^2/day must enter the lower Jordan River.
    iv. Multiply the load of OM/m^2/day times the area in the lower Jordan River to yield daily load of OM.
d. In summary, daily Other OM = total Daily OM – Daily VSS.

These calculations are used below in Chapter 4 to calculate allocations for FPOM and Other OM.

2.8 SUMMARY

The upper segments of the Jordan River constitute the primary “inflow” to the lower Jordan River, defined herein as the section of the river downstream of 2100 South. DO levels in the lower Jordan River do not meet water quality standards, as demonstrated in Section 2.1. This DO impairment is the result of both physical and biological factors. Available data suggest that warm water temperatures during the late summer account for seasonal reductions in DO but not the DO deficits observed year round in the lower Jordan River, despite positive calculated reaeration rates of 2 to 4 mg/L/day (Figure D.2 Appendix D). Physical characteristics such as temperature, flow, and channel morphology cannot be the sole cause of low DO concentrations in the lower Jordan River. Calculated reaeration rates for the lower Jordan River are positive, substantial, and in some cases underestimated when compared to measured values. In all cases, Jordan River reaeration rates are positive. These results point to biological and inorganic processes as important in accounting for these DO deficits.

As illustrated in Figure 2.3, there are several biological processes that consume DO, including BOD in the water column, SOD from the bottom sediments, and diurnal fluctuations from daytime photosynthesis and nighttime respiration by algae and other aquatic plants. BOD has been measured at 3.0 to 5.5 mg/L over a 5-day period (Figure D.4 Appendix D), so it alone could consume half of the potential reaeration that is estimated to occur in the lower Jordan River. The presence of aerobic decomposition processes occurring in the water column is also supported by substantial proportions of OM in suspended sediments (Figure D.5 Appendix D).

SOD also appears to be a major factor contributing to low DO concentrations. Recent measurements at one site in the lower Jordan River found SOD rates that would create an oxygen demand on the water column of over 2 mg/L/day. SOD has been measured in other rivers with characteristics similar to the Jordan River. The Tualatin River in Oregon, for example, was found to have a median SOD of 2.3 mg/L. At these rates, SOD consumes over half of the DO provided through natural reaeration. Moreover, flows in the Jordan River are capable of resuspending a large proportion of organic-rich bottom sediments, further contributing to both BOD and downstream SOD, and helping to explain why DO is lower, and DO violations are more frequent, in the lower Jordan River than upstream.

Finally, there is evidence of algal populations growing in the lower Jordan River, both upstream of and within the lower segments. Algae not only cause large diurnal fluctuations in DO, measured at 3 to 5 mg/L, but when they die they contribute to the BOD and SOD load.

The critical condition for DO in the lower Jordan River is early morning during the warm days of late summer, particularly during years when Utah Lake levels are low, resulting in discharges to the Jordan River that are late, low in volume, relatively warm, and carrying high OM loads. The critical condition may not occur every year.

The QUAL2Kw model was used to predict water quality responses to changes in pollutant inputs. This model was calibrated to synoptic monitoring events that were representative of critical conditions. Through analysis of various scenarios, reducing nutrient loads will not resolve the DO impairments in the lower Jordan River. Reducing OM, both fine and coarse, will be essential to reducing the DO demand and increasing DO concentrations in the water column as well as at the sediment interface.

Due to analytical uncertainties a MOS in the DO endpoint of 1.0 mg/L is warranted as a reasonable addition to the minimum 4.5 mg/L DO concentration for the reproductive season for warm water fish. It should be applied year round, as OM delivered year round affects DO during the critical period.

Subsequent chapters will explore details of the pollutant loads from various sources in the Jordan River watershed and the load allocation necessary to prevent DO impairment in the lower Jordan River.

3.0 POLLUTANT SOURCE ANALYSIS

As discussed in Chapter 2, the most significant demand on DO is from bacterial decomposition of organic matter (OM). Based on this conclusion, the methods and results of calculating OM pollutant loads for each significant pollutant source are discussed in Chapter 3. This information is used to support the bulk wasteload and load allocations defined in Chapter 4.

3.1. JORDAN RIVER ORGANIC MATTER

OM is found in both fresh and saline waterbodies throughout the world, including rivers, lakes, estuaries, and oceans. Organic matter in rivers and lakes can come from external sources or be generated within the water column by aquatic plants and organisms that feed on these plants. In most natural ecosystems, total OM is comprised of both living and dead organisms. Dead OM can be present in either a particulate or dissolved state (Figure 2.6). A threshold defining Coarse Particulate Organic Matter (CPOM) from Fine Particulate Organic Matter (FPOM) is roughly 1 mm. This threshold is a concern primarily in regard to limits associated with water quality sampling methods and determining if an accurate measure of Total OM can be made. The threshold is also useful in understanding and subsequently developing management practices to control OM pollutant loads.

OM in the Jordan River consists of both living and dead material in a range of coarse and fine particle 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. Fast rates of decomposition and oxygen consumption are associated with sources of OM that have been mechanically or biologically processed and degraded into smaller and more basic components. Slower rates of decomposition occur from large woody material or vegetation with high lignin content. Transport processes can assist decomposition as CPOM is broken up into smaller FPOM particles while moving downstream through suspension, deposition, and resuspension.

The majority of living OM in the Jordan River is comprised of algae suspended in the water column. Algal biomass can be estimated from chlorophyll-a, which is a pigment of photosynthesis and generally accounts for 1 to 2 percent of total algal biomass. Other forms of OM containing chlorophyll-a include leaves, seeds, and grass clippings. These forms of organic material comprise some of the CPOM load but are not generally represented by chlorophyll-a measurements collected from the water column.

Dead OM (detritus) in the Jordan River includes all non-living plant and animal cell tissue. For the purposes of this TMDL, detritus is considered to consist of dead plant tissue including material that died after entering the river, primarily algae, and material that was already dead. The rate at which detritus decays and the magnitude of oxygen loss is dependent upon characteristics that are unique to the source material as well as surrounding conditions. A description of the many factors that influence OM decomposition and oxygen loss is included in Chapter 2.

FPOM stays in suspension and is more likely to be collected in routine measurements of Total Suspended Solids (TSS). FPOM is composed primarily of living and dead phytoplankton and disintegrating remains of larger materials. In general, FPOM is more readily decomposed than CPOM due to its partially degraded condition.

CPOM, on the other hand, consists of mats of phytoplankton, detached periphyton, bits and pieces of vegetation, and remnants of decaying organic material that entered waterbodies via surface runoff.

CPOM may float on the surface or be dense enough to be carried along the river bottom, but is not accurately represented in water quality grab samples. Heavy inputs of CPOM enter the Jordan River in erratic patterns, such as during spring snowmelt, floods, or rain-on-snow events, where it settles and begins to disintegrate. OM becomes resuspended during high-flow events and moves downriver over time. It eventually settles (along with FPOM) in slow-moving reaches of the Jordan River, and gradually breaks down through aerobic and anaerobic decomposition, and contributes to SOD. As described in Chapter 2, it was necessary to prescribe an additional amount of SOD throughout the Jordan River, especially in the lower Jordan River, in order to match measured SOD rates, measured DO values and calibrate the QUAL2Kw model to a critical condition known to result in low DO levels. It is assumed that this prescribed SOD builds up over time from settling OM that is delivered by upstream flows.

3.2 JORDAN RIVER OM POLLUTANT SOURCE CHARACTERISTICS

Following an extensive review of published literature, monitoring data, and local input, seven categories of pollutant sources were identified that contribute OM pollutant loading to the Jordan River. These categories include the following point and nonpoint sources:

- Point Sources:
  - WWTPs
  - Stormwater
- Nonpoint sources:
  - Utah Lake
  - Tributaries
  - Diffuse Runoff
  - Return Flows from Irrigation Canals
  - Natural Background

Pollutant source categories in the study area are shown in Figure 3.1, including geographic locations for each source with the exception of natural background. Conditions and processes that contribute natural background loads are not limited to a specific location within the watershed.

3.2.1 WASTEWATER TREATMENT PLANTS

Three wastewater treatment plants discharge treated effluent to the Jordan River (Table 3.1). The South Davis South Wastewater Treatment Plant (SDWTP) discharges to the lower Jordan River below Cudahy Lane. Central Valley Water Reclamation Facility (CVWRF) is located less than 2 miles upstream of 2100 South. The South Valley Water Reclamation Facility (SVWRF) discharges to the Jordan River just below 7800 South and about 10 miles upstream of 2100 South. The new Jordan Basin Water Reclamation Facility will discharge to the Jordan River near the Corner Canyon Creek confluence and is anticipated to be online by 2012. The concentration of OM in treated effluent depends on the treatment process used by each facility. The influent to each plant receives primary treatment to remove solids. Different combinations of secondary treatment methods are then used by each plant to treat for a range of constituents required by their respective UPDES permits. Total OM in WWTP discharge is comprised primarily of FPOM due to mechanical and biological processes used in primary and secondary treatment although no settling data has been collected on WWTP effluent suspended solids.

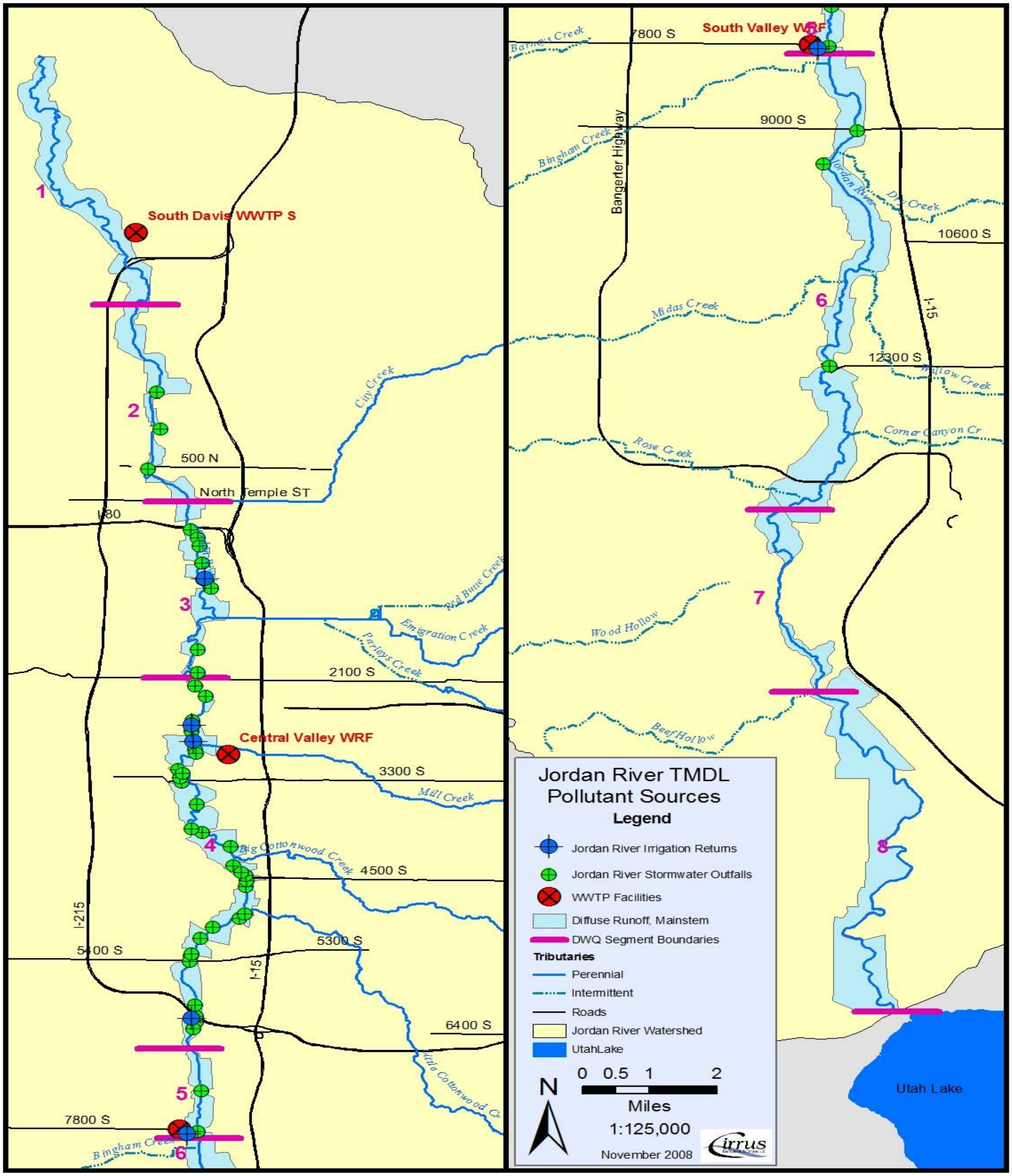

Figure 3.1. Jordan River OM pollutant source categories.

Table 3.1. UPDES facilities discharging to the Jordan River and tributaries.			
Name	**UPDES Permit**	**Location**	**Receiving Water**
South Davis South Wastewater Treatment Plant	UT0021628	2500 West Center Street, North Salt Lake City	Jordan River below Cudahy Lane.
Central Valley Water Reclamation Facility	UT0024392	800 West Central Valley Road, Salt Lake City	Mill Creek ½ mile above Jordan River confluence.
South Valley Water Reclamation Facility	UT0024384	7495 South, 1300 West, West Jordan	Jordan River ½ mile downstream of 7800 South crossing.
Jordan Basin Water Reclamation Facility	UT0025852	13826 South Jordan Basin Lane (1300 West), Riverton	Jordan River at Bangerter Highway.

3.2.2 STORMWATER

Stormwater discharge is regulated by the Utah DWQ as delegated by the EPA in accordance with the Clean Water Act. These regulations are incorporated into Phase 1 and Phase 2 stormwater permits. Stormwater systems that serve populations greater than 100,000 are regulated with Phase 1 permits while Phase 2 permits are applied to small populations. Three Phase 1 permittees are located in the study area including Salt Lake County, Salt Lake City, and Utah Department of Transportation (UDOT). The following 14 communities have Phase 2 permits within the study area including:

Bluffdale	Midvale	South Salt Lake
Draper	Murray	Taylorsville
Herriman	Riverton	West Jordan
Holladay	Sandy	West Valley
Lehi	South Jordan	

These communities discharge stormwater to the Jordan River. Note that Figure 3.1 indicates there are no points of stormwater discharge entering DWQ Segment 1 (located in Davis County). The location of stormwater catchments and canal overflows are shown in Figure C.1 of Appendix C.

Stormwater flows collect and transport OM from developed, impervious surfaces such as streets, parking lots, sidewalks, and gutters. OM is also contributed by surrounding plants and animals to stormwater conveyed in open canals and ponds. Springtime stormwater flows generally contain high OM loads that have accumulated over the previous fall and winter. OM concentrations in stormwater often decrease over the season due to removal by previous storms and management practices that increase the efficiency of OM removal such as street sweeping and routine maintenance of debris basins and other devices. High intensity storms move more CPOM than low intensity storms due to higher peak flows.

Table 3.2 shows a detailed list of total serviced acres in stormwater catchments that discharge to the Jordan River by municipality. Separate totals are provided for catchments that discharge directly to the Jordan River or to tributary streams.

Table 3.2. Stormwater catchment areas (ac) that contribute stormwater flow to the Jordan River.			
Jurisdiction	**Serviced Area Discharging Directly to the Jordan River[1]**	**Serviced Area Discharging to Tributaries**	**Total Area Contributing Stormwater Discharge**
Bluffdale		239	239
County	4,776	13,104	17,881
Draper		4,816	4,816
Lehi	3,483		3,483
Midvale	372		372
Murray	2,428	987	3,415
Riverton	124	1,176	1,299
Salt Lake City	6,776	8,214	14,991
Sandy	3,786	2,003	5,789
South Jordan	200	805	1,005
South Salt Lake	477	1,848	2,325
UDOT	397	16	413
West Jordan	5,670	801	6,471
West Valley	6,375		6,375
TOTAL	34,866	34,009	68,876

[1] Direct discharge to the Jordan River includes stormwater catchments that discharge to stormwater collection drains flowing to the Jordan River.

3.2.3 UTAH LAKE

OM discharged from Utah Lake consists of living and dead OM. Buoyant OM particles floating or suspended in the water passes through the outlet gate or through the pumps during dry years (Larsen 2010b).

Utah Lake is a nutrient enriched, eutrophic lake that produces blue-green algae blooms during the summer and late fall (Utah DWQ undated). The dominant algal species include *Aphanizomenon flos-aquae*, *Anabaena spiroides*, and species of *Microsystis*. Blue-green algae are considered a nuisance due to their negative impact on aesthetics and production of cyanotoxins. Despite Utah Lake's eutrophic state, DO impairment has not been identified, likely as a result of its frequent mixing. It has been assessed as impaired for total phosphorus with DWQ conducting on-going studies to understand the physical and chemical dynamics of this unique waterbody. A preliminary assessment of external Total P loading to Utah Lake has determined that approximately 75 percent of the annual total comes from WWTPs (PSOMAS/SWCA 2007).

The impact of Utah Lake algae on the Jordan River has been studied recently (Rushforth and Rushforth 2009a) and discussed in Chapter 2. Seasonal effects from Utah Lake are evident as shown by the relative contributions of Chlorophyta (green algae) and Cyanophyta (blue-green algae) into the Jordan River. During the months of July and August, Jordan River algal taxa are dominated by Cyanophyta, a lake species adapted to open water.

Diatom communities in the Jordan River are also being studied (Rushforth and Rushforth 2010). Periphyton samples were collected from near bank sediments as well as from the water column. This study did not find large deposits of algal material typically found in large, slow-moving rivers.

Measurements of benthic samples from the Jordan River include species that are tolerant of high levels of salinity, nutrients, scouring, sedimentation and low levels of DO (Rushforth and Rushforth 2010).

3.2.4 Tributaries

OM from tributaries reaches the Jordan River through 13 stream channels including seven perennial and six intermittent streams (Figure 3.1). All streams are perennial in their upper reaches, but flows in some streams are diverted for culinary and agricultural uses. Additional flow (and OM) is still delivered to the Jordan River by tributary streams that receive stormwater discharge.

Natural background loads of OM are delivered to headwater reaches of tributary streams in the form of organic litter and other particles small enough to be detached and transported by surface runoff. Larger OM particles, including leaves, branches, and woody debris also fall directly into the channel. Debris basins are located on many of the larger east side tributaries near the valley edge. Debris basins trap large material transported in peak flows occurring in seasonal runoff and storm events. Consequently, stream flow in valley segments carries relatively smaller OM particles that pass through these structures. As OM travels downstream it is physically or biologically broken up into smaller pieces, converting a portion of it from CPOM to FPOM.

Additional OM is contributed to tributaries by valley sources. Stormwater discharge enters tributaries directly or indirectly as overflow from canals that receive stormwater from upstream sources. Areas adjacent to stream channels deliver additional OM in the form of diffuse runoff that contains OM particles from landscaped and naturally vegetated areas. OM and sediment loads are evident in channel deposits dredged from tributaries to maintain their peak flow capacity.

3.2.5 Diffuse Runoff

Diffuse runoff is defined as surface runoff from areas outside of stormwater catchments that flows directly to the Jordan River. OM that is small enough to be transported by surface runoff is carried to the Jordan River from these areas. Figure 3.1 identifies areas with potential to contribute diffuse runoff to the Jordan River. In general, the boundaries for these areas were defined by stormwater catchments as well as the nearest upslope canal paralleling the Jordan River. Canals are designed to prevent surface inflow and can be used to define surface runoff patterns similar to a stormwater catchment boundary. Table 3.3 shows acres for each municipality that contributes diffuse runoff to the mainstem Jordan River.

3.2.6 Return Flows From Irrigation Canals

The irrigation return flow system can be classified into three subsystems that extend from the point of diversion at the river to the point where return flows enter the river (Law 1971). These subsystems include (1) the canal segment between the diversion from the river downstream to the farm, (2) irrigated areas on the farm itself, and (3) from the farm downstream to the receiving waterbody. The water quality of return flows is influenced by each subsystem. This classification method was used to assess changes in water quality that affect irrigation return flows.

In regard to subsystems 1 and 3, canals can generate internal OM loads through algal growth or external loads from leaves, grass, and other vegetation that fall into canals. In regard to subsystem 2, OM is transported during flood irrigation practices that remove FPOM or smaller CPOM particulates. This process can occur both in furrow crops where water flow remains concentrated, or in fields where water is spread diffusely through grass pastures or hay crops and has a higher exposure to OM particulates.

The location of irrigation return flows that contribute flow and OM to the Jordan River are shown above in Figure 3.1 and described in Table C.2 of Appendix C.

Table 3.3. Areas (ac) contributing diffuse runoff directly to the mainstem Jordan River.

Municipality	DWQ Segment								Total
	1	2	3	4	5	6	7	8	
Bluffdale						446	519	13	978
Davis County	241								241
Draper City						483			483
Lehi								1,031	1,031
Midvale					157	182			339
Murray				475	14				489
North Salt Lake	425								425
Riverton						506			506
Salt Lake City	2	419	522	3					946
Salt Lake County	595	220		64					880
Sandy						41			41
Sandy City						140			140
Saratoga Springs								407	407
South Jordan						715			715
South Salt Lake				281					281
Taylorsville				323					323
Utah County								890	890
West Jordan					134	263			397
West Valley				290					290
Grand Total	1,264	639	522	1,436	305	2,776	519	2,341	9,802

3.2.7 Natural Background

This category includes OM contributed by natural or non-anthropogenic sources not accounted for elsewhere in this analysis. Natural background loads can be associated with any natural process that is not enhanced or induced by human activity. Natural background loads are by definition not controllable.

The OM sources considered in the assessment of natural background loading to the Jordan River include: OM loads to headwater reaches of tributary streams, leaf litter and other OM entering the river from trees and vegetation that line the riparian corridor, the portion of OM contributed by Utah Lake that is not influenced by anthropogenic inputs, and naturally occurring levels of soil erosion and stream channel dynamics. As described in Chapter 4, OM loading from Utah Lake is not considered for load reductions in this TMDL. A discussion of how OM loads from Utah Lake will be addressed in future phases of the TMDL process is included in Chapter 5.

The Jordan River has experienced significant lateral movement and bank erosion during the past century (CH2M Hill 1992). Much of this migration has occurred during infrequent and extreme flooding events. One study completed on the Jordan River above Turner Dam (DWQ Segment 8) identified channel movements during the past century of 200 to 1,500 feet on meander bends (JE Fuller 2007). One of the more recent significant events includes the 1983 through 1987 floods when river reaches from Turner Dam down to 2100 South experienced lateral movement ranging from 34 to 675 ft (CH2M Hill 1992). During normal flow regimes, lateral movement is considered to be generally less than 1 ft/yr. Sediment loads have been recently calculated from this source (Stantec 2010b). Load calculations were based on field estimates of bank condition, measured flows, bank depth, segment length, and modeled estimates of bank shear stress.

Table 3.4 shows bank erosion by segment for the Jordan River. The highest levels of sediment loading occurred from Segment 7 below Turner Dam, and from Utah Lake to Turner Dam. Organic matter contributed by bank erosion and sediment loading is dependent upon the organic content of bank material which could vary considerably in the river corridor. Organic content of soils can be influenced by land cover and land use. Riparian areas adjacent to the Jordan River have been heavily influenced by development and are scarce.

Table 3.4 Jordan River bank erosion sediment loading estimates (Stantec 2010b).

DWQ Segment	Length (mi)	Bank Erosion Sediment Loads (kg/yr)
1	6.9	278,776
2	4.4	310,074
3	4.5	256,823
4	8.8	522,264
5	1.7	155,309
6	11.1	668,955
7	4.2	3,702,202
8	9.6	1,174,526
TOTAL		**7,068,928**

3.3 EXISTING JORDAN RIVER OM DATA

Measurements of OM from pollutant sources to the Jordan River or from the river itself began in 2006 with measurements of VSS during two synoptic surveys. Since that time, additional measurements of OM and the resulting oxygen demand resulting from OM decomposition have been conducted. Due to the need to incorporate variation that occurs between seasons and years, direct and indirect (proxy) measures of OM are used in this TMDL. The sections below describe existing direct and indirect OM data records and the methods used to assess them. As mentioned previously, this document considers data up to 2009, and does not consider 2010 data. The next phase of the TMDL will consider data collected after 2009 to assess and validate the 303(d) impairment listing. Until that time, this report will not examine data past 2009.

3.3.1 DIRECT OM MEASUREMENTS - VOLATILE SUSPENDED SOLIDS

Existing OM data is primarily composed of VSS measurements that represent the FPOM portion of Total OM in this study. The standard method to measure VSS begins by filtering a representative sample to separate solid and dissolved fractions. After drying the filter at 105 °C the mass of TSS is measured. The filter and all OM on the filter are then combusted at 550 °C. The remaining mass is a measure of ISS. VSS is determined by the difference between TSS and ISS, the mass volatilized through burning (Dickson 2010).

Table 3.5 lists direct measurements of VSS collected from 2006 through 2010 by DWQ and WWTPs. Mean VSS concentrations from the mainstem Jordan River ranged from 6 to 12 mg/L. Most mainstem stations had VSS concentrations of 7 to 9 mg/L, including the Utah Lake outlet. Mean VSS concentration from WWTPs were 4 to 7 mg/L and lower than most mainstem concentrations. Tributaries had a mean VSS concentration between 8 and 9 mg/L. The VSS monitoring station for Mill Creek was located below the CVWRF outfall. This resulted in relatively lower VSS concentrations for Mill Creek as a result of dilution by the facility discharge. The high standard deviation in VSS concentrations relative to the mean for most of the sources and locations represents the high variability in water quality of surface runoff. The WWTPs are much more consistent in quality owing to their respective process design. Long term monitoring on tributaries will be required to better characterize OM loads given their inherent variability in VSS concentration and flow.

Table 3.5. Number of VSS samples collected during the recent past from select Jordan River monitoring stations and pollutant sources.

		Number of Samples					VSS concentration (mg/L)			
Station ID	**Station Name**	**2006**	**2007**	**2009**	**2010**	**Total**	**Mean**	**Max**	**Min**	**Std. Dev.**
Mainstem										
4990885	Burnham Dam	6	5	5	3	19	7.8	17	2.8	3.8
4991800	Jordan R. 1000 ft. below S Davis S WWTP			8	7	15	9.4	16.5	2.8	4.3
4991820	Jordan R. Cudahy Lane	8	13	11	8	40	9.1	34.8	2	5.8
4991890	Jordan R. 500 N	6	5	3	2	16	11.9	70	4.4	15.7
4991940	Jordan R. 400 S			5	8	13	5.8	10	1.6	2.6
4992290	Jordan R. 1700 S	6	10	8	9	33	6.8	18	2.5	3.4
4992320	Jordan R. 2100 S	6	3	3		12	10.3	21.6	5.6	5.1
4992890	Jordan R. 3900/4100 S crossing	6	5	5	1	17	10.0	28	4.8	6.2
4994090	Jordan R. 5400 S			8	3	11	8.3	12	3.6	2.6
4994170	Jordan R. 7800 S			10	8	18	7.7	17	2.4	3.5
4994270	Jordan R. 9000 S	6	5	6	7	24	7.6	22	2.4	5.1
4994520	Jordan R. Bangerter Highway	8	5	3		16	9.3	15.6	4.2	4.0
4994600	Jordan R. Bluffdale Road			9	6	15	9.4	32.4	3.2	7.2
4994720	Jordan River Narrows			5	6	11	9.2	17.1	1.2	5.4
WWTPs										
4991810	SDWTP	6	5	13	7	31	7.3	15.2	1.2	3.6
4992500	CVWRF	6	5	14	6	31	5.1	11.2	2	1.8
4994160	SVWRF	6	5	12	6	29	3.5	7	0.5	1.7
Tributaries										
4991920	North Temple Conduit (City Creek)	5	4	13		22	8.2	78.5	0.4	20.2
4992070	1300 S Storm Sewer (Red Butte Creek, Emigration Creek, Parleys Creek)	6	5	21	7	39	8.5	67	1.2	12.9
4992510	Mill Creek at 900 W 2900 S (below CVWRF)			6	3	9	5.4	17.1	2	4.7
4992970	Big Cottonwood Creek	6	11	10	7	34	8.0	45	1.2	8.1
4993580	Little Cottonwood Creek	6	5	13	8	32	8.5	36	0.8	7.6

Table 3.5 (cont'd). Number of VSS samples collected during the recent past from select Jordan River monitoring stations and pollutant sources.										
		Number of Samples					VSS concentration (mg/L)			
Station ID	**Station Name**	**2006**	**2007**	**2009**	**2010**	**Total**	**Mean**	**Max**	**Min**	**Std. Dev.**
Utah Lake										
4994790	Jordan R. Utah Lake outlet	6	13	12	6	37	8.7	21	2.8	3.9
Stormwater										
4992330	2100 S Storm Sewer at mouth	6	11	13	8	38	8.4	21.6	2.8	4.1
4992390	Decker Pond outflow above Jordan River			9	8	17	7.9	31	1.2	6.6
DEL-01[1]	Commercial / Residential Landuse Mix – County				1	1	13	13	13	-
DEL-05[1]	Light Industrial Landuse – County				1	1	37	37	37	-
Irrigation Return Flow										
	South Jordan Canal				1	1	9.2	9.2	9.2	-
[1] Only one sample available for this station.										

The spatial and temporal limits of the VSS data set make it difficult to accurately characterize each pollutant source. Although the number of VSS samples shown in Table 3.5 is high for most mainstem stations and several pollutant sources, 35 to 100 percent of these samples were collected during four synoptic monitoring events. Proxy measurements of OM, including TSS and Biochemical Oxygen Demand (BOD_5), were also used to capture the full range of seasonality and longer-term effects of wet and dry years. As discussed below, proxy measurements of VSS or FPOM, including TSS and Biochemical Oxygen Demand (BOD_5), were also used to capture the full range of seasonality and longer-term effects of wet and dry years.

Sampling methodology also limits accurate measurements of Total OM. The size of organic material included in a VSS sample is limited to the width of the bottle mouth and could potentially include both FPOM and relatively small CPOM suspended in the water column. As a result, both of these OM fractions could be included in a VSS measurement. Grab samples are not likely to include larger CPOM particles floating on the water surface or moving along the river bed. Stormwater monitoring is further restricted in regard to OM particle size. At present, stormwater samples are usually collected with automated sampling devices that rely on vacuum pumps and small diameter tubes (less than 1 in.).

Efforts are currently being made to collect CPOM data from tributaries where they enter the valley and at their confluence with the Jordan River (Miller 2010b). This data set will be reviewed and incorporated into future TMDL efforts.

3.3.2 Proxy OM measurements – Total Suspended Solids

TSS is a measurement of organic and inorganic suspended material. The OM in a TSS sample includes both living and dead material. As previously mentioned, standard sample bottle size constrains the size of OM particles measured in a TSS sample.

The relationship between paired measurements of TSS and VSS is displayed in Figure 3.2 for select time periods. The regression equations show paired samples are poorly correlated during August of both years when concentrations of both TSS and VSS are relatively low but a relationship develops as concentrations increase in the fall and late winter / early spring. The negative r-squared value shown for the August 2006 data set is an artifact of the way Microsoft Excel calculates a linear regression when the trend line is forced to intercept the y-axis at zero. Since VSS is a component of TSS, it is assumed there will always be some TSS when VSS is measured. However, plots in Figure 3.2 indicate the TSS:VSS relationship does change between seasons and years and is positive.

The changing relationship between VSS and TSS is perhaps a result of the different frontal and convective types of storm systems that occur during these parts of the year. Localized and short duration convective storms in August may be more variable in their ability to transport TSS loads while the more widespread and sustained frontal systems that occur from late fall through early spring may transport a more consistent proportion of both sediment and OM and at potentially higher concentrations.

Seasonal changes in OM characteristics could also affect the VSS:TSS relationship. External and internal contributions of OM particles to receiving waterbodies are likely to be different in each season. Some of the seasonal factors influencing OM contributions include vegetation life cycles (leaf drop), intensity and duration of runoff (snowmelt, rain-on-snow, or rain events), and instream conditions that influence algae growth (turbidity, temperature, flow).

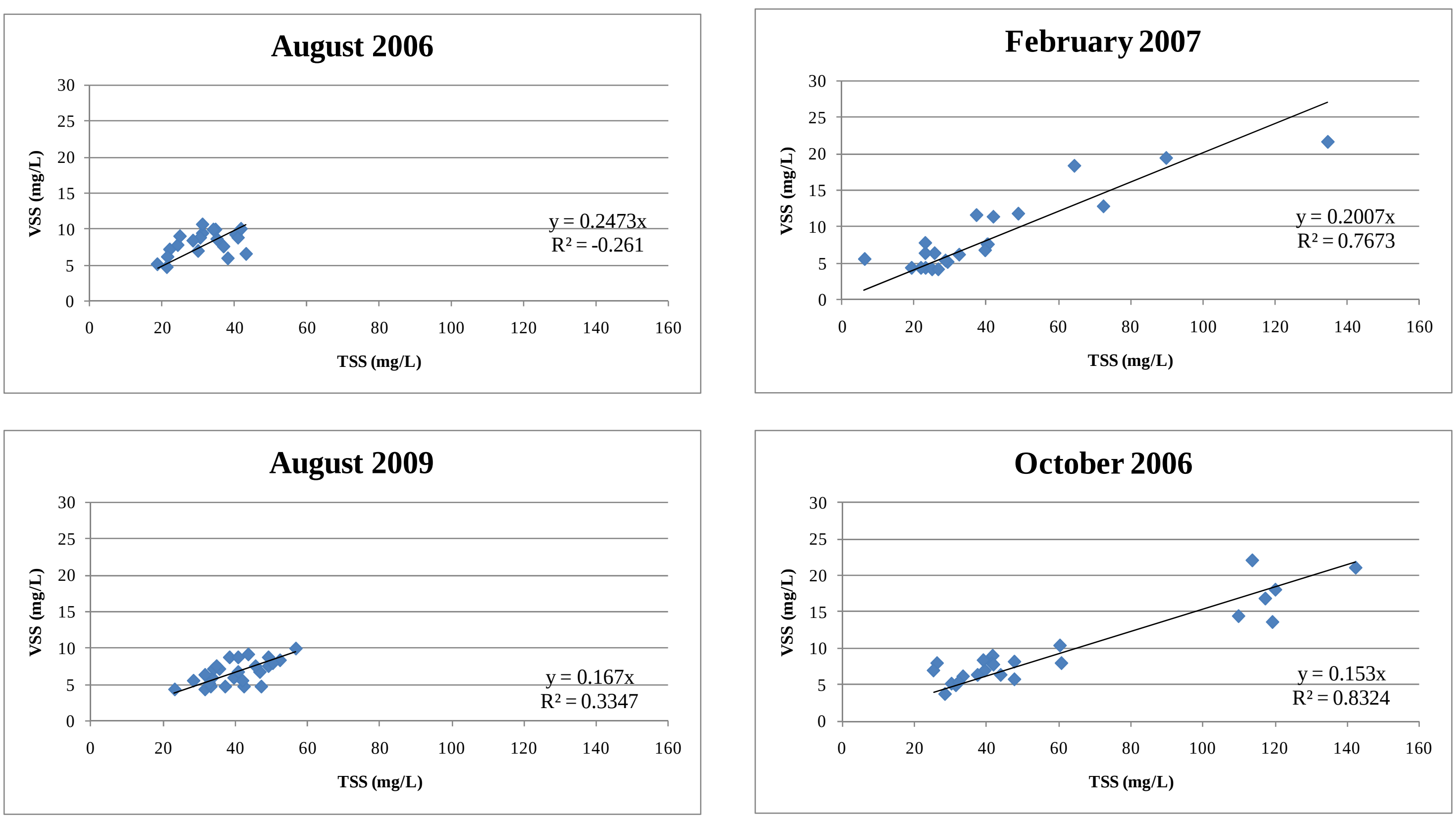

Figure 3.2. Linear correlation between paired measurements of TSS to VSS collected from mainstem Jordan River stations during four synoptic events.

In summary, although there remains some uncertainty in the precise relationship between TSS and VSS, these constituents are positively correlated. Robust TSS data records have been collected at some locations on the Jordan River and incorporate longer cycles of wet and dry years and seasonal variations that occur within these years. Therefore TSS data and the relationship between TSS and VSS can help characterize the magnitude and variation of OM loading in the Jordan River.

3.3.3 Proxy OM measurements – Biochemical Oxygen Demand

In the water column BOD quantifies the amount of oxygen consumed by micro-organisms during aerobic decomposition of OM and was used as a surrogate measure to indicate the OM content in water. BOD may also serve as a proxy measure of OM, specifically FPOM, as it ultimately results in either BOD or SOD.

The relationship between OM and oxygen consumption measured as BOD can be defined based on the stoichiometry of OM that quantifies the reactants and products of the decomposition process. The stoichiometry of OM and BOD is based on values provided in the QUAL2Kw model (Chapra and Pelletier 2008) that state 1 g of OM contains 0.4 g C and 2.69 g of oxygen (or BOD) are consumed for every 1 g of C. Therefore:

$$1\ g\ OM \times \frac{0.4\, g\, C}{1\, g\, OM} \times \frac{2.69\, g\, O}{1\, g\, C} = 1.076\ \ g\ \ O\ (BOD)$$

The inverse of this relationship can also be applied to determine the grams of OM needed to consume a given amount of oxygen.

3.4 CALCULATING OM LOADS

Previous analyses of OM in the Jordan River have considered only sources that were directly measured. OM load calculations presented in this section rely on a combination of direct and proxy measurements, computer modeling, and reasonable assumptions that together quantify total OM.

3.4.1 Differentiating FPOM and CPOM

Total OM is comprised of FPOM and CPOM. A description of the characteristics and process that influence each fraction by pollutant source was reviewed above. Separating OM pollutant loads into these two size categories is necessary to improve understanding of the loading process and direct future water quality improvement efforts. Of greater importance to the TMDL process at this point is defining Total OM using available data. A more precise understanding of the relative contribution that each size category contributes to Total OM will be determined in future TMDL phases.

3.4.2 FPOM – Current Loads

3.4.2.1 An FPOM Model

FPOM is analogous to VSS that has been measured directly during the five synoptic events of 2006 through 2009 and for several months in 2009 and 2010 (Table 3.5). These data were combined with other measures correlated with FPOM as described above to develop a model for estimating loads from earlier periods that can also be applied to future conditions.

The FPOM model is particularly useful in calculating the effect of settling and dissolution on loads between their source and the lower Jordan River. Two main steps are used in calculating permissible FPOM loads at 2100 South. FPOM loads are determined at their source from data that correlates with

FPOM including TSS or BOD. The source loads are then transported downstream to 2100 South after accounting for losses based on travel time, rates of settling and dissolution, and diversions.

3.4.2.2 Calculating FPOM Pollutant Loads at the Source

Table 3.6 lists the sources of FPOM and their distance from the downstream end of Segment 1 as well as their distance upstream from the beginning of the lower Jordan River at 2100 South.

As shown above in Figure 3.2 there is a strong correlation between VSS and TSS during some seasons and years. Where FPOM and TSS were measured during synoptic events along with historical TSS data, a ratio of FPOM:TSS was used to estimate historic FPOM loads. Such sources include Utah Lake, gaged tributaries, and WWTPs. For several smaller un-gaged tributaries with no FPOM measurements, a proxy from similar tributaries was used. Where historical monthly TSS data were available, the FPOM:TSS ratio was applied to yield monthly FPOM loads throughout the year.

Where there was BOD data but no VSS data, a ratio of 1:1.076 for FPOM:BOD was used, based on the stoichiometric ratio developed for QUAL2Kw of 1 mg of OM consuming 1.076 mg of DO. This technique was used for stormwater, diffuse runoff, and irrigation return flow. For stormwater and diffuse runoff, the Event Mean Concentration (EMC) for BOD_5 based on stormwater monitoring were used (Stantec 2006b). All data used to calculate monthly FPOM loads, including FPOM:TSS ratios and BOD, TSS, and FPOM loads were calculated within a Microsoft Excel spreadsheet. The details of calculating FPOM are in Appendix F.

3.4.2.3 Calculating Residual FPOM Loads Downstream of 2100 South

OM is removed from the water column in four ways: settlement, dissolution, diversion, and consumption by bacterial decomposition. The removal of the FPOM portion of OM through bacterial consumption is not significant for the length of the Jordan River based on rates of bacterial growth provided in the QUAL2Kw literature and the relatively short travel time to the river terminus at Burton Dam.

To account for settlement and dissolution of FPOM, the travel times from sources upstream of 2100 South were calculated, and settlement and dissolution rates from QUAL2Kw were used to calculate the losses. Diffuse sources were calculated as if they entered the Jordan River midway in each segment.

To account for loss of FPOM loads from the Jordan River by diversions, the monthly flows at the diversion point and into each canal were used to calculate the percent of water passing each of the major diversions in each month. This percent was then applied to reduce the load continuing downstream from the diversion.

The remaining FPOM load after settlement, solution, and diversions yielded a ratio used to determine the net residual load for each month and for each source upstream of 2100 South. The inverse of this ratio was used later in scaling permissible loads upstream from 2100 South to the source location, which produced a permissible load at the source. Reductions due to settlement, dissolution, or diversions were not necessary for loads entering the lower Jordan River directly below 2100 South.

The difference between estimated loads from the various sources at 2100 South and those calculated from the FPOM:TSS ratios based on TSS measurements at 2100 South required a correction factor for future loads as described below.

3.4.2.4 FPOM Results – Current

Table 3.6 shows estimated annual FPOM loads for all pollutant sources that contribute to the Jordan River, including sources located upstream and downstream of 2100 South. Annual FPOM pollutant loads at their source range from 417 kg/yr from Corner Canyon Creek to over 3.7 million kg/yr from Utah Lake. Stormwater from Segment 4 is the second largest source of FPOM at about 1.4 million kg/yr, followed by stormwater from Segment 6 and Segment 3 at about 470,000 kg/yr each and Big Cottonwood Creek at 386,581 kg/yr. The total annual FPOM source load for all stormwater is 2,794,253 kg/yr compared to natural discharge (no stormwater) from tributaries at 969,537 kg/yr. WWTP facilities and irrigation return flows contribute 611,500 and 341,146 kg/yr respectively.

Settling, dissolution, and irrigation diversions reduce pollutant loads between the sources and 2100 South by about 30 percent. The largest contributor to this difference is Utah Lake as annual loads are reduced by about 55 percent from about 3.7 million to 1.7 million kg/yr. Note that any pollutant loads in Table 3.6 that are located downstream of 2100 South are not reduced between source and point of entry, as they enter the lower Jordan River directly.

As noted in previous sections, the Surplus Canal conveys much of the water in the Jordan River just above the three most downstream river segments impaired for DO. This is reflected in the difference between loading at 2100 South and loading into the lower Jordan River, shown in columns four and five of Table 3.6.

The percent of each source to the total FPOM load in the lower Jordan River is shown in the sixth column of Table 3.6. Stormwater loads from Segment 6 contribute almost 25 percent to the total FPOM loads followed by Utah Lake at nearly 16 percent, Segment 2 Stormwater at 14 percent, Segment 4 Stormwater at 12 percent, Emigration Creek at 5 percent, and Segment 3 Stormwater and CVWRF at about 4 percent.

The total FPOM contribution from stormwater makes up about 55 percent of the annual load to the lower Jordan River. Natural flow from tributaries contributes about 16 percent, WWTPs about 8 percent while irrigation return flow contributes about 3 percent.

FPOM pollutant sources that discharge directly to the lower Jordan River downstream of 2100 South contribute 52 percent of the total FPOM load. This relatively large proportion compared to source loads is due to the diversion of upstream loads by the Surplus Canal.

3.4.3 FPOM – Future Loads

3.4.3.1 Extending the FPOM Model

Future loads and load reductions at each source were calculated using the same methodology as for current loads, taking into account the new JBWRF, and future loads and flows.

3.4.3.2 Calculating FPOM Pollutant Loads at the Source

Future loads of TSS and BOD_5 were taken from *Technical Memoranda: Updated Current Pollutant Source Characterization, Projected Future Pollutants – No Action, Critical Conditions, Endpoints, and Permissible Loads, A Proportional Load Allocation.* (Cirrus 2010c). FPOM loading was estimated using the same FPOM:TSS or FPOM:BOD_5 ratios as in the current load analysis.

3.4.3.3 FPOM Results – Future Loads

Future FPOM pollutant loads at their source are shown in column two of Table 3.7. Future loads show the effect of future flows and also include the new JBWRF which will discharge to the Jordan River near the Corner Canyon Creek confluence.

Table 3.6. Current loads of FPOM[1] to the Jordan River (kg/yr).						
Source	**Location (km)**	**Distance from 2100 South (km)**	**Load at Source**	**Load at 2100 South above Surplus Canal**	**Load to Lower Jordan River below Surplus Canal**	**Percent Contribution to Lower Jordan River**
Utah Lake	51.4	35.9	3,723,624	1,684,035	299,505	16.78%
Stormwater Segment 8	44.7	29.2	126,150	77,202	14,520	0.81%
Diffuse Runoff Segment 8	44.7	29.2	4,729	3,007	556	0.03%
Diffuse Runoff Segment 7	39.6	24.1	1,048	874	163	0.01%
Rose Creek	36.7	21.1	869	781	116	0.01%
Corner Canyon Creek	35.4	19.9	417	375	64	0.00%
JBWRF	34.5	19.0	0	0	0	0.00%
Stormwater Segment 6	31.9	16.3	475,760	425,917	80,205	4.49%
Diffuse Runoff Segment 6	31.9	16.3	5,606	5,031	938	0.05%
Midas/Butterfield Creek	31.4	15.8	1,299	1,191	176	0.01%
Willow Creek	31.1	15.5	0	0	0	0.00%
Dry Creek	28.6	13.0	2,993	2,796	553	0.03%
Bingham Creek	26.4	10.9	2,437	2,308	342	0.02%
Irrigation Return Flow Segment 6	26.3	10.7	151,004	137,984	27,253	1.53%
SVWRF	25.8	10.3	219,550	204,679	39,763	2.23%
Stormwater Segment 5	25.5	9.9	55,825	52,342	9,873	0.55%
Diffuse Runoff Segment 5	25.5	9.9	617	579	108	0.01%
Little Cottonwood Creek	21.4	5.9	287,540	270,889	41,568	2.33%
Big Cottonwood Creek	20.5	5.0	386,581	376,357	53,255	2.98%
Stormwater Segment 4	20.2	4.7	1,394,717	1,357,465	228,271	12.79%
Diffuse Runoff Segment 4	20.2	4.7	2,900	2,819	528	0.03%
Mill Creek	17.1	1.6	85,433	84,567	14,809	0.83%
CVWRF	17.1	1.6	353,091	349,193	70,878	3.97%
Irrigation Return Flow Segment 4	17.0	1.5	190,142	188,134	37,512	2.10%
Parleys Creek	14.0	0.0	29,847	29,847	29,847	1.67%
Emigration Creek	14.0	0.0	98,187	98,187	98,187	5.50%
Red Butte Creek	14.0	0.0	58,502	58,502	58,502	3.28%
Stormwater Segment 3	13.4	0.0	472,296	472,296	472,296	26.47%
Diffuse Runoff Segment 3	13.4	0.0	1,054	1,054	1,054	0.06%
City Creek	11.2	0.0	15,430	15,430	15,430	0.86%
Stormwater Segment 2	9.2	0.0	145,524	145,524	145,524	8.15%
Diffuse Runoff Segment 2	9.2	0.0	1,291	1,291	1,291	0.07%
SDSWWTP	4.7	0.0	38,859	38,859	38,859	2.18%
Diffuse Runoff Segment 1	3.6	0.0	2,552	2,552	2,552	0.14%
TOTAL			8,335,876	6,092,068	1,784,500	100.00%

[1] A detailed description of the data and methods used to calculate FPOM loads can be found in Cirrus (2010c).

Table 3.7. Estimated future loads of FPOM to the Jordan River (kg/yr).[1]						
Source	**Location (km)**	**Distance from 2100 South (km)**	**Load at Source**	**Load at 2100 South above Surplus Canal**	**Load to Lower Jordan River below Surplus Canal**	**Percent Contribution on to Lower Jordan River**
Utah Lake	51.4	35.9	3,723,624	1,684,035	299,505	13.78%
Stormwater Segment 8	44.7	29.2	121,298	74,232	13,962	0.64%
Diffuse Runoff Segment 8	**44.7**	**29.2**	**14,819**	**9,423**	**1,742**	**0.08%**
Diffuse Runoff Segment 7	**39.6**	**24.1**	**4,089**	**3,410**	**634**	**0.03%**
Rose Creek	36.7	21.1	869	781	116	0.01%
Corner Canyon Creek	35.4	19.9	417	375	64	0.00%
JBWRF[2]	**34.5**	**19.0**	**285,789**	**251,124**	**48,039**	**2.21%**
Stormwater Segment 6	**31.9**	**16.3**	**775,039**	**693,842**	**130,659**	**6.01%**
Diffuse Runoff Segment 6	**31.9**	**16.3**	**19,858**	**17,822**	**3,324**	**0.15%**
Midas/Butterfield Creek	31.4	15.8	1,299	1,191	176	0.01%
Willow Creek	31.1	15.5	0	0	0	0.00%
Dry Creek	28.6	13.0	2,993	2,796	553	0.03%
Bingham Creek	26.4	10.9	2,437	2,308	342	0.02%
Irrigation Return Flow Segment 6	26.3	10.7	151,004	137,984	27,253	1.25%
SVWRF	**25.8**	**10.3**	**304,503**	**284,419**	**54,778**	**2.52%**
Stormwater Segment 5	**25.5**	**9.9**	**88,785**	**83,246**	**15,702**	**0.72%**
Diffuse Runoff Segment 5	**25.5**	**9.9**	**2,903**	**2,725**	**509**	**0.02%**
Little Cottonwood Creek	21.4	5.9	239,498	225,550	34,211	1.57%
Big Cottonwood Creek	20.5	5.0	364,849	355,200	50,261	2.31%
Stormwater Segment 4	**20.2**	**4.7**	**2,477,474**	**2,410,361**	**419,107**	**19.28%**
Diffuse Runoff Segment 4	**20.2**	**4.7**	**12,538**	**12,185**	**2,280**	**0.10%**
Mill Creek	17.1	1.6	-28,720	-28,431	-4,895	-0.23%
CVWRF	**17.1**	**1.6**	**474,182**	**468,941**	**94,519**	**4.35%**
Irrigation Return Flow Segment 4	17.0	1.5	190,142	188,134	37,512	1.73%
Parleys Creek	14.0	0.0	33,055	33,055	33,055	1.52%
Emigration Creek	14.0	0.0	92,335	92,335	92,335	4.25%
Red Butte Creek	14.0	0.0	59,996	59,996	59,996	2.76%
Stormwater Segment 3	13.4	0.0	519,924	519,924	519,924	23.91%
Diffuse Runoff Segment 3	**13.4**	**0.0**	**4,327**	**4,327**	**4,327**	**0.20%**
City Creek	11.2	0.0	16,078	16,078	16,078	0.74%
Stormwater Segment 2	9.2	0.0	145,137	145,137	145,137	6.68%
Diffuse Runoff Segment 2	**9.2**	**0.0**	**4,883**	**4,883**	**4,883**	**0.22%**
SDWTP	**4.7**	**0.0**	**61,461**	**61,461**	**61,461**	**2.83%**
Diffuse Runoff Segment 1	**3.6**	**0.0**	**6,516**	**6,516**	**6,516**	**0.30%**
TOTAL			**10,173,400**	**7,825,362**	**2,174,064**	**100.00%**

[1] Bold text indicates pollutant sources whose **percent contribution** at 2100 South increased in comparison to current contribution.

[2] Future FPOM load from JBWRF based on estimated TSS concentration of 5.0 mg/L provided by G. Mayne during personal communication with H. Arens (DWQ) on 4/27/11.

Future FPOM loads from Utah Lake remain the same as existing loads. Future FPOM loads from Stormwater in Segment 4 are still the second largest source of FPOM, followed by stormwater in Segment 6, Stormwater in Segment 3, and CVWRF. Future FPOM source loads for CVWRF increase roughly 34 percent over current loads. Future FPOM loads for Little Cottonwood Creek, Mill Creek, and Emigration Creek decrease 5 to 15 percent from current loads due to increased diversions for municipal culinary use.

The future annual FPOM source load for all stormwater is 4,251,638 kg/yr compared to WWTP facilities at 1,125,935 kg/yr. Natural discharge (no stormwater) from tributaries is 785,106 kg/yr.

Future source loads from stormwater are expected to increase about 52 percent from current loads, due to increased development and expansion of serviced areas within existing catchments. Stormwater from Segment 4 alone is expected to increase by 78 percent. WWTP loads are expected to increase in the future due to the new JBWRF facility and increased discharge from existing WWTP facilities. Large increases (approximately 250 percent) are expected in diffuse runoff loads due to increased development within these areas. However, the total future load from this source still contributes a very small (<1 percent) portion to the total FPOM source load. Future loads from irrigation return flows are the same as current loads, due to trends that indicate little change in agricultural land and water use.

Residual FPOM loads delivered to the Jordan River at 2100 South and to the lower Jordan River under future conditions are shown in columns three and four of Table 3.7, respectively. Similar to current conditions, the reduction in pollutant loads between the source and the lower Jordan River is about 30 percent. Segment 3 Stormwater is the single largest contributor of FPOM to the lower Jordan River under future conditions (23 percent) and about 5 percent greater than FPOM loads from Segment 4 Stormwater. The future FPOM load from stormwater is about 60 percent of the total load to the lower Jordan River. The total future FPOM load to the lower Jordan River from WWTPs is approximately 11 percent, an increase of 3 percent over existing conditions. FPOM loads from tributaries and irrigation return flows contribute about 12 percent and 3 percent of the total FPOM load to the lower Jordan River, respectively.

FPOM pollutant sources located below 2100 South contribute approximately 46 percent of the total FPOM load under future conditions. This represents a decrease of about 6 percent of the total compared to current conditions.

3.4.4 Organic Matter Contributing to SOD – Current Loads

3.4.4.1 A Model to Define Organic Matter contributing to SOD

Though CPOM loads are known to occur, a standard protocol for measuring CPOM does not exist and hence no credible and repeatable data is available to quantify contributions to the river. In order to calibrate the QUAL2Kw model it was necessary to prescribe up to 3.5 g/m^2/day of SOD, a result largely of bacterial decomposition of settled FPOM and CPOM produced outside of the 6-day model run. This prescribed SOD rate suggests sources of FPOM and CPOM that accumulate over long periods of time. Based on the stoichiometry of OM in the water column and sediment chemistry, it is possible to estimate this mass of OM. Measured SOD values indicate a significant loss of DO in many segments of the Jordan River (Goel and Hogsett 2009, Goel and Hogsett 2010). Additional data collected in future phases of the TMDL will enable a better understanding of processes and pollutant sources that contribute to SOD.

3.4.4.2 Calculating Residual FPOM Loads Downstream of 2100 South

Future loads of FPOM assumed the same settling and dissolution rates and canal diversions, resulting in similar reductions in loads at 2100 South. All major increases in flows are expected to come from WWTPs that enter the Jordan River downstream of the North Jordan Canal, the last diversion on the Jordan River upstream of 2100 South.

Sources of OM used in the QUAL2Kw model that contribute to DO demanding processes included:

a. Dead OM entering the lower Jordan River from upstream sources or sources directly discharging to the lower Jordan River. Detritus was calculated by subtracting the mass of living algae from the measured VSS.

b. Living algae, estimated from chlorophyll-a measurements, some of which may die and either be decomposed in the water column or settle to the bottom and contribute to SOD.

c. Soluble carbonaceous BOD (ScBOD) from dissolving detritus.

QUAL2Kw generates SOD during the 6-day model run from algae dying to become detritus and detritus entering the river from upstream, some of which settles to the bottom. Model calibration required an extra "prescribed" SOD that was added to match observed DO levels. The prescribed SOD values were within the ranges measured in the field by Goel and Hogsett (2009). This prescribed SOD is assumed to come from settled FPOM and CPOM loading previous to the model run.

Prescribed SOD (in g O_2/m^2/day) is a result of decomposing OM, through both bacterial respiration and oxidation of NH_4 and CH_4. The stoichiometric ratio from QUAL2Kw of 1 g C per 2.69 g DO was used to estimate DO demand because nearly all C is converted to CO_2 in decomposition processes. The stoichiometry of these processes also uses a ratio of 0.4 g C per 1 g OM. Therefore, for each g O_2/m^2/day of prescribed SOD, the load of OM to the lower Jordan River can be calculated as:

$$Average\ OM\ To\ Jordan\ River = \frac{1\,g\,C}{2.69\,g\,O} \times \frac{1\,g\,OM}{0.4\,g\,C} = 0.9293\ g\ \ OM/m^2\,d$$

This loading rate was multiplied by the area of the river bottom in the lower Jordan River to yield an average daily load of OM. This additional load of OM contributes to the prescribed SOD and is composed of both CPOM and FPOM. Although there is no data to define the fractions of FPOM and CPOM that contribute to SOD it is not critical at this stage in the TMDL process. In general, CPOM is attributable to all sources of OM except WWTPs because sewage treatment processes remove or break down CPOM into FPOM. Ultimately, all sizes of OM may need to be reduced in order to reduce SOD.

3.4.4.3 Model Results

Current OM loads contributing to SOD were calculated as described above and are included in Table 3.8. Nonpoint sources upstream of 2100 South contribute the majority of this OM load. Much of the OM is probably transported by surface runoff during storms and spring snowmelt.

Table 3.8. OM loads contributing to SOD in the lower Jordan River (kg/yr).

		Load at Source	**Load to Lower Jordan River**	**Percent Contribution to Lower Jordan River**
Point Sources	Above 2100 South	132,724	25,551	5.8%
	Below 2100 South	43,604	43,604	9.9%
Nonpoint Sources	Above 2100 South	2,094,670	274,983	62.4%
	Below 2100 South	96,884	96,884	22.0%
Total		2,367,882	441,022	100.0%

3.5 SUMMARY

OM in the Jordan River consists of both living and dead material in a range of fine and coarse particle sizes. An unknown portion of CPOM is transformed into FPOM as it is transported downstream in a repeating sequence of suspension, deposition, and resuspension. Characteristics of OM in the Jordan River vary by pollutant source and by season.

OM source loads entering the Jordan River upstream of 2100 South decrease due to settling, dissolution, and diversion. Inputs at the source were calculated and then reduced according to these processes and the distance travelled before delivery to the lower Jordan River.

Seven pollutant sources contribute OM to the Jordan River including Utah Lake, WWTPs, stormwater, tributaries, diffuse runoff, irrigation return flow, and natural background. The geographic location and processes that influence loading patterns from each source are well known but direct measurements of FPOM and CPOM are limited. Proxy measurements of OM, including TSS and BOD_5 were used in a spreadsheet model to define FPOM pollutant loads for each source for current and future conditions.

Current FPOM loads to the lower Jordan River are estimated at 1,784,500 kg/yr. Stormwater from Segment 3 is the largest single contributor at about 25 percent of the total FPOM load. Stormwater loads of FPOM collectively contribute about 53 percent with Segment 2 and Segment 3 alone providing about 35 percent of FPOM to the lower Jordan River. Natural flow from tributaries contributes about 18 percent, three WWTPs contribute 8 percent, and irrigation return flow and diffuse runoff account for the remainder.

Future FPOM loads to the lower Jordan River in 2030 are projected to be 2,174,064 kg/yr or a 22 percent increase from existing conditions. Factors underlying this increase include construction of the JBWRF, increased discharge from existing WWTPs, and increased stormwater discharge to tributaries and the mainstem Jordan River. Segment 3 stormwater remains the single biggest contributor of OM (about 24 percent) to the lower Jordan River, followed by Segment 4 stormwater (about 19 percent). Total stormwater FPOM loads combined input would increase slightly to 57 percent. The four WWTPs would contribute approximately 12 percent.

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 lower Jordan occur year-round.

Current loads of OM that contribute to SOD in the lower Jordan River are estimated at 441,022 kg/yr. About 85 percent of this amount is generated by nonpoint sources, the remainder by point sources. About 68 percent of the total enters the Jordan River above 2100 South. The methodology used to estimate OM loads contributing to SOD does not allow projection of future loads.

Table 3.9 shows total estimated current OM loading and the combined values for FPOM and other OM sources contributing to SOD in the lower Jordan River. As stated previously, the exact proportions of coarse and fine OM are not currently known. OM particle size categories provide useful information in support of critical processes that affect movement and deposition of OM between sources and the lower Jordan River. Total OM is defined in this report with a combination of direct measurements and computer modeling and is assumed to include all OM particle sizes. Bulk (total) OM loads shown in Table 3.9 show pollutant loads at the source and the resulting load to the lower Jordan River after accounting for diversions and processes of settling and dissolution.

The pollutant loads calculated in this chapter will be the basis for bulk load allocations defined in Chapter 4. Additional data collection completed in Phase 2 of the TMDL will provide greater certainty in regards to pollutant source loading, and the fate and transport of OM loads. This additional knowledge will be used to update the values shown in Table 3.9.

Table 3.9. Current bulk OM loads to the lower Jordan River (kg/yr).

Sources		Current Loads at the Source	Current Loads to Lower Jordan River
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

4.0 BULK LOAD ALLOCATIONS

4.1 INTRODUCTION

The analysis in Chapter 2 and Appendix D identified Organic Matter (OM) as the pollutant of concern in resolving DO impairment in the lower Jordan River. This chapter documents the calculation of the permissible OM load capacity based on a *concentration* of OM in the QUAL2Kw water quality model that will not violate a *target* model DO concentration during the most critical conditions of late summer. The target model DO concentration (5.5 mg/L) is based on the instantaneous minimum DO water quality standard (4.5 mg/L) plus a 1.0 mg/L implicit Margin of Safety (MOS) to account for analytical uncertainty and environmental variability. Permissible loads are allocated among point and nonpoint pollutant sources based on their respective load contributions to the lower Jordan River to achieve the 4.5 mg/L DO water quality standard and restore the aquatic life beneficial use. Note the target model DO concentration of 5.5 mg/L is not proposed as a new water quality standard for the lower Jordan River. It is simply used in the QUAL2Kw model to determine a concentration of OM that will meet the existing 4.5 mg/L DO standard. The OM concentration determined by QUAL2Kw is then used to calculate the load capacity for the lower Jordan River.

Load allocations are the maximum allowable mass of the pollutant of concern assigned to sources based on the permissible load capacity. Load allocations can account for both current and future pollutant loads if data is available. Future loads should reflect trends that influence existing pollutant sources as well as sources that may not currently exist. Growth and development will produce increased discharge from WWTPs, stormwater, and areas of diffuse runoff.

A bulk allocation is presented in Table 4.1 for current total OM loads that would restore DO levels to water quality standards and achieve full support of the aquatic life beneficial use. This OM reduction includes all forms of OM – FPOM, CPOM, and any other OM. Bulk loads are presented due to uncertainty regarding specific sources of various kinds and timing of OM. Future monitoring and investigation of OM sources and their interactions with DO will be used in the next phase of study to develop load allocations for individual sources and to account for future growth.

4.2 GUIDANCE AND DEFINITIONS

4.2.1 REGULATORY GUIDANCE

The development of load allocations should consider several factors including:

- **Sustainability:** Will the load allocation be sustainable over a period of time that will achieve and maintain desired levels of water quality?

- **Technically sound:** Are the methods used to determine the cause-and-effect relationship between pollutant source reductions and water quality response technically sound?

- **Politically feasible:** Do load allocations accommodate political realities that affect a phased TMDL?

- **Affordable:** What is the cost of achieving load allocations for each pollutant source?

- **Achievable:** Based on consideration of the above factors, are load allocations reasonably achievable?

Wasteload Allocations (WLAs) include all NPDES permitted point sources with an individual allocation for both current and future pollutant sources. Information describing each point source, including permit numbers and geographical locations, is included in Cirrus (2009b). Nonpoint Source Load Allocations (LAs) identify the permissible load assigned to nonpoint sources of pollution.

4.2.2 Load Capacity

The load capacity is the greatest amount of permissible loading of the pollutant of concern which a waterbody can receive without causing it to violate water quality standards (EPA 1999). An adaptive approach is considered necessary for achieving the load capacity defined in this TMDL due to the need to better understand the relationship between OM pollutant sources, load capacity, and the desired response in DO levels. Permissible loads must safeguard against uncertainty by including an implicit MOS in the establishment of the DO endpoint or an explicit MOS in the final load allocation. The rationale for an implicit MOS was described in Chapter 2. In the next phase of this TMDL the selection of an implicit or explicit MOS may be revisited based upon a better understanding of OM loads.

It is important to note that the TMDL load capacity is the sum total of all load allocations. Load allocations are distributed among pollutant sources in a manner appropriate, equitable, and meaningful to stakeholders. This approach was used because of the uncertainty in the CPOM and other OM load sources. This will be adjusted in Phase 2 to account for all revised sources of OM and will be based on additional monitoring data and greater understanding of loading processes and methods that can be used to reduce OM pollutant loads.

4.2.3 Current and Future Loads

Pollutant sources that contribute to the current load observed at 2100 South have been defined (Cirrus 2010c) and were reviewed in Chapter 3. Based on development trends and population growth, loads for most sources may increase through the year 2030. Load allocations must take into account current and future pollutant sources and provide assurance that the water quality endpoint will be met under both scenarios.

4.2.4 Time Scale and Data Availability

The permissible load must result in meeting the water quality endpoint year round. Allocations should also consider seasonal variations that influence pollutant loading. For this TMDL, the annual permissible load is based on a concentration of OM that would meet the desired DO endpoint during the most critical time period of the year. This same concentration is then applied to all months of the year to protect against buildup of OM that contributes to SOD in the lower Jordan River. The daily permissible load is based on a simple daily average of the annual permissible load. If appropriate, the updated TMDL report completed in Phase 2 may utilize seasonal load allocations to account for actual loading of all sources to the system.

4.2.5 Load Allocation Scenario

The load allocation method presented in this study allocates loads from each source in proportion to their contribution to the total load to the lower Jordan River. The reduction needed to meet the permissible load is distributed among pollutant sources based on their percent contribution to the Jordan River below 2100 South after accounting for losses from settling, dissolution and diversion. For example, if one source contributes 20 percent of the load below 2100 South, 20 percent of the load reduction is allocated to that source. As stated above, this load allocation scenario may be modified in Phase 2 based on further load source identification, seasonal variability, and sensitivity analysis of each load as more data becomes available.

4.3 PERMISSIBLE LOAD AND OM ALLOCATIONS

4.3.1 REDUCTIONS TO MEET PERMISSIBLE LOADS

The target model endpoint for DO is equivalent to the minimum DO water quality standard of 4.5 mg/L plus an implicit MOS of 1.0 mg/L to account for analytical uncertainty, for a total of 5.5 mg/L (Table 2.5). Since OM gradually accumulates in the lower Jordan River and contributes to the critical condition in August the permissible OM concentration for August is applied to every month to ensure attainment of the DO water quality standard.

The permissible load to the lower Jordan River was calculated from the target concentration of FPOM of 4.5 mg/L and historic flows at 2100 South. The same OM concentration was used to calculate both current and future load allocations because over the long term it is the concentration rather than the load that determines the amount of OM available for settling and thus the amount of bacterial decomposition of OM and resulting consumption of DO. The percent reduction needed to meet permissible loads of FPOM at 2100 South was applied to existing CPOM loads to obtain a permissible load for this OM category.

Details of load reductions are provided in tables in Appendix G. Permissible loads are allocated based on the proportional contribution of each source to loads in the lower Jordan River and are calculated to achieve the model DO endpoint of 5.5 mg/L. Daily permissible loads are the average daily value of the annual permissible loads.

4.3.2 BULK OM LOAD ALLOCATIONS

Table 4.1 shows a bulk load allocation for current total estimated OM for both point and nonpoint sources and for both upstream and downstream of the lower Jordan River at 2100 South. This load allocation includes a sufficiently conservative implicit MOS, so an additional explicit MOS is not necessary. The next phase of the TMDL will incorporate additional monitoring data that will refine both the total OM loads as well as the relative proportions of OM particle size categories (i.e. fine and coarse) that comprise the total load. The allocations shown in Table 4.1 should be considered as one scenario for achieving the permissible load. These values will be updated in Phase 2 of the TMDL as more data becomes available to assess load reductions and realistic ways to achieve reductions alter the loads shown in Table 4.1 as CPOM and other OM loads are better identified.

Table 4.1. Bulk allocations of existing total OM loads (kg/yr) to meet DO water quality standards in the lower Jordan River.

Source	Loads into Lower Jordan River	Contribution into Lower Jordan River (%)	Permissible Loads into Lower Jordan River	Daily Permissible Loads into Lower Jordan River (kg)	Percent Reduction into Lower Jordan River (%)
Point Sources Upstream of 2100 South	469,062	21%	283,185	776	40%
Point Sources Downstream of 2100 South	700,282	31%	405,858	1,112	42%
Nonpoint Sources Upstream of 2100 South	752,429	34%	545,532	1,495	27%
Nonpoint Sources Downstream of 2100 South	303,749	14%	139,055	381	54%
Total	**2,225,523**	**100%**	**1,373,630**	**3,763**	**38%**

5.0 A PHASED TMDL FOR THE LOWER JORDAN RIVER

5.1 INTRODUCTION

A phased TMDL is presented that offers a path forward for establishing our current understanding of the effects of excessive OM loading into the Jordan River and the load reductions necessary for resolving the DO impairment in the lower Jordan River.

5.2 PHASED TMDLS, ADAPTIVE IMPLEMENTATION, AND A SCHEDULE FOR THE LOWER JORDAN RIVER

5.2.1 PHASED TMDLS

The establishment of a phased TMDL is appropriate in cases where the cause of impairment, and necessary reductions to resolve the impairment, are known but there is still significant uncertainty regarding the sources of OM loading. 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).

Phased TMDLs require the establishment of a schedule for refining wasteload and load allocations based on the collection of additional data. Following additional data gathering and analysis the TMDL is revised to specify individual load allocations and recommend more specific actions to meet LAs and WLAs.

In the case of the Jordan River TMDL for DO, sources of analytical uncertainty that will be investigated include:

- Improving understanding of DO response to OM loading and refine load reductions needed to meet the DO endpoint.
- Identifying sources and sinks of OM at a finer spatial and seasonal resolution.
- Defining an OM budget for the Jordan River that includes both natural and anthropogenic sources.

5.2.2 ADAPTIVE IMPLEMENTATION

TMDLs rely on effective strategies to restore water quality. A flexible, adaptive implementation strategy for the lower Jordan River is appropriate given the current level of uncertainty associated with the following:

- Sources, concentrations, and seasonal variability of OM.
- Water quality response to changes in OM.
- Fate and transport of OM and accumulation that contributes to SOD.
- Effectiveness and economic feasibility of BMPs and BATs in reducing OM.

Furthermore, treating OM from stormwater and tributaries or upgrading WWTPs would require significant capital expense, so it is important to better understand the reductions required and environmental benefits gained before implementing capital-intensive strategies. Use of the QUAL2Kw model will assist in this effort by allowing appropriate sensitivity analysis of alternatives.

The adaptive implementation approach uses "an iterative process in which TMDL objectives and the implementation plans to meet those objectives [are] regularly reassessed during the ongoing implementation of controls. The central theory of adaptive implementation is that uncertainty can be reduced over time only by studying and modeling watershed and water quality responses to load reductions, implementing controls, and then carefully and methodically assessing the results in order to learn while doing" (Shabman et al. 2007).

Adaptive implementation allows for changes in strategy as new information is acquired and includes milestones to ensure progress toward the water quality goals. These milestones include the analysis and results of intensive monitoring of water quality indicators, pollutant loading, implementation success, and waterbody response (EPA 2006).

5.2.3 Proposed Phases and Schedule

Future implementation of this TMDL is designed in three phases set forth in Table 5.1. Note that the TMDL process is currently in Phase I. The general approach in Phase II of the TMDL process is to better understand OM loading and DO impacts. Measures to reduce OM loading that can be easily adapted with little or no capital cost can be implemented as new information becomes available. More specifically, the goals of Phase II include (1) commence an aggressive effort to define OM source loading, (2) define processes that affect transport and deposition of OM loads contributing to SOD, and (3) move forward with reasonably affordable strategies that reduce existing OM loads. The design of large capital improvements and incurring long-term financial commitments will not be made until the necessity and benefit of such efforts are fully understood in future phases. As information becomes more conclusive, decisions can be made in Phase III and Phase IV about the need to commit capital cost to reducing source loads.

5.3 PHASE I AND II IMPLEMENTATION COMPONENTS

5.3.1 Public Involvement

The Jordan River Technical Advisory Committee (TAC) and the Scientific Review Committee have been instrumental in providing and reviewing information used in Phase I of this TMDL study and offering constructive input through several drafts of this report and supporting documents. Committee members include those with experience in Jordan River watershed water quality issues, those responding to a solicitation published on the Jordan River Watershed Council email listserv, and suggestions from members at the first TAC meeting.

There are 49 TAC members and 7 members on the Scientific Review Committee (Appendix H). Representatives on the TAC came from a variety of interests and backgrounds, including environmental concerns, wildlife protection, business and industry, WWTPs, city, county, state, and federal public agencies, public health, private citizens, sporting and recreational interests, and other interest groups (e.g. Jordan River Commission).

Table 5.1. Phased TMDL and adaptive implementation plan timeline.
Phase II (2012–2018):
a. Continue DO monitoring to validate and further refine the nature and extent of impairment.
b. Characterize source loads of FPOM and CPOM through an organic matter budget in a variety of seasonal conditions.
c. Inventory existing stormwater BMP infrastructure and evaluate potential stormwater management practices needed to achieve water quality endpoints.
d. Coordinate with municipalities to develop a more comprehensive stormwater data collection program.
e. Evaluate different flow regimes to achieve water quality standards at different times of year during low, medium and high flows.
f. Investigate sources of OM loads to Utah Lake, how they can be reduced, and impacts on OM loads at the lake's outlet.
g. Complete additional monitoring on irrigation return flows including locations, seasonality, flows, and water quality.
h. Investigate implications of load reductions to the greater watershed system, including Utah Lake, Jordan River, and Great Salt Lake.
i. Design an educational outreach campaign to educate the public on the water quality impacts of OM loading into the lower Jordan River and BMPs that can be employed to reduce the loading.
j. Investigate operational enhancements at WWTPs to reduce OM loading to the lower Jordan River.
k. Reevaluate implicit MOS based on additional OM data collection.
l. Research viability of in stream artificial aeration and effects on DO in the lower Jordan River.
m. Investigate the feasibility of achieving load reductions and determine the cost/benefit of controls.
n. Refine source loads, WLA and LA for CPOM and FPOM, or other pollutants as necessary.
o. Assign WLAs and LAs to all point and nonpoint sources.
p. Submit revised TMDL for EPA approval in April 2018.
Phase III (2018–2023)
a. Adopt revised TMDL.
b. Complete design work on measures to treat pollutants of concern from point and nonpoint sources to meet LAs and WLAs as directed by Phase II studies.
c. Design and implement BMPs and structures to meet stormwater WLAs as directed by Phase II studies.
d. Implement land use management practices that reduce runoff from diffuse sources (outside of stormwater catchments) and stormwater catchments.
Phase IV (2023–2028)
a. Finalize construction upgrades for all point sources and nonpoint sources needed to meet WLAs and LAs.
b. Meet all DO water quality standards.

The Committees met on average every 6 weeks beginning in the fall of 2009, and attendance has ranged from 17 to 27 people per meeting. Meetings were held:

- October 28, 2009
- December 15, 2009
- January 20, 2010
- March 3, 2010
- April 19, 2010
- June 15–16, 2010 (Scientific Review Committee and WWTP representatives)
- July 19, 26 (Scientific Review Committee and WWTP representatives)
- August 12, 2010
- September 7, 2010

Committee members were sent drafts of documents for review at least 1 week before each meeting and had an additional week after each meeting to review and comment. Each meeting included a presentation of the information in the document and provided an opportunity for the Committee to ask questions and discuss concerns with each other. At the end of the 7-month review process, the Committees were given a compendium of all the documents with their incorporated comments and provided an additional 4-week comment period.

Additionally, DWQ has presented updates on the Jordan River TMDL at a number of public meetings, including the Salt Lake Countywide Watershed Symposium, River Network's annual River Rally, and the Utah Nonpoint Source Water Quality Conference.

Following the adoption of this TMDL, the DWQ and TAC will create a short presentation to educate constituents and the public about the phased TMDL. Additional information on the public participation component can be found in Salt Lake County's WaQSP approach. DWQ will work closely with Salt Lake County to find ways to involve a wider audience. Some of the tasks to involve the public include:

- Identifying the cities, agencies, and interest groups who want to participate in the watershed planning process.

- Identifying events, meetings, and venues to present the TMDL.

- Identifying venues and events easily and frequently utilized by the public where educational kiosks and information could be presented.

The TAC will assist with management plan implementation by setting priorities for restoration and BMP implementation projects and by periodically reviewing progress toward water quality improvement goals. They will also be helpful in identifying funding needs and sources of support for specific implementation and education projects.

5.3.2 Monitoring Strategy

5.3.2.1 Data Requirements

Additional monitoring will be required throughout the future phases of this TMDL to better characterize the sources of OM and water quality response to OM reductions in the lower Jordan River. A joint effort will need to be made by all stakeholders to monitor ambient water quality, SOD, source loading of OM, storm event loading, and characteristics of OM that affect DO response in the lower Jordan River.

To better understand CPOM, new study methodologies will be needed to determine the supplies of OM in sediments available for resuspension, the transport and fate of CPOM, and settlement and dissolution rates.

CPOM will be very difficult to measure directly because of the variable nature of its transport – in space, within the water column, and in time, both seasonally and with respect to storm events. A limited number of CPOM measurements have currently been made (Miller 2010b). Further investigations will be needed by DWQ and other stakeholders to quantify both the source loads and the processes that influence OM contributions to SOD (including both CPOM and FPOM). All monitoring efforts undertaken by stakeholders will need to conform to a DWQ-approved Standard Operating Procedure (SOP), or agreed upon process with DWQ to meet the consistency and integrity standards of the TMDL process.

Other measurements of OM, as chlorophyll-a, VSS or TSS, have been monitored on a monthly basis for this TMDL study and may serve as proxy measurements. In spring of 2010, sampling frequency was increased to every 2 weeks for May and June and then every 4 weeks for the rest of the summer. It will be essential to continue measuring these parameters at least monthly for the next several years. Eventually, it may be possible to rely on source-specific correlations between OM – both FPOM and CPOM – and other, simpler measurements, such as TSS.

Water quality is also now being measured at the ends of the following canals where tailwater may return to the Jordan River:

- Utah Lake Distributing Canal
- East Jordan Canal
- Jordan and Salt Lake City Canal
- Jacob-Welby Canal
- South Jordan Canal
- North Jordan Canal

Watersheds throughout the state undergo intensive monitoring by DWQ staff on a 6-year rotation. The previous intensive monitoring cycle for the Jordan River occurred between October 2009 and the end of September 2010. The next intensive monitoring cycle was scheduled to begin in October 2015, but the need to establish usable correlations between OM and other parameters may justify a more concerted effort before that time. Cooperative monitoring on the part of municipalities and other stakeholders will provide additional, critical data to DWQ measurements, particularly from smaller tributaries and stormwater outfalls.

The sites listed in Table 5.2 have been identified for monitoring on a monthly basis. These locations were chosen based on their proximity to DWQ segment breaks, availability of historical water quality data, previously chosen compliance points, and availability of long-term flow records relevant to major inputs into the Jordan River. Continuous flow measurements collected by the USGS, Salt Lake County, and the Upper Jordan River Commissioner have also been identified for some sites.

Table 5.2. Proposed monitoring stations on Jordan River, tributaries, WWTPs, and diversions.				
Station Number	**Station Description**	**Type**	**Compliance Point**	**Continuous Flow**
4990890	Jordan River at Burnham Dam	Mainstem	X	
4991290	Surplus Canal Northwest of Airport	Diversion		
4991810	South Davis South WWTP	WWTP		
4991820	Jordan River at Cudahy Lane above South Davis South WWTP (Use 500 North correlate to Cudahy Lane staff gage)	Mainstem	X	X
4991890	Jordan River at 500 North Crossing – SL Co. Gage	Mainstem		X
4992290	Jordan River at 1700 South above drain outfall – USGS Gage	Mainstem		X
4992320	Jordan River 1100 West and 2100 South – USGS Gage	Mainstem		X
4992480	Mill Creek above confluence with Jordan River – SL Co. Gage	Tributary		
4992500	Central Valley WRF	WWTP		
4992890	Jordan River 3900 – 4100 South Crossing	Mainstem		
4992970	Big Cottonwood Ck. above Jordan River at 500 West 4200 South – SL Co. Gage	Tributary		
4993580	Little Cottonwood Ck. 4900 South 600 West, Salt Lake City – SL Co. Gage	Tributary		
4994090	Jordan River above 5400 South at pedestrian bridge	Mainstem	X	
4994160	South Valley WRF	WWTP		
4994170	Jordan River at 7800 South Crossing above South Valley WWTP	Mainstem	X	
4994270	Jordan River at 9000 South Crossing – SL Co. Gage	Mainstem		X
4994600	Jordan River at Bluffdale Road crossing	Mainstem	X	
4994720	Jordan Narrows at Gaging Station	Mainstem	X	X
4994790	Jordan River at Utah Lake outlet & Utah Hwy 121 crossing	Mainstem		

5.3.2.2 Model Refinement

Models for estimating OM would benefit from paired measurements of TSS and FPOM measured as VSS, taken at more frequent intervals throughout the year. The QUAL2Kw model used to assess the effect of OM and other pollutants on DO used these inputs and relied on numerous assumptions, outlined in Appendix F and in Stantec (2010a). A Monte Carlo sensitivity analysis was applied to the calibrated QUAL2Kw model and indicated that prescribed SOD and bottom algae parameter values account for 84–94 percent of the model variance (Stantec 2011; Appendix E). This suggests that these parameters are very important in determining the model's predictions, so efforts should be made to refine these parameter values through the collection and analysis of additional data.

Salt Lake County is completing work on another water quality model based on the Hydrological Simulation Program - FORTRAN package (HSPF). Where QUAL2Kw is essentially a steady-state model and evaluates water quality only over a 6-day period, the HSPF is a dynamic model capable of assessing water quality over larger spatial and temporal scales. It is particularly useful for evaluating the effects of high and low precipitation over multiple years and the water quality response to nonpoint source pollution control.

5.3.3 Efforts To Improve Water Quality

5.3.3.1 Goals

Implementation efforts in Phase II will focus on actions to increase understanding of OM loading without incurring long-term commitments for capital investment. These actions are referred to as Best Management Practices (BMPs) because they entail operational and behavioral changes rather than major structural improvements. These management efforts will focus on preventing, reducing, and treating water discharges and runoff. Limiting the amount of impervious surface is a prime consideration for reducing runoff and pollutants. Maintaining existing wetland, riparian and vegetated infiltration features will yield additional benefits. The efforts to improve water quality that are presented in Section 5.3.3 are known to reduce pollutant loads of OM and other constituents. They are not currently required by the TMDL but should be considered during Phase II as opportunities are reviewed to reduce pollutant loads.

A large-scale implementation planning effort was conducted by Salt Lake County Watershed Planning and Flood Control in August of 2009 and detailed in the Water Quality Stewardship Plan, or WaQSP (Salt Lake County 2009). In this document, a number of projects were researched and detailed in order to achieve water quality improvements throughout the watershed. The public outreach messages identified in the Implementation Plan from the WaQSP will provide guidance for the phased TMDL process. Some of the implementation strategies identified in the WaQSP that the TMDL will focus on include:

- Identify the audiences.
- Develop the message.
- Identify and implement tools and methods for public outreach, such as:
    - Speaking engagements to public groups (chambers of commerce, service clubs).
    - Websites (DWQ website, Jordan River Watershed Council website, TAC members' websites).
    - Print materials (flyers, brochures, fact sheets).
    - Public interest articles.
    - Newspaper articles and radio interviews.
    - School programs.
    - Informational displays in public places (libraries, post offices, trailheads, water agencies, fairs, community events).

5.3.3.2 Flow Modification

Efforts will continue to understand better how the flow regimes in the lower Jordan River below the Surplus Canal diversion affect sedimentation and SOD. Working with the appropriate local entities, an evaluation of different flow regimes to achieve water quality standards at different times of year during low, medium and high flows will be considered in the next phase. This information will build upon the assessment of DO violations and flow regimes already completed for two locations on the lower Jordan River including 1700 South and Cudahy Lane. Results of this assessment are shown in Appendix D Tables D2 and D3. Computer modeling and additional DO monitoring could provide support to future evaluations. Additionally, exploration into actions that can be taken within the confines of existing water rights will be explored.

5.3.3.3 Point Source – WWTPs

The first step in identifying programmatic changes in WWTP operations is an internal assessment of current practices. WWTP managers have fine-tuned operations to remove OM through biological and physical treatment to meet permit requirements at lowest cost. Management strategies for further reducing OM loads may be available from WWTP operations in other regions of the country.

Consistent with the goal of Phase II, large capital improvements targeting OM load reductions at WWTPs should await additional data on the characterization of OM and the environmental benefits of reducing it. However, OM load reductions should still be a consideration as WWTP facilities plan for other improvements.

5.3.3.4 Point Source – Stormwater

The current network of stormwater catchments and discharge locations is complex. Therefore, an initial goal of Phase II efforts to reduce OM loading from stormwater is a comprehensive inventory of the stormwater system and practices that are currently being used to minimize sediment and OM loading to receiving water bodies. This phase does not propose new means of managing stormwater but recommends a continuation and expansion of existing practices as well as targeting priority areas based on new data. Possible BMPs and structures for controlling OM in the Jordan River watershed are listed in Table 5.3. Some of these structural controls, including retention ponds and flow splitters, are already in use, as are practices such as street sweeping, maintenance of sediment collection structures, and public education.

Table 5.4 lists some BMPs that focus on changes in behavior or practices. Improvements for controlling OM loading through behavioral changes are relatively inexpensive in comparison to costs associated with land purchase and construction. BMPs in Table 5.4 require ongoing public education programs and reviews of municipal operations. However, planning for more capital-intensive structures, such as those that involve the purchase of land or larger construction projects is also appropriate as opportunity and available resources dictate.

Table 5.3 Best management practices for controlling OM from stormwater sources.

Practice or Application	Description and Examples
Retention systems	Ponds or subterranean chambers (e.g., vaults and oversized pipes) designed to eliminate stormwater discharge for some events and reduce peak flows and erosion.
Detention systems	Dry ponds and swales slow stormwater runoff, reducing erosion and soil loss. Detained water is subsequently released or allowed to infiltrate.
Flow control structures	Flow rates or the distribution of storm runoff are controlled through the use of permeable weirs and flow splitters.
Inverted catch basin outlets	Already implemented by Salt Lake County Stormwater Programs, inverted outlets provide low-cost structural solutions to reduce pollutants such as floatables, trash, free oils, and sediment. Other pre-treatment structures reduce bacteria, more effectively capture hydrocarbons, and help with full trash capture.
Infiltration systems	Vegetated basins and trenches, or onsite landscape areas, allow increased infiltration of runoff water and retention. This system is appropriate for retrofitting existing developments.
Constructed wetlands	Creation (using dams or modifying drainages) of wetlands offers a means to retain sediment and dissolved nutrients while providing wildlife habitat and aesthetic value. Wetlands can often be incorporated into community landscape improvement efforts.
Filtration systems	Includes a variety of vegetated (e.g., grassed filter strips), mechanical (e.g., sand filter chambers and underground filter cascades), and landscape design approaches for removing materials from runoff water.
Debris Basins	Specially engineered and constructed basin for storing large amounts of sediment and OM moving in an ephemeral stream channel. Require design by qualified engineers and are most effective in depositional or runout areas that have large storage capacity. Head cutting can result from improperly located or constructed debris basins. Must be designed with large vehicle access to the basins so they can be cleaned out periodically. Maintenance is a key factor in effectiveness of this treatment.

Table 5.4. Runoff pollution prevention BMPs.	
Practice or Application	**Description and Examples**
Impervious surface reduction	Reducing the amount of impervious surface, particularly on driveways and parking areas, promotes infiltration and reduces the volume of stormwater runoff. Other opportunities include infiltration trenches or basins in landscape designs, limiting the use of curbs on streets and driveways, and parking lot designs that include pervious vegetated areas.
Housekeeping	Included are routine removal of street debris (i.e., street sweeping), management of animal wastes, improved landscape maintenance and collection of yard wastes, and structures (e.g., grit chambers, inverted outlets) to retain coarse materials.
Construction practices	Protection of temporarily disturbed surfaces by appropriate grading practices, sequenced construction activities, and vehicle track maintenance (e.g., use of pads of solid or aggregate material).
Soil erosion control	Maintenance of vegetative cover and the use of mulch or geo-textiles to reduce loss of soils and associated nutrients and organic material.
Sediment control	Use of structural barriers (e.g., check dams and berms) and silt curtains to trap and retain suspended material.
Rain gardens	A rain garden is a planted depression that allows rainwater runoff to be absorbed from impervious urban areas such as roofs, driveways, walkways, parking lots, and compacted lawns. This reduces rain runoff by allowing stormwater to soak into the ground instead of flowing into storm drains.

5.3.3.5 Nonpoint Source – Utah Lake

OM loads from Utah Lake are a combination of natural and anthropogenic sources. A study of Total P and TDS to Utah Lake was completed recently (PSOMAS/SWCA 2007) and identified loads from tributaries, springs, WWTPs, and groundwater. WWTPs contributed about 75 percent of the external Total P load to the lake. An assessment of internal nutrient sources related to bottom sediments and their influence on algae growth is currently in progress.

It is not known how much of the OM load from Utah Lake is anthropogenic. The level of effort and methods required to effectively reduce OM loads from Utah Lake is also unknown. Additional studies completed during the next phase of the Jordan River TMDL will help define anthropogenic loads from Utah Lake to the Jordan River. Based on this information, appropriate BMPs and BATs will be identified to reduce OM loads from Utah Lake.

5.3.3.6 Nonpoint Source – Tributaries

The upper reaches of tributaries are a natural source of OM. Downstream of the valley margins, tributaries also transport stormwater, irrigation return flows, and flows to satisfy exchange agreements. BMPs that reduce OM loads (Section 5.3.3.3) in tributaries include minimizing irrigation return flows by only diverting the amount of water needed to meet crop demands. The network of canals and exchange agreements is complex and may benefit from improved water management structures and management strategies that would reduce OM loading.

Where additional structures or repair of existing facilities are contemplated, designs should consider structures such as those in Table 5.3 to retain and settle suspended OM. Significant capital improvements targeting OM reduction should await additional data gathering to ensure efficient use of capital.

5.3.3.7 Nonpoint Source – Diffuse Sources

Programmatic actions to reduce nonpoint diffuse sources of OM are similar to those for stormwater. Ongoing public education efforts are critical to achieve better land management practices that will improve Jordan River water quality.

5.3.3.8 Nonpoint Source – Irrigation Return Flows

Due to the complexity of the Jordan Basin, including diversions and water rights, there may be return flows to the Jordan River at various points along the waterway not accounted for in this analysis. These return flows contain OM loads from both Utah Lake and the Jordan River. Additional data collection should be conducted in the next phase where these sources return to the Jordan River. Additionally, the consumptive demand of diversions should be evaluated to determine if return flows can be reduced while satisfying the beneficial use of those diversions.

The most effective BMP for reducing OM loads from irrigation return flows would be to divert and deliver only those flows that will actually be applied to the land. Conversion from flood to sprinkler irrigation has also been proven to be effective in reducing return flows. Based on historical declines in agricultural land and associated irrigation needs, it is anticipated that water rights downstream of irrigation return flows will not be impacted due to any decrease in irrigation return flows.

Canals also serve as stormwater conveyances, so public education targeted at improving stormwater quality such as discouraging adjacent landowners from dumping yard wastes into the canals are also important.

5.3.3.9 Natural Background – Utah Lake

For the purposes of this first phase of the TMDL, Utah Lake is considered a "natural" source and is not allocated load reductions. However, water quality studies are ongoing in Utah Lake and programs are underway to reduce algae growth and TSS to improve aquatic habitat. These plans should incorporate considerations of OM loading, especially from living algae and detritus, to the upper Jordan River.

Recommendations for capital investment planning that could perhaps reduce OM loading include changing the location of the inlet for the pumps used to provide flows for water rights in the Jordan River and structures to block floating algae from reaching the outlet.

5.3.3.10 Natural Background – Groundwater

Groundwater is not a source of OM.

5.4 PHASE III AND IV IMPLEMENTATION COMPONENTS

Subsequent implementation phases will build on both the refined understanding of OM loading and the effectiveness of BMPs implemented in Phase II. New data will be available within the first 8 years to provide more detailed load allocations. This new data will also better target specific sources of OM. Since structures that reduce, retain, and treat stormwater and runoff from nonpoint sources are less complex and less costly than those for WWTPs, it should be possible to finish designs and begin construction of these facilities during Phase III.

5.5 MECHANICAL RE-OXYGENATION

The ultimate goal of this TMDL is to ensure that the lower Jordan River meets DO water quality standards. An argument can be made that it does not matter how minimum DO concentrations are achieved. Controlling OM at the source may require contributors of point source pollution to incur substantial capital costs and significant changes to attitudes and behavior on the part of a broad citizenry.

Data on the frequency of DO violations is only available at infrequent intervals, but DO does not normally violate minimum standards every day or even every hour during days when violations do occur, even during critical periods. It may be more economical to simply add oxygen to the water only during those times when DO levels approach the minimum water quality standard. A preliminary study has been sponsored by a consortium of WWTPs to investigate technologies that would monitor DO on a continuous basis and introduce oxygen in the lower Jordan River on an as-needed basis. In stream artificial aeration may be a viable solution that will be researched and considered in the next phase of the TMDL, following an evaluation of potential downstream effects through predictive modeling prior to implementing this remediation strategy.

The advantages of such an approach are:

- Avoiding large capital costs.
- Avoiding difficulties of changing attitudes and behavior.
- Less risk and greater assurance in achieving desired water quality response.
- Immediate improvements in DO.

Some of the disadvantages of such an approach are:

- Addressing DO impairment without reducing pollutant loads would allow OM loading to continue unchecked.
- Danger of structural failures during critical hours.
- Difficulty of maintaining automated monitoring equipment throughout the 16 mi of the lower Jordan River.
- More than one DO mixing site may be necessary to remedy DO levels along the three impaired segments.

5.6 SUMMARY

Although calibrated models point directly to OM as the pollutant of concern for DO in the lower Jordan River, there are many and substantial uncertainties. These include the characteristics of OM (sources, transport, composition, and seasonal patterns), the effectiveness of strategies to reduce OM, and the effect of reducing suspended OM loads on DO without first removing the OM that already exists in the sediments of the lower Jordan River.

It therefore seems inadvisable to immediately require sources to dramatically reduce their loads via traditional WLAs and LAs. It makes more sense to acknowledge the *probable* impact of OM on DO, as revealed by water quality models, but strive to gather additional data to strengthen those models and characterize the geographic and temporal patterns of OM before incurring long term commitments to capital improvements.

A phased approach to implementing this TMDL is therefore suggested by this study. Phase I was the identification of OM as the pollutant of concern and included the development of models to calculate loading from various sources, both point and nonpoint. These models benefitted from frequent review and refinements suggested by the TAC, the Scientific Review Committee, and others, and allowed for the estimation of load reductions necessary to achieve the desired DO target, especially during the critical period.

A phased TMDL does not mean “no action,” however. Phase II prescribes intense and targeted data collection, as well as implementation of remedies that require little more than behavioral and procedural changes on the parts of both individual citizens and facilities. These should yield real water quality improvements even though concerted design and construction efforts are postponed until a better understanding of the problem is achieved. This approach prevents capital from being committed until Phase III, final design, and Phase IV (including major construction, if necessary), can take advantage of better targeting.

In the end, both point and nonpoint sources will need to share the responsibility of reducing OM loads to achieve the DO standards, but there are a variety of practices that may prove effective. While these investigations continue, it may also be worthwhile considering mechanical reaeration to achieve DO standards in the short term, even as the problem is being understood better. Coordination and cooperation will be essential to ensure both cost-effective and environmentally-effective results.

REFERENCES

Arnow, T. 1965. Utah State Engineer, Water Circular No. 1, Ground Water in the Jordan Valley, Salt Lake County, Utah.

Arnow, T. and D. Stephens. 1990. Hydrologic Characteristics of the Great Salt Lake, Utah: 1847–1986. U.S. Geological Survey Water Supply Paper 2332.

Baker, M. 2010a. Summary and Interpretation of 2009 Jordan River Chlorophyll Bioassay Results. Utah State University. Logan, Utah.

Baker, M. 2010b. Adjunct Assistant Professor (Aquatic Ecology), Watershed Sciences Department, College of Natural Resources, Utah State University, Logan, Utah. Personal communication with B. Dixon (Environmental Scientist) Cirrus Ecological Solutions re. 2010 nutrient amendment research on the Jordan River.

Best-Wong, B. 2006. Clarification Regarding “Phased” Total Maximum Daily Loads. Memorandum from Benita Best-Wong, Supervisor Assessment and Watershed Protection Division to Water Division Directors, Regions 1–10. United States Environmental Protection Agency. August 2, 2006.

BioWest, Inc. 1987. Fishery and macroinvertebrate studies of the Jordan River in Salt Lake County. Submitted to the Central Valley Water Reclamation Facility Board.

Borup, B. and N. Haws. 1999. Jordan River Flow Analysis. Civil and Environmental Engineering Department, Brigham Young University, Provo, Utah. Prepared for the State of Utah, Department of Environmental Quality, Division of Water Quality.

Bowen Collins. 2003. 2002 Southwest Canal and Creek Study. Volume 1 of 2. Prepared for Salt Lake County Engineering Division. Prepared by Bowen Collins and Associates Inc. 756 East 12200 South, Draper, Utah. April 2003.

Bowen Collins. 2007. Major Conveyance Study Report. Prepared for Salt Lake City Department of Public Utilities. Prepared by Bowen Collins and Associates Inc. 756 East 12200 South, Draper, Utah.

Brown, L.C. and Barnwell, T.O. 1987. The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS, EPA/600/3-87-007, U.S. Environmental Protection Agency, Athens, GA.

Brown and Caldwell. 2006. Draft technical memorandum No. 1. Salt Lake County Water Quality Stewardship Plan Wastewater Element.

Centerville City. 2007. Summary of South Davis South Wastewater Treatment Plant. South Davis Sewer District. Public Works Department, Centerville City, Centerville, UT. See <http://www.centervilleut.net/publicworks.southdavissewer.html> Accessed June 2008.

CH2M Hill. 1992. Jordan River Stability Study. Submitted to Salt Lake County by CH2M Hill, December 1992.

CH2M Hill. 2005. Jordan River Return Flow Study. Recycled Water Coalition.

Chapra, S.C. 1997. Surface Water-Quality Modeling. McGraw-Hill Publishers.

Chapra, S.C. and G.J. Pelletier. 2003. QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality (Beta Version): Documentation and Users Manual. Civil and Environmental Engineering Dept., Tufts University, Medford, MA.Churchill, M.A., Elmore, H.L., and Buckingham, R.A. 1962. The prediction of stream reaeration rates. J. Sanit. Engrg. Div., ASCE, 88{4),1–46.

Chapra, S. and G. Pelletier. 2008. QUAL2Kw theory and documentation (version 5.1) A modeling framework for simulating river and stream water quality. Environmental Assessment Program, Washington State University, Olympia, WA.

Chapra, S. 2010. Personal communication during meetings July 15–16, 2010 to review QUAL2Kw model calibration. Salt Lake City, UT.

Cirrus (Cirrus Ecological Solutions, LC). 2007. Lower Jordan River TMDL: Work Element 1 – Evaluation of Existing Information. Cirrus Ecological Solutions, LC, Logan, Utah.

Cirrus. 2009a. Jordan River TMDL DO Linkage Symposium April 20, 2009 – A Synopsis. Prepared by Cirrus Ecological Solutions, LC and Stantec Consulting, Inc. for Utah Division of Water Quality. June 22, 2009.

Cirrus. 2009b. Jordan River TMDL: Public Draft Work Element 2 – Pollutant Identification and Loading. Prepared by Cirrus Ecological Solutions, LC and Stantec Consulting, Inc. for Utah Division of Water Quality. January 2009.

Cirrus. 2010a. Jordan River TMDL Phase II Technical Memo: Critical Conditions, Endpoints, and Permissible Loads in the Jordan River. Cirrus Ecological Solutions, LC, Logan, Utah.

Cirrus. 2010b. Jordan River TMDL Phase II: Technical Memo: Future Loads and TMDL Compliance Points. Cirrus Ecological Solutions, LC, Logan, Utah.

Cirrus. 2010c. Technical Memoranda: Updated Current Pollutant Source Characterization, Projected Future Pollutants – No Action, Critical Conditions, Endpoints, and Permissible Loads, A Proportional Load Allocation. Prepared by Cirrus Ecological Solutions, LC and Stantec Consulting, Inc. for Utah Division of Water Quality. June 30, 2010.

Cirrus. 2010d. Jordan River TMDL Phase II: Update to Linkage Analysis Related to Dissolved Oxygen in the Lower Jordan River. Logan, Utah. Prepared by Cirrus Ecological Solutions, LC and Stantec Consulting, Inc. for Utah Division of Water Quality. April 20, 2010.

Coon (Coon, King, and Knowlton Engineers). 1982. Salt Lake County Area-Wide Water Study. Metropolitan Water District of Salt Lake City, Salt Lake County Water Conservancy District, Salt Lake City Corporation. Prepared by Coon, King and Knowlton Engineers; Eckhoff, Watson, and Preator Engineering; Horrocks and Corollo Engineers; James M. Montgomery Consulting Engineers; and Utah Division of Water Resources.

Dickson, S. 2010. Laboratory Scientist, Utah Environmental Health Laboratory. Personal communication with E. Duffin Watershed Scientist, Cirrus Ecological Solutions LC, Logan, Utah, re. measurement protocol for Total Suspended Solids and Volatile Suspended Solids.

Dodds, W.K., J.R. Jones, and E.B. Welch. 1998. Suggested Classification of Stream Trophic State: Distributions of Temperate Stream Types by Chlorophyll, Total Nitrogen and Phosphorus. Water Resources (32) 5:1455–1462.

Doyle, C. D. and D. D. Lynch. 2003. Sediment oxygen demand in Lake Ewauna and the Klamath River, Oregon, June 2003: U.S. Geological Survey Scientific Investigations Report 2005-5228, 14 p.

Dupont, R. 2010. Professor, Department of Civil and Environmental Engineering; Head, Division of Environmental Engineering, Utah Water Research Laboratory, Utah State University. Personal communication with E. Duffin Watershed Scientist, Cirrus Ecological Solutions LC, Logan, Utah, re. nitrification rates of Jordan River water.

EPA (United States Environmental Protection Agency). 1991. Guidance for Water Quality Based Decisions: The TMDL Process. Assessment and Watershed Protection Division, U.S. Environmental Protection Agency, Washington, D.C. 20460.

EPA. 1999. Protocol for Developing Nutrient TMDLs, First Edition. Office of Water. EPA-841-B-99-007.

EPA. 2000. Nutrient Criteria Technical Guidance Manual Rivers and Streams, Office of Water, EPA-822-B-00-002.

EPA. 2006. Guidance Clarification Regarding "Phased" Total Maximum Daily Loads. Memorandum to Water Division Directors Regions I-X, August 2, 2006. Available from http://www.epa.gov/OWOW/tmdl/decisions/http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/tmdl_clarification_letter.cfm

EPA. 2009. Empirical Approaches for Nutrient Criteria Derivation (Draft). Prepared by: United States Environmental Protection Agency, Office of Water, Office of Science and Technology Science Advisory Board Review. August 17, 2009.

Goel, R. and M. Hogsett. 2009. Interim Status Report [on Sediment Oxidation Demand and Reaeration]. University of Utah. Salt Lake City, Utah.

Goel, R. and M. Hogsett. 2010. SOD, nutrient fluxes, sediment mineralogy and reaeration in the Jordan River. presentation at 4th Salt Lake Countywide Watershed Symposium. University of Utah.

GOPB (Governors Office of Planning and Budget). 2008. 2008 Baseline City Population Projections 2000–2060. Data available at: http://www.governor.state.ut.us/dea/popprojections.html.

Hansen, D. 2005. Appendix K Groundwater Memo. Jordan River Return Flow Study. Memo to B. Luce (Hansen Allen, & Luce Inc.) regarding Jordan River Return Flows Study – Groundwater.

Hely, A.G., R.W. Mower, and C.A. Harr. 1971. Water Resources of Salt Lake County, Utah. With a section on geologic setting by Ted Arnow. Prepared by the U.S. Geological Survey in cooperation with the Utah Department of Natural Resources Division of Water Rights. State of Utah Department of Natural Resources Technical Publication 31.

Hickey, K., M. Greenblatt, D. Galya, and R. Isaac. 2002. National TMDL Science and Policy, Proceedings of the Water Environment Federation. pp. 357-366(10) .

Holdsworth, I.K. 1985. A preliminary groundwater flow and solute transport model along Bingham Creek in western Salt Lake County, Utah. Utah State University Master's Thesis.

Hooten, L. Undated. Utah Lake & Jordan River: Water Rights and Management Plan. Salt Lake City Department of Public Utilities, Salt Lake City, UT. See http://www.recreation.slco.org/planning/PDFdocs/JRT_Master_Plan.pdf. Accessed December 2008.

Howell, T. 2003. Irrigation Efficiency. United States Department of Agriculture (USDA), Bushland, Texas, USA. Encyclopedia of Water Science. DOI: 10.1081/E-EWS 120010252. Marcel Dekker, Inc.

JE Fuller (J.E. Fuller Hydrology and Geomorphology Inc.). 2007. Jordan River Corridor Preservation Study. Prepared for City of Saratoga Springs. Prepared by J.E. Fuller Hydrology and Geomorphology Inc. and CH2MHill. March 2007.

JVWCD (Jordan Valley Water Conservancy District). 2010. Southwest Jordan Valley Groundwater Project. See http://www.jvwcd.org/swjvgp/default.aspx Accessed October 2010.

Lambert, P.M. 1995. Numerical Simulation of Ground-Water Flow in Basin-Fill Material in Salt Lake Valley, Utah. Technical Publication No. 110-B. Unites States Geological Survey, Utah Department of Natural Resources Division of Water Rights, and the Utah Department of Environmental Quality Division of Water Quality.

Larsen, J. 2009. Annual Report for Utah Lake and Jordan River Distribution System for Year 2009. Submitted to Kent L. Jones, State Engineer by Utah Lake and Jordan River Distribution System.

Larsen, J. 2010a. Gate Opening and Pump Use History at Pump Station at Utah Lake 2000–2010. Data provided to Utah DWQ by John Larsen, Jordan River Commissioner.

Larsen, J. 2010b. Upper Jordan River Commissioner. Personal communication with E. Duffin, Watershed Scientist, Cirrus Ecological Solutions LC, Logan, Utah, re. design and operation of gates at outlet to Utah Lake. November 1, 2010.

Law, J. 1971. National Irrigation Return Flow Research and Development Program. Environmental Protection Agency, Washington, D.C.

Miller, T. 2010a. Data set collected by T. Miller including measurements of BOD-5, CBOD-5, NH_3-N, NO_2-N, NO_3-N, o-PO_4, PO_4, TKN, TSS, and VSS taken from the Jordan River and its tributaries during 2009–2010.

Miller, T. 2010b. Research scientist, Jordan River/Farmington Bay Water Quality Council. Personal communication with E. Duffin (Watershed Scientist) Cirrus Ecological Solutions, LC, B. Dixon (Environmental Scientist) Cirrus Ecological Solutions, LC, and H. Arens (Environmental Scientist) Utah Division of Water Quality, re. Organic Matter data collection efforts for the Jordan River. August 5, 2010.

Pelletier, Greg. 2009. YASAI.xla – A modified version of an open-source add-in for Excel to provide additional functions for Monte Carlo simulation. Washington Department of Ecology. http://www.ecy.wa.gov/programs/eap/models.html.

PSOMAS/SWCA. 2007. Utah Lake TMDL: Pollutant Loading Assessment and Designated Beneficial Use Impairment Assessment. Final Draft. Prepared for State of Utah Division of Water Quality.

Richardson, G.B. 1906. Underground Water in the Valleys of Utah Lake and Jordan River, Utah. U.S. Geological Survey. Water-Supply and Irrigation Paper No. 157.

Rounds, S. A. and M. C. Doyle. 1997. Sediment Oxygen Demand in the Tualatin River Basin, Oregon, 1992-96, U.S. Geological Survey, Water-Resources Investigations Report 97-4103.

Rushforth, S. R. and S.J. Rushforth. 2009a. Assessment of the Periphyton Communities of the Jordan River; July – October 2009. Utah Valley University. Orem, Utah.

Rushforth, S. R. and S.J. Rushforth. 2009b. Assessment of the Phytoplankton Floras of the Jordan River; July – October 2009. Utah Valley University. Orem, Utah.

Rushforth, S.R. and S.J. Rushforth. 2010. Diatom Analysis of 2009 Jordan River Bottom Sediment Samples. Rushforth Phycology, LLC. May 13, 2010.

Salt Lake County. 1978. Area-Wide Water Quality Management Plan. Salt Lake County Council of Governments 208 Water Quality Plan. Salt Lake County Council of Governments, Salt Lake County Public Works Water Quality and Water Pollution Control.

Salt Lake County. 2006. 2005 Stormwater Quality Data Technical Report. Department of Public Works. Salt Lake City, Utah. Salt Lake County Division of Engineering and Flood Control.

Salt Lake County. 2009. Salt Lake Countywide Water Quality Stewardship Plan. Prepared for Salt Lake County, Division of Engineering and Flood Control, Salt Lake City, UT. Prepared by Stantec Consulting, Brown and Caldwell, Cirrus Ecological Solutions, Dan Jones and Associates, Sullivan's Solutions, URS, and Wikstrom Economic and Planning Consultants.

Salt Lake County. 2010. Salt Lake County, Utah – Code of Ordinances Title 19 – Zoning Chapter 19.72 – Foothills and Canyons Overlay Zone. Municipal Code – Salt Lake County, Utah. Codified through ordinance no. 1683, passed August 31, 2010 (Supp. No. 19, Update 1). Downloaded on October 20, 2010 from http://library.municode.com/index.aspx?clientId=16602&stateId=44&stateName=Utah.

Saltelli, A. 1999. Scheme for Sensitivity Analysis, http://en.wikipedia.org/wiki/Sensitivity_analysis

Shabman, L., K. Reckhow, M.B. Beck, J. Benaman, S. Chapra, P. Freedman, M. Nellor, J. Rudek, D. Schwer, T. Stiles, and C. Stow. 2007. Adaptive Implementation of Water Quality Improvement Plans: Opportunities and Challenges. Nicholas School of the Environment and Earth Sciences, Nicholas Institute, Duke University. Available from http://www.tmdls.net/docs/AIPaperFinal9-07.pdf.

Stantec (Stantec Consulting, Inc.). 2006a. DRAFT Lower Jordan River TMDL: Work Element 4 – Flow and Water Quality Modeling Report, Prepared for: Utah State Division of Water Quality, Department of Environmental Quality.

Stantec. 2006b. 2005 Stormwater Quality Data Technical Report – Salt Lake County, Utah. Salt Lake County Engineering Division, Salt Lake City Engineering, Utah Department of Transportation-Division 2.

Stantec. 2010a. Jordan River TMDL: 2010 QUAL2Kw Model Calibration Technical Memo Public Draft, Prepared for: Utah State Division of Water Quality, Department of Environmental Quality. February 22, 2010. 18 pp.

Stantec. 2010b. Jordan River In-Stream Bank Erosion Calculations. Technical Memorandum prepared for Utah Division of Water Quality, Department of Environmental Quality. November 12, 2010. 10 pp.

Stantec. 2011. Jordan River QUAL2Kw Uncertainty Analysis. Technical Memorandum prepared for Utah Division of Water Quality, Department of Environmental Quality. January 27, 2011. 15 pp.

Taylor, G.H. and R.M. Legette. 1949. Ground Water in the Jordan Valley, Utah. U.S. Geological Survey. Prepared in cooperation with Salt Lake City. Geological Survey Water-Supply Paper 1029.

UAC (Utah Administrative Code). 2010. Table 2.14.2 Numeric Criteria for Aquatic Wildlife and Table 2.14.5 Specific Criteria for Dissolved Oxygen for Jordan River, Surplus Canal, and State Canal. Rule R317-2-14 Standards of Quality for Waters of the State Numeric Criteria. As in effect September 1, 2010.

Utah DWQ (Utah Division of Water Quality). Undated. Utah Clean Lakes Study. Prepared by H. Judd, Environmental Scientist, Utah Division of Water Quality.

Utah DWQ. 1994. Utah Lake Clean Lakes Study. Utah Division of Water Quality Department of Environmental Quality.

Utah DWQ. 2008a. Utah 2008 Integrated Report – Part III Utah 2008 Integrated Report 303(d) List. Utah Division of Water Quality, Utah Department of Environmental Quality. May 2008.

Utah DWQ. 2008b. Chapter 2.15 Biological Beneficial Use Support Assessment Procedure. Utah 2008 Integrated Report – Part II 305 (b) Assessment. Utah Division of Water Quality, Utah Department of Environmental Quality. May 2008.

Utah DWQ. 2008c. Part 1 – Water Quality Assessment Guidance. Utah Division of Water Quality, Utah Department of Environmental Quality. May 2008.

Utah DWQ. 2010. Jordan River TMDL QUAL2Kw model refinement. Prepared by N. Von Stackelberg P.E., Environmental Scientist, Water Quality Management Section, Engineering and Water Quality Branch, Utah Division of Water Quality, Utah Department of Environmental Quality.

Utah DWRi (Utah Division of Water Rights). 1992. Utah Lake and Jordan River Operating Procedures and Flood Management Plan. Utah Division of Water Rights, Utah Department of Natural Resources.

Utah DWRe (Utah Division of Water Resources) 1997. Utah State Water Plan for the Jordan River Basin. State of Utah Department of Natural Resources, Division of Water Resources, Salt Lake City, UT.

Utah DWRe. 2010. Jordan River Basin Planning for the Future. State of Utah Department of Natural Resources, Division of Water Resources, Salt Lake City, UT.

United States District Court. 2005. United States District Court ruling in Minnesota Center for Environmental Advocacy v. EPA. No. 03-5450, 2005 WL 1490331. D. Minn. June 23, 2005.

USFS (United States Forest Service). 2003. Wasatch-Cache National Forest Revised Plan. USFS Wasatch-Cache National Forest. Salt Lake City, Utah, United States Department of Agriculture.

Zhang, H. X. and S. L. Yu. 2006. Defining the critical condition in the TMDL development process: continuous, statistical or event-based approach, *Water Environment & Technology* , 2334–2349.

APPENDICES

Appendix A. Acronyms and Abbreviations used in the Jordan River TMDL Analyses
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APPENDIX A. ACRONYMS AND ABBREVIATIONS USED IN THE JORDAN RIVER TMDL ANALYSES

ac-ft	acre-feet
atm	atmosphere
BOD	Biochemical Oxygen Demand (5-day at 25°C)
BUA	Beneficial Use Assessment
cBOD	carbonaceous Biochemical Oxygen Demand
cfs	cubic feet per second
CH_4	Methane
CO_2	Carbon Dioxide
CUWCD	Central Utah Water Conservancy District
CVWRF	Central Valley Water Reclamation Facility
DEQ	Utah Department of Environmental Quality
Dissolved P	Dissolved Phosphorus
DMR	Discharge Monitoring Report
DO	Dissolved Oxygen
DWQ	Utah Division of Water Quality
DWR	Utah Division of Water Resources
DWRi	Utah Division of Water Rights
EC_e	Electrical Conductivity of the extract
E. coli	Escherichia coliform
EMC	Event Mean Concentration
EPA	Environmental Protection Agency
ft	feet
ISS	Inorganic suspended solids
JVWCD	Jordan Valley Water Conservancy District
KUCC	Kennecott Utah Copper Corporation
L	liter
LDCs	Load duration curves
mg	milligram
mgd	million gallons per day
mi^2	square miles
MOS	Margin of Safety
MWDSLS	Metropolitan Water District of Salt Lake and Sandy
nBOD	Nitrogenous biochemical oxygen demand
NH_4-N	Ammonia Nitrogen
NO_3	Nitrate
NO_2	Nitrite
NO_3-N	Nitrate nitrogen
NO_2-N	Nitrite nitrogen
OM	Organic Matter
RIVPACS	River Invertebrate Prediction and Classification System
ScBOD	Soluble carbonaceous biochemical oxygen demand
SDWTP	South Davis South Wastewater Treatment Plant
SLCWRP	Salt Lake City Water Reclamation Plant
SVWRF	South Valley Water Reclamation Facility
TDS	Total dissolved solids
TMDL	Total Maximum Daily Load
Total P	Total phosphorus
TOC	Total organic carbon
TSS	Total suspended solids
UDOT	Utah Department of Transportation
UPDES	Utah Pollutant Discharge Elimination System
USBOR	United States Bureau of Reclamation
USDOI	United States Department of the Interior
Utah Lake System	Utah Lake Drainage Basin Water Delivery System
VSS	Volatile suspended solids
WWTPs	Waste water treatment plants
yr	year

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APPENDIX B. ANNOTATED BIBLIOGRAPHY

This appendix includes an annotated bibliography of select publications that were produced during the Jordan River TMDL process (Table B.1). It is not an exhaustive list but does include the final version of reports that define individual portions of the TMDL. Detailed descriptions of methods and results can be found in each document. All documents are the result of several rounds of administrative and stakeholder review and have been updated to include responses to these comments where applicable. Most documents have been available to the public on DWQs website and all documents can be provided upon request.

Table B.1. Annotated bibliography of selected documents produced during the Jordan River TMDL process 2005-2011.		
Date	**Citation**	**Description**
August 2005	Lower Jordan River 2005 Water Quality and Flow Model	Potential water quality and hydraulic flow models were evaluated for use on the lower Jordan River TMDL. The selected models should be able to run multiple pollutant discharge and flow scenarios from the outlet of Utah Lake to its terminus.
June 2006	Lower Jordan River TMDL: Work Element 1 – Evaluation of Existing Information.	The purpose of this document is to provide a review of the available information necessary to support a defensible TMDL for the Lower Jordan River including segment 1 (Farmington Bay to Davis County boundary) and segment 2 (Davis County boundary to North Temple).
July 2006	Work Element 4 – Flow and Water Quality Modeling Report	A hydraulic flow and a water quality model were developed of the Jordan River from Utah Lake to Farmington Bay in order to provide a decision support tool and support waste load allocations as part of future phases of the TMDL process. The purpose of this document is to describe the selection, creation and calibration of the models.
July 2006	Work Element 4 – Flow and Water Quality Modeling Report Volume 2: Technical Appendices	Technical appendices to modeling report including: • Appendix A: Model Selection Memorandum • Appendix B: Jordan River Hydrology Memorandum • Appendix C: Stormwater Memorandum • Appendix D: Dissolved Oxygen Interactions in QUAL2K • Appendix E: HEC-RAS Model Input • Appendix F: HEC-RAS Model Output • Appendix G: QUAL2K Model Calibration Input and Output • Appendix H: QUAL2K Model Validation Input and Output
March 2007	Jordan River TMDL: Work Element 1 – Evaluation of Existing Information	The purpose of this report is to document the process of acquiring, compiling, reviewing, evaluating, and summarizing the existing information necessary to support a defensible Total Maximum Daily Load (TMDL) Water Quality Study addressing impaired segments of the Jordan River. It includes an evaluation of available flow, water quality, and biological data that could be used to support a TMDL for impaired Jordan River segments included on the 2004 303(d) list.
April 2007	Jordan River TMDL – Utah Lake Sensitivity Analysis	The purpose of this technical memorandum is to summarize the methodology and results of an evaluation of the effect of Utah Lake on the water quality in the Jordan River. The previously developed QUAL2K model of the Jordan River was used for this analysis.

Table B.1 (cont'd). Annotated bibliography of selected documents produced during the Jordan River TMDL process 2005-2011.		
Date	**Citation**	**Description**
September 2008	Jordan River TMDL: QUAL2K Model Parameter Sensitivity Analysis Report	This report presents the methodology and results of the sensitivity analysis and verification conducted on selected parameters in the QUAL2K model. The objective of the analysis is to improve the understanding of the relative importance and significance of selected model parameters. The results of the sensitivity analysis will help identify data collection needs, as well as improve the efficiency and accuracy of the model calibration effort.
June 2009	Jordan River TMDL DO Linkage Symposium April 20, 2009 – A Synopsis	To help build a consensus on this vital component (DO linkage) of the Jordan River TMDL process, the Division of Water Quality (DWQ) convened a symposium of agency personnel, scientists, and key stakeholders to review the conclusions of the linkage analysis provided in the Work Element 2 report and recommend additional data that would help clarify questions regarding these water processes. This report describes the symposium (Section 1), provides an overview of the linkage analysis (Section 2), describes in detail the discussion associated with each process (Sections 3 – 6), and outlines issues and data collection needs to address in furthering our understanding of the four processes and their interactions. It focuses on the discussion that occurred on the four processes, the interactions among them, and the identified information needs.
July 2009	Jordan River TMDL: Work Element 2 – Pollutant Identification and Loading	The purpose of this report is to set the stage for the next steps in the Jordan River TMDL process by analyzing and documenting key variables and processes influencing water quality in the target watershed. The intent of the Work Element 2 report is to characterize pollutant sources and processes that influence water quality in the Jordan River watershed. The principal components of the report are a water budget, pollutant source characterization, linkage analysis, and beneficial use impairment assessment. It incorporates the detailed water quality, flow, and biological data sets included in the Work Element 1 report (Cirrus 2007) as well as information and analysis from other supporting sources. The full report includes 10 appendices with detailed information that support results provided in the main body of the report.
February 2010	Jordan River TMDL: 2010 QUAL2Kw Model Calibration Technical Memo	The purpose of this technical memorandum is to summarize the calibration of the QUAL2Kw model of the Jordan River. The original 2006 QUAL2K model calibration and validation was determined to be insufficient due to a complete lack of or limited observed data, including reaeration, shading, nutrient speciation, free floating and fixed algae, and sediment oxygen demand. Subsequently, a three-year intensive data gathering effort was undertaken in order to better understand the causes of the DO impairment in the lower Jordan River and to collect additional data for the model calibration. The full report includes three appendices: Appendix A: Model Input, Appendix B: Collaborative Calibration, and Appendix C: Model Output.
February 2010	Jordan River TDML QUAL2Kw Model Validation	The purpose of this memorandum is to summarize the methodology and results of a validation run for a calibrated QUAL2Kw model of the Jordan River. The model calibration was performed by Stantec Consulting and is summarized in a separate technical memorandum.

Table B.1 (cont'd). Annotated bibliography of selected documents produced during the Jordan River TMDL process 2005-2011.		
Date	**Citation**	**Description**
June 2010	Jordan River TMDL Phase II Technical Memoranda: Updated Current Pollutant Source Characterization, Projected Future Pollutants – No Action, Critical Conditions, Endpoints, and Permissible Loads - A Proportional Load Allocation	This primary purpose of this report is to combine all findings from recent technical memos into one document. Each chapter reproduces sections from the final versions of those documents. It does not attempt to revisit the detailed analyses conducted during this TMDL process. As a result, VSS and similar metrics of organic matter have not been added to the chapters on existing and future loads. Instead, the most recent data on this pollutant of concern for DO has been added to the chapter on proportional load allocations. The final chapter offers a map for releasing a final TMDL in spring 2011 and beginning implementation of load reductions to achieve DO standards.
June 2010	Jordan River TMDL Responses to Comments on Recent Technical Memoranda.	This document responds to comments received through May 19, 2010 by the Jordan River TMDL Technical Advisory Committee to the following technical memos: • Jordan River TMDL Phase II: DRAFT Technical Memo: Updated Pollutant Source Characterization. • Jordan River TMDL Phase II: DRAFT Technical Memo: Future Loads and TMDL Compliance Points. • Jordan River TMDL Phase II: DRAFT Technical Memo: Update to Linkage Analysis Related to Dissolved Oxygen in the Lower Jordan River, January 13, 2010 • Jordan River TMDL Phase II: DRAFT Technical Memo: Critical Conditions, Endpoints, and Permissible Loads in the Jordan River. • Jordan River TMDL Phase II: DRAFT Technical Memo: Load Allocations for Pollutant Sources Contributing to Impairment of Dissolved Oxygen in the Jordan.
January 2011	Jordan River QUAL2Kw Uncertainty Analysis	The purpose of this technical memorandum is to summarize the results of an uncertainty analysis of 47 parameters/inputs of the QUAL2Kw model of the Jordan River and explain the implications for the TMDL study. This memorandum documents the uncertainty analysis results of the mean and minimum dissolved oxygen levels at three locations along the Jordan River. The purpose of the uncertainty analysis is to: provide a level of confidence in use of the model as a decision support tool, identify sensitivity of individual parameters/inputs to overall uncertainty in the model and its use as an assessment tool for the load allocation phase of the TMDL. It will also aid in the selection of an appropriate factor of safety for TMDL determination.

APPENDIX C. JORDAN RIVER WATER BUDGET

A detailed description of all flow sources and the methods used to define the Jordan River water budget are presented below. These details are excerpts from an earlier water budget published in 2009 (Cirrus 2009b). This discussion contains sufficient information to provide the reader with critical details of seasonal and longer term flow patterns that subsequently influence pollutant loading to the lower Jordan River. Supporting data that support the results of the Jordan River water budget are available electronically in database or spreadsheet formats, and will be provided to stakeholders upon request. The full citation of documents referenced in Appendix C can be found in the references section of the main report.

C.1 FLOW SOURCES

The Jordan River is a highly managed riverine system due to regulation of discharge from Utah Lake, tributary flows, irrigation diversions, and flood control practices. Numerous studies of inflows and outflows to the Jordan River watershed have previously been completed to address interactions between these water resource categories (Coon 1982, Utah DWRe 1997, Borup and Haws 1999, CH2M Hill 2005). Results of these studies have varied due to the period of assessment, project objectives, and methods used to define water budget components. A separate assessment of inflows and outflows was completed for the Jordan River to more precisely meet needs of the TMDL (Cirrus 2009b).

Following a review of published literature, discussions with stakeholders, and an assessment of available flow monitoring data, the following sources of flow to the Jordan River were identified:

- Utah Lake – the existing outlet from the lake is the original surface water source for the Jordan River.
- Tributaries – gaged and ungaged.
- Permitted Discharge – effluent from wastewater treatment plants.
- Stormwater – surface runoff from collection systems that discharge via direct outfalls or larger storm drains and tributaries that receive stormwater and eventually enter the Jordan River.
- Diffuse Runoff – surface runoff outside of stormwater catchments that contributes sheet flows into the Jordan River.
- Irrigation Diversions and Return Flows – flows diverted to irrigation canals and the return of unused irrigation water discharging from canals to the Jordan River directly.
- Groundwater.

C.1.1 UTAH LAKE

Utah Lake is located in northern Utah County and is one of the largest freshwater lakes in the western United States. The lake covers approximately 145 mi^2 yet contains only 1 million ac-ft of water due to a shallow average depth of 9–10 feet (Utah DWQ 1994). Utah Lake is the origin of the Jordan River and the single largest contributor of flow. Discharge to the Jordan River accounts for approximately 51 percent of outflow from the lake (PSOMAS/SWCA 2007). The remaining outflow is partitioned between evaporation (42 percent) and groundwater seepage (7 percent).

Utah Lake discharge to the Jordan River is managed according to downstream water rights and guidelines in the *Utah Lake and Jordan River Operating Procedures and Flood Management Plan* (Utah DWRi 1992). This plan limits Jordan River flows to less than 3,400 cfs at the 2100 South diversion and defines a maximum lake elevation of 4,489 feet above sea level. Gates controlling the lake outlet are typically closed after the irrigation season and remain closed until sufficient storage is accumulated in the lake to meet downstream water rights for the following year. When needed, lake storage is decreased by releasing flows to the Jordan River prior to spring snowmelt to accommodate predicted tributary contributions during the runoff season (Hooton undated). During dry years, the lake is pumped to move water into the Jordan River. A review of historical records during the recent past (2000–2010) indicates the gates were opened February–April and during 2003–2004 remained closed throughout the year (Larsen 2010a). Pumping from the lake occurred during 7 years, beginning as early as April.

No direct measurements of discharge from the outlet of Utah Lake have been identified for recent years although monthly outflow estimates are published each year in the Jordan River Commissioners' annual report (Larsen 2009). The nearest flow monitoring station is 9.4 miles downstream of the lake outlet at Turner Dam. Discharge from the lake was estimated using Jordan River flow measurements at Turner Dam, adding inflow contributions between Utah Lake and the dam (e.g. stormwater discharge, diffuse runoff, and groundwater) and then deducting the amount of water diverted to canals.

C.1.2 TRIBUTARIES

A total of seven perennial tributary streams contribute flow to the Jordan River, all of which are located on the east side of the watershed (Figure 1.3). The remaining nine tributary streams are considered to be intermittent (Coon 1982). However, stormwater flow and groundwater accretion result in perennial flow in some segments of these streams (Cirrus 2009b). Similar to other montane watersheds in Utah, snowmelt and spring runoff during the months of March–June make significant seasonal contributions to all Jordan River tributary streams. The difference in natural tributary flow patterns between perennial and intermittent tributaries is primarily due to the size of contributing watershed areas, elevation, and annual snow accumulation.

Tributaries to the Jordan River have been significantly affected by urban development. Substantial amounts of flow are diverted from tributaries between the valley margin and the Jordan River for all streams that enter the Salt Lake Valley. A detailed description of diversions and other structures that influence flows in major tributaries between the canyon mouths and Jordan River is provided in the *Salt Lake County Area Wide Water Study* (Coon 1982) and more recently in the *Salt Lake County Water Quality Stewardship Plan* (Salt Lake County 2009).

High quality water is diverted at the valley edge from perennial stream channels for culinary use and replaced with lower quality water from Utah Lake according to water rights exchange agreements. These exchange flows are delivered to the canal providing water to irrigation share holders and not to the stream itself. As a result, portions of the Big Cottonwood and Little Cottonwood Creek stream channels are dewatered entirely during some or all of the year, and flows are decreased in other perennial streams as well (Salt Lake County 2009). In 1995, more than 50 percent of the Salt Lake City culinary water supply was based on exchange agreements (Hooton undated). Four of the seven perennial streams are routed through dense urban centers in the North Temple conduit (City Creek) and 1300 South conduit (Red Butte Creek, Emigration Creek, and Parleys Creek). Recent developments to downtown Salt Lake City have exposed City Creek for a short segment before returning to the North Temple conduit.

All natural flows are diverted from most intermittent channels during the months of April–October for irrigation purposes (Coon 1982). The lower segments of intermittent channels maintain some flow due to groundwater accretion and stormwater. Flow from the upper Bingham Creek watershed is entirely diverted by the Kennecott Utah Copper Corporation (KUCC) and used for dust suppression and other operational needs (Salt Lake County 2009).

Flow in most perennial streams has been measured continuously by stream gages over a period of several decades and provided the basis for monthly and annual flow values. Total flow in intermittent streams is defined in this report as the sum of natural flow estimates (Coon 1982) and calculations of stormwater discharge (Cirrus 2009b). Salt Lake County has installed continuous flow gages on several intermittent tributaries on the east and west side that will support future efforts to define tributary flows.

C.1.3 Wastewater Treatment Plants

Three UPDES point sources discharge reclaimed wastewater effluent to the Jordan River or its tributaries (see Figure 1.3 in the main report). South Valley Water Reclamation Facility (SVWRF) is the most upstream facility, located at 7495 South 1300 West in West Jordan, Utah. The facility treats wastewater, generally from Midvale, West Jordan, South Jordan, Riverton, Bluffdale, Draper, Copperton, and unincorporated areas located in south Salt Lake County. The plant began operations in 1985 with an initial treatment capacity of approximately 25 mgd and was upgraded to 38 mgd in 1992 (Brown and Caldwell 2006). The facility discharges directly to the Jordan River just downstream of the 7800 South crossing.

The Central Valley Water Reclamation Facility (CVWRF) is located at 800 West Central Valley Road in Salt Lake City. It receives wastewater from five sewage collection districts and two municipalities. These entities include districts located in Granger-Hunter, Kearns, Taylorsville-Bennion, Salt Lake City (District 1) and Salt Lake County (Cottonwood) as well as the cities of Murray and South Salt Lake. Construction of CVWRF was completed in 1985 with a design capacity of 75 mgd. Discharge enters Mill Creek approximately 1 mile above its confluence with the Jordan River.

The South Davis South Wastewater Treatment Plant (SDWTP) is located at 2500 West Center Street in North Salt Lake City and is one of two plants that service the south half of Davis County including the municipalities of Bountiful, Centerville, North Salt Lake, West Bountiful, Woods Cross, and unincorporated areas south of Lund Lane in Davis County (Centerville City 2007). It began operation in 1962 and has a treatment capacity of 4 mgd. Discharge from the facility enters the Jordan River just downstream of the Cudahy Lane bridge.

Flows from each facility were calculated from monthly Discharge Monitoring Report (DMR) documents submitted to the Utah DWQ Permitting Section by each facility. Monthly flows from each facility are consistent and typically vary less than 10 percent.

C.1.4 Stormwater

Stormwater runoff is produced in catchment basins that collect and discharge flow to waterbodies designated for flood control including drains, canals, tributaries, and the Jordan River. Runoff from areas outside of defined stormwater catchment systems is considered in this report as diffuse runoff. Figure C.1 shows the location of stormwater catchments considered in the Jordan River TMDL.

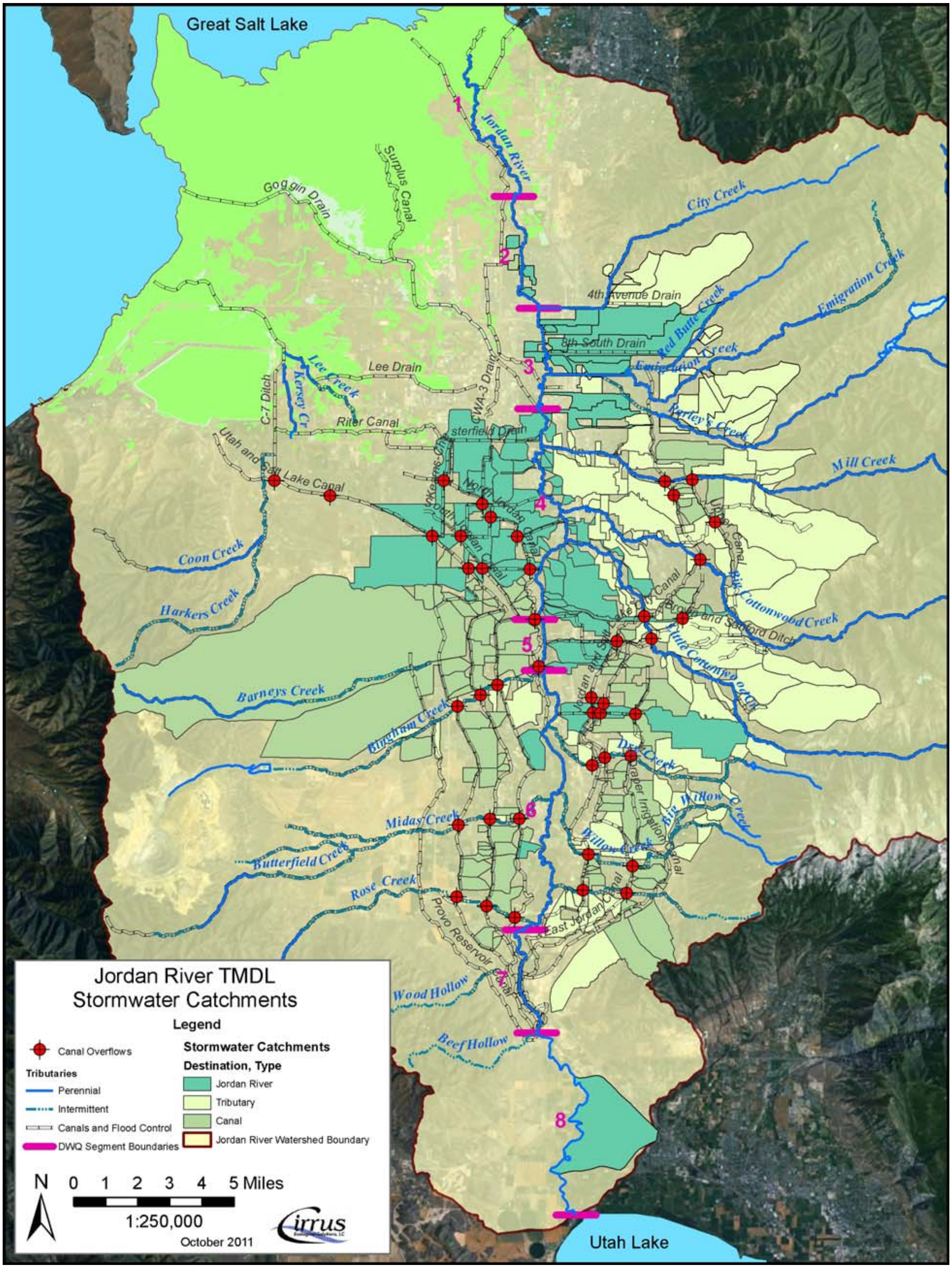

Figure C.1. Jordan River TMDL stormwater catchments.

The amount of stormwater discharge produced by a given catchment is a function of the area serviced, precipitation amount, percent of impervious surface, and land-cover type. Stormwater catchments on the east side of the Jordan River are more abundant and incorporate a higher percent of serviced area in comparison to the west side. Review of precipitation data shows that intense precipitation is generated in localized storm events along the Wasatch Front and can result in high stormwater discharge. Snowmelt is generally considered to produce minimal stormwater flow unless conditions such as rain-on-snow events or rapid warming occur (Salt Lake County 2006).

The percent of impervious surface is greater in highly developed commercial or industrial areas located near the north central area of the watershed in comparison to rural or low-intensity residential neighborhoods located in the south central and west areas of the watershed. Traditionally, land-cover types on the west side of the watershed have a lower density of impervious surface and incorporate more open space than the east side. However, urban and industrial development of areas west of the Jordan River is occurring at a rapid pace.

Stormwater flows are transferred to the Jordan River through four different processes including:

- Discharge from catchments to gaged tributaries above stream gages via canal overflow or directly to stream channels.
- Discharge from catchments directly to gaged tributaries below the gage or to canals with overflows to gaged tributaries below the gage.
- Discharge from catchments to the Jordan River either directly, to drains connected to the Jordan River, or to canals with overflows to those drains.
- Discharge from catchments to ungaged tributaries directly to stream channels or via canal overflows.

Stormwater flow calculations were based on methods used by UPDES stormwater permittees in annual monitoring reports (Salt Lake County 2006). Flow calculations used annual precipitation and correction factors that account for measurable storms that produce no runoff and the influence of impervious surface (Cirrus 2009b).

Similar to stormwater runoff collected in catchments, runoff from areas outside of catchments is a function of surface area, precipitation, and land-cover type, and it can discharge into the Jordan River directly or via gaged or ungaged tributaries. Most canals are constructed so as not to allow surface runoff and avoid overflow conditions.

C.1.5 Diffuse Runoff

As defined by this report, runoff is reported as “diffuse” only from areas adjacent to the mainstem of the Jordan River. Diffuse runoff entering gaged tributaries below the gage was added to the gage data and reported for each tributary. Diffuse runoff to ungaged tributaries was considered part of the natural flow in the area-altitude models used to estimate monthly runoff from snowmelt and rain events.

C.1.6 Irrigation Diversions and Return Flow

Significant outflows from the Jordan River result from eight major diversions that support 11 canals located on the east and west side of the river. These structures transport water for irrigation, flood control, or public water supply purposes. Diversions from the river occur primarily from late spring through early fall although some canals divert water year round for flood control and public water supply.

Diversions are regulated by the Division of Water Rights and recorded by irrigation companies through continuous flow gages or infrequent manual measurements. Three canal diversions are located above Turner Dam at the Narrows. Two other canals originate approximately 2 miles downstream of Turner Dam at the Joint Diversion. The largest diversion is the Surplus Canal, located at 2100 South, which functions as a flood control structure to protect neighborhoods along the lower Jordan River. Below 2100 South, the Jordan River channel is smaller and retains only a small fraction of the total flow above 2100 South. The lowest diversion from the Jordan River is located about 1.5 miles upstream from the terminal end of the river channel and delivers water to the State Canal. Flow in the State Canal supplies water rights and transports effluent from the North Davis North WWTP.

Irrigation return flows are defined for this analysis as water volumes at the terminal end of canals. Return flows from irrigation do not include stormwater discharge to canals. Groundwater recharge mechanisms associated with irrigation include canal seepage and deep percolation from irrigated fields. These water volumes are reflected in groundwater flows to the Jordan River and are not considered in estimates of irrigation return flow. Shallow groundwater flow is collected from irrigated fields with drain tiles that discharge to canals. Flows of this type are included in return flow estimates.

Flows for irrigation are typically diverted from the Jordan River to canals during the months of May–October. Some variation is associated with the start and end date of the irrigation season based on demand for irrigation water during any given year. Factors influencing demand for irrigation water include total irrigated crop land, crop type, and annual precipitation levels. Irrigation type also influences return flows. Flood irrigation practices apply water in excess of crop demand. Efficiencies range from 50–80 percent, with excess water returned to canals as tailwater (Howell 2003).

Six of the 11 major canal systems direct their return flows to the Jordan River (Table C.1). Local knowledge of canal operation and maintenance was used as a starting point to define reasonable estimates of return flow from irrigation canals. Based on roughly 30 years of experience, Salt Lake County Division of Engineering and Flood Control provided estimates of the percent of total diverted flow that remained in canals near their terminal ends. These estimates were translated into monthly values based on average monthly flow at the point of diversion, and a correction factor derived from measured data.

Table C.1. Location of return flows from canals.

Name	Receiving Water	Termination Point	Jordan River Mile
Jacob-Welby Canal (aka Provo Reservoir Canal)	Jordan River	7800 South[1]	26.3
Utah Lake Distribution Canal	Jordan River	6200 South[2]	24.1
Utah and Salt Lake Canal	Great Salt Lake	C-7 Ditch[2]	N/A
Draper Irrigation Canal	Jordan River	East Jordan Canal[1]	17.3
East Jordan Canal	Jordan River	East Bench Canal[1] (Upper Canal)	17.3
South Jordan Canal	Jordan River	Kearns-Chesterfield Drain[2]	17.0
Jordan & Salt Lake Canal	Jordan River	800 South Storm Drain[1]	14.2
North Jordan Canal	Jordan River	Kearns-Chesterfield Drain[2]	17.0
Surplus Canal	Great Salt Lake	Goggin Drain & North Point Canal[1]	N/A
State Canal	Great Salt Lake	Farmington Bay[3]	N/A

[1] Salt Lake County 1978.

[2] Bowen Collins 2003.

[3] USGS Farmington 7.5 minute topographic map, USGS National Hydrologic Dataset High Resolution 1:24,000 scale.

C.1.7 GROUNDWATER

General groundwater flow patterns and flow estimates in the Jordan River watershed have been previously defined based on physical characteristics and extent of local geologic features that define aquifers and recharge areas in the Salt Lake Valley (Richardson 1906, Taylor and Leggette 1949, Arnow 1965, Hely et al. 1971, Lambert 1995). The amount of groundwater discharge to the Jordan River is a function of annual and seasonal recharge volumes. Groundwater is generated by precipitation, snowmelt runoff, seepage from irrigation canals, flood irrigation, and any other source that contributes water to aquifer formations discharging to the Jordan River.

Groundwater in the Jordan River basin generally occurs in four aquifer formations including (1) a confined artesian aquifer, (2) a deep unconfined aquifer located between the confined aquifer and the valley margins, (3) a shallow unconfined aquifer overlaying the artesian aquifer, and (4) local unconfined perched aquifers (Hely et al. 1971). The principal aquifer is generally composed of the confined artesian aquifer and the deep unconfined aquifer located near the valley margins. The ultimate source of the majority of groundwater used in Salt Lake County is the principal aquifer.

Groundwater flow in the Salt Lake Valley is generally toward the Jordan River. Water enters the aquifer in recharge areas at the base of mountains on the east, west, and south of the valley and moves towards the river, except for groundwater from the northern Oquirrh Mountains, which flows directly to the Great Salt Lake (Arnow 1965). Transmissivity of the aquifer ranges from less than 10,000 ft^2/day at the valley edges to over 50,000 ft^2/day around the creeks flowing out of the Wasatch Range (Lambert 1995). Studies have estimated the hydraulic conductivity of the confining layer of the aquifer to be 0.016 ft/day near the Great Salt Lake and 0.049 ft/day between Holladay and Murray, UT (Hely et al. 1971). Holdsworth (1985) estimated hydraulic conductivity for unconsolidated base fill at 130 ft/day.

CH2M Hill (2005) modeled groundwater inflows to the Jordan River for natural and irrigation sources during average hydrologic conditions. Model results indicated that groundwater inflow from natural sources was approximately 40,000 ac-ft/year and approximately 50,000 ac-ft/year from irrigation sources. A technical memorandum (Hansen 2005) included in CH2M Hill (2005) defined groundwater inflows by Jordan River segment. Groundwater contributions during wet and dry years showed relatively minor differences. The greatest flow contribution from groundwater during all years occurred between 9400 South and 13200 South and decreased steadily with distance downstream to 2100 South. Total annual groundwater flow to the Jordan River ranged from approximately 111,000 to 128,000 ac-ft.

Groundwater discharge to the Jordan River above Turner Dam was not included in the CH2MHill analysis. Therefore, groundwater inflow was calculated separately for this segment during periods when there was no discharge from Utah Lake. In these months, groundwater, stormwater, and diffuse runoff are the only sources of water to the river. Using similar calculations for stormwater and diffuse runoff as described above allowed separation of groundwater from these other two variables.

C.2 WATER BUDGET RESULTS

The Jordan River water budget provides a means for accounting for all inflows and outflows, including flow sources that have not been directly measured. A summary of the water budget results is provided in Chapter 1 of the Jordan River TMDL report. Table C.2 in this section presents an average annual water budget for the Jordan River. Inflows and outflows described in this section are shown in relation to their influence on different sections of the river from Utah Lake to Burton Dam. The boundaries of the eight DWQ Segments of the Jordan River used by DWQ do not align exactly with gaging stations with long term data so the divisions below were based on the location of gages with adequate long-term records:

- Utah Lake to 9000 South (includes 02 Jordan River Combined gage at Turner Dam).
- 9000 South to 2100 South.
- 2100 South to 500 North.
- 500 North to Cudahy Lane.
- Cudahy Lane to Burton Dam.

Each section begins with the measured flow at the start of that section. The various sources of additional inflows and diversions or outflows follow. The "Predicted Flow" value is a total of the initial measured flow and the inflows and outflows within that section. The "Difference" is the difference between the calculated total and the measured mainstem flow as a percentage of the measured flow at the end of the section, resulting from inaccurate measurements, unsynchronized timing of measurements, and incomplete records.

The section with the largest error is between 9000 South and 2100 South, with an unexplained shortage of 36,700 ac-ft, or about 6 percent of the initial flow, over 12 miles of river, or less than 1 percent per mile. This section is perhaps the most complex in terms of land use with three major tributaries and the greatest catchment area for stormwater. The next greatest error occurs in the highest section, between Utah Lake and 9000 South, with an unexplained loss of 6,774 ac-ft, or about 3 percent over 23 miles, or approximately 0.1 percent per mile. This is the longest section, and has the greatest number and magnitude of diversions. Overall, this check indicates a high level of accuracy in the water budget on a section-by-section basis.

Reconciliation is not possible for the end of the Jordan River at Burton Dam because there is no gage at that site. The total flow predicted by this water budget – from Utah Lake to Burton Dam and unadjusted by actual intermediate gage readings – is approximately 120,000 ac-ft.

Following a comparison of the detailed flow budget with gage measurements, we found a high level of accuracy on a section-by-section basis. The largest difference between the flow budget gage data occurred between 9000 South and 2100 South.

Table C.2. Jordan River water budget calculations and percent error.			
Utah Lake to 9000 South - Mile 51.4 to 28.1			
Description	**Data Source**	**Inflows and (Outflows) (ac-ft)**	
Measured Mainstem Flow			
Utah Lake Outlet	Jordan River Station 02 Combined minus groundwater, stormwater, and upstream diversions.		**413,766**
Inflows			
Rose Creek	Salt Lake Co. (Coon 1982)	219	
Corner Canyon Creek	Salt Lake Co. (Coon 1982)	2,087	
Midas/Butterfield Creek	Salt Lake Co. (Coon 1982)	820	
Willow Creek	Salt Lake Co. (Coon 1982)	997	
Dry Creek	Salt Lake Co. (Coon 1982)	3,639	
Stormwater	Stantec 2006a	3,481	
Diffuse Runoff	Cirrus 2007	862	
Irrigation Tailwater	Salt Lake County 2006	8,032	
Groundwater	CH2M Hill 2005	71,847	
Subtotal			**91,984**
Outflows			
Utah Lake Distributing Canal	04.01.01 Utah Lake Distributing Canal	(26,135)	
Jacob-Welby Canal	05.01.07 Jordan Valley Water Conservancy District	(28,051)	
East Jordan Canal	06.03.01 East Jordan Irrigation Company (57-7637)	(35,711)	
Draper Canal	06.04 Draper Irrigation Co. (57-23)	(9,329)	
Salt Lake City - East Jordan	06.03.02 Salt Lake City Co. E. Jordan Canal	(12,608)	
Utah and Salt Lake Canal	06.02.01 Utah & Salt Lake Canal (59-3499)	(42,495)	
Jordan and Salt Lake City Canal	07.01 Salt Lake City Corp - Jordan & Salt Lake Canal	(7,888)	
South Jordan Canal	07.02 South Jordan Canal (Total)	(24,464)	
North Jordan Canal	10.01.01 North Jordan Irrigation Co. (59-3496)	(6,638)	
Subtotal			**(193,320)**
Predicted Flow			**312,430**
Measured Mainstem Flow			
Jordan River - 9000 South	USGS Station 10167230		**303,991**
Difference as percent of Measured Flow			**(2.8%)**

Table C.2. (cont'd) Jordan River water budget calculations and percent error.			
9000 South to 2100 South - Mile 28.1 to 16.1			
Description	**Data Source**	**Inflows and (Outflows) (ac-ft)**	
Measured Mainstem Flow			
Jordan River - 9000 South	USGS Station 10167230		**303,991**
Inflows			
Bingham Creek	Salt Lake Co. (Coon 1982)	1,146	
SVWRF	UT0024384 Effluent	28,061	
Little Cottonwood Creek	10168000 - Little Cottonwood Creek at Jordan River near Salt Lake City, UT.	33,204	
Big Cottonwood Creek	10169500 Big Cottonwood Creek at Jordan River near Salt Lake City, UT.	42,609	
Mill Creek	10170250 - Mill Creek at Jordan River near Salt Lake City, UT.	17,601	
CVWRF	UT0024392 Effluent - Discharge from Central Valley Water Reclamation Facility	61,041	
Stormwater	Stantec 2006a	12,227	
Diffuse Runoff	Cirrus 2007	382	
Irrigation Tailwater	Salt Lake County 2006	9,584	
Groundwater	CH2M Hill 2005	27,354	
Subtotal			**233,209**
Outflows			
None		0	
Subtotal			**0**
Predicted Flow			**537,200**
Measured Mainstem Flow			
Jordan River - 2100 South	10170490 – Combined Flow Jordan River & Surplus Canal at Salt Lake City, UT - 2100 S		**573,900**
Difference as percent of Measured Flow			**6.4%**

Table C.2. (cont'd) Jordan River water budget calculations and percent error.		
2100 South to 500 North - Mile 16.1 to 10.2		
Description	**Data Source**	**Inflows and (Outflows) (ac-ft)**
Measured Mainstem Flow		
Jordan River - 2100 South	10170490 – Combined Flow Jordan River & Surplus Canal at Salt Lake City, UT - 2100 S	**573,900**
Inflows		
1300 South Conduits	10171600 - Parleys Creek at Suicide Rock near Salt Lake City, UT. 10172000 - Emigration Creek near Salt Lake City, UT. 10172300 - Red Butte Creek at 1600 East at Salt Lake City, UT.	24,029
City Creek Conduit	10172499 - City Creek (Channel) near Salt Lake City, UT.	8,141
Stormwater	Stantec 2006a	4,580
Diffuse Runoff	Cirrus 2007	124
Irrigation Tailwater	Salt Lake County 2006	N/A
Groundwater	CH2M Hill 2005	13,930
Subtotal		**50,804**
Outflows		
Surplus Canal	10170500 - Surplus Canal at Salt Lake City, UT	(466,533)
Subtotal		**(466,533)**
Predicted Flow		**158,171**
Measured Mainstem Flow		
Jordan River - 500 North	10172550 - Jordan River at 500 North at Salt Lake City, UT	**158,640**
Difference as percent of Measured Flow		**0.3%**

Table C.2. (cont'd) Jordan River water budget calculations and percent error.			
500 North to Cudahy Lane - Mile 10.2 to 5.1			
Description	**Data Source**	**Inflows and (Outflows) (ac-ft)**	
Measured Mainstem Flow			
Jordan River - 500 North	10172550 - Jordan River at 500 North at Salt Lake City, UT.		**158,640**
Inflows			
Stormwater	Stantec 2006a	108	
Diffuse Runoff	Cirrus 2007	134	
Irrigation Tailwater	Salt Lake County 2006	N/A	
Groundwater	CH2M Hill 2005	6,365	
Subtotal			**6,607**
Outflows			
None		0	
Subtotal			**0**
Predicted Flow			**165,247**
Measured Mainstem Flow			
Cudahy Lane	Cudahy Lane		**164,097**
Difference as percent of Measured Flow			**0.7%**
Cudahy Lane to Burton Dam - Mile 5.1 to 0			
Description	**Data Source**	**Inflows and (Outflows) (ac-ft)**	
Measured Mainstem Flow			
Cudahy Lane	DWR-Cudahy Lane	164,097	**164,097**
Inflows			
SDWTP	UT0021628 Effluent	2,599	
Stormwater	Stantec 2006a	0	
Diffuse Runoff	Cirrus 2007	151	
Irrigation Tailwater	Salt Lake County 2006	0	
Groundwater	CH2M Hill 2005	3,554	
Subtotal			**6,304**
Outflows			
State Canal	4990880 - Jordan River at State Canal Road crossing.	(51,612)	
Subtotal			**(51,612)**
Predicted Flow			**118,790**
Measured Mainstem Flow			
Burton Dam	Not measured.		**N/A**
Difference as percent of Measured Flow			**N/A**

APPENDIX D. ANALYSIS OF EXISTING DATA ON PROCESSES AFFECTING DO IN THE LOWER JORDAN RIVER

D.1 INTRODUCTION

Figure 2.3 of the TMDL report presented a conceptual framework for processes affecting Dissolved Oxygen (DO) in the Jordan River. These processes were described above in general terms in Section 2.3. This appendix presents data and evidence for these processes occurring in the Jordan River, especially in the lower Jordan River, i.e., those segments downstream of the Surplus Canal diversion at 2100 South. In summary, these four processes are:

1. Physical factors, including water temperature and channel characteristics that influence reaeration from the atmosphere.

2. Aerobic decomposition of OM and inorganic nitrification of NH_4 in the water column (measurable as bio-chemical oxygen demand, or BOD).

3. Aerobic decomposition of OM and inorganic oxidation at the interface between the water column and bottom sediments (measurable as sediment oxygen demand, or SOD).

4. Algal growth generating a net increase in DO during daylight hours and net consumption of DO associated with respiration during the night.

D.2 PHYSICAL LIMITATIONS – TEMPERATURE, DO SOLUBILITY, AND REAERATION

Oxygen is more soluble in cold water than in warm water, and Figure D.1 compares average monthly water temperatures with saturated DO concentrations as a function of those water temperatures for the long-term record (1995–2008) at Cudahy Lane, 1700 South, and 2100 South. Table D.1 compares the measured mean monthly concentrations of DO with calculated saturated DO concentrations at the observed mean monthly temperatures for the same period at the same three stations. The result is a persistent deficit between saturated – the potential – and observed DO of 0.8–1.7 mg/L. Seasonal differences in water temperature can account for seasonal differences in DO but cannot fully account for a deficit in DO year round.

Since natural reaeration processes will tend to move DO toward saturated concentrations, this persistent DO deficit means that demand on DO is exceeding natural reaeration rates within the water column throughout the year.

The potential for reaeration can be calculated using formulas that take into account factors such as channel characteristics, flow, and depth (Figure D.2). Using the formulas found by Stantec (2006b) to be most applicable to the lower Jordan River, reaeration should be occurring at a rate of 2–4 mg/L/day in the summer and early fall.

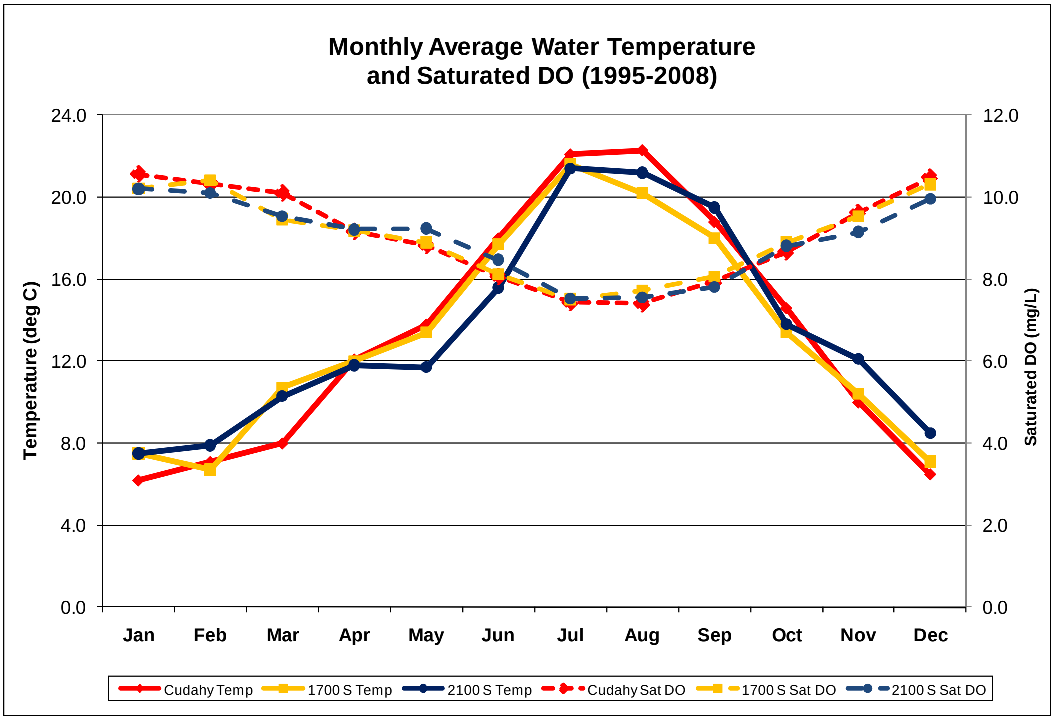

Figure D.1. Monthly average water temperatures and saturated DO concentrations in the lower Jordan River.

Table D.1. Deficit in DO between saturated and observed mean concentrations by month averaged for stations in the lower Jordan River (2100 South, 1700 South, Cudahy Lane)[1] (1995–2008).

Month	Mean Temp (°C)	Mean Observed DO Concentration (mg/L)	Mean Saturated DO Concentration (mg/L)	Deficit in DO (mg/L)
Jan	7.1	8.9	10.3	1.4
Feb	7.2	9.5	10.3	0.8
Mar	9.7	8.8	9.7	0.9
Apr	12.0	8.2	9.2	1.0
May	13.0	8.2	9.0	0.8
Jun	17.1	7.0	8.2	1.2
Jul	21.7	6.1	7.5	1.4
Aug	21.2	5.8	7.6	1.7
Sep	18.8	7.0	7.9	0.9
Oct	13.9	7.2	8.8	1.6
Nov	10.8	8.4	9.4	1.0
Dec	7.4	9.3	10.3	1.0

[1] Calculated at typical atmospheric pressures in the Salt Lake Valley and accurate for the observed average salinity of less than 2,000 µmhos/cm (Cirrus 2007).

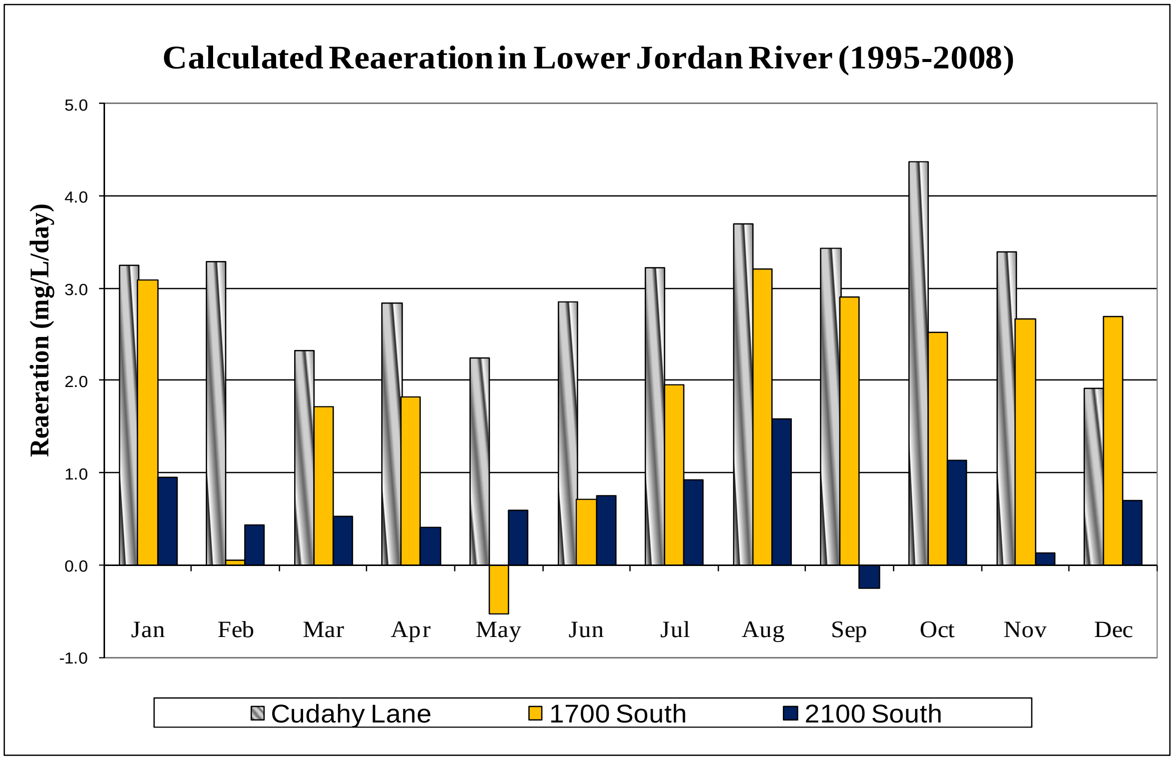

Figure D.2. Calculated reaeration in the lower Jordan River.

In September 2009, Goel and Hogsett (2009) measured oxygen diffusion in several sections of the Jordan River and used this data to calculate reaeration rates. Their methods involved measuring oxygen concentrations in a floating test chamber kept in constant contact with the water surface in seven segments of the Jordan River, including two locations in the lower Jordan River below 2100 South. They first purged the chamber of oxygen to levels below ambient atmospheric levels and then measured oxygen concentrations over time as they were restored toward normal from DO in the water. Air temperatures in the chamber were kept within 1 degree C of the water temperature. The dome was allowed to float down the river attended by a boat which was only paddled as necessary to maintain a position in the center of the river and so as to avoid obstructions. When encountering obstructions such as rapids and low head dams, the dome was removed from the water and portaged around the obstruction. Reaeration calculations were made from the longest uninterrupted time period in each section. Average river depths for the calculations were taken from previous flow studies completed as part of the TMDL process (Cirrus 2009b).

Table D.2 shows less than ideal agreement between reaeration rates calculated by Goel and Hogsett based on measured diffusion and those calculated based on channel characteristics, flow, and temperature, shown in Figure D.2. Nevertheless, these data suggest that values calculated from river channel characteristics, flows, and temperatures values may understate actual reaeration by at least half in some reaches. In any case, positive reaeration rates are evident.

Table D.2. Reaeration rates[1] on the Jordan River 2009.			
Reaeration from Measured Diffusion Rates[2]		Reaeration Calculated Only from Mean Flows and Channel Characteristics[3]	
River Section	**Reaeration Rate (1/day)**	**Comparable Location**	**Reaeration Rate (1/day)**
Redwood Road to Legacy Nature Preserve	0.6	Cudahy Lane	1.9
1700 South to 900 South	4.1	1700 South	2.3
3300 South to 2100 South	7.1	2100 South	0.9
5400 South to 4170 South	4.6	N/A	N/A
9000 South to 7800 South	16.5	N/A	N/A
12600 South to 10600 South	10.2	N/A	N/A
Lehi	3.4	N/A	N/A

[1] Reaeration rates are in units of 1/time. They apply to the current deficit between existing and saturated conditions. As the existing concentration changes, the reaeration constant, in units of mass/volume/time, also changes. Hence, calculations of the actual change in concentration must be integrated over time as DO approaches or recedes from saturated values.

[2] Source: Goel and Hogsett (2009).

[3] Source: Cirrus (2009a) for relevant sections based on average flows for September.

Based on calculated transit times and the positive reaeration rates from Figure D.2 for water in the river – probably understated – DO concentrations in the lower Jordan River should be increasing by at least 0.8–1.6 mg/L in the reach between 2100 South and Cudahy Lane, and at least 1.7–3.4 mg/L between 2100 South and Burton Dam. Instead, as illustrated in Figure 2.1 of the main report, DO concentrations are decreasing downstream of 1700 South. This indicates that factors other than reaeration rates are responsible for the low DO levels.

DO deficit conditions are not limited to low flow conditions, however, although low flows would tend to produce less turbulence and therefore less reaeration. Paired measurements of flow and DO collected at both Cudahy Lane and 1700 South indicate that low DO concentrations are distributed across a range of flow conditions (Table D.3 and Table D.4, respectively, for a longer period of record for flows). Although the percentage of samples violating DO criteria was greatest in the 40–70 percentile flow range, there are significant violations across all flow percentile ranges, especially at Cudahy Lane.

The slowing of the Jordan River in its lower reaches has detrimental effects beyond reduced reaeration. Figure D.3 shows channel elevations and Table D.5 shows hydraulic characteristics of the river (Stantec 2006a). While low flows do limit reaeration, a more important effect of these lower velocities resulting from shallower slopes may be longer transit times which allow for more organic decomposition within the water column and more settling of decaying organic material, contributing to both increased BOD and SOD and consequently lower DO. These processes are discussed below.

Table D.3. Assessment of paired measurements of flow (cfs) and DO (mg/L) for the Jordan River at Cudahy Lane (1980–2005).[1]

WQ Station: 4991820 - Jordan River at Cudahy Lane

Flow Station: 10172250 - Jordan River at 500 North correlated to Cudahy Lane

Flow Percentile Ranges	Median Observed Flow (cfs)	DO Sample Distribution	% Violate Chronic Criterion	% Violate Acute Criterion	Mean DO (mg/L)	Min DO (mg/L)	Max DO (mg/L)
0–10	111	21	23.8	0	6.8	4.3	9.4
10–20	139	24	8.3	4.2	7.3	3.3	18.8
20–30	157	23	30.4	13.0	6.0	1.7	9.3
30–40	178	27	22.2	3.7	6.9	2.7	13.4
40–50	196	20	25.0	20.0	6.2	0.1	9.3
50–60	214	24	33.3	16.7	6.4	1.8	9.4
60–70	237	21	33.3	9.5	6.3	3.4	10.8
70–80	259	16	31.3	12.5	6.3	0	8.9
80–90	296	19	21.1	10.5	6.8	3	9.2
90–100	380	21	19.0	4.8	7.1	4.4	8.9

[1] Columns 4 and 5 indicate the percent of paired flow-DO measurements that violate chronic DO (5.5 mg/L) and acute DO (4.0 Aug–April and 4.5 May–July) criteria. Flow percentile ranges are based on a flow correlation between Cudahy Lane and 500 North using available data collected during 1980–2005.

Table D.4. Assessment of paired measurements of flow (cfs) and DO (mg/L) for the Jordan River at 1700 South (1980–2005).[1]

WQ Station: 1017100 - Jordan River at 1700 South

Flow Station: 1017100 - Jordan River at 1700 South

Flow Percentile Ranges	Median Observed Flow (cfs)	DO Sample Distribution	% Violate Chronic Criterion	% Violate Acute Criterion	Mean DO (mg/L)	Min DO (mg/L)	Max DO (mg/L)
0–10	71	20	0	0	8.5	6.5	10.6
10–20	107	18	16.7	0	7.3	5	10.6
20–30	118	18	5.5	0	8	5.2	10
30–40	127	17	5.9	0	7.9	5	11.2
40–50	137	17	17.6	0	7.3	4.8	11.5
50–60	147	22	22.7	9.1	7.6	4.1	10.4
60–70	158	16	0	0	7.6	5.8	9.4
70–80	171	22	9.1	9.1	8.2	3.7	12.7
80–90	189	25	16	0	7.8	4.9	11.5
90–100	232	13	0	0	8.3	6	10.6

[1]Columns 4 and 5 indicate the percent of paired flow-DO measurements that violate chronic DO (5.5 mg/L) and acute DO (4.0 Aug–April and 4.5 May–July) criteria. Flow percentile ranges are based on available flow data collected from 1700 South during 1980–2005.

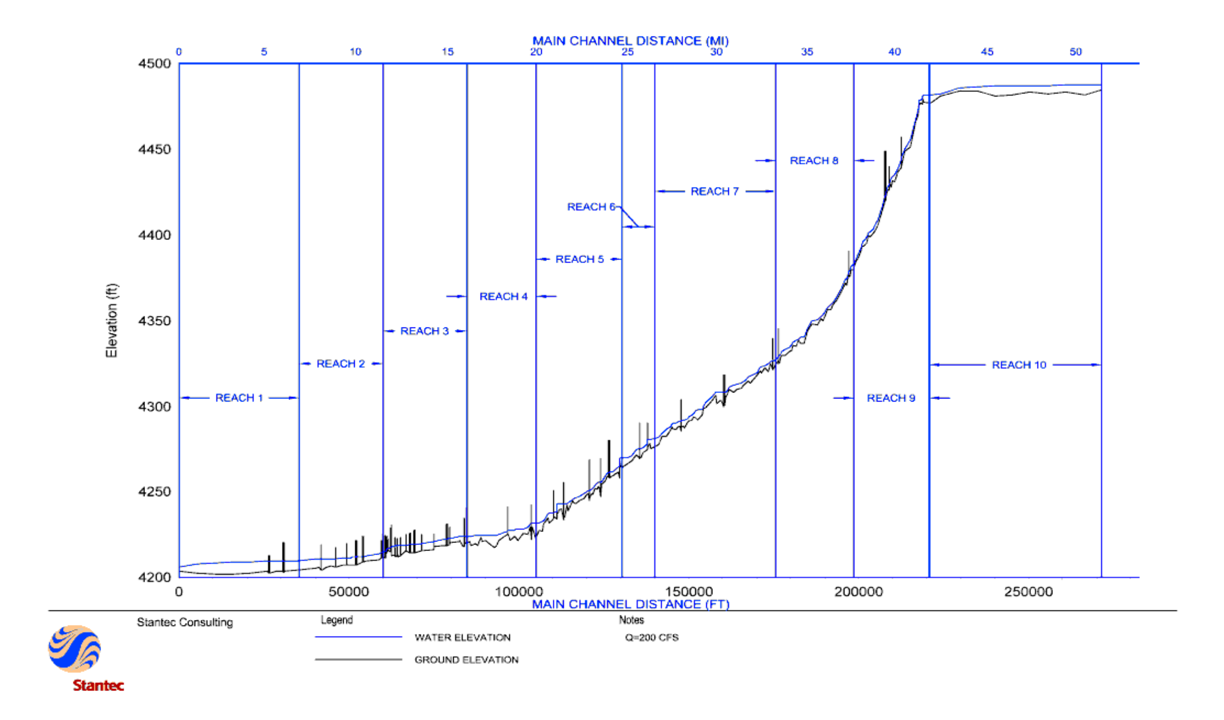

Figure D.3. Jordan River elevations (Reaches 1–3 are the same as DWQ Segments 1–3 and correspond to the lower Jordan River from Burton Dam upstream to 2100 South) (Reproduced from Figure 4-3 in Stantec 2006a.)

Table D.5. Velocities and transit times of DWQ Segments at 200 cfs. (Stantec 2006a).

DWQ Segment	Segment Description	Segment Length (mi)	Average Slope (ft/mi)	Average Hydraulic Depth (ft)	Average Velocity (ft/s)	Travel Time (hr)
8	Utah Lake to Narrows	9.6	0.8	2.5	0.6	23.1
7	Narrows to Bluffdale Road	4.3	22.7	1.7	2.4	2.6
6	Bluffdale Road to 7800 South	11.0	9.3	1.6	2.1	7.8
5	7800 South to 6400 South	1.7	6.7	2.3	1.7	1.5
4	6400 South to 2100 South	8.9	5.2	2.2	1.4	9.6
3	2100 South to North Temple	4.5	1.4	2.7	1.5	4.5
2	North Temple to Davis County	4.4	1.7	2.9	1.2	5.3
1	Davis County line to Farmington Bay	6.9	0.1	3.5	1.0	10.5
	Totals	**51.3**				**64.9**

D.3 AEROBIC DECOMPOSITION OF ORGANIC MATTER IN THE WATER COLUMN

D.3.1 BIOCHEMICAL OXYGEN DEMAND

Since physical reaeration should be moving the lower Jordan River toward saturated DO concentrations but DO is actually decreasing, other process(es) must be demanding DO faster than physical reaeration can supply it. One of these processes is the demand for DO that accompanies decomposition of OM in the water column. Another is the demand for DO resulting from nitrification of NH_4.

BOD is the most direct measure of oxygen demand and usually refers to BOD_5, a 5-day analysis in a laboratory environment of a water sample. The procedure starts with a "grab" sample of river water, and measures DO concentrations before, sometimes during, and after it is kept for 5 days in the dark (to suppress photosynthesis) and held at a constant 20°C temperature. The BOD_5 measurement can be made with or without nitrification inhibitors. If inhibitors are added, the consumption of DO is primarily due to aerobic bacterial decomposition of the OM that was in the sample. This is typically referred to as Carbonaceous BOD_5 ($cBOD_5$). If inhibitors are not added, the DO loss results from a combination of both aerobic organic decomposition and inorganic processes such as nitrification. The difference between $cBOD_5$ and BOD_5, respectively with and without inhibitors, yields the nitrogenous, or inorganic, BOD (nBOD).

Unfortunately, there is often confusion when interpreting values for BOD as to whether the measurement included nitrification inhibitors. However, most values contributed to DWQ records found on EPA's STORET database are thought to have included these inhibitors and thus measured cBOD. Even if they did not, however, it is often the case that nitrifying bacteria do not compete well against aerobic bacteria, and thus nBOD may not be significant until after the 5-day measurement period. In actual measurements of cBOD and nBOD, Dupont found that recognizable nitrification effects appeared around day 8 and, while nBOD rates were higher (DO is consumed faster by nitrification processes), the ultimate nBOD was a fraction of the ultimate cBOD – 1.3 mg/L vs. 5.4 mg/L, respectively (Dupont 2010, personal communication).

Further complicating the interpretation of BOD measurements is that all OM does not break down at the same rate. Some materials, such as excretions from metabolism, are composed of simple compounds which can be readily metabolized by bacteria, requiring higher initial demands on, and faster declines of, DO – i.e., material with a "fast BOD" rate. Structural components of plants such as leaves and branches, on the other hand, are more resistant to decomposition and exhibit a slower rate of decay and a lower demand on DO – "slow BOD." Differences in proportions of fast and slow BOD may, in fact, point to different pollutant sources.

Even without distinguishing among the details of BOD measurements, BOD in the lower Jordan River supports a conclusion of significant DO demand due to decomposing OM. Figure D.4 shows a bimodal distribution in monthly average BOD, peaking in early spring and again in late summer. Note that DO violations in the river occur primarily in the warmer months of summer (see Section 2.2.2 of the main report). This is consistent with potentially different sources of BOD in different seasons – e.g., slowly decomposing plant detritus from flushing flows in the spring and decaying matter from plankton growth in summer. It is known that rates of BOD are strongly affected by temperature (Cirrus 2010c), which is also consistent with the fact that DO violations occur only in summer in the lower river. It is worth mentioning at this point that SOD rates should also be faster in warmer water, which would contribute to the lower DO in summer. (However, data from Goel and Hogsett, discussed below, show that SOD may not behave quite that simply.)

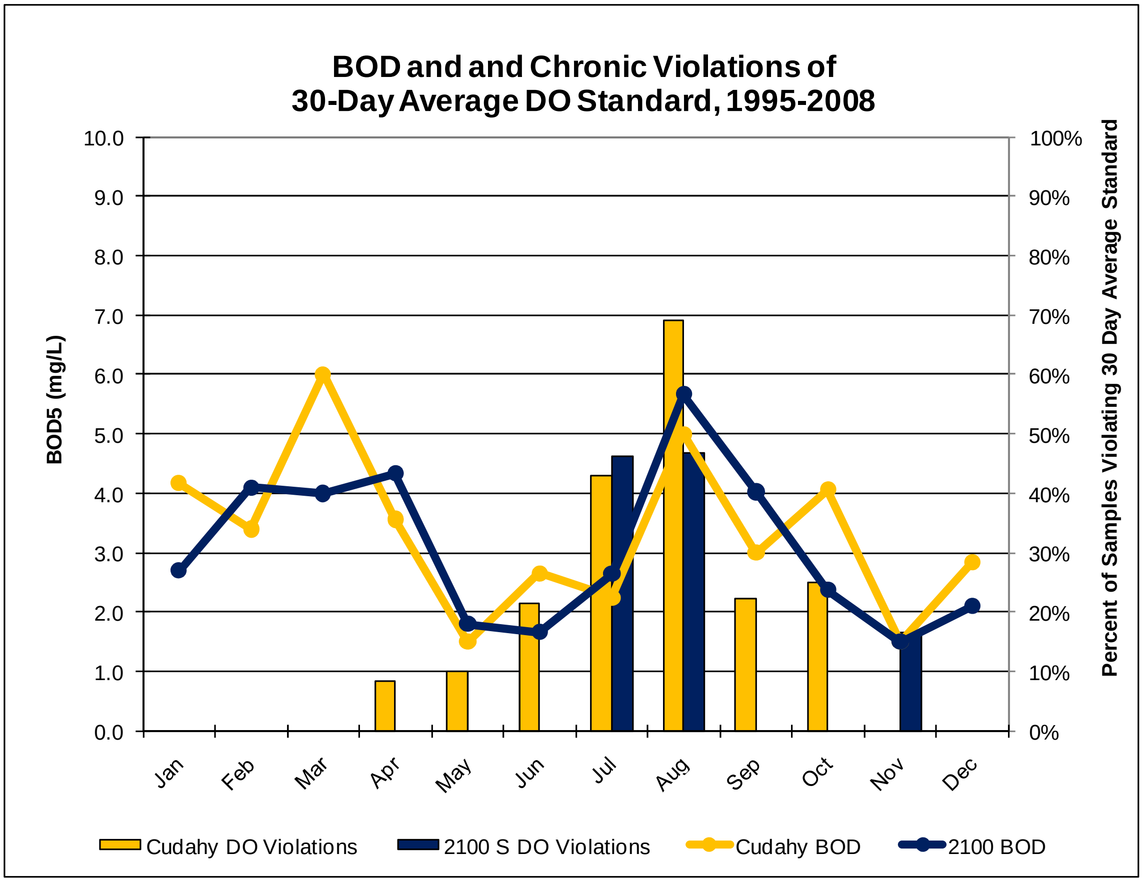

Figure D.4. Monthly average BOD (lines, plotted on left axis) and percent violations of 30-day DO standard at Cudahy Lane and 2100 South (columns, plotted on right axis).

D.3.2 Algae as a Source of Organic Matter

Additional evidence of excess OM comes from concentrations of chlorophyll-a, an indicator of algae, at eutrophic levels (above 30 ug/L) throughout the Jordan River (Cirrus 2009b and reproduced below as Figure D.19). Algae generally senesce within 48 hours, thus providing a nearly immediate source of OM for decomposition.

More recent studies provide additional evidence of the abundance of nutrients for algal growth. In a recent longitudinal nutrient limitation study, Baker (2010a) incubated control (grab) samples of Jordan River water in the river, without amending them with N or P, at different depths and locations between Utah Lake and Burnham Dam. After 2–3 days, Baker found chlorophyll-a concentrations peaking over 180 ug/L at 6400 South, approximately 1.5 miles below the outfall of the SVWRF (results reproduced in Figure D.5 below). At 1700 South, the concentration of chlorophyll-a was still higher than 100 ug/L.

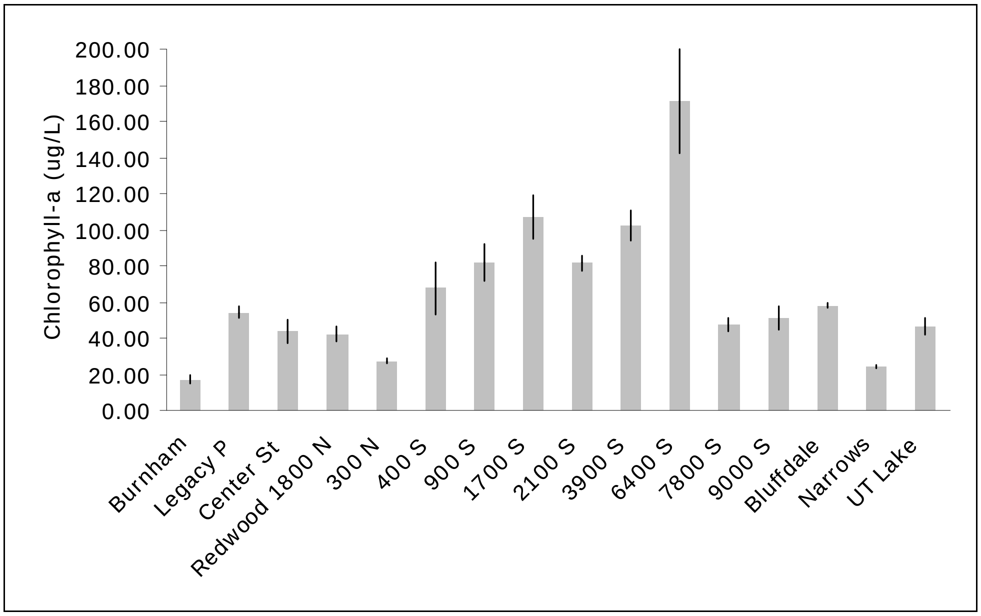

Figure D.5. Chlorophyll-a concentrations in control samples taken from and incubated for 2–3 days in the Jordan River in August 2009 (Baker 2010a).

Baker also amended samples of Jordan River water with N, P, or both and incubated them for 2–3 days at mid-depths in the Jordan River before analyzing them for chlorophyll-a. Between 7800 South (just above the discharge from SVWRF) and Center Street (Cudahy Lane) test samples were unresponsive to added nutrients, and it was not until more than 3 miles further downstream at Burnham Dam that algae were again responsive to both N and P. These results (based on sample sizes of 3–5) are reproduced in Figure D.6.

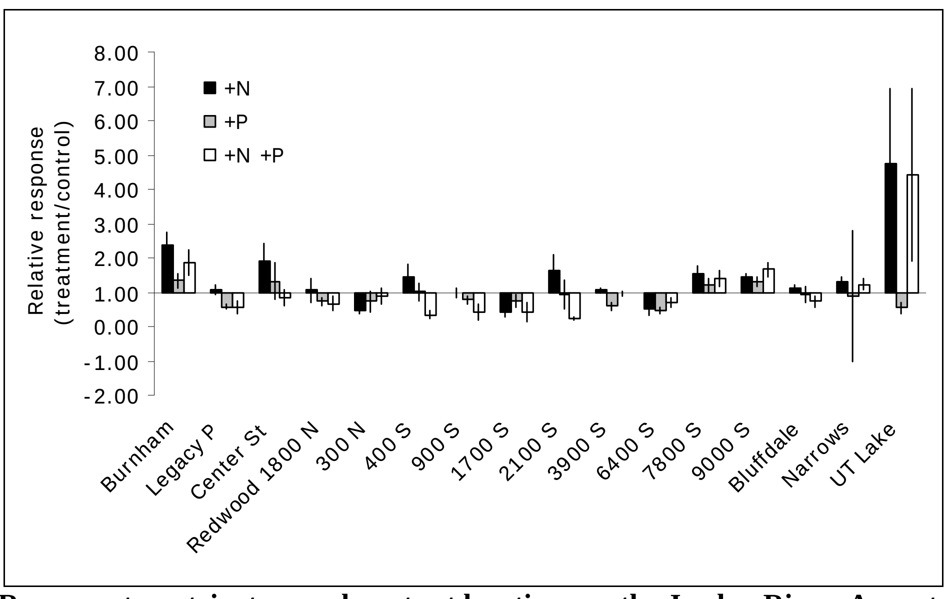

Figure D.6. Response to nutrient amendments at locations on the Jordan River, August 2009 (Baker 2010a.)

Also of interest in the Baker nutrient study was that at some sites, amendments of P alone actually inhibited algal growth. While no direct measurements of heterotrophic organisms were made, some of these organisms have a greater affinity for P than does algae, and thus could, when higher concentrations of P become available, out-compete the algae for the available N. (Baker 2010b)

In an experiment examining the response of periphyton to nutrients, Baker placed controls that were not amended with either N or P at three depths in the river and compared the growth of chlorophyll-a after 17 days between shallow or deep controls with mid-depth controls. The deeply placed controls in the lower Jordan River developed less chlorophyll-a and the shallow controls more chlorophyll-a than controls at mid-depth, leading Baker to conclude that significant light limitation occurs in the lower Jordan River. Studies of BOD_5 and ratios of Volatile Suspended Solids to Total Suspended Solids (VSS:TSS) (Cirrus 2009b) and algal species composition (Rushforth and Rushforth, 2009a and 2009b, discussed below), lead to the conclusion that much of this light attenuation comes from suspended OM.

D.3.3 Volatile Suspended Solids

Other direct evidence of OM in the water column is that a substantial portion of the suspended material in the water column is organic in nature. Figure D.7 shows ratios of VSS:TSS collected during synoptic and routine monitoring from August 2006 through mid-June 2010. (These data include measurements from STORET as well as data collected by Miller 2010a.) Average values of VSS:TSS ratios ranged from 15–24 percent for stations along the Jordan River. Ratios of paired values for individual stations and dates ranged from 6–57 percent.

Some of the OM comes from tributaries to the Jordan River. Figure D.8 shows that City Creek, 1300 South Conduit (capturing flows from Red Butte Creek, Emigration Creek, and Parleys Creek), Big Cottonwood Creek, and Little Cottonwood Creek all deliver ratios of VSS:TSS that are similar to averaged values in the Jordan River.

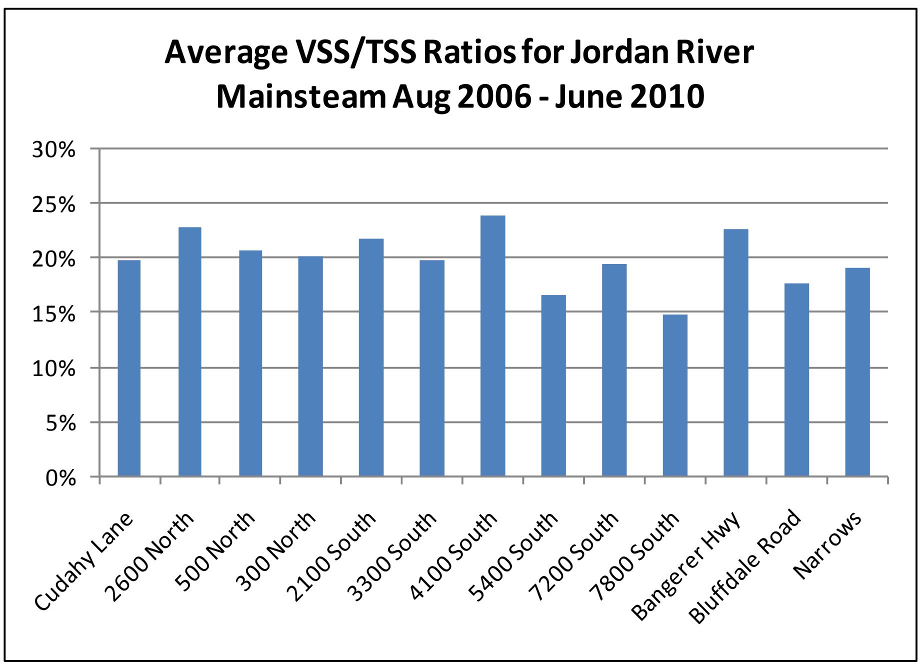

Figure D.7. Ratio of VSS:TSS measured in the Jordan River.

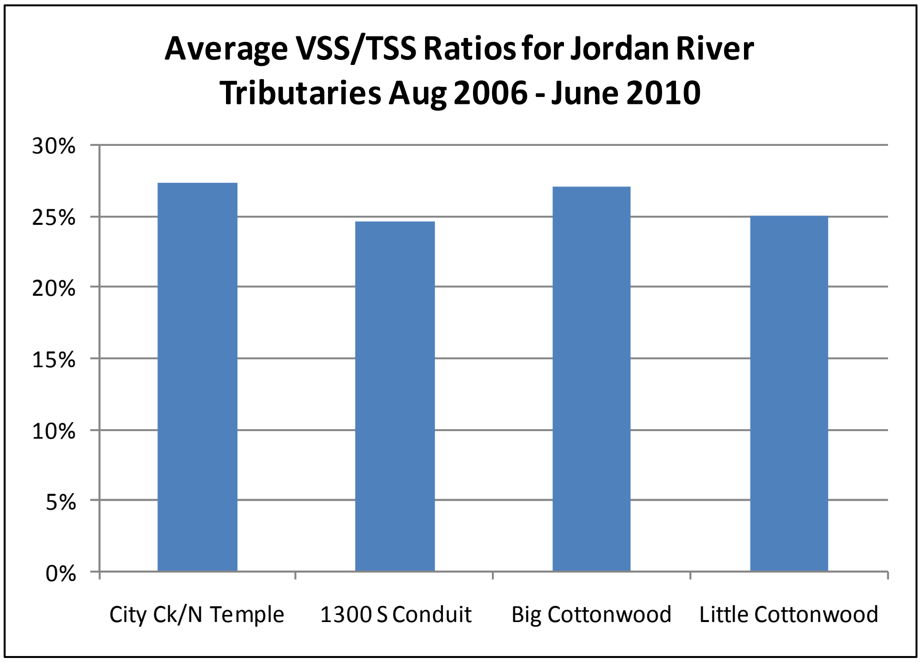

Figure D.8. Ratio of VSS to TSS measured from Jordan River tributaries.

D.3.4 Overall Effect of Aerobic Decomposition on DO

A crude calculation of the effect of BOD on water column DO using predicted travel times in the lower Jordan River yields the following at typical summertime water temperatures:

- Demand on DO from aerobic bacterial decomposition (BOD) between 2100 South and Cudahy Lane could be 0.4–0.7 mg/L (based on BOD of 3.0–5.5 mg/L and 0.4 days of travel time)

  (Reaeration could provide 0.8–1.6 mg/L in this time.)

- Demand on DO from aerobic bacterial decomposition (BOD) from 2100 South to 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)

  (Reaeration could provide 1.7–3.4 mg/L in this time.)

BOD could, therefore, potentially account for over half of the DO provided by reaeration.

D.4 AEROBIC DECOMPOSITION OF ORGANIC MATTER AND OXIDATION OF INORGANIC COMPOUNDS IN SEDIMENTS - SOD

SOD is similar to BOD, but occurs at the boundary layer between bottom sediments and the water column. SOD results from aerobic decomposition of OM and the oxidation of inorganic compounds such as methane and ammonium and is expressed as a mass of oxygen consumed per unit area of bottom sediments per time (typically $g/m^2/day$).

While aerobic bacterial digestion of the most recently deposited organic material consumes oxygen directly from the water column, older, buried layers of organic material processed by anaerobic bacteria also eventually result in an oxygen demand. The anaerobic bacteria convert carbon in the buried OM to methane and nitrogen to ammonium. As the methane diffuses into the aerobic layer above, some of it is oxidized into CO_2 and water. The diffusing ammonium is oxidized into nitrate NO_3 and water, and then the nitrate combines with some of the methane and is further oxidized to produce nitrogen gas, CO_2, and water (Chapra 1997).

Some authors regard SOD as the major cause of low DO concentrations in slow moving rivers or rivers with high levels of OM (Doyle and Lynch 2003). OM has a greater affinity for finer particles, such as silt that settles from slow moving water. SOD is a complex phenomenon, however. In some river systems with sediments of coarser sands and gravels SOD is much greater than the OM in the water column (Rounds and Doyle 1997), while in other river systems the reverse is true (Doyle and Lynch 2003).

SOD is difficult to measure because it requires sealing a test chamber on the river bottom to measure DO without disturbing the sediments. As a result, only recently have the instruments been built and careful measurements made of SOD in the Jordan River. Goel and Hogsett (2009, 2010) successfully constructed and deployed SOD chambers at several sites on the Jordan River during 2009 and 2010, including seven sites downstream of 2100 South. They measured SOD rates between 0.84 g/m^2/day below 1700 South (within a mile of turbulence created where the lower Jordan River is diverted from the bottom of the river at the diversion to the Surplus Canal) and 3.37 g/m^2/day (downstream of the SDWTP; Table D.6). Of particular interest is that some winter rates were higher than summer rates. Since SOD should increase with warmer water, this indicates either substantial variability in measurements or potential additional OM loading in late fall or early winter. The average SOD in the lower Jordan River for all seasons, and unadjusted for temperature, was approximately 1.7 g/m^2/day.

There is other supporting evidence of conditions that would result in a large SOD component contributing to low DO in the lower Jordan River. Settling of OM is suggested by chlorophyll-a and diurnal DO studies that indicate a substantial amount of suspended algae upstream of the lower Jordan River section (Section D.5), and VSS:TSS ratios that demonstrate a substantial source of suspended OM even in the middle reaches of the river (Figure D.8). The potential for settling of suspended matter is high due to the shallow gradient of the river below 2100 South. Moreover, because the Surplus Canal diverts most of the total flow at 2100 South, the lower Jordan River slows in velocity. Past researchers have reported that bottom sediments are composed primarily of silts and fine sands that have a higher affinity for OM than coarser substrates (BioWest 1987).

Table D.6. SOD in lower Jordan River, 2009 and 2010. (Goel and Hogsett 2010)

Site	River Mile	Measured SOD_T (g/m^2/day)			
		Summer 2009	Winter 2010	Spring 2010	Summer 2010
Legacy Nature Preserve NE	4.9	1.66, 2.87	3.03	2.64	3.37
Legacy Nature Preserve SW Site	5.1	2.91			
Legacy Nature Preserve Upper Site	5.0	2.19	1.55	3.27	
DWQ Building (former)	11.0	1.7	1.15	3.18	1.84
900 South (North)	13.0	1.29	2.04	1.66	
900 South (South)	13.1	1.53	0.92	0.92	
1700 South	15.0	0.84	1.45	1.82	

The measurements of SOD reported above indicate rates that are equivalent to SOD in other similar rivers. For example, Rounds and Doyle (1997) measured SOD in the Tualatin River in Oregon, a river very similar to the Jordan River in the following respects:

- 712 mi^2. watershed (Jordan River watershed approximately 856 mi^2).
- 302,000 population (Salt Lake County approximately 970,000 in 2005).
- 200 cfs summer (lower Jordan River mean monthly flows 190–320 cfs)
- Channel 50 ft. wide, slope 1.3 ft/mi (lower Jordan River bottom width 35–45 ft and 0.9–1.7 ft/mi).

SOD in the Tualatin was measured at 0.6–4.4 g/m^2/day, with an average of 2.3 g/m^2/day, very similar to rates measured by Goel. Comparing the physical reaeration rates to these SOD values of approximately 1.7 mg/L between 2100 South and Burton Dam shows that SOD alone could account for over half of the potential physical reaeration.

It also appears likely that in the lower Jordan River flow velocities are high enough to occasionally resuspend the bottom sediments, exposing them to aerobic bacterial decomposition, further reducing DO through BOD. Figure D.9 shows Hjulstrøm's diagram, which plots two curves representing (1) the minimum stream velocity required to erode sediments of varying sizes from the stream bed based on a flow depth of 1 meter, and (2) the minimum velocity required to transport sediments of varying sizes. Notice that for coarser sediments (sand and gravel) it takes only a slightly higher velocity to erode particles than it takes to continue to transport them. For small particles (clay and silt) considerably higher velocities are required for erosion than for transportation due to cohesion resulting from electrostatic attraction. Surface flow velocities would need to be greater at depths that exceed 1 meter in order to maintain an equivalent erosive force at the channel bottom.

Stantec (2006b) modeled the mean hydraulic depth of the lower Jordan River at 0.8 to 1.1 meters, and velocities of 30–45 cm/sec at flows of 200 cfs, approximately the average flow of the lower Jordan River. A comparison of these findings to Hjulstrøm's diagram shows that velocities in the Jordan River would be capable of eroding a wide range of particle sizes, from silts to coarse sands and, once disturbed, transporting particles ranging from clays to small pebbles.

In short, there are sources of OM both from upstream and from algal growth within the lower Jordan River. Some of this OM would be expected to settle out at the lower flows in the lower Jordan River and contribute to a significant SOD. With even small increases in water velocities, these sediments could then be resuspended to contribute to BOD in the water column or resettle to increase the SOD in segments further downstream.

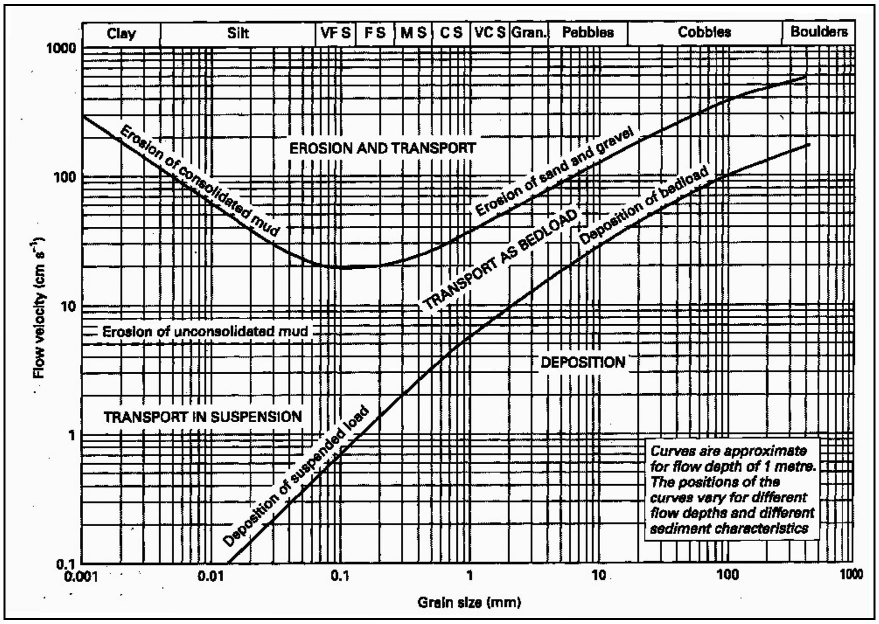

Figure D.9. Hjulstrøm's diagram showing flows necessary to transport different particle sizes.

D.5 ALGAL GROWTH AND NIGHTTIME CONSUMPTION OF DO

The fourth major factor influencing DO in the lower Jordan River is the growth of phytoplankton – suspended algae – facilitated by dissolved nutrients and sunlight.

D.5.1 PLANT PHOTOSYNTHESIS AND RESPIRATION – ALGAL EFFECTS

Plant photosynthesis produces diurnal DO swings, necessitating measurements more frequent than occasional grab samples. In order to obtain a better understanding of plant photosynthesis effects, diurnal measurements of DO, pH, and temperature were made using Troll 9000 automated sensors at various sites along the Jordan River for multiple days in June 2006, August 2006, October 2006, February–March 2007, September 2007, and August 2009. Table D.7 shows the months when data was gathered at each site.

Hourly measurements of DO taken in June, August, and October 2006, February–March 2007, and August 2009 are shown in Figures D.10–D.14 for sites on the lower Jordan River, and in Figures D.15 and D.16 for sites on the upper Jordan River. Diurnal data collected in September 2007 was presented previously in Chapter 1.

Diurnal patterns evident in these plots of DO concentrations provide compelling evidence of the effect of phytoplankton in the lower Jordan River. In summer months, DO concentrations commonly rise during the day and fall at night, consistent with photosynthesis (oxygen production) dominating during daytime hours and respiration (oxygen depletion) dominating during the night. Further, diurnal peaks occur in late afternoon, consistent with a photosynthetic response to maximum solar radiation. By October, when light levels have declined, DO swings at the most downstream stations in the lower Jordan River are irregular and decoupled from solar patterns.

Table D.7. Synoptic monitoring events.

Station	Jun 2006		Aug 2006		Oct 2006		Feb–Mar 2007		Sep 2007		Aug 2009	
	Diurnal[1]	Wet	Diurnal[1]	Wet	Diurnal[1]	Wet	Diurnal[1]	Wet	Diurnal[1]	Wet	Diurnal[1,2]	Wet
Main stem Jordan River												
Utah Lake	x	No data	x	x	x	x	x	x	x	x	x	x
Bangerter	x		x	x	x	x	x	x	x	x	x	x
9000 South	x		x	x	x	x	x	x	x	x	x	x
3900/4100 South[3]	x		x	x	x	x	x	x	x	x	x	x
2100 South	x		x	x		x	x	x	x	x	x	x
1700 South			x	x	x	x		x		x	x	x
North Temple						x		x		x		x
500 North	x		x	x	x	x	x	x	x	x	x	x
1800 North	x											
2600 North						x		x				x
Cudahy	x		x	x	x	x	x	x	x	x	x	x
Burnham			x	x	x	x	x	x	x	x	x	x
Tributaries												
LCC		No data		x		x		x		x		x
BCC				x		x		x		x		x
Mill Creek				x		x		x		x		x
1300 South				x		x		x		x		x
City Creek				x								x
Wastewater Treatment Plant Discharges												
SVWRF				x				x		x		x
CVWRF				x				x		x		x
SDWTP				x				x		x		x

[1] "Diurnal" = automated hourly measurements of DO, temperature, pH; "Wet" = grab samples also taken for measurements of BOD-carbonaceous, ScBOD-5, TSS, volatile TSS, alkalinity, nitrite, nitrate, orthophosphate, ammonia nitrogen, total Kjeldahl nitrogen, nitrogen, Total P. No Wet data was collected in June 2006.
[2] Data includes Miller (2010a) where possible.
[3] 3900 South and 4100 South are considered to have the same water quality values. 4100 South was monitored in June and August of 2006 and for diurnal data in August 2006; all other data was taken at 3900 South.

Phytoplankton populations are prevalent in all of the Jordan River, and diurnal DO patterns are evident as far upstream as Utah Lake. These indicate a robust algal biomass and, ultimately, loads of OM available for bacterial decomposition.

There are some interesting differences between upstream and downstream diurnal patterns. In the lower Jordan River, the magnitude of the diurnal cycles among sites is very similar in June, but by August the diurnal effect is largest near the 2100 South monitoring site with smaller effects further downstream at Cudahy Lane. This is consistent with typically higher Total P concentrations at the 2100 South site providing a more conducive environment for algal growth as shown in Table D.8. However, as discussed above, P is apparently not limiting to algal growth in this section of the river (Baker 2010a), while light attenuation due to increased suspended OM appears to limit periphyton growth in the lower reaches. This may explain the observed reductions in diurnal cycles between these two sites.

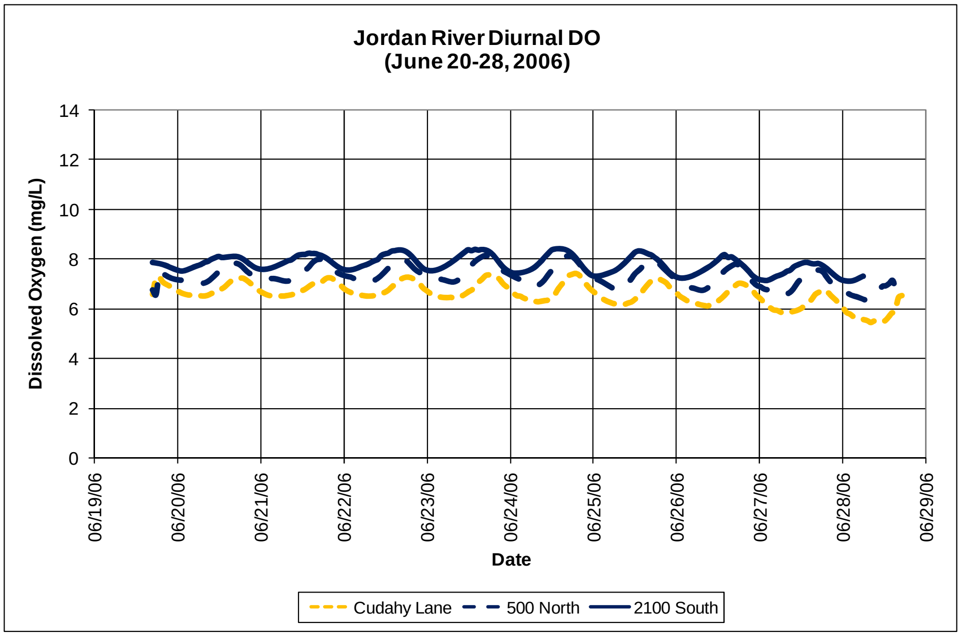

Figure D.10. Diurnal DO concentrations in the lower Jordan River in June 2006 (dates indicate midnight of day beginning).

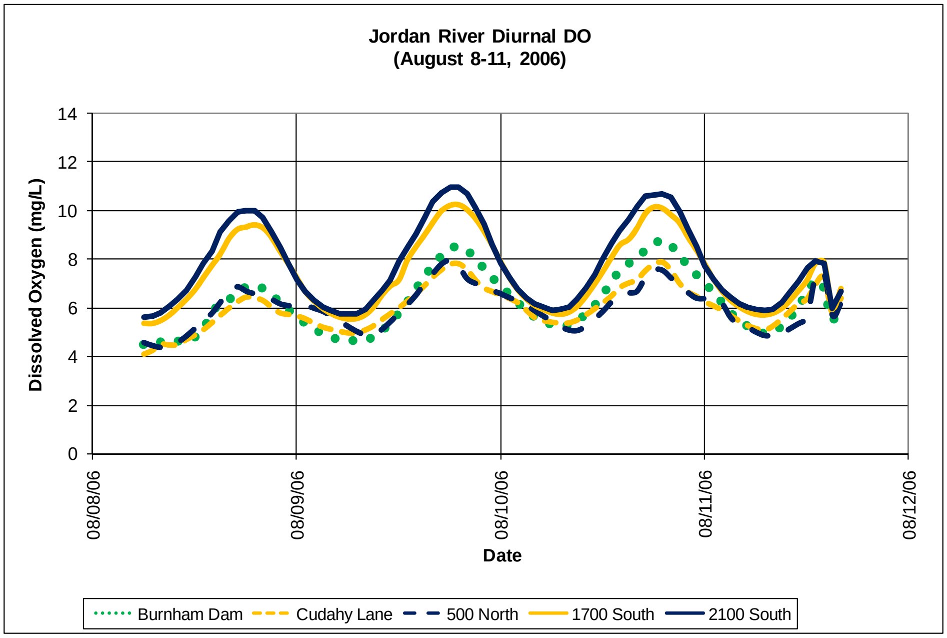

Figure D.11. Diurnal DO concentrations in the lower Jordan River in August 2006 (dates indicate midnight of day beginning).

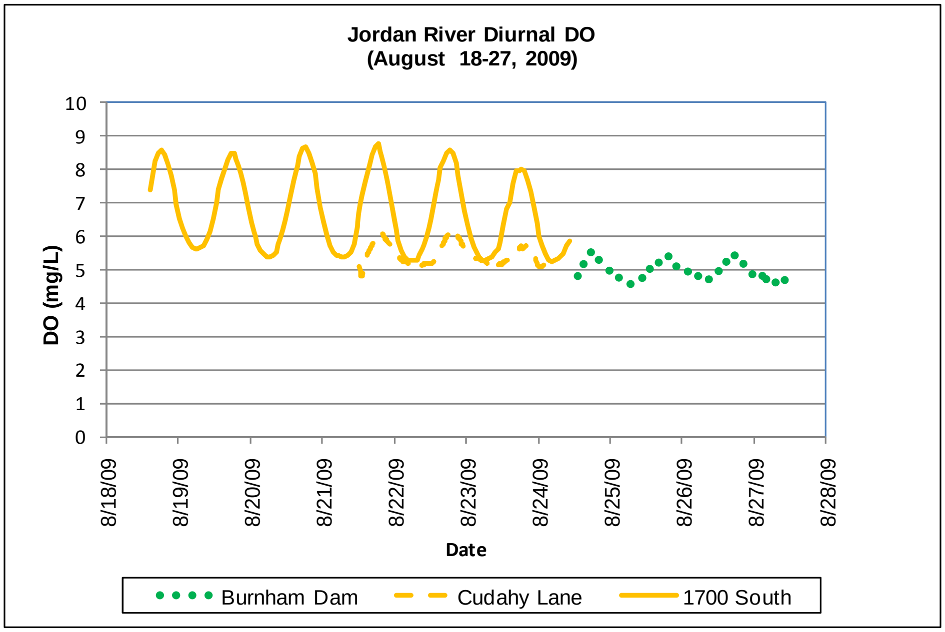

Figure D.12. Diurnal DO concentrations in the lower Jordan River in August 2009 (dates indicate midnight of day beginning).

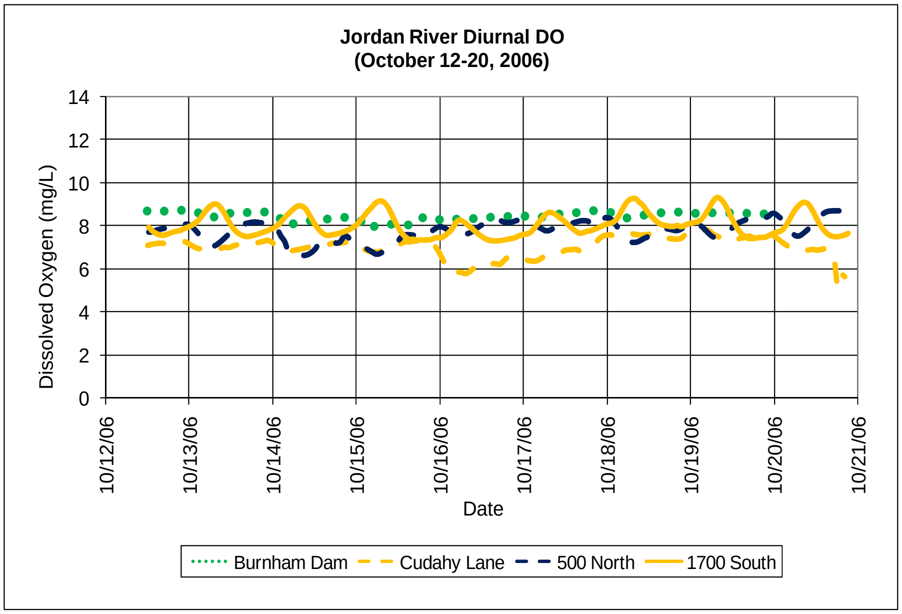

Figure D.13. Diurnal DO concentrations in the lower Jordan River in October 2006 (dates indicate midnight of day beginning).

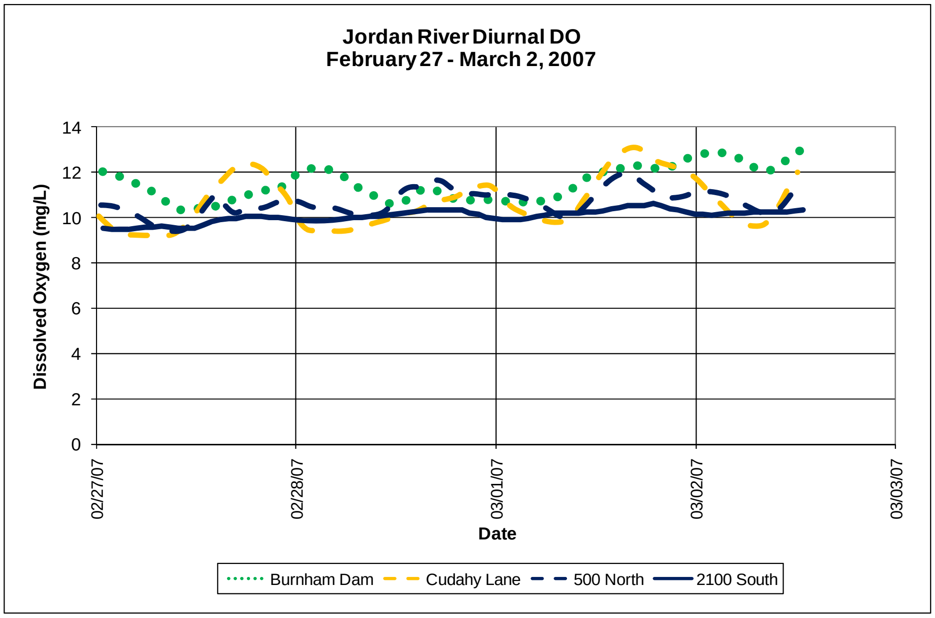

Figure D.14. Diurnal DO Concentrations in the lower Jordan River in February–March 2007 (dates indicate midnight of day beginning).

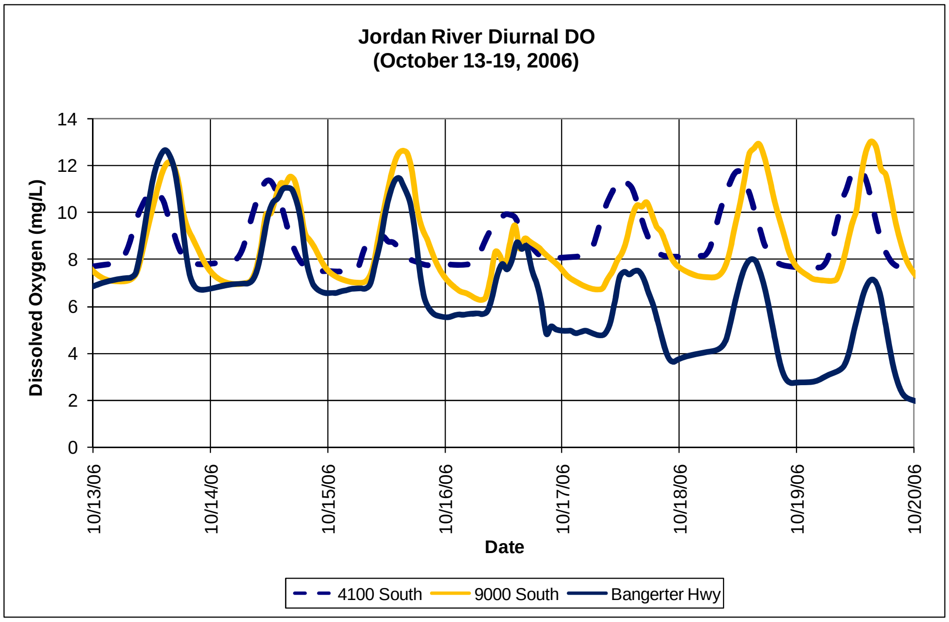

Figure D.15. Diurnal DO concentrations in the upper Jordan River in October 2006 (dates indicate midnight of day beginning; drift at Bangerter Highway likely a probe malfunction, but still demonstrates a robust diurnal phenomenon).

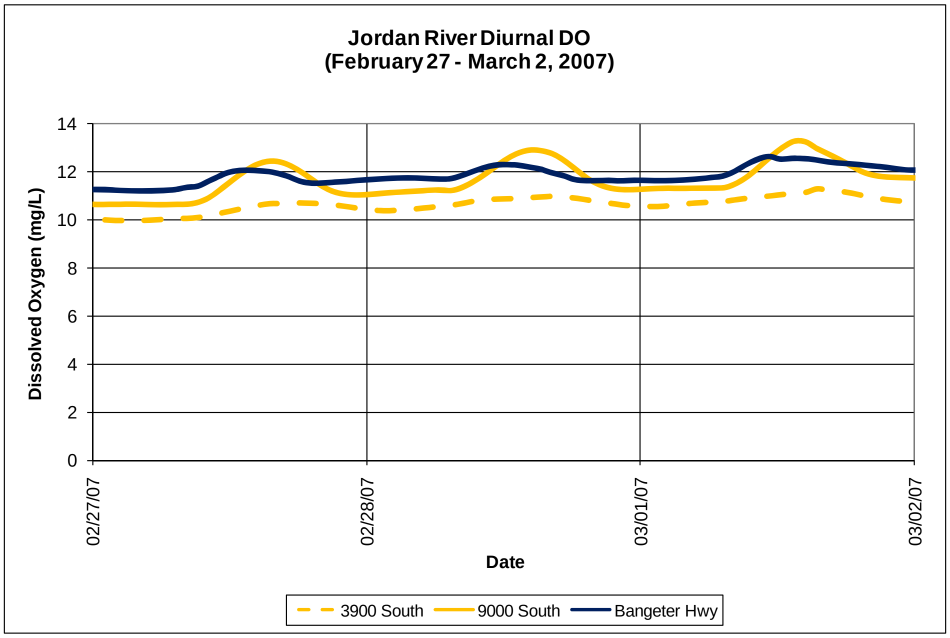

Figure D.16. Diurnal DO concentrations in the upper Jordan River in February–March 2007 (dates indicate midnight of day beginning).

Table D.8. Mean monthly Total P (mg/L) for 2100 South and Cudahy Lane on the lower Jordan River (1995–2005).

Month	Total P 2100 South (4992320)	Sample size	Total P Cudahy Lane (4991820)	Number
Jan	1.09	12	0.75	3
Feb	0.96	7	0.57	2
Mar	0.63	10	0.43	3
Apr	0.72	9	0.46	3
May	0.70	11	0.52	6
Jun	0.83	11	0.63	8
Jul	1.15	9	0.87	5
Aug	1.10	5	0.79	2
Sep	1.56	3	0.90	1
Oct	0.74	5	0.77	1
Nov	1.03	8	0.77	1
Dec	1.13	3	0.64	2

Stations above 2100 South show a distinct diurnal pattern of DO into October, which is dampened but still evident even into February. (The gradually declining pattern for Bangerter Highway is probably due to a problem with the DO part of the probe, as the pH for that probe did not exhibit any deterioration, but it still illustrates a robust diurnal pattern.)

D.5.2 Estimates of Algal Organic Matter

Fluctuations in diurnal DO concentrations establish that algal growth is robust throughout the Jordan River. Since algae have a relatively short life cycle, substantial portions of these algal populations die and contribute to suspended OM in downstream segments of the lower Jordan River.

Algal biomass can be estimated from concentrations of chlorophyll-a, a pigment of photosynthesis that generally represents 1–2 percent of total algal biomass. Direct measurements of chlorophyll-a from the phytoplankton sampled in August and October of 2006 are presented in Figure D.17 and show concentrations for several sites along the Jordan River between Utah Lake and Burnham Dam.

Utah Lake is a major source of algae for the Jordan River. In August, chlorophyll-a concentrations increase to almost 85 µg /L at Bangerter Highway but drop to less than 30 µg/L at 9000 South, then rise again slightly after inflows from Big and Little Cottonwood canyons before declining steadily and leveling off at approximately 25 µg/L in the lower Jordan River. A final small increase occurs at Burnham Dam, just before the river empties into a system of large ponds managed by the Burnham Duck Club that ultimately discharge to Farmington Bay. In October chlorophyll-a concentrations are not only lower overall, averaging around 10 µg /L, but changes in concentrations are much less pronounced, consistent with lower light levels and smaller DO fluctuations.

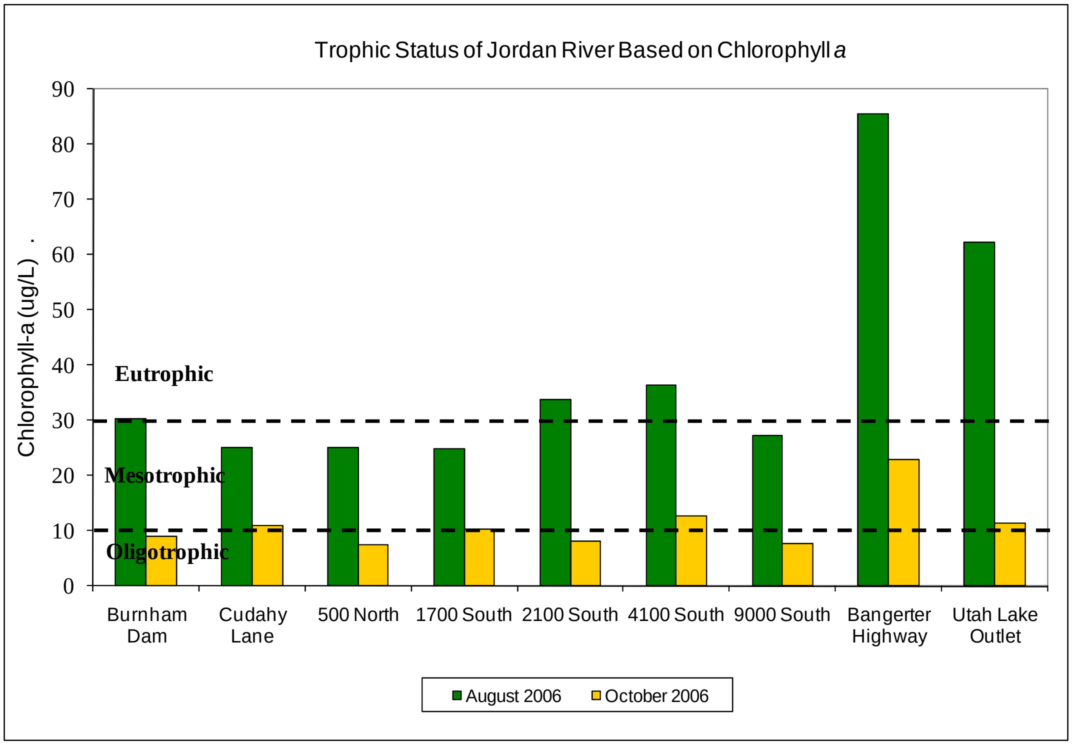

Figure D.17. Trophic status (Dodds et al. 1998) of Jordan River based on synoptic measurements of Chlorophyll-a collected during 2006.

More recent research has characterized the algae of the Jordan River in more detail. Rushforth and Rushforth (2009a) measured biomass as well as species composition and abundance of phytoplankton in the water column at 20 sites on the Jordan River and its tributaries between July and October 2009. In July, phytoplankton biomass was highest at the Utah Lake outlet and, with the exception of a small increase between 7800 South and 6400 South, declined steadily all the way to Burnham Dam. Concentrations at the Utah Lake outlet were similar in August, but declined dramatically by 9000 South and stayed at this level to Burnham Dam, except for a slight increase at 900 South. Rushforths' summary graph is reproduced as Figure D.18 below.

In June, species of phytoplankton in the Jordan River were dominated by *Chlorophyta* (green algae) and *Bacillariophyta*. By July, however, species were dominated by *Cyanophyta* taxa (blue-green algae), a group well adapted to open water but typically less well suited to riverine environments. By August, species composition had shifted slightly but was still dominated by *Cyanophyta* taxa. The dominance of *Cyanophyta* points to Utah Lake as the source of most of the algae in the Jordan River during late summer. Although other taxa should be more competitive in the riverine environment, they probably do not have time to replace the dying *Cyanophyta* in the approximately 3–4 days of travel time from Utah Lake to the Great Salt Lake.

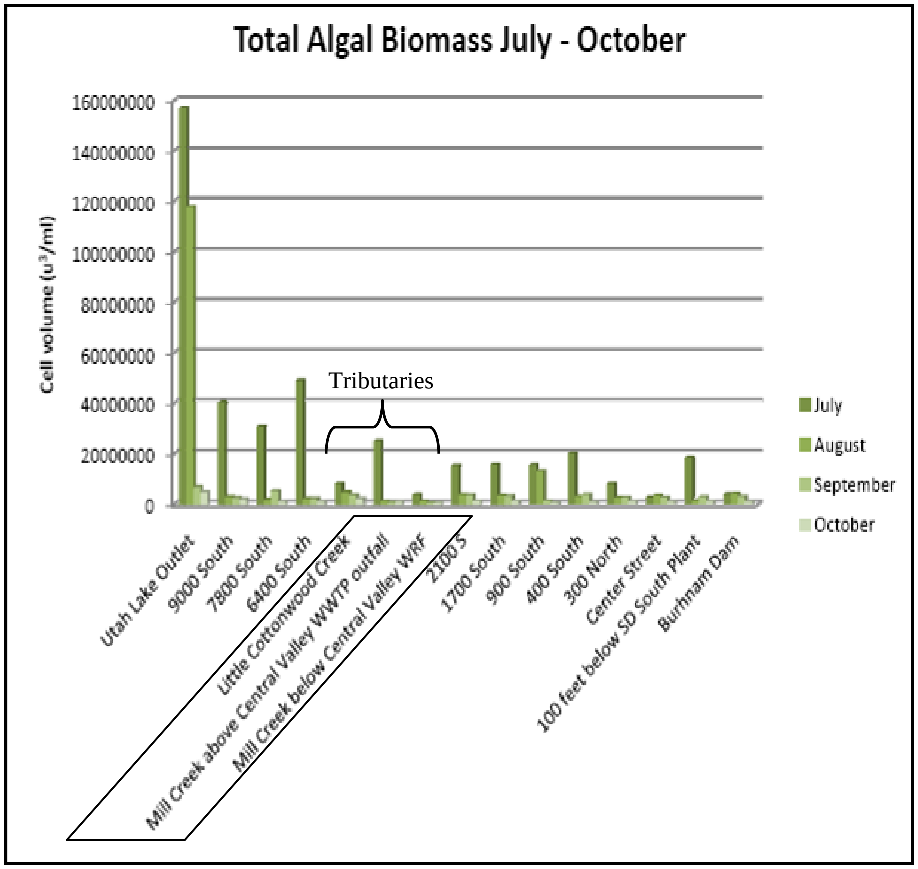

Figure D.18. Algal biomass by site, Jordan River July, August, September, and October 2009. (Reproduced from Figure 16 in Rushforth and Rushforth 2009b.)

Rushforth and Rushforth also analyzed periphyton from the bottom of the Jordan River for species composition. They found very little evidence of phytoplankton species in the periphyton of the lower Jordan River, indicating that the algae senescing in the upper and middle parts of the Jordan River stay suspended in the water column. This could very likely be the cause of light limitation below 2100 South noted by Baker (2010a).

D.5.3 Limits on Algal Growth

One means of evaluating nutrient limitation for algal growth is to calculate the ratio of Total N:P. Ideal ratios of N:P for algal growth are 10:1 or greater. Chapra (1997) considers an N:P ratio in water that is less than 7.2:1 nitrogen-limiting. Conversely, higher ratios would imply that phosphorus will limit growth of algae and aquatic plants.

Monitoring data collected by Utah DWQ from the lower Jordan River 1978–2005 indicate low N:P ratios. Table D.9 shows N:P ratios for three monitoring sites based on averages of available measurements of TKN, N-N, and Total P. All ratios are below the ideal N:P ratio for maximum algal growth, suggesting that N may be the limiting nutrient. This does not suggest that P is not a pollutant of concern, however, as there are many sources of additional N which could create P-limiting conditions.

Table D.9. Average N:P ratios measured at locations on the lower Jordan River (1978–2005).			
Station	**Total N (n TKN, n N-N)**	**Total P (n)**	**TN/TP Ratio**
Cudahy Lane	2.73 (139, 188)	0.92 (257)	6.22
North Temple	2.39 (22, 8)	1.32 (29)	5.40
2100 South	2.41 (21, 41)	1.19 (65)	4.90

D.6 CONCLUSION

Available data suggest that warmer summertime water temperatures account for seasonal reductions in DO but not the DO deficits observed year round in the lower Jordan River, despite positive reaeration rates of 2–4 mg/L/day. Physical characteristics such as temperature, flow, and channel morphology cannot be the sole cause of low DO concentrations in the lower Jordan River. In fact, reaeration rates in the lower Jordan River are more than double those in the reaches immediately above, where DO does not violate water quality standards. This implicates biological and inorganic processes as important in accounting for these DO deficits.

There are several biological processes that consume DO, including BOD in the water column, SOD from the bottom sediments, and diurnal fluctuations from daytime photosynthesis and nighttime respiration by algae and other aquatic plants. BOD has been measured at 3.0–5.5 mg/L over a 5-day period (Figure D.4), so it could account for half of the potential reaeration in the lower Jordan. The presence of aerobic decomposition processes occurring in the water column is also supported by substantial proportions of OM in suspended sediments (Figure D.5).

SOD also appears to be a major factor in low DO rates. Recent measurements in the lower Jordan River found SOD rates that would create an oxygen demand on the water column of over 2 mg/L/day. SOD has been measured in other rivers with characteristics similar to the Jordan River. The Tualatin River in Oregon, for example, was found to have a median SOD of 2.3 mg/L. At these rates, SOD could also consume over half of the DO provided through natural reaeration. Moreover, flows in the Jordan River are probably capable of resuspending a large proportion of these organic-rich bottom sediments, further contributing to both BOD and downstream SOD, and helping to explain why DO is lower, and DO violations are more frequent, in the lower Jordan River than upstream.

Finally, there is evidence of robust algal populations growing in the lower Jordan River, both upstream of and within the lower segments. Algae not only cause large diurnal fluctuations in DO – measured at 3–5 mg/L – but when they die they contribute to the BOD and SOD load.

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APPENDIX E. JORDAN RIVER QUAL2KW UNCERTAINTY ANALYSIS

This appendix documents a technical memorandum completed by Stantec Inc. as part of an effort to address uncertainty in QUAL2Kw model results. The full citation of the original document is included above in Appendix B as part of the work completed during the Jordan TMDL process. The full citation of other documents referenced in Appendix E can be found in the references section of the main report.

E.1 INTRODUCTION

The purpose of this appendix is to summarize the results of an uncertainty analysis of 47 parameters/inputs of the QUAL2Kw model of the Jordan River and explain the implications for the TMDL study. This memorandum will document the uncertainty analysis results of the mean and minimum dissolved oxygen levels at three locations along the Jordan River. The purpose of the uncertainty analysis is to: (1) provide a level of confidence in use of the model as a decision support tool, (2) identify sensitivity of individual parameters/inputs to overall uncertainty in the model, and (3) help define an appropriate factor of safety for the TMDL.

The 47 parameters/inputs chosen for uncertainty analysis were selected by the Utah Division of Water Quality (DWQ), Stantec and Cirrus to gain a greater understanding of their contribution to dissolved oxygen (DO) levels. Focus of the uncertainty analysis is on organic matter and other factors that greatly affect DO such as: detritus, phytoplankton, soluble carbonaceous biological oxygen demand, sediment oxygen demand and reaction rates.

E.2 METHODOLOGY

The uncertainty analysis was conducted by using YASAIw (Pelletier 2009), a program which integrates into QUAL2Kw and runs a Monte Carlo simulation. The software allows the user to specify input variables based on a given probability distribution defined by a mean value and a standard deviation. The program also allows the user to specify output variables of interest, which are used to calculate statistics and conduct the sensitivity analysis at the end of the model runs. The uncertainty analysis was performed using the calibrated model for the August 2009 synoptic survey.

The uncertainty analysis is conducted by running the QUAL2Kw model in a loop that repeats a specified number of times. For this analysis, 2,000 iterations were completed. Each time the model run is repeated, the program generates a new set of randomly varied input variables. The program records the input values and output value at the end of each run, and then repeats the process. At the end of the uncertainty analysis, the model can output histograms and probability density functions for each output variable. These plots can be used to show the mean value of the output as well as the characteristics of its variance.

The sensitivity analysis routine uses the Spearman's rank order correlation to determine the sensitivity of each input. The routine also calculates contribution to variance by squaring the rank order correlation and normalizing it to 100 percent. This analysis can be used to rank the input variables in order of significance to the final output and its variance.

Figure E.1 shows a schematic of sensitivity/uncertainty analysis. In the middle of the figure is the simulation model with its model structures, resolution levels, parameters and data inputs. On the left, are the data inputs and their random variations. On the bottom are the model parameters with their random variations. These random variations go into the model and come out in the form of an uncertainty analysis with a random distribution for each of the output variables and a sensitivity analysis with a listing of variables and a percentage of contribution.

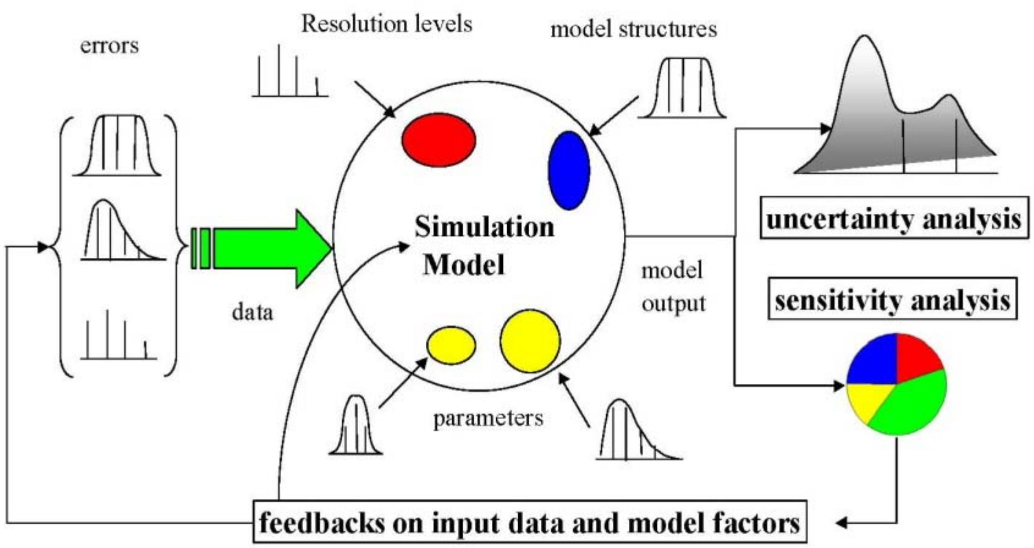

Figure E.1. Scheme for Sensitivity Analysis (Saltelli 1999)

E.3 INPUT VARIABLES

The input parameters that were set up for the uncertainty analysis were chosen based on their significance in the model calibration and their significance to dissolved oxygen levels. Inputs that were well characterized as part of the modeling process were not generally considered in the analysis. The emphasis was on parameters that have not been very well characterized and may require further study in later phases of the TMDL study.

The inputs fall into several categories including: model rate parameters, reach specific parameters, diffuse sources, point sources, headwaters and tributaries. See Tables E.1 though E.6 for a listing of the variables and their characteristics.

The model rate inputs are global parameters that control overall reaction rates in each reach. The analysis was conducted for those rate parameters that most significantly affect dissolved oxygen levels. The mean value for each rate input was the rate used in the final calibrated model. Standard deviations for these rates were set at ten percent of the mean values (See Table E.1 for model rate inputs). A typical standard deviation of ten percent was agreed upon by the Utah DWQ, Stantec and Cirrus as appropriate for calibrated rates.

Table E.1. Model Rate Inputs.						
Variable	**Dist.**	**Units**	**Mean**	**Std. Dev.**	**Min**	**Max**
Model Rate Parameters:						
Slow CBOD Oxidation	Lognormal	/day	0.20	0.02	0.00	5.00
Ammonia Nitrification	Normal	/day	2.00	0.20	0.05	3.00
Max Phytoplankton Growth Rate	Normal	/day	2.00	0.20	1.50	3.00
Max Bottom Plant Growth Rate	Lognormal	gD/m2/d or /d	50.0	5.00	50.0	200
Detritus Dissolution Rate	Normal	/day	0.10	0.05	0.05	0.50
Detritus Settling Rate	Normal	m/day	0.10	0.05	0.05	0.50

The model reach parameters are specific to each reach of the model. The reach parameters that were chosen for this analysis are: bottom algae coverage and prescribed Sediment Oxygen Demand (SOD). These parameters are believed to greatly affect dissolved oxygen levels in the stream and are not well understood. Standard deviations for these parameters were set at twenty percent of the mean values, which was agreed upon by the Utah DWQ, Stantec and Cirrus as appropriate due to the additional uncertainty associated with these inputs (See Table E.2 for model reach parameters).

Groundwater inflow into the Jordan River was one of the considerations for the QUAL2Kw model. The water quality of the groundwater is not well understood and the inputs are based on assumed values. These parameters were added to the model to see how significant the groundwater inflow influences the model output (See Table E.3).

Irrigation return flows were also considered to be sources in the model. There were two locations where these flows were considered to be significant: at 7800 South and at the Kearns-Chesterfield drain. These input water quality values were based on measured values at the point of diversion and assuming no transformations in the irrigation canal. The standard deviation for CBOD was based on 20 percent of the mean while phytoplankton used the average standard deviation for all phytoplankton measurements used as inputs to the calibrated model. Due to the lack of data available for these parameters at these locations, they were added to the sensitivity analysis to see how significant an effect the return flow water quality parameters have on the model (See Table E.4 for Irrigation Return Flows).

The headwaters conditions at Utah Lake are based on measured values and actual standard deviations. Mean values from these measurements were used for the analysis (see Table E.5 for the Headwaters at Utah Lake).

The tributaries and Publicly Owned Treatment Works (POTW) were characterized based on measured data. Actual standard deviations and mean values were used for the analysis (See Table E.6 for the Tributaries and POTW).

The water quality parameters that were of the most interest for the point sources and diffuse sources were: phytoplankton, Soluble Carbonaceous Biological Oxygen Demand (ScBOD), and detritus. All three of these parameters have the greatest effect on dissolved oxygen levels in the stream. Phytoplankton is significant for its contribution to diel DO fluctuations and changes in bioavailability of organic matter; CBOD for its overall contribution to DO demand; and detritus or Particulate Organic Matter (POM) for its longer term contribution to oxygen demand in the stream.

Table E.2. Model Reach Parameters.						
Variable	**Dist.**	**Units**	**Mean**	**Std. Dev.**	**Min**	**Max**
Reach Parameters:						
Reach 0 to 31: Bottom Algae Coverage	Normal	%	0.10	0.02	0.05	0.15
Reach 32 to 115: Bottom Algae Coverage	Normal	%	0.80	0.16	0.40	1.20
Reach 116 to 129: Bottom Algae Coverage	Normal	%	0.40	0.08	0.20	0.60
Reach 130 to 166: Bottom Algae Coverage	Normal	%	0.20	0.04	0.10	0.30
Reach 0 to 75: Prescribed SOD	Normal	gO2/m2/d	1.00	0.20	0.50	1.50
Reach 76 to 82: Prescribed SOD	Normal	gO2/m2/d	2.00	0.40	1.00	3.00
Reach 83 to 128: Prescribed SOD	Normal	gO2/m2/d	3.00	0.60	1.50	4.50
Reach 129 to 166: Prescribed SOD	Normal	gO2/m2/d	3.50	0.70	1.75	5.25

Table E.3. Groundwater Sources.						
Variable	**Dist.**	**Units**	**Mean**	**Std. Dev.**	**Min**	**Max**
Diffuse Sources:						
Groundwater: Ammonia	Normal	ug/L	500	100		
Groundwater: CBOD Slow	Normal	mgO2/L	2.00	0.40		

Table E.4. Irrigation Return Flows.						
Variable	**Dist.**	**Units**	**Mean**	**Std. Dev.**	**Min**	**Max**
Point Sources - Irrigation Return Flows:						
7800 South Drain: CBOD Slow	Normal	mgO2/L	0.51	0.10	0.00	0.82
7800 South Drain: Phytoplankton	Normal	ug/L	0.00	4.09	0.00	12.3
Kearns-Chesterfield Drain: CBOD Slow	Normal	mgO2/L	0.51	0.10	0.00	0.82
Kearns-Chesterfield Drain: Phytoplankton	Normal	ug/L	0.00	4.09	0.00	12.3

Table E.5. Headwaters at Utah Lake.						
Variable	**Dist.**	**Units**	**Mean**	**Std. Dev.**	**Min**	**Max**
Headwaters:						
Headwaters at Utah Lake Phytoplankton	Normal	ugA/L	26.5	9.40	0.00	54.7
Headwaters at Utah Lake Detritus (POM)	Normal	mgD/L	4.30	0.70	0.00	6.40
Headwaters at Utah Lake CBOD Slow	Normal	mgO2/L	1.35	1.22	0.00	5.01

Table E.6. Tributaries and Publicly Owned Treatment Works (POTWs).						
Variable	**Dist.**	**Units**	**Mean**	**Std. Dev.**	**Min**	**Max**
Point Sources - Tributaries:						
South Valley WWTP Phytoplankton	Normal	ugA/L	1.60	0.60	0.0	3.40
South Valley WWTP Detritus (POM)	Normal	mgD/L	3.00	0.70	0.0	5.10
South Valley WWTP CBOD Slow	Normal	mgO2/L	2.28	0.46	0.0	3.66
Little Cottonwood Creek Phytoplankton	Normal	ugA/L	25.7	18.6	0.0	81.5
Little Cottonwood Creek Detritus (POM)	Normal	mgD/L	4.90	0.90	0.0	7.60
Little Cottonwood Creek CBOD Slow	Normal	mgO2/L	3.48	1.54	0.0	8.10
Big Cottonwood Creek Phytoplankton	Normal	ugA/L	22.0	4.80	0.0	36.4
Big Cottonwood Creek Detritus (POM)	Normal	mgD/L	5.30	0.50	0.0	6.80
Big Cottonwood Creek CBOD Slow	Normal	mgO2/L	1.18	1.07	0.0	4.39
Central Valley WWTP Phytoplankton	Normal	ugA/L	2.70	1.00	0.0	5.70
Central Valley WWTP Detritus (POM)	Normal	mgD/L	4.80	0.70	0.0	6.90
Central Valley WWTP CBOD Slow	Normal	mgO2/L	2.61	0.74	0.0	4.83
1300 S. Conduit Phytoplankton	Normal	ugA/L	10.5	0.90	0.0	13.2
1300 S. Conduit Detritus (POM)	Normal	mgD/L	1.50	0.40	0.0	2.70
1300 S. Conduit CBOD Slow	Normal	mgO2/L	1.56	0.70	0.0	3.66
N. Temple Conduit Phytoplankton	Normal	ugA/L	0.60	0.50	0.0	2.10
N. Temple Conduit Detritus (POM)	Normal	mgD/L	1.00	0.60	0.0	2.80
N. Temple Conduit CBOD Slow	Normal	mgO2/L	3.49	1.37	0.0	7.60
South Davis South WWTP Phytoplankton	Normal	ugA/L	8.20	0.50	0.0	9.70
South Davis South WWTP Detritus (POM)	Normal	mgD/L	4.40	0.80	0.0	6.80
South Davis South WWTP CBOD Slow	Normal	mgO2/L	3.91	1.06	0.0	7.09
Mill Creek above Central Valley Phytoplankton	Normal	ugA/L	8.30	0.50	0.0	9.80
Mill Creek above Central Valley Detritus (POM)	Normal	mgD/L	2.20	0.80	0.0	4.60
Mill Creek above Central Valley CBOD Slow	Normal	mgO2/L	0.81	0.16	0.0	1.30

E.4 OUTPUT VARIABLES

Dissolved oxygen was chosen as the output constituent of interest because of its importance as a final end-point for load allocations. The three output locations were chosen as a way to look at how DO varies spatially along the lower Jordan River and to see if changes in input values affect certain areas of the river more than others. Minimum and mean DO were chosen to determine what the effects of variation have on overall DO in the river over the course of the model run and the actual minimum DO, which is of direct interest for load allocation purposes (See Table E.7 for a listing of the six output variables).

Table E.7. Output Variables.	
Forecasts of Water Quality	**Units**
minimum DO at Burnham Dam	mg/L
mean DO at Burnham Dam	mg/L
minimum DO at Cudahy Lane	mg/L
mean DO at Cudahy Lane	mg/L
minimum DO at 2100 South	mg/L
mean DO at 2100 South	mg/L

E.5 RESULTS AND DISCUSSION

Frequency histograms were developed for this analysis to show the extent of variation for each output variable. Figures E.2 through E.7 were developed based on a bin size of 0.01 and provide a frequency distribution for the data. Each histogram was fit with a lognormal probability density function to determine a mean value and calculate a 90 percent Confidence Interval (CI). This information is useful because it quickly characterizes the variation of the output. The mean value is the most likely value of the output and the 90 percent confidence interval is the range of values for which there is a 90 percent chance that the simulation output will be contained by.

The frequency and confidence interval information could be used as part of the TMDL study to select an appropriate safety factor for load allocations. The analysis can be used to ensure that even though model inputs and outputs are uncertain, the 90 percent confidence interval value for dissolved oxygen in the lower Jordan River is still above the water quality standard.

Below each histogram is a listing of the top ten most sensitive input variables and the relative contribution to variance for each of the outputs is provided below the histograms. These tables are useful because they characterize the inputs that are most significant. For the purposes of modeling, variables that come near the top of the sensitivity list are those that need additional study and characterization.

The DO values presented in the report reflect values during the model period in August of 2009. DO values for other dates and years will reflect the conditions in those time periods.

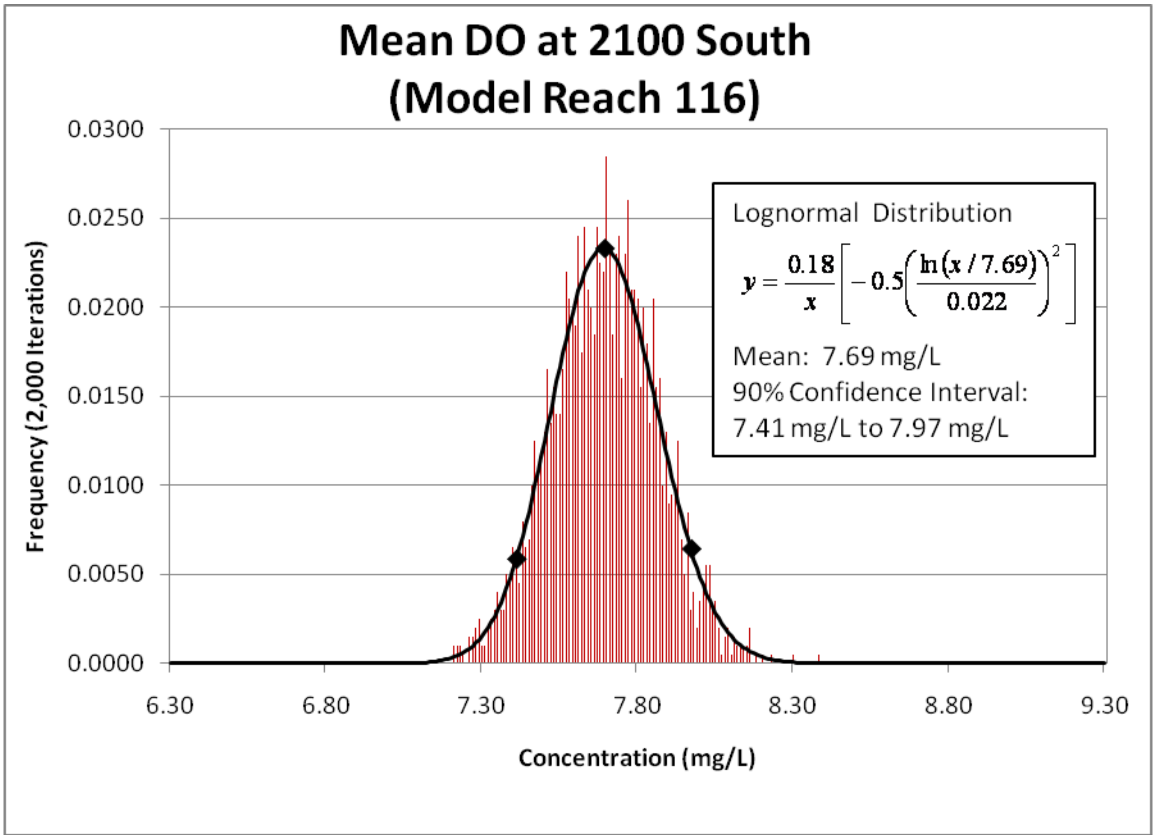

Figure E.2. Frequency distribution of mean DO at 2100 South.

These results indicate the contribution that each parameter has to the variance of mean DO at 2100 South. The ten greatest contributors are included in Table E.8 below:

Table E.8. Mean DO at 2100 South Sensitivity Analysis.

Assumption	Correlation *	Contribution to Variance
Reach 32 to 115: Bottom Algae Coverage	0.8207	71.14%
Reach 83 to 128: Prescribed SOD	-0.4349	20.00%
Max Bottom Plant Growth Rate	0.2010	4.28%
Headwaters at Utah Lake Phytoplankton	0.0870	0.84%
Max Phytoplankton Growth Rate	0.0770	0.63%
Ammonia Nitrification	-0.0725	0.56%
Slow CBOD Oxidation	-0.0478	0.25%
Headwaters at Utah Lake Detritus (POM)	-0.0366	0.17%
Headwaters at Utah Lake CBOD Slow	-0.0237	0.14%
N. Temple Conduit CBOD Slow	-0.0118	0.14%

*Spearman’s rank correlation coefficient is a measure of statistical dependence between two variables. The sign of the correlation indicates the direction of association between the independent variable and the dependent variable. A value of zero indicates that there is no tendency for the dependent variable to either increase or decrease when the independent variable changes.

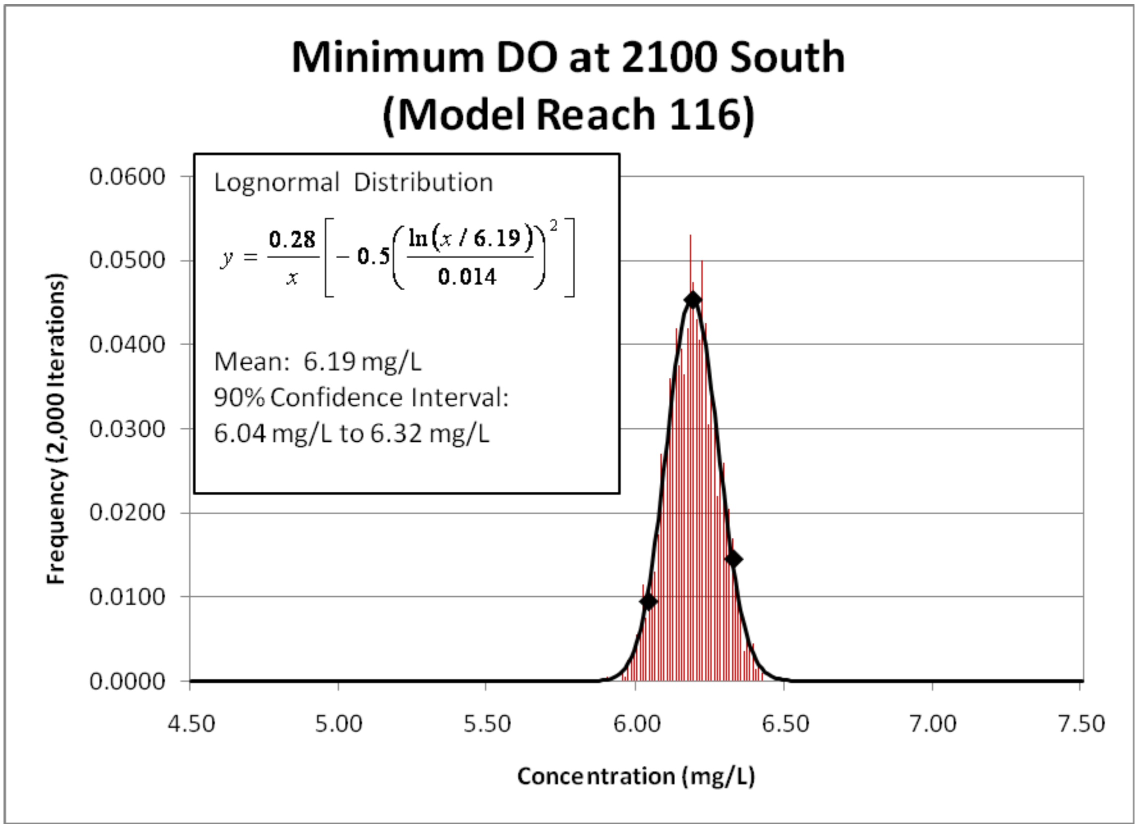

Figure E.3. Frequency distribution of minimum DO at 2100 South.

These results indicate the contribution that each parameter has to the variance of minimum DO at 2100 South. The ten greatest contributors are included in Table E.9 below:

Table E.9. Minimum DO at 2100 South Sensitivity Analysis.

Assumption	Correlation	Contribution to Variance
Reach 83 to 128: Prescribed SOD	-0.9509	89.30%
Reach 32 to 115: Bottom Algae Coverage	-0.1886	3.52%
Ammonia Nitrification	-0.1543	2.46%
Detritus Settling Rate	-0.1156	1.32%
Max Bottom Plant Growth Rate	-0.0891	0.81%
7800 South Drain: Phytoplankton	-0.0512	0.34%
Headwaters at Utah Lake CBOD Slow	-0.0529	0.28%
Big Cottonwood Creek CBOD Slow	-0.0164	0.27%
Central Valley WWTP Detritus (POM)	-0.0400	0.18%
Kearns-Chesterfield Drain: CBOD Slow	0.0355	0.15%

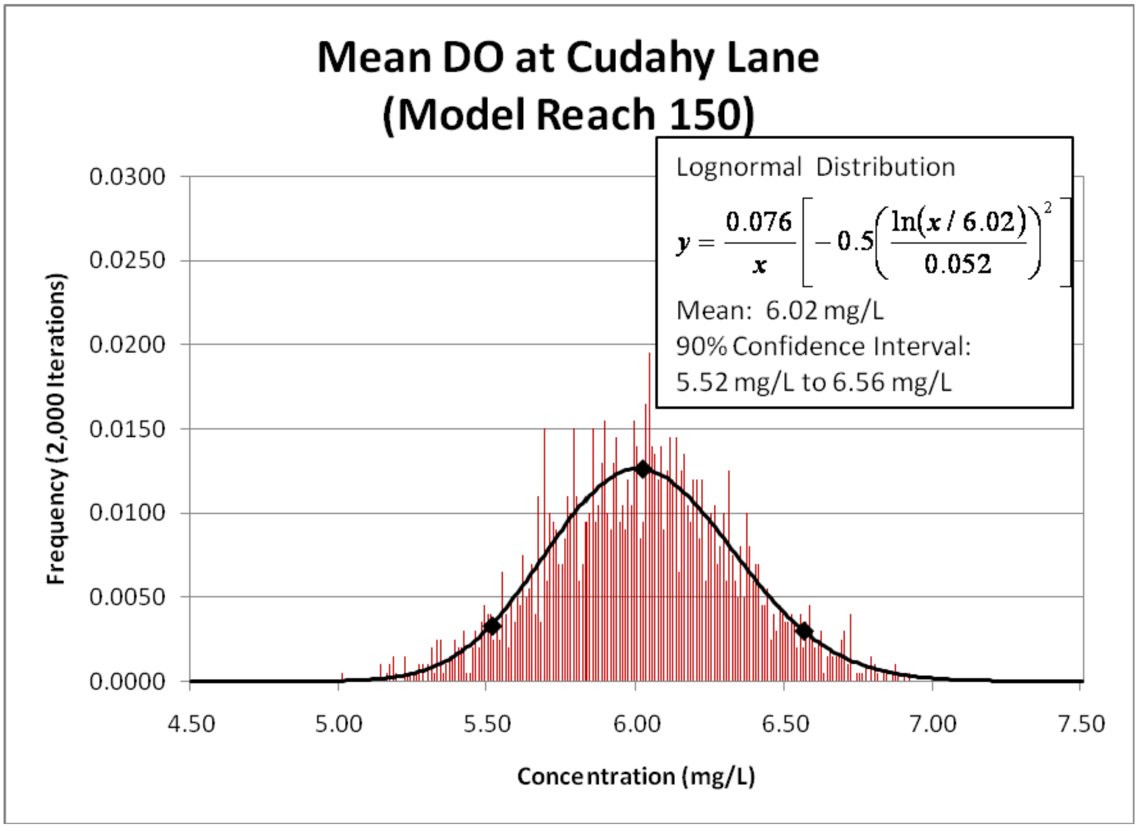

Figure E.4. Frequency distribution of mean DO at Cudahy Lane.

The results indicate the contribution that each parameter has to the variance of mean DO at Cudahy Lane. The ten greatest contributors are included in Table E.10 below:

Table E.10. Mean DO at Cudahy Lane Sensitivity Analysis.

Assumption	Correlation	Contribution to Variance
Reach 129 to 166: Prescribed SOD	-0.7573	60.33%
Reach 130 to 166: Bottom Algae Coverage	0.3436	12.42%
Reach 116 to 129: Bottom Algae Coverage	0.3403	12.22%
Max Bottom Plant Growth Rate	0.2071	4.54%
Max Phytoplankton Growth Rate	0.1661	2.91%
Headwaters at Utah Lake Phytoplankton	-0.1169	1.48%
Reach 83 to 128: Prescribed SOD	0.1157	1.42%
Ammonia Nitrification	-0.0779	0.66%
Groundwater: Ammonia	-0.0699	0.54%
Detritus Settling Rate	-0.0083	0.35%

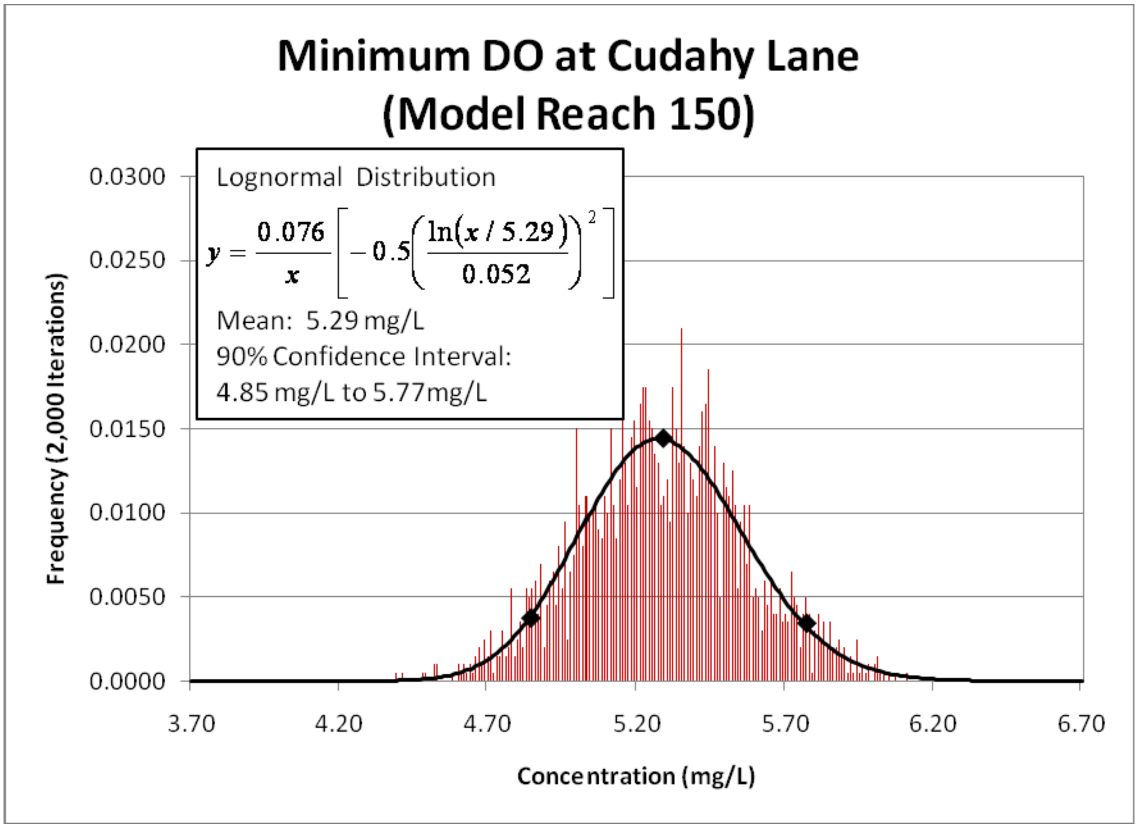

Figure E.5. Frequency distribution of minimum DO at Cudahy Lane.

The results indicate the contribution that each parameter has to the variance of minimum DO at Cudahy Lane. The ten greatest contributors are included in Table E.11 below:

Table E.11. Minimum DO at Cudahy Lane Sensitivity Analysis.

Assumption	Correlation	Contribution to Variance
Reach 129 to 166: Prescribed SOD	-0.8715	77.95%
Reach 116 to 129: Bottom Algae Coverage	0.3378	11.71%
Max Bottom Plant Growth Rate	0.1488	2.29%
Reach 83 to 128: Prescribed SOD	-0.1363	1.92%
Reach 130 to 166: Bottom Algae Coverage	0.1043	1.12%
Reach 32 to 115: Bottom Algae Coverage	0.0035	0.95%
Detritus Settling Rate	-0.0821	0.70%
Groundwater: Ammonia	0.0078	0.51%
Ammonia Nitrification	-0.0649	0.43%
Headwaters at Utah Lake CBOD Slow	-0.0597	0.37%

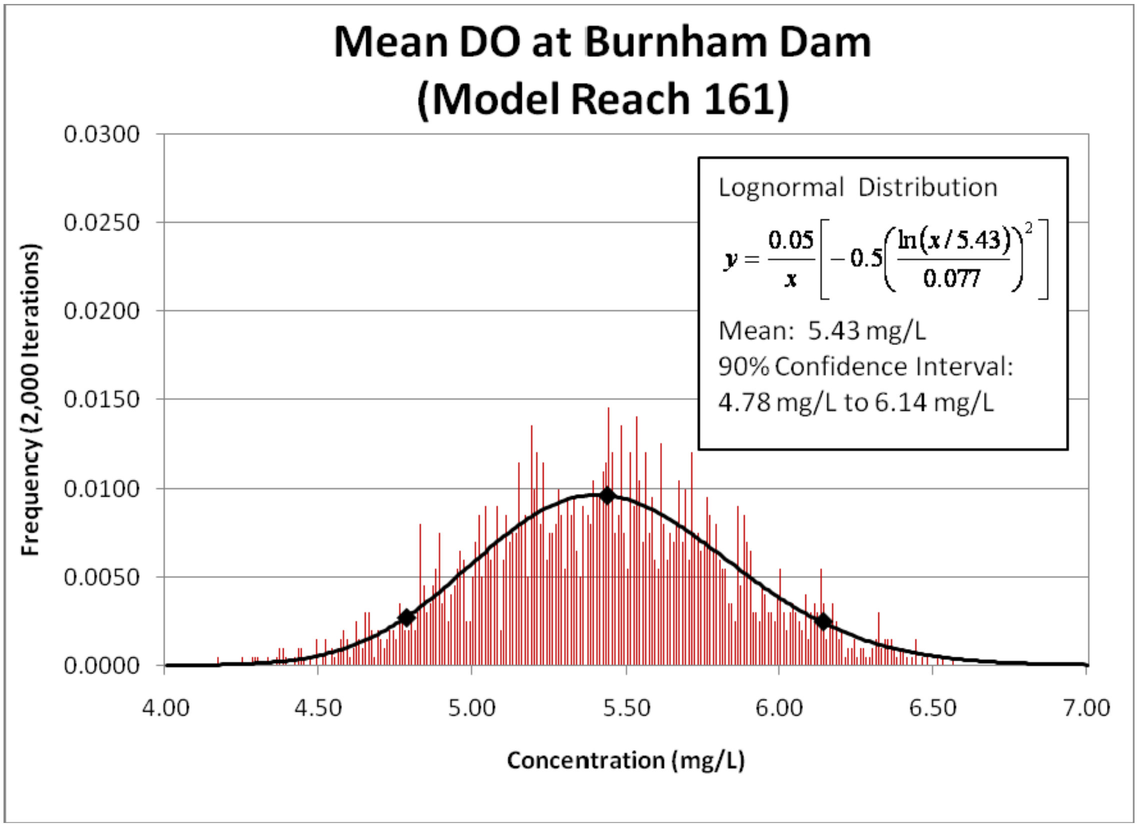

Figure E.6. Frequency distribution of mean DO at Burnham Dam.

These results indicate the contribution that each parameter has to the variance of mean DO at Burnham Dam. The ten greatest contributors are included in Table E.12 below:

Table E.12. Mean DO at Burnham Dam Sensitivity Analysis.

Assumption	Correlation	Contribution to Variance
Reach 129 to 166: Prescribed SOD	-0.7922	65.40%
Reach 130 to 166: Bottom Algae Coverage	0.3688	14.23%
Reach 116 to 129: Bottom Algae Coverage	0.2459	6.30%
Max Bottom Plant Growth Rate	0.1822	3.49%
Max Phytoplankton Growth Rate	0.1928	3.89%
Headwaters at Utah Lake Phytoplankton	0.1227	1.58%
Reach 83 to 128: Prescribed SOD	-0.0644	0.47%
Ammonia Nitrification	-0.0844	0.75%
Big Cottonwood Creek Phytoplankton	0.0593	0.37%
N. Temple Conduit CBOD Slow	-0.0029	0.32%

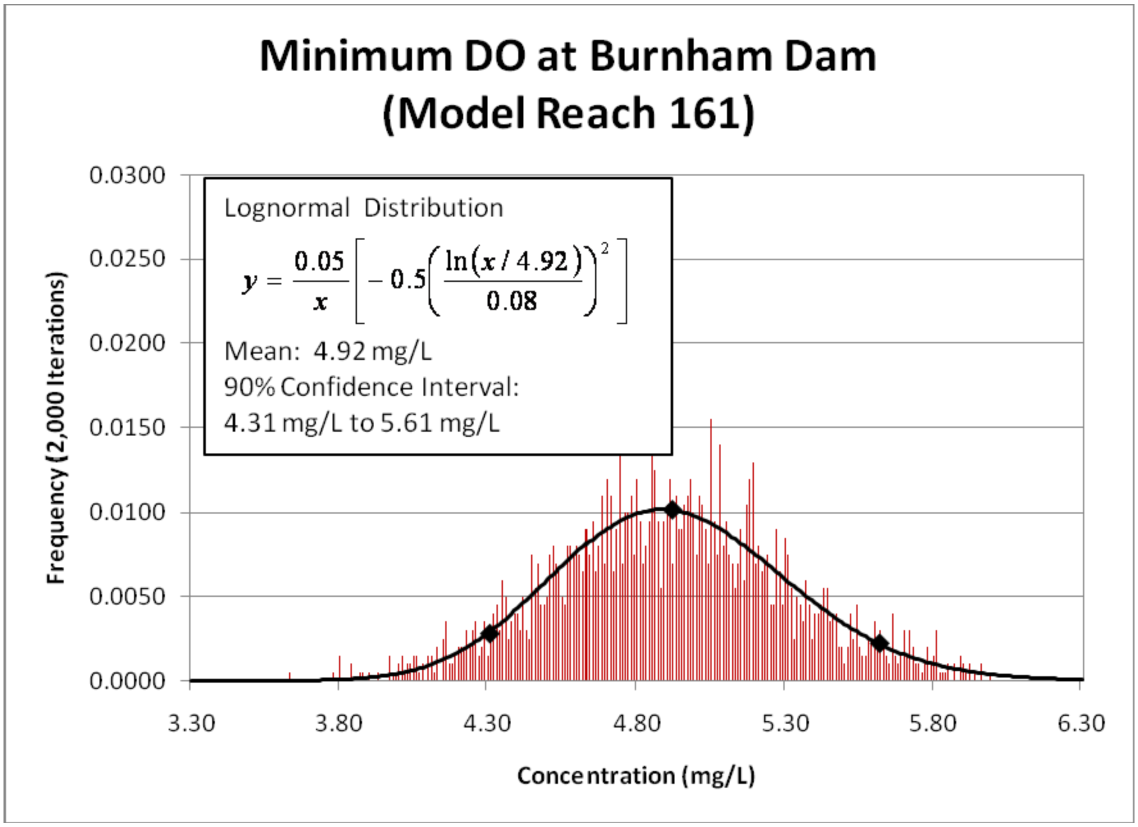

Figure E.7. Frequency distribution of minimum DO at Burnham Dam.

These results indicate the contribution that each parameter has to the variance of minimum DO at Burnham Dam. The ten greatest contributors are included in Table E.13 below:

Table E.13. Minimum DO at Burnham Dam Sensitivity Analysis.

Assumption	Correlation	Contribution to Variance
Reach 129 to 166: Prescribed SOD	-0.8307	71.55%
Reach 116 to 129: Bottom Algae Coverage	0.3739	14.50%
Reach 130 to 166: Bottom Algae Coverage	0.2156	4.85%
Max Bottom Plant Growth Rate	0.1801	3.39%
Reach 83 to 128: Prescribed SOD	-0.0880	0.81%
Max Phytoplankton Growth Rate	0.0859	0.77%
Ammonia Nitrification	-0.0732	0.56%
Detritus Dissolution Rate	-0.0622	0.40%
Detritus Settling Rate	0.0071	0.33%
Slow CBOD Oxidation	-0.0553	0.32%

E.6 CONCLUSION AND RECOMMENDATIONS

The output of the sensitivity and uncertainty analysis can be used to determine the model inputs that are most significant and need the most study and research. In each of the lists of output variables, prescribed SOD and bottom algae coverage emerge as the top two variables that affect DO. In fact, in each case these two variables contribute to over 70% of the variation on the model outputs. Table E.14 on the following page lists the important reaches in the model and shows their values of prescribed SOD and bottom algae coverage.

The variables that emerged from the 2,000 iteration sensitivity analysis as being particularly important to the model are:

- Reach 32 to 115: Bottom Algae Coverage (above Surplus Canal) – DO at Jordan River at 2100 South.
- Reach 83 to 128: Prescribed SOD (South Valley WWTP to 1300 S Conduit) – DO at Jordan River at 2100 South.
- Reach 129 to 166: Prescribed SOD (Below North Temple Conduit) – DO at Cudahy Lane and Burnham Dam.
- Reach 130 to 166: Bottom Algae Coverage (Below UP&L Diversion) – DO at Cudahy Lane and Burnham Dam.

The output of this analysis can also be used to characterize the potential DO variation due to modeling error by looking at the uncertainty histograms and confidence intervals. The mean values, 90% confidence intervals, and the percentage of the confidence interval relative to the mean are listed below. These values are only applicable for the model period during August of 2009:

- Mean DO at 2100 South:
  - Mean: **7.69 mg/L**;
  - 90% CI: **7.41 mg/L** to **7.97 mg/L (±7.3%)**
- Minimum DO at 2100 South:
  - Mean: **6.19 mg/L**;
  - 90% CI: **6.04 mg/L** to **6.32 mg/L (±4.5%)**
- Mean DO at Burnham Dam:
  - Mean: **5.43 mg/L**;
  - 90% CI: **4.78 mg/L** to **6.14 mg/L (±25.0%)**
- Minimum DO at Burnham Dam:
  - Mean: **4.92 mg/L**;
  - 90% CI: **4.31 mg/L** to **5.61 mg/L (±26.4%)**
- Mean DO at Cudahy Lane:
  - Mean: **6.02 mg/L**;
  - 90% CI: **5.52 mg/L** to **6.56 mg/L (±17.3%)**
- Minimum DO at Cudahy Lane:
  - Mean: **5.29 mg/L**;
  - 90% CI: **4.85 mg/L** to **5.77 mg/L (±17.4%)**

Table E.14. Reach Specific Parameters.

Description	Reach Number	Prescribed SOD Input Value	Bottom Algae Coverage Input Value
Utah Lake	0	1 gO2/m2/d	10%
Jordan Valley Pump Station	31	1 gO2/m2/d	10%
Turner Dam	32	1 gO2/m2/d	80%
Joint Dam	37	1 gO2/m2/d	80%
Segment 6	45	1 gO2/m2/d	80%
DS Rose Creek	48	1 gO2/m2/d	80%
Corner Canyon Creek	52	1 gO2/m2/d	80%
Proposed WWTP	55	1 gO2/m2/d	80%
Hydraulic Reach 7	59	1 gO2/m2/d	80%
Midas Creek	65	1 gO2/m2/d	80%
Willow Creek	66	1 gO2/m2/d	80%
North Jordan Canal	73	1 gO2/m2/d	80%
Dry Creek	74	1 gO2/m2/d	80%
	75	1 gO2/m2/d	80%
9000 South Conduit	76	2 gO2/m2/d	80%
Bingham Creek	81	2 gO2/m2/d	80%
Segment 5	82	2 gO2/m2/d	80%
South Valley WWTP	83	3 gO2/m2/d	80%
Segment 4	86	3 gO2/m2/d	80%
6400 South Weir	87	3 gO2/m2/d	80%
Little Cottonwood Creek	97	3 gO2/m2/d	80%
Brighton Canal	98	3 gO2/m2/d	80%
Big Cottonwood Creek	100	3 gO2/m2/d	80%
Hydraulic Reach 4	102	3 gO2/m2/d	80%
Mill Creek/Central Valley WWTP	111	3 gO2/m2/d	80%
Surplus Canal Diversion	115	3 gO2/m2/d	80%
Segment 3	116	3 gO2/m2/d	40%
DS 1300 South Conduit	121	3 gO2/m2/d	40%
	128	3 gO2/m2/d	40%
UP&L Diversion	129	3.5 gO2/m2/d	40%
North Temple Conduit	130	3.5 gO2/m2/d	20%
Segment 1	143	3.5 gO2/m2/d	20%
Cudahy Lane	150	3.5 gO2/m2/d	20%
South Davis South WWTP	151	3.5 gO2/m2/d	20%
Burnham Dam	161	3.5 gO2/m2/d	20%
Burton Dam	166	3.5 gO2/m2/d	20%

Color Descriptions:

Tributary Stream

Waste Water Treatment Plant

Dam/Diversion

APPENDIX F. ASSUMPTIONS REGARDING CALCULATIONS OF FPOM TO JORDAN RIVER FROM SOURCES

Concentrations of FPOM are equivalent to measurements of Volatile Suspended Solids (VSS), a component of Total Suspended Solids (TSS). Only a few FPOM measurements have only been made, and only concentrated in the last few years, so a FPOM model was developed to estimate longer-term concentrations of FPOM based on ratios to other water quality constituents. In many cases, FPOM:TSS ratios could be used, but where TSS data was not available for all months, different ratios were sometimes used for four 4 different seasons. In still other cases, the numbers of TSS measurements were not reasonably sufficient for FPOM:TSS ratios, so the relationship between FPOM and BOD was used. The following list discloses the assumptions used in determining FPOM from TSS or BOD.

1. Utah Lake, WWTPs, tributaries, and mainstem of the Jordan River at 2100 South – Used FPOM:TSS ratios for Utah Lake, WWTPs, major tributaries (except where noted below), and 2100 South where DWQ and Theron Miller collected FPOM and TSS data in 2006-2010. Used averages of adjacent months when months were missing entirely or the FPOM:TSS ratios exceeded 1.0 (not limited to paired measurements). Would not expect much ISS to come out of a still lake, but very high TSS and low FPOM in Aug 2006. Pumps were never operated during any of synoptic periods.
2. Stormwater in all segments: Used BOD:FPOM relationship in all periods, did not update to add data for 2009 or 2010.
3. Diffuse Runoff in all segments: Used BOD:FPOM relationship in all periods, did not update to add data for 2009 or 2010.
4. Rose Creek: Loads based on assumed stormwater and similar flows from Butterfield Creek. Used BOD:FPOM of 1.076:1 relationship in all periods.
5. Corner Canyon Creek: Loads based on assumed stormwater and similar flows from Butterfield Creek. Used BOD:FPOM of 1.076:1 relationship in all periods.
6. Midas Creek: Loads based on assumed stormwater and similar flows from Butterfield Creek. Used BOD:FPOM of 1.076:1 relationship in all periods.
7. Willow Creek: Loads based on assumed stormwater and similar flows from Butterfield Creek. Used BOD:FPOM of 1.076:1 relationship in all periods.
8. Dry Creek: Loads based on assumed stormwater and similar flows from Butterfield Creek. Used BOD:FPOM of 1.076:1 relationship in all periods.
9. 9000 South Conduit: load already accounted for in Segment 6 Stormwater.
10. Bingham Creek: Loads based on assumed stormwater and similar flows from Butterfield Creek. Used BOD:FPOM of 1.076:1 relationship in all periods.
11. UT Lake Distributing Canal Return Flow: load already accounted for in Segment 6 Irrigation Return Flow.
12. JWC Return Flow: load already accounted for in Segment 6 Irrigation Return Flow.
13. East Jordan Canal Return Flow: load already accounted for in Segment 6 Irrigation Return Flow.
14. South Jordan Canal Return Flow: load already accounted for in Segment 6 Irrigation Return Flow.
15. North Jordan Canal Return Flow: load already accounted for in Segment 6 Irrigation Return Flow.
16. Jordan and SLCi Canal Return Flow: load already accounted for in Segment 6 Irrigation Return Flow.

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APPENDIX G. LOAD ALLOCATIONS FOR FPOM AND OTHER ORGANIC MATTER

The appendix provides detailed information on FPOM and Other OM load allocations for point and nonpoint sources. The results shown in the tables below (Tables G.1 though G.3) are summarized in the main body of the report in Chapter 4.

Table G.1. Annual and daily bulk load allocation of existing FPOM loads of point and nonpoint sources to the lower Jordan River.

Source	Load into Lower Jordan River (kg/yr)	Permissible Load into Lower Jordan River (kg/yr)	Daily Permissible Loads into Lower Jordan River (kg)	Percent Reduction into Lower Jordan River (%)
Point Sources Upstream of 2100 South	443,511	271,173	743	39%
Point Sources Downstream of 2100 South	780,660	458,506	1,256	41%
Nonpoint Sources Upstream of 2100 South	477,446	397,439	1,089	17%
Nonpoint Sources Downstream of 2100 South	206,864	88,025	241	57%
Total	**1,908,481**	**1,215,143**	**3,329**	**36%**

Table G.2. Annual and daily bulk load allocation of future FPOM loads to point and nonpoint sources to the lower Jordan River.				
Source	**Load into Lower Jordan River (kg/yr)**	**Permissible Load into Lower Jordan River (kg/yr)**	**Daily Permissible Loads into Lower Jordan River (kg)**	**Percent Reduction into Lower Jordan River (%)**
Point Sources Upstream of 2100 South	776,766	360,203	987	54%
Point Sources Downstream of 2100 South	850,502	375,287	1,028	56%
Nonpoint Sources Upstream of 2100 South	453,588	365,128	1,000	20%
Nonpoint Sources Downstream of 2100 South	217,190	75,694	207	65%
Total	**2,298,046**	**1,176,312**	**3,223**	**49%**

Table G.3. Other Organic Matter Loads to the lower Jordan River (kg/yr).				
Source	**Load into Lower Jordan River (kg/yr)**	**Permissible Load into Lower Jordan River (kg/yr)**	**Daily Permissible Loads into Lower Jordan River (kg)**	**Percent Reduction into Lower Jordan River (%)**
Point Sources Upstream of 2100 South	25,551	13,823	32	6%
Point Sources Downstream of 2100 South	43,604	23,590	55	10%
Nonpoint Sources Upstream of 2100 South	274,983	148,766	346	62%
Nonpoint Sources Downstream of 2100 South	96,884	52,414	122	22%
Total	**441,022**	**238,593**	**555**	**100%**

APPENDIX H. TAC MEMBERSHIP

Table H.1. List of Technical Advisor Committee Members and Attendance at meetings.

**Note: Each TAC member and SRC member received all emails and documents and had the opportunity to comment on the draft, regardless of attendance at meetings.*

		28-Oct-09	15-Dec-09	15-Dec-09	20-Jan-10	3-Mar-10	19-Apr-10	15/16-July-10	11-Aug-10	7-Sep-10
TAC Member	**Work Affiliation**	**Kick-Off Meeting**	**Updated Loads, Future Loads and Compliance Points**	**Collaborative Calibration Meeting**	**Linkage Analysis Update**	**Critical Conditions, Endpoints and Permissible Loads**	**Load Allocations**	**Chapra Model Review Meeting**	**Update, OM and DO, Phased TMDL, Invited discussion**	**Pollutants of Concern and Load Calculations, FPOM, CPOM, Stormwater Mngrs Meeting, Public Outreach**
Agency: County/State/Federal										
Carl Adams	DWQ Watershed Protection Section Manager	X		X	X	X	X	X	X	X
Hilary Arens	DWQ Watershed Protection Section	X	X	X	X	X	X		X	X
Kimberly Asmus Hersey	Utah Division of Wildlife Resources									
Nathan Darnall	U.S. Fish & Wildlife Service									
Royal Delegge	Salt Lake County Department of Health									
Jim Harris	DWQ Monitoring Section Manager									

Table H.1. (cont.) List of Technical Advisor Committee Members and Attendance at meetings.

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Agency: County/State/Federal (cont.)										
John Isanhart	Fish and Wildlife Services									
Briant Kimball	USGS	X	X			X	X		X	
John Luft	DNR/ Division of Wildlife Resources									
Ron Lund	Salt Lake County Department of Health	X			X					
John Mann	DWRi, Utah Lake/Jordan River Regional Engineer									
Jeff Ostermiller	DWQ Water Quality Management Section Manager	X								
Nick Von Stackelberg	DWQ Watershed Management Section			X				X		X

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Agency: County/State/Federal (cont.)										
Dave Wham	DWQ Water Quality- Utah Lake TMDL Coordinator			X	X	X	X	X		X
John Whitehead	DWQ Branch Manager					X		X		
Jack Wilbur	Dept of Ag; NPS Information and Education Coordinator					X				
Gregory Williams	Utah Division of Water Resources	X	X		X		X			X
Business										
Glenn Eurick	Kennecott Copper Senior Engineer	X	X		X		X		X	
Libby Reder	eBay; Head of Environmental Initiatives									
Grace Sperry	Keller Williams Realty	X				X			X	

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Consultants										
Bryan Dixon	Cirrus Ecological Solutions	X			X	X	X		X	X
Eric Duffin	Cirrus Ecological Solutions	X	X	X	X	X	X	X	X	X
Karen Nichols	Stantec Inc.				X	X	X		X	
Ken Spiers	Bowen Collins & Associates, Inc.						X		X	
Environmental/Non-profit										
Adriann Boogaard	River Enthusiast		X		X					
Lynn DeFreitas	Friends of Great Salt Lake									
Merritt Frey	Water Quality Board/River Network	X	X							
Wayne Martinson	National Audubon Society	X	X		X	X				
Eric McCulley	Legacy Parkway	X	X		X	X			X	
Dan Potts	Aquatic Life Enthusiast	X	X			X				

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Environmental/Non-Profit (cont'd)										
Jeff Salt	Great Salt Lake Water Keepers	X	X			X	X		X	
Gwen Springmeyer	Utah Rivers Council									
Bruce Waddell	Great Salt Lake Alliance	X	X		X	X			X	
Municipality										
Steve Burgon	Salt Lake County Storm Water	X	X							
Dan Drumiler	Salt Lake County Stormwater Section Manager									
Stephanie Duer	Salt Lake City Water Dept.	X								
Marian Hubbard	Jordan River Watershed Council/ Salt Lake County	X			X	X	X		X	
Dan Johnson	West Valley City	X	X							

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Municipality (cont'd)										
Emy Maloutas	Salt Lake City Open Space Lands Program Manager									X
Jeff Niermeyer	Salt Lake City Public Utilities								X	X
Anna Reeves	East Mill Creek Community Council									
Florence Reynolds	Salt Lake City Public Utilities	X			X	X	X		X	
Aaron Sainsbury	South Jordan City	X								
Natural Resources										
Mark Atencio	Jordan Valley Water Conservation District	X								
Lisa Coverdale	UT-NRCS-Irrigation Water Management									

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Natural Resources (cont'd)										
Kerry Goodrich	UT-NRCS-Irrigation Water Management									
Dave Hanson	UT-NRCS-Irrigation Water Management								X	X
Lynn Jensen	Lower Jordan River Commissioner									
John Larsen	Jordan River Commissioner						X			
POTWs										
Garland Mayne	Jordan Basin Water Reclamation Facility General Manager						X		X	
Theron Miller	Representing Jordan River POTWs	X	X	X	X	X	X	X	X	X

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POTWs (cont'd)										
Bill Moellmer	Representing Jordan River POTWs	X	X	X		X	X	X		X
Matt Myers	South Davis Sewer District					X				
Lee Rawlings	South Valley Water Reclamation Facility	X	X		X	X			X	X
Scientific Review Committee										
Michelle Baker	USU Department of Biological Science									
Ryan Dupont	Utah Water Research Laboratory	X			X	X		X	X	
Ramesh Goel	University of Utah Department of Civil and Environmental Eng.	X							X	

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Scientific Review Committee (cont'd)										
Mitch Hogsett	University of Utah Department of Civil and Environmental Eng.	X				X			X	X
Bethany Neilson	USU Department of Civil and Environmental Engineering			X		X		X		
Sam Rushforth	Utah Valley University								X	
Sandie Spence	US EPA-Utah TMDL Specialist						X		X	

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