Jordan River TMDL:

Work Element 2 – Pollutant Identification and Loading

Prepared for:

Utah State Division of Water Quality
Dept. of Environmental Quality
288 North 1460 West
Salt Lake City, UT 84114-4870

Prepared by:

Cirrus Ecological Solutions, LC
965 South 100 West, Suite 200
Logan, UT 84321

Stantec Inc.
3995 South 700 East, Suite 300
Salt Lake City, UT 84107

July 2009

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

ac-ft	acre-feet
atm	atmosphere
BOD	Biochemical Oxygen Demand (5-day at 25°C)
BUA	Beneficial Use Assessment
cfs	cubic feet per second
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
JVWCD	Jordan Valley Water Conservancy District
KUCC	Kennecott Utah Copper Corporation
L	liter
LDCs	Load Duration Curves
mg	milligram
mgd	million gallons per day
MOS	Margin of Safety
MWDSLS	Metropolitan Water District of Salt Lake and Sandy
NH_4	Total Ammonia
RIVPACS	River Invertebrate Prediction and Classification System
SDWTP	South Davis 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
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 Sediments
WWTPs	Waste water treatment plants
yr	year

This page is intentionally left blank.

EXECUTIVE SUMMARY

The Work Element 2 report is the second in a series of three reports that will conclude with a draft TMDL document for the Jordan River. 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. The results of each component are summarized below.

WATER BUDGET

Several existing water budgets for the Jordan River were identified and reviewed as part of this study, but a new budget based on available flow records from 1980–2005 was needed to meet the requirements of this TMDL process. This new budget accounted for known inflows and outflows, including Utah Lake, tributaries, permitted discharge, stormwater, diffuse runoff, irrigation return flows, groundwater, and irrigation diversions. It addressed five sub-sections of the river bounded by Utah Lake, 9000 South, 2100 South, 500 North, Cudahy Lane, and Burton Dam. The largest discrepancies found between calculated and measured flows were for the 12-mile section from 9000 South to 2100 South. These discrepancies were relatively small on a percent-per-mile basis at less than 0.6 percent per mile. Some of the most important ramifications for water quality indicated by the budget were for the section below 2100 South, where annual flows in the Jordan River are reduced by approximately 80 percent by flood control diversions to the Surplus Canal.

POLLUTANT SOURCE CHARACTERIZATION

Pollutant sources that contribute loading to the Jordan River were characterized on a monthly basis. Loads from Utah Lake, seven monitored tributaries located east of the Jordan River, and three permitted discharges were calculated based on available records of continuous flow (1980–2005) and routine monitoring of water quality (1995–2005). Stormwater loads from outfalls that discharge directly to the Jordan River were computed from average annual precipitation, storm event monitoring of representative catchments (Stantec 2006a), and mapping information that defined specific outfall locations and boundaries of stormwater catchments. Estimates of flow and water quality for the remaining pollutant sources (unmonitored tributaries, diffuse runoff, return flow from irrigation canals, and groundwater) were calculated using a combination of data and information collected from adjacent monitored tributaries, published literature, and GIS assessments. Pollutant loads were calculated for five parameters of concern including TDS, TSS, BOD, NH_4, and Total P.

Calculated loads showed substantial decreases below canal diversions at Turner Dam, followed by gains from various pollutant sources downstream to 2100 South. A large decrease in loading was again observed below this point as flows and loads were diverted to the Surplus Canal. Load calculations indicated that permitted discharges are a significant contributor to the total annual load of Total P, BOD, and NH_4. In a similar manner, Utah Lake makes a substantial contribution to the total annual load of TSS and TDS.

Note that loads for permitted discharge are 20–30 percent lower than loads shown in the Public Draft version of this report. This was due to erroneous use of daily maximum flow values reported in the DMR data instead of the 30-day average flow value. Pollutant loads shown in this report for permitted discharges are based on the 30-day average flow value.

The accuracy of load calculations was evaluated with a mass balance assessment that compared the net balance of calculated incoming and outgoing loads for a segment of the Jordan River against a measured load at an appropriate mainstem monitoring location. Large differences (100–200 percent) were noted between predicted and measured loads for a few DWQ Segments, while several segments showed differences ranging from 50–100 percent. Differences seemed to be inversely correlated with the length of the river segment. Some of the greatest differences were noted between Utah Lake and 2100 South.

Interpreting these differences, it is important to note that the mass balance approach does not account for significant chemical and biological processes that influence concentrations between upstream and downstream locations. Poor characterization of pollutant sources can also contribute to differences between predicted and measured loads.

With the exception of NH_4, differences between predicted and measured loads for all pollutants of concern decreased substantially below 2100 South. Significant improvements in the mass balance for TDS and Total P were noted between the Narrows and 2100 South when incoming and outgoing loads were totaled for the entire reach rather than assessing each DWQ segment individually.

LINKAGE ANALYSIS

The most complex water quality issue addressed in this TMDL is low DO in the lower segments of the Jordan River. An analysis was completed to address the linkages among pollutant sources and physical and biological processes that influence low DO levels and impairment in the river, particularly below 2100 South.

This DO impairment is the result of both physical and biological factors. Available data suggest that warmer summertime water temperatures alone could account for seasonal reductions in DO in the lower Jordan River. However, year-round deficits exist, despite positive reaeration rates of 1.5–2.5 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. Collectively, this information indicates that DO levels would meet numeric criteria if biological processes were not consuming DO faster than it is being replenished.

Several biological processes consume DO in the Jordan River, 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, so it alone could account for low concentrations of DO in the lower Jordan. The occurrence of aerobic decomposition processes in the water column is also supported by substantial amounts of organic matter in suspended sediments.

SOD is probably also a major factor in low DO rates, but it has not been well studied in the Jordan River. Recent preliminary 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. At these rates, SOD alone would consume nearly all the DO provided through natural reaeration. Moreover, flows in the Jordan River are probably capable of resuspending many of these highly organic bottom sediments, further contributing to both BOD and downstream SOD, and helping to explain why DO is lower, and DO violations are higher, 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.

BENEFICIAL USE IMPAIRMENT ASSESSMENT

This assessment is intended to determine if water quality, coupled with other physical and biological factors, supports the beneficial uses established for each segment of the Jordan River and if the current chemical, biological and physical data support the 303(d) listings. There are four assigned beneficial use categories for the Jordan River including Class 2B Secondary Contact Recreation, Class 3A Cold Water Aquatic Life, Class 3B Warm Water Aquatic Life, and Class 4 Agriculture. Non-support for each of these beneficial uses is identified on the 2008 303(d) List for some segments of the Jordan River.

Water quality data on E. coli substantiates the non-supporting designation for 2B beneficial uses for DWQ Segments 2, 3, and 5. The data also indicates DWQ Segments 1 and 4 exceed the established criteria for secondary contact recreation. This water quality impairment in itself is likely not a significant constraint on recreational use of the Jordan River, but it is one of several basic factors that diminish the overall appeal and safety of the river and its corridor for recreationists. Other factors include physical changes to the natural setting, and high flow volumes, channelization, and bank erosion. Some of these factors are associated with water quality but most are not.

Segments 5–7 are listed for exceeding the 3A temperature criterion (<20°C), and the data review supports this listing. DWQ Segments 1–3 are currently listed as not supporting Class 3B beneficial use based on the DO criterion, and the review of data collected during 2004 to 2005 indicates that DWQ Segments 4 and 7 also do not support this use.

Examination of the combined water quality, physical habitat, and biological factors indicates that the Jordan River's overall support of the assigned 3A and 3B beneficial uses is marginal. The interactions among these limiting factors are complex, but some generalities emerge in regard to each classification. High temperature levels, low DO and damage to physical habitat create unfavorable conditions for spawning and egg laying by desirable aquatic species. Rough fish dominate in many segments of the Jordan River and further support impairment of aquatic life. Overall, the respective 3A and 3B beneficial use designations remain appropriate, though impairments of water quality, physical, and biological factors limit the level of support for these uses.

The reviewed TDS data indicates non-support of the Class 4 criteria in DWQ Segment 1, 4, 5, 7, and 8. This is consistent with the 2008 303(d) List, with the exception of DWQ Segment 2, which is on the list but should not be based on this data, and DWQ Segment 4 which is not on the list but should be according to this review.

These elevated TDS levels adversely affect vegetable, forage, and hay crop production in the Jordan River watershed. While vegetables are grown on limited acreages in the watershed, pasture and forage production are the most common uses of irrigated land. Even TDS levels below the 1,200 mg/L criterion can affect these crops. Small grains such as wheat and rye are more tolerant to salinity and should not be affected by TDS from irrigation water. These TDS levels also adversely affect the productivity of bluegrass lawns and garden vegetables when canal water is used in secondary systems for landscape irrigation.

The amount of land used for agriculture in Salt Lake County is declining as development increases to meet the needs of the area's growing population. Therefore, although TDS levels are high in the upper segments of the river where irrigation water is diverted, other factors play a greater role in determining the future of agriculture in Salt Lake County. At this point, the Class 4 designation remains appropriate, with water quality impairment among the factors that increasingly limit local agriculture.

1.0 INTRODUCTION

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. 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. This information is critical to developing a sound, scientifically defensible TMDL for the Jordan River. The organization and content of the report are outlined below.

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. An annual water budget for the Jordan River was developed (Chapter 2 Water Budget) to define the hydrologic influence of inflows and outflows between Utah Lake and Burton Dam. These calculations were based primarily on existing flow records collected from the Jordan River, tributaries, diversions, and permitted discharges. Flows were also modeled or calculated from other significant inflow sources including groundwater, stormwater, irrigation return flow, and diffuse runoff. A hydrologic assessment of this type is necessary to understand and validate the magnitude of pollutant loading.

All significant Jordan River pollutant sources were characterized based on a review of monitoring data, field surveys, scientific literature, regulatory documents, GIS information, and stakeholder input. This effort is detailed in Chapter 3, Pollutant Source Characterization, and provides a means to identify, map, and characterize all significant causes and sources of point and nonpoint source pollution that contribute loading to segments of the Jordan River. The following pollutant source categories are reviewed:

- Utah Lake
- Mainstem Jordan River
- Tributaries
- UPDES Point Sources
- Stormwater
- Diffuse Runoff
- Return Flows from Irrigation Canals
- Groundwater
- Natural Background

In addition to the assessment of each pollutant source, data collected at monitoring stations on the mainstem Jordan River was used to calculate pollutant loads as assessed with pollutant load duration curves. Results of this assessment are also included in Chapter 3.

The pollutants of concern addressed in this report include parameters associated with impaired DWQ Segments of the Jordan River shown on the Utah 2008 303(d) List as well as related parameters that can be linked to pollutants of concern. These pollutants of concern and their precursors include:

- Total Ammonia (NH_4)
- Biochemical Oxygen Demand (BOD)
- Total Phosphorus (Total P)
- Dissolved Phosphorus (Dissolved P)
- Total Dissolved Solids (TDS)
- Total Suspended Solids (TSS)
- Escherichia coliform (E. coli)

Table 1.1 indicates parameters that appear on the Utah 2008 303(d) List. Figure 1.1 displays the geographic location of each DWQ Segment.

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

DWQ Segment	Beneficial Use and Support Status[1]							303(d) Pollutant of Concern	Standards for Pollutant of Concern
	River Mileage	1C	2B	3A	3B	3D	4		
1	0–6.9				NS		NS	**(3B)** Dissolved Oxygen **(4)** Salinity/TDS/Chlorides	**(3B)** Aug–Apr = 4 mg/L, May–Jul = 4.5 mg/L **(4)** 1,200 mg/L
2	6.9–11.4		NS		NS		NS	**(2B)** E. coli **(3B)** Dissolved Oxygen **(4)** Salinity/TDS/Chlorides	**(2B)** Max=940 col/100 mL, Geo. .Mean=206 col/100 mL **(3A)** Aug–Apr = 4 mg/L, May–Jul = 4.5 mg/L **(4)** 1,200 mg/L
3	11.4–15.9		NS		NS			**(2B)** E. coli **(3B)** Dissolved Oxygen **(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
4	15.9–24.7			[2]				None	None
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)** 20°C **(4)** 1,200 mg/L
6	26.4–37.6			NS				**(3A)** Temperature	**(3A)** 20°C
7	37.6–41.8			NS			NS	**(3A)** Temperature **(4)** Salinity/TDS/Chlorides	**(3A)** 20°C **(4)** 1,200 mg/L
8	41.8–51.4						NS	**(4)** Salinity/TDS/Chlorides	**(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] Beneficial use class 3A applies to DWQ segment 4 above the confluence with Little Cottonwood Creek.

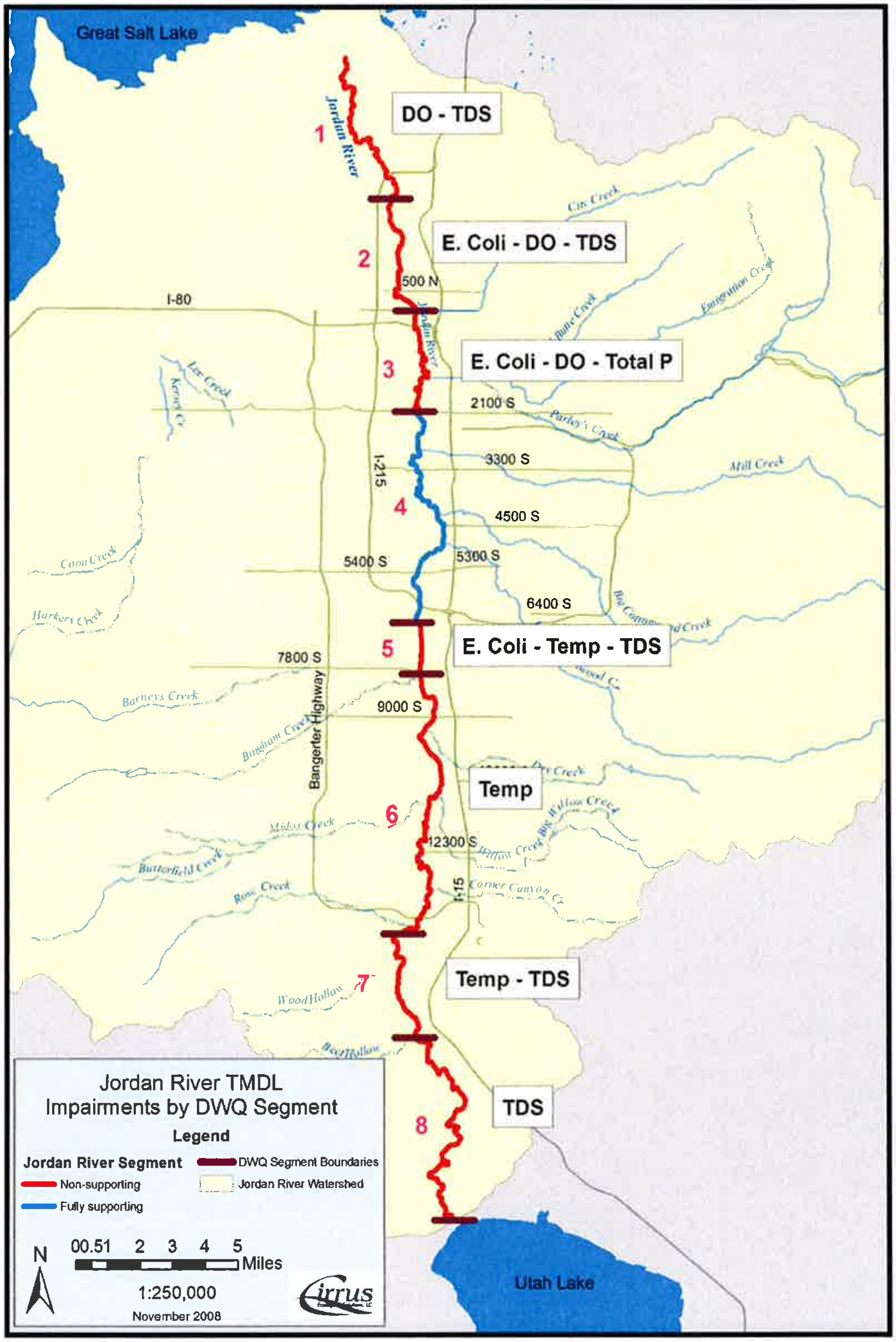


Figure 1.1. DWQ Segments and water quality impairments on the Jordan River.

Temperature and E. coli are not addressed in this report. Traditional methods of load calculations do not apply to temperature. The necessary assessment required to address temperature impairment will be completed at a future date. In regard to E. coli, the limited number of measurements that are currently available are not sufficient to characterize pollutant sources or calculate loads. Assessment of this parameter will be completed as additional monitoring data becomes available.

A linkage assessment is typically used in the TMDL process to define the relationships between water quality and pollutant sources. A linkage assessment was completed for this report (Chapter 4) to document and quantify the relationships between DO and known chemical/biological processes that affect DO levels. The linkage assessment primarily focused on four processes known to influence riverine DO concentrations. These processes include algae, bacteria, oxidation of organic matter, and mixing rates between the atmosphere and water column.

Completing this report, the beneficial use of impaired Jordan River segments is addressed in a Beneficial Use Assessment (Chapter 5) to verify the 303(d) listing and characterize the nature and extent of impairment to beneficial use categories assigned to the Jordan River by the Utah Division of Water Quality (DWQ). Table 1.2 describes Utah's beneficial use designation for each class. DWQ Segments that appear on the 2008 303(d) List are considered impaired due to consistent violation of water quality standards that protect beneficial use of resources associated with recreation, aquatic wildlife, and agriculture.

Table 1.2. Beneficial uses designation description within each class under the Utah Administrative Code R317-2-6, Use Designations.

Class	Use Classification	Description
Class 1	1A	Reserved
	1B	Reserved
	1C	Protected for domestic purposes with prior treatment by treatment processes as required by the Utah Division of Drinking Water.
Class 2	2A	Protected for primary contact recreation such as swimming.
	2B	Protected for secondary contact recreation such as boating, wading, or similar uses.
Class 3	3A	Protected for cold water species of game fish and other cold water aquatic life, including the necessary aquatic organisms in their food chain.
	3B	Protected for warm water species of game fish and other warm water aquatic life, including the necessary aquatic organisms in their food chain.
	3C	Protected for non-game fish and other aquatic life, included the necessary aquatic organisms in their food chain.
	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.
	3E	Severely habitat-limited waters. Narrative standards will be applied to protect these waters for aquatic wildlife.
Class 4	4	Protected for agricultural uses including irrigation of crops and stock watering.
Class 5	5	The Great Salt Lake. Protected for primary and secondary contact recreation, aquatic wildlife, and mineral extraction.

Collectively, this information integrates the data and information compiled during the first phase of this TMDL process to document and quantify the key variables and processes influencing water quality in the Jordan River watershed. As this information will provide the foundation for the subsequent, action-oriented phases of the TMDL process, it must be as accurate and complete as possible. Assembling this information in this concise, organized format allows the DWQ and stakeholders to proceed with a common understanding of the issues at hand.

Recommendations for further studies and additional data to better understand flows, water quality, DO linkages, and beneficial uses are organized in Appendix A.

This page intentionally left blank.

2.0 WATER BUDGET

2.1 INTRODUCTION

Although the ultimate allocation in a TMDL is the load, or mass, of a pollutant, a water budget is important for managing water quality in a river for two reasons. First, for many beneficial uses the most critical concern is concentration, which is a function of both mass and flow. Second, since some sources (e.g., wastewater treatment plants) are relatively constant in flow and concentration, others (e.g., precipitation runoff) vary diurnally, seasonally, or annually. It is therefore important to consider flow in order to predict concentrations and loads.

A water budget is analogous to a financial budget, but accounts for inflows and outflows of water. Historical accounting of flows is the best start to creating a future budget, and a budget can be created for any time span – month, season, or year – and for any stretch of river for which there is data and a need for management.

This water budget relies on historical flow data as well as modeling based on various assumptions and proxy measurements. Channel flows have been monitored at various gages on the mainstem as well as on some of the tributaries and canals. However they do not provide a complete picture. Stream gage data varies in temporal coverage as well as completeness of datasets. Gages are not always located at the boundaries of segments designated for water quality monitoring, and not every tributary and canal is monitored. Moreover, even within this small watershed, subtle but important interbasin transfers occur, such as when stormwater collected in a canal is discharged by a "canal overflow" structure where the canal crosses the next tributary. Further, some sources such as diffuse runoff from storm events are impossible to measure directly.

This budget starts with estimates of flows from Utah Lake, the initial source of the Jordan River. Along the way, various inflows and outflows have been calculated and combined for sections of the Jordan River, ending at Burnham Dam, less than 2 miles above Burton Dam where the river discharges into Farmington Bay.

Previous studies have provided estimates of flows in the Jordan River watershed, but most are either out of date or are not directly relevant to this water budget, as they were designed to meet different objectives. Nevertheless, this section starts with an overview of these other studies. A description of each category of inflow and outflow follows, with the methods used to calculate them. The annual budget of inflows and outflows, beginning at Utah Lake and ending at Burnham Dam, is provided in Table 2.15 at the end of this chapter. At several points along the river, stream gages in the mainstem show a "subtotal" of the inputs and outputs, with the difference between the calculated and measured flows.

2.2 PREVIOUS STUDIES

Results of previous studies on inflows to and outflows from the Jordan River are summarized in Table 2.1. A brief discussion of each follows.

Table 2.1. Summary of water balance information collected from previous flow studies completed for the Jordan River Basin (ac-ft/year).

	Hely et al. (1971)	Coon et al. (1982)	Utah Division of Water Resources (1997)	Borup and Haws (1999)	CH2M Hill (2005)
Flow Data Period	1964–1968	1962–1975	1941–1990	1989–1998	2003
Inflows					
Outflow from Utah Lake	226,200	280,000	308,000	224,802	115,300
Tributary Streams	178,770	170,176	177,800	31,131	81,000
Precipitation	464,000	N/A	N/A	N/A	N/A
Groundwater	139,000	N/A	N/A	5,828	94,200
Imported	48,150	72,000	N/A	N/A	N/A
WWTP	N/A	100,890	93,000	116,564	87,600
Other	9,500	N/A	N/A	56,112	77,600
Subtotal	**1,065,620**	**522,176**	**401,000**	**434,437**	**406,200**
Outflows					
Industrial	27,000	144,300	N/A	N/A	N/A
Canals		N/A	140,000	368,335	147,400
Irrigation	176,000	299,200	N/A	N/A	N/A
Water Supply	39,000	124,900	68,190	N/A	N/A
Surface Outflow to Great Salt Lake	324,000	N/A	N/A	N/A	N/A
Subsurface Outflow	4,000	N/A	N/A	N/A	N/A
Groundwater Recharge	367,000	N/A	20,000	N/A	N/A
Other	128,620	33,700	1,077,004	N/A	N/A
Subtotal	**1,065,620**	**568,400**	**1,305,194**	**368,335**	**147,400**

2.2.1 WATER RESOURCES OF SALT LAKE COUNTY, UTAH (HELY ET AL. 1971)

Hely et al. (1971) addressed the water resources of Salt Lake County with respect to opportunities for future water development. With the county's population growing and large quantities of "unused" water flowing to the Great Salt Lake, policy makers were considering how to develop additional water supplies. The goal of this study was to gain understanding of stream flow and groundwater in the county to further this purpose. Inflows, outflows, groundwater, and potential reservoirs and diversions were studied.

Results shown in Table 2.1 were calculated from annual averages of data from the water years 1964–1968. Inflow from Utah Lake was calculated from average gage measurements at Turner Dam in the Jordan Narrows (206,300 ac-ft) plus the water diverted just upstream by the Jordan Narrows Pump Station (formerly operated by the Salt Lake County Water Conservancy District; 19,900 ac-ft, excluding 5,600 ac-ft of water coming from the Provo River) and pumped to the Utah Lake Distributing Company canal. The value for tributary stream inflow to the Jordan River included gage data from seven Wasatch Mountain streams (Big and Little Cottonwood creeks, Mill Creek, Parley's Creek, Emigration Creek, Red Butte Creek, and City Creek), estimated flows from ungaged tributaries on the east side of the valley, and estimated flows from Oquirrh Mountain streams from the west. The precipitation value is for the valley floor and was derived from a map of mean annual precipitation in the Jordan River Valley. Groundwater was that discharging into the Jordan River below Turner Dam. Imported water came from basins above Utah Lake (primarily the Provo River), and other inflow included runoff from a Kennecott Copper Corporation pipeline.

Outflows involved more complex assumptions and calculations parceling broad categories of flows in various ways to account for more detailed uses. Evapotranspiration included industrial, irrigation, water supply, and waterfowl management area losses. Surface outflow was outflow from the Jordan River valley to the Great Salt Lake via various canals and drains. Subsurface outflow was only the net gain in groundwater, whereas groundwater recharge included water that seeped from tributaries, creeks, canals, fields, lawns, etc. The "other" category included evapotranspiration of groundwater and water at waterfowl management areas and a miscellaneous component.

2.2.2 SALT LAKE COUNTY AREA-WIDE WATER STUDY (COON ET AL. 1982)

Coon et al. (1982) was also completed in response to growing population and water demand in Salt Lake County. They sought to identify all surface water sources within and imported to the county, determine the sources of unused water discharging into the Great Salt Lake, and estimate costs and feasibility of developing surplus water sources. It was prompted in part by delays in the construction of the Central Utah Project. Groundwater sources were not assessed in this study.

Results shown in Table 2.1 were calculated from annual averages of data for 1962–1975. These numbers included water used throughout the County, not just from the Jordan River. No citation was given for the amount of water coming from Utah Lake to the Jordan River each year. Stream flow from gaged streams was estimated by analyzing long-term flow data from varying time periods. Flows from ungaged streams were estimated using the "area-altitude" method, which uses precipitation and runoff values from elevation bands in a gaged watershed to calculate a runoff value per acre for comparable bands in the ungaged watershed. Imported water came from the Weber and Duchesne rivers via Deer Creek Reservoir as well as from springs in Tooele County.

Information on water uses came from two previous studies, Glenne (1977) and Hansen et al. (1979). Industrial water was "diverted by or delivered to the larger industries in the County." Most of this went to Kennecott Copper, and most industries were assumed to consume less than 10 percent of diversions. Municipal water was that delivered via municipal water systems.

2.2.3 UTAH STATE WATER PLAN JORDAN RIVER BASIN (UTAH DIVISION OF WATER RESOURCES 1997)

The 1997 Utah State Water Plan provided guidance for the use, management, and conservation of state water supplies. As part of the state water planning process, more detailed plans were prepared for each of the 11 hydrologic basins in the state, including the Jordan River Basin. The goal of this plan was to evaluate all water resources in Salt Lake County and provide information to local decision makers to use in future water initiatives.

Results of this study, also shown in Table 2.1, cover several different time periods. Utah Lake outflow data, measured at the Jordan Narrows, was averaged from data collected from 1941 – 1990. Tributary stream data was taken from Coon et al. (1982). WWTP discharge was taken from facility records for 1994–1995.

Water usage included water diverted to canals, estimated from the amount of water developed for irrigation in the Jordan Basin. Water supply was that diverted for public supply from Wasatch Mountain streams. No years were given for either of these values. The groundwater recharge value came from Hely et al. (1971), but was limited to seepage from creek channels for the period 1964–1968.

2.2.4 JORDAN RIVER FLOW ANALYSIS (BORUP AND HAWS 1999)

Borup and Haws (1999) was part of a larger DEQ project to re-evaluate Utah Pollutant Discharge Elimination System (UPDES) permits for Salt Lake County water treatment plants and estimate TMDL requirements. This study focused on Jordan River flows. Flow values were provided seasonally in cfs. Seasonal values were averaged and converted to ac-ft.

In order to ensure adequate river water quality even during "dry periods" when discharge from WWTPs can have the most detrimental effect, flows for this study were calculated using EPA's 7-Q-10 regulation, which relies on the lowest 7-day average flow in the most recent 10-year period. The 10-year period was 1989–1998. Readings at river gages during these dry periods used as "control points" for the WWTPs were:

- South Valley Water Reclamation Facility: 9000 South gage (USGS gage 10167230).
- Central Valley Water Reclamation Facility: 2100 South Combined Flow gage less inputs from Mill Creek 1.5 miles upstream (USGS gage 10170490).
- South Davis South and South Davis North Wastewater Treatment Plant: 500 North gage (USGS gage 10172550).

Inflows from ungaged tributaries were estimated by correlating flows reported in the 1997 Jordan River Basin Plan (DWR 1997) with Big Cottonwood Creek flow. Seasonal groundwater flux values were added to the 9000 South measurements.

Outflows were limited to canal diversions.

2.2.5 JORDAN RIVER RETURN FLOW STUDY (CH2M HILL 2005)

The purpose of the CH2M Hill (2005) study was to evaluate the effects of future water reuse projects on Jordan River flows. Inflows and outflows were accounted for and return flows were quantified. A water balance simulation tool was created using this data to run scenarios based on population, land use, and precipitation to predict the effects of reuse projects.

Results of this study, also shown in Table 2.1, are from the year 2003, which was used in the model to simulate a dry year. Utah Lake flow to the Jordan River was calculated using recorded monthly flows of canals diverted at Turner Dam from the river upstream of the Joint Diversion Dam, plus some assumed winter flow. This number also included groundwater and surface inflows between Utah Lake and Turner Dam. Stream flow was determined using six Wasatch Mountain streams (Big and Little Cottonwood, Mill, Red Butte, City, and Parley's creeks). Both natural and irrigation return flow components were analyzed for groundwater using a USGS model, but only the data from natural flow is shown in the table. Wastewater discharge was estimated based on population and water use, as well as the percent of sewage each city in the county contributes to the total flow for each member agency (sewer district). The "Other" category included groundwater and surface water return flows.

Water quantities in this study were generally lower than those from other studies mentioned here in part because this study intentionally focused on an abnormally dry year, 2003, and in part because not all sources of water were considered.

2.3 WATER BUDGET CALCULATIONS

2.3.1 OVERVIEW

As might be expected from the different time periods and different objectives addressed in the studies described above, there are differences among these previous characterizations of Jordan River flows. Newer data helps, as does a more complete inclusion of inflows and diversions. The major inflows to and outflows from the Jordan River analyzed in this present study were:

- Utah Lake – the natural 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 discharged via outfalls directly to 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.

While each of these inflows and outflows are specific, discreet values at any point in time, they are not all easy to quantify. Some variables such as groundwater and diffuse runoff cannot be measured directly and must be inferred. Accounting for rain or snow is particularly complex because some of the precipitation is captured as runoff in stormwater catchment infrastructure, some runs over the ground into surface waterways, and some percolates into the ground water. The water caught in stormwater infrastructure may enter the Jordan River above or below a gage on a gaged tributary, it may discharge directly to the mainstem of the river, it may enter an ungaged tributary, or it may empty into a canal. Canal overflows have been built where canals cross natural tributaries to spill stormwater in order to avoid damage to canals and to avoid exceeding legal diversion flows. Figure 2.1 illustrates where stormwater is accounted for in this water budget. Other values, such as the actual amount of water diverted to canals and the return flow from canals, are often not measured, and even records from mainstem and tributary gages can be spotty and inconsistent. As a result of such problems, compiling a practical water budget requires creative thinking on how to assemble the inflows and outflows, prioritize the higher quality data sets, employ valid proxy measures when hard data is not available, build in internal checks, and decide when minor inconsistencies do not warrant further attention.

This process can blur some of the distinctions among various inflow and outflow components, but the internal checks indicate that the budget has relatively low error. At the outset, it is useful to clarify in brief, summary terms how each inflow and outflow component was defined and quantified in this analysis, as shown in Table 2.2. Each component is then described in detail under subsequent headings, and values for the components are presented below in the Annual Water Budget Summary (Section 2.2.10).

Table 2.2. Summary definition and quantification of inflow and outflow components.

Inflow/Outflow Component	Definition	Quantification
Utah Lake Inflow	Total inflow from Utah Lake outfall into Jordan River.	Calculated from reports of releases from Utah Lake, gages on the Jordan River below Turner Dam, and flows to diversions between Utah Lake and Turner Dam.
Gaged Tributary Inflow	Total flow at tributary gages, plus stormwater and diffuse runoff entering tributary below gage but above confluence with Jordan River.	Various tributary gages; stormwater and diffuse runoff calculations based on size of catchments, area draining into the tributary below the gage, precipitation, and land use or cover.
Ungaged Tributary Inflow	"Natural" flows plus stormwater input and diffuse runoff.	"Natural" flows estimated by area-altitude method (which includes "diffuse" runoff); stormwater added based on size of catchments, precipitation, and land use or cover.
Permitted Discharge	Direct discharge from WWTPs.	WWTPs Discharge Monitoring Reports.
Stormwater Inflow	Runoff (including snowmelt) to the Jordan River collected in constructed catchment systems and discharged directly or via drains to the Jordan River.	Calculations based on size of catchments, precipitation, and land use or cover.
(Direct) Diffuse Runoff Inflow	Stormwater runoff from areas outside established catchments and flowing overland directly to the Jordan River.	Calculations based on size of collection area, precipitation, and land use or cover.
Irrigation Outflow	Diversions to irrigation canals.	Gages at points of diversion and reports from water users.
Irrigation Return Inflow	Discharge from canal outfalls to into Jordan River.	Published Salt Lake County data adjusted based on the few instances of gaged canal outfalls.
Groundwater Inflow		Published studies; estimated for reach above Turner Dam by subtracting all other inputs from gaged flow during period when Utah Lake is not discharging.

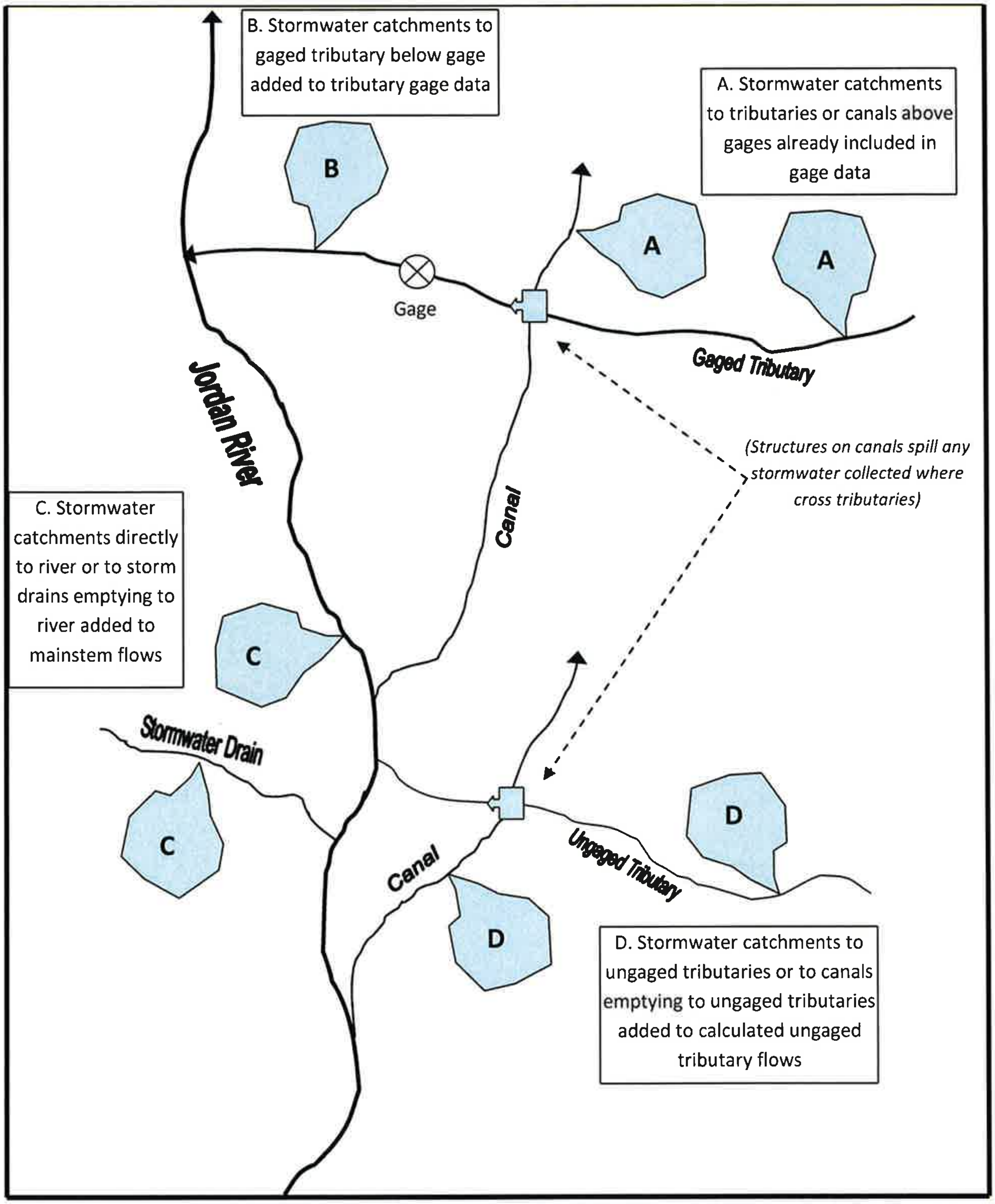


Figure 2.1. Categorization of flows and loads from stormwater catchments. "A" catchments are already included in gaged tributary flows; "B" catchments are added to gaged tributary flows; "C" catchments are reported as "Stormwater" into mainstem; "D" catchments are added into calculated flows for ungaged tributaries.

Note that groundwater recharge is another potential outflow from the Jordan River. However, since the river channel lies in the bottom of the watershed and connects two lakes at a shallow gradient, groundwater recharge is believed to be minimal and less than groundwater inflow. As a result, it was not considered further in this analysis. While some of the previous studies discussed above dealt with groundwater recharge, they were generally citing its occurrence at higher levels in the watershed.

As noted in Table 2.1, this water budget relied on data from several sources, but published records of gage data provided the most reliable measurements. For some flow components (i.e., Utah Lake, gaged tributary inflow, permitted discharges, and irrigation outflows), gage data in itself provided the values included in the analysis. For other inflows and outflows (i.e., ungaged tributaries, stormwater, diffuse runoff, irrigation return flows, and groundwater), gage data was used to calculate inferred values and to check results.

Table 2.3 lists the stream gages from which data was taken along with the time span and number of measurements used in this analysis. Whenever possible, a beginning year of 1980 was selected in order to have a common hydrologic period with modern collection procedures and the possibility of 15 years of data for analysis. The locations, expressed in terms of river miles, are the distance on the Jordan River upstream from Burton Dam of mainstem river gages, the diversion point of canals, or the confluence of tributaries with the mainstem of the Jordan River.

Some of the canal diversions result in return flows directly or indirectly to the Jordan River, while others contribute return flow to the Great Salt Lake. Table 2.4 shows where flows from these diversions return.

Data on flows in the Jordan River mainstem and gaged tributaries come from databases maintained by the USGS of continuous flow measurements recorded by the USGS itself, by the DWQ, or Salt Lake County, or from the DWRi. In a few cases (e.g., Jordan River at Cudahy Lane and at State Canal road crossing), DWQ has collected enough instantaneous flow measurements during water quality sampling to provide an historical record. Flows from permitted discharges are reported on a daily basis by the wastewater treatment plants in their Discharge Monitoring Reports.

Data on diversions, including pumping operations, is collected by the DWRi from stream gages or reports provided by canal and water supply companies and organizations. The calculated or inferred values for other inflows and outflows are discussed below under the associated headings.

Table 2.3. Location of stream and other flow gages used in water budget.

Water Body	ID Number and Station Name (w/ Water Right)	River Mile	Period of Record (years)	Number of Measurements
Mainstem				
Utah Lake Outlet	No gage.	51.4		
Jordan River At (Above) Turner Dam	Jordan River 02 Combined Flow.	Approx. 42.0	1980–2005	9,279
9000 South	10167230 – Jordan River at 90th South near Midvale.	28.1	1980–2004	9,029
2100 South	10170490 – Combined Flow Jordan River & Surplus Canal at Salt Lake City, UT - 2100 South.	16.1	1980–2003	8,309

Table 2.3. (cont'd) Location of stream and other flow gages used in water budget.

Water Body	ID Number and Station Name (w/ Water Right)	River Mile	Period of Record (years)	Number of Measure-ments
1700 South	10171000 – Jordan River at 1700 South at Salt Lake City, UT.	15.3	1980–2003	8,674
500 North	10172550 – Jordan River at 5th North at Salt Lake City, UT.	10.2	1980–2002	7,002
Jordan River at Cudahy Lane	Cudahy Lane.	5.1	1991–1994, 2002–2004, 2006	2,604
Canals				
Utah Lake Distribution Canal and Jordan Valley Pump Station	04.01.04 Utah Lake Distribution Canal.	41.9	1980–2004	4,579
Jacob-Welby Canal	05.01.07 Jordan Valley Water Conservancy Dist.	41.9	1989–2005	1,772
Utah and Salt Lake Canal	06.02.01 Utah & Salt Lake Canal (59-3499).	41.8	1980–2005	4,904
Draper Irrigation Canal	06.04 Draper Irrigation Co. (57-23).	41.8	1980–2005	3,986
East Jordan Canal	06.03.01 East Jordan Irrigation Company (57-7637).	41.8	1980–2005	4,952
South Jordan Canal	07.02 South Jordan Canal (Total).	39.9	1980–2004	4,680
Jordan and Salt Lake Canal	Salt Lake City Corp – Jordan & Salt Lake Canal.	39.9	1980–2003	4,086
North Jordan Canal	10.01.01 North Jordan Irrigation Co. (59-3496).	28.8	1980–2005	5,800
Surplus Canal	10170500 – Surplus Canal at Salt Lake City, UT.	16.0	1980–2003	8,309
State Canal	4990880 – Jordan River at State Canal Road crossing.	1.7	1980–2005	156
Gaged Tributaries				
Little Cottonwood Creek	10168000– Little Cottonwood Creek at Jordan River near Salt Lake City, UT.	21.7	1980–2005	6,711
Big Cottonwood Creek	10169500 Big Cottonwood Cr at Jordan River near Salt Lake City, UT.	20.6	1980–2005	8,041
Mill Creek	10170250 – Mill Creek at Jordan River near Salt Lake City, UT.	17.3	1980–2005	7,120
Emigration Creek	10172000 – Emigration Creek near Salt Lake City, UT.	14.2	1980–2005	6,199
Parley's Creek	10171600 – Parleys Creek at Suicide Rock near Salt Lake City, UT.	14.2	1980–2005	9,103
Red Butte Creek	10172300 – Red Butte Creek at 1600 East at Salt Lake City, UT.	14.2	1984–2005	6,438
City Creek	10172499 – City Creek (Channel) near Salt Lake City, UT.	11.5	1980–2005	8,570
WWTPs				
SVWRF	UT0024384 Effluent – Discharge from South Valley Water Reclamation Facility.	26.2	2000–2005	70

Table 2.3. (cont'd) Location of stream and other flow gages used in water budget.

Water Body	ID Number and Station Name (w/ Water Right)	River Mile	Period of Record (years)	Number of Measurements
CVWRF	UT0024392 Effluent – Discharge from Central Valley Water Reclamation Facility.	17.6	2001–2005	95
SDWTP	UT0021628 Effluent – Discharge from South Davis South Wastewater Treatment Plant.	5.1	2001–2005	60

Table 2.4. 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.

2.3.2 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 square miles yet contains only 1 million ac-ft of water due to a shallow average depth of 9–10 feet (DWQ 1994). Utah Lake is the Jordan River's origin and the single largest contributor of flow (Figure 2.2).

Utah Lake discharge to the Jordan River is controlled according to guidelines in the Utah Lake Water Distribution Management Plan (DWRi 1992). The Jordan River receives the only surface discharge from Utah Lake and 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).

No direct measurements of discharge from the outlet of Utah Lake have been identified for recent years. The nearest downstream monitoring station is at the Turner Dam, 9.4 miles below. It is possible, however, to estimate the lake's discharge by adjusting the flows reported at this station by adding back the contributions of stormwater from catchments, diffuse runoff, and groundwater and then deducting the amount of water that has been diverted for municipal and irrigation uses between the lake's outfall and the monitoring station.

Two large diversions occur at Turner Dam, one on either side of the dam: the "East Jordan Canal" and the "Utah and Salt Lake Canal." The "station" at Turner Dam appears to be gage readings in these two channels and in the Jordan River itself below the dam. Data for this station is recorded by the DWRi as "02 Jordan River Combined Flow," more particularly described as "Combined Flow – Jordan River, Utah & Salt Lake Canal and East Jordan Canal at the Jordan Narrows." It is worth noting that the DWRi has found significant discrepancies in reported flows in some recent years, but no explanation is offered. A complete history of this station is beyond the scope of this report, but it appears to be the most valid and useful measurement of Jordan River flows available near the river's source, with records reported back to January 1, 1950.

As noted above, in order to estimate the initial contribution of Utah Lake water, contributions from both runoff and groundwater discharge must be deducted from the "02 Jordan River Combined Flow" gage readings. Runoff comes from two sources: stormwater collected in municipal stormwater catchment systems and diffuse runoff that flows over the ground and into the Jordan River directly. Both are functions of area, precipitation, a coefficient that estimates the percentage of storms that result in any measurable runoff, and a second coefficient that estimates the percentage of the runoff that makes it to a surface water body. This last coefficient is based on land cover and the percentage of a municipality serviced by stormwater structures. The only municipal stormwater catchment in this segment of the Jordan River collects surface runoff on 3,483 acres of service area in Lehi, which accounts for an average of 2,048 ac-ft of inflow per year. An additional approximately 4,263 acres of land provide diffuse runoff directly into this segment of the Jordan River, providing for 395 ac-ft/year.

An estimate of inflow from groundwater discharge was obtained by analyzing gage readings for the "02 Jordan River Combined Flow" gage in winter months of November through March for periods when flows into the Jordan River from Utah Lake are reported to be zero. All flow observed at Jordan River Station 02 during this time represents inflow from groundwater sources combined with stormwater discharge from municipalities upstream of Turner Dam. The average of these months is 11,018 ac-ft/year. Groundwater flow was therefore the difference between this total inflow and that calculated from stormwater modeling described above, or 8,574 ac-ft/year.

The final adjustment to data from the "02 Jordan River Combined" gage requires adding back in flows diverted between Utah Lake and Turner Dam. The two diversions on this stretch of the Jordan River are both located at the Jordan Narrows Pump Station 0.1 miles upstream of Turner Dam. Water is pumped during the irrigation season to the Utah Lake Distributing Company and the Welby-Jacob Canal (also known as Jacob-Welby or Provo Reservoir Canal), both located on the west side of the Jordan River. The average annual flow diverted to the Utah Lake Distributing Company is 26,135 ac-ft and to the Welby-Jacob Canal is 28,051 ac-ft.

Table 2.5 summarizes the calculated total average annual flow from Utah Lake.

Table 2.5. Utah Lake annual outflow summary.

	Annual Flow (ac-ft)
02 Jordan River Combined Flow	372,906
Less Stormwater Inflows from Catchments	(2,048)
Less Diffuse Runoff Inflows	(395)
Less Groundwater Inflows	(8,574)
Plus Diversion to Utah Lake Distributing Co.	26,135
Plus Diversion to Welby-Jacob Canal	28,051
Utah Lake Outflow	**416,074**

2.3.3 TRIBUTARIES

Natural stream channels joining 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. Diverted water is used for municipal or agricultural purposes. As a result of these diversions, portions of some stream channels are dewatered entirely during some or all of the year. Flows are also affected by water rights exchange agreements that allow upstream diverted water to be replaced downstream with lower quality water from Utah Lake. A detailed description of diversions and other structures that influence flows in the major tributaries between the canyon mouths and Jordan River is provided in the *Salt Lake County Area Wide Water Study* (Coon et al. 1982) and more recently in the *Salt Lake County Water Quality Stewardship Plan* (Salt Lake County 2009). Figure 2.2 indicates the location of both perennial and intermittent tributary streams that discharge to the Jordan River. Table 2.6 lists the general hydrologic descriptions of the tributary streams that empty into the Jordan River.

For the purposes of this discussion, Jordan River tributaries can be organized into gaged and ungaged streams. All perennial tributary stream channels on the east side of the Jordan River are instrumented for continuous flow measurement and account for all sources of inflow including natural instream hydrology (i.e., headwater flows and groundwater inflow) and additional flows contributed by stormwater discharge and diffuse runoff. Table 2.7 shows these gaging stations with the periods of assessment, number of observations, and average annual flows used in this report. Average flow values from these gaged tributaries were calculated using available measurements of mean daily flow collected by Salt Lake County and the USGS during 1980–2005.

Selected monitoring stations on several east-side tributaries, including Parley's Creek, Emigration Creek, Red Butte Creek, and City Creek, are located some distance above the Jordan River. These stations were selected based on the amount of data available as well as location with respect to the 1300 South conduit that transports flow from these streams through municipal areas and into the Jordan River.

Figure 2.2. Tributaries to the Jordan River including Utah Lake and perennial and intermittent stream channels.

Table 2.6. Hydrologic description of selected stream channels in the Jordan River basin.

Name	Hydrologic status[1]	Flow gage	Termination point	Comments/Data Source
Beef Hollow Creek	Intermittent	None	Utah Lake Distributing Canal.	Seasonal flows cross Welby-Jacob Canal in a siphon and terminate at Utah Lake Distributing Canal. Stream channel no longer exists below Utah Lake Distributing Canal.
Wood Hollow Creek	Intermittent	None	Agricultural fields west of Jordan Narrows.	Seasonal flow is transferred across Jacob-Welby Canal and dispersed on agricultural fields west of Camp Williams.
Rose Creek	Intermittent	None	Jordan River near 14200 South.	Although creek is primarily intermittent, perennial flows are sustained in lower segments due to stormwater discharge and groundwater accretion. Municipalities hold water rights to 100% of flow and creek is dewatered in valley during irrigation season.
Midas/Butterfield Creek	Canyon Perennial; Valley Intermittent	USGS 403011112062801[2]	Jordan River near 11200 South.	Both creeks are heavily influenced by irrigation diversions in their upper segments. Lower Butterfield Creek and Midas Creek accumulate stormwater discharge and groundwater inflow before reaching the Jordan River.
Bingham Creek	Canyon Perennial; Valley Intermittent	DWQ 4994180[3]	Jordan River near 8000 South.	Perennial flow above canyon mouth is completely diverted by KUCC into retention ponds. Flows accumulate in valley segments through stormwater discharge and groundwater accretion.
Barney's Creek	Canyon Perennial; Valley Intermittent	None	Wetland treatment facility near 4800 West.	Flow above canyon mouth is completely diverted by KUCC. Flows in valley portion of creek are from stormwater discharge and groundwater accretion. Wetland treatment facility will be connected to Jordan River in 2008–09.
Corner Canyon Creek	Intermittent	None	Jordan River near 13400 South.	Flows are highly seasonal and produced by snowmelt or thunderstorms. The channel is dewatered by approximately nine diversions for municipal and irrigation use. Lower valley segments accumulate flow from stormwater discharge and groundwater accretion.
Willow Creek	Canyon Perennial; Valley Intermittent	None	Jordan River near 11000 South.	Headwater tributaries include Big and Little Willow Creek canyons and , Rocky Mouth Canyon. All canyon flows from Bear Canyon and Cherry Canyon (south of Willow Creek Canyon) are diverted by private entities and the City of Riverton. Spring runoff from canyon watersheds is diverted to the Draper Irrigation Canal and eventually to Dry Creek. Valley segments of Willow Creek and Little Willow Creek are seasonally dewatered by diversions but accumulate flow through stormwater discharge and groundwater accretion.

Table 2.6. (cont'd) Hydrologic description of selected stream channels in the Jordan River basin.

Name	Hydrologic status[1]	Flow gage	Termination point	Comments/Data Source
Dry Creek	Canyon Perennial; Valley Intermittent	None	Jordan River near 9400 South.	Valley portion of creek receives flow from Bells Canyon, Middle Fork Dry Creek, and South Fork Dry Creek. Nearby watersheds including Rocky Mouth Canyon and Big and Little Willow Creek canyons contribute seasonal flow to Dry Creek through irrigation canals. Lower Dry Creek is seasonally dewatered by diversions. Additional flows accumulate through stormwater discharge and groundwater accretion..
Little Cottonwood Creek	Perennial	USGS 10168000	Jordan River near 4800 South.	All flow is diverted to the Murray Power Plant below the canyon mouth during July–April. Flows are withdrawn for municipal use into a water treatment plant which can dewater channel segments below this point during the non-irrigation season. Flow is restored further downstream through water rights exchange agreements.
Big Cottonwood Creek	Perennial	USGS 10169500	Jordan River near 4100 South	Flows are reduced by the Stairs Power Plant and Salt Lake City Water Treatment plant in the canyon. Channel is dewatered seasonally from the water treatment plant downstream to the East Jordan Canal. Flow is restored below the canal through a water rights exchange agreement.
Mill Creek	Perennial	USGS 10170250	Jordan River near 2800 South.	Creek is heavily diverted during irrigation season but not dewatered. Flow from CVWRF enters creek below gage.
Parley's Creek	Perennial	USGS 10171600	Jordan River at 1300 South.	Perennial flow enters storm drain near State Street. Flow is combined in drain with inflow from Emigration Creek and Parley's Creek for approximately 2 miles before discharging to the Jordan River at 1300 South.
Emigration Creek	Perennial	USGS 10172000	Jordan River at 1300 South.	Perennial flows are diverted in lower canyon and upper valley segments for water supply and irrigation. Remaining flow enters a storm drain near Westminster College at 900 East. Flow is combined in drain with inflow from Red Butte Creek and Parley's Creek for approximately 2 miles before discharging to the Jordan River at 1300 South.
Red Butte Creek	Perennial	USGS 10172300	Jordan River at 1300 South.	Perennial flow enters storm drain near 1100 East. Flow is combined in drain with inflow from Red Butte Creek and Parley's Creek for approximately 2 miles before discharging to the Jordan River at 1300 South.
City Creek	Perennial	USGS 10172499	Jordan River at North Temple.	Flows in canyon are reduced by Salt Lake City Water Treatment Plant. Although Salt Lake City maintains water rights to 100% of flow, the creek is typically not dewatered. Perennial flow enters a storm drain near State Street and 2nd Ave. Flows are transported through 2 miles of conduit before discharging to the Jordan River.

Table 2.6. (cont'd) Hydrologic description of selected stream channels in the Jordan River basin.

[1] Indicates general hydrologic status of the creek. Some minor segments of creek may differ from this characterization due to flow diversions or inflows from groundwater or stormwater.

[2] Continuous flow is currently monitored at this site by Salt Lake County. Due to concerns regarding the reliability and accuracy of measurements, this data is not published. In addition, this gage is located near the valley margin and would not represent discharge to the Jordan River.

[3] Instantaneous flow measurements were collected at DWQ 4994180 during routine monitoring completed in 1994–95, 2000, and 2004.

Data sources:

Coon et al. 1982, Bowen Collins 2003, and Salt Lake County 2009. Personal communication Salt Lake County Division of Engineering and Flood Control, Personal communication West Jordan City Division of Engineering.

Table 2.7. Gaged tributaries to the Jordan River.

Station Name	Assessment period	# Obs.	Annual Flow at Gage (ac-ft)	Stormwater and Diffuse Runoff Below Gage (ac-ft)	Total Flow (ac-ft)
10168000 – Little Cottonwood Creek at Jordan River near Salt Lake City, UT.	1980–2005	6,711	33,204	0	33,204
10169500 Big Cottonwood Cr at Jordan River near Salt Lake City, UT.	1980–2005	8,041	42,609	0	42,609
10170250 – Mill Creek at Jordan River near Salt Lake City, UT.	1980–2005	7,120	17,601	0	17,601
10171600 – Parleys Cr at Suicide Rock near Salt Lake City, UT.	1980–2005	9,103	10,691	2,009	12,700
10172000 – Emigration Creek near Salt Lake City, UT.	1980–2005	6,199	6,966	1,126	8,092
10172300 – Red Butte Cr at 1600 East at Salt Lake City, UT.	1984–2005	6,438	3,029	207	3,236
10172499 – City Creek (Channel) near Salt Lake City, UT.	1980–2005	8,570	5,936	4,202	8,141
Total Flow From Gaged Tributaries			**120,036**	**5,548**	**125,548**

Estimates for natural flow in ungaged tributaries are presented in Table 2.8 and were taken from Coon et al. (1982) which relied on the area-altitude method. This method provides an estimate of stream flow by comparing the area found in prescribed elevation ranges for an ungaged watershed to those in a gaged watershed. Average annual precipitation is then correlated for each elevation range. Based on these two variables, the average flow from the gaged watershed is then correlated to the ungaged watershed to produce an estimate of the mean annual 50th percentile flow. Monthly distribution of the annual flow estimate is based on monthly precipitation. The two watersheds should have characteristics that are similar including annual precipitation amounts, monthly distribution and type of precipitation, elevation, slope, aspect, geology, and vegetation.

Table 2.8. Total flow to Jordan River mainstem via ungaged tributaries (ac-ft).

Tributary	Annual "Natural" [1] Flow (ac-ft)	Stormwater Flow[2] (ac-ft)	Total Flow (ac-ft)
Rose Creek	79	140	219
Corner Canyon	626	1,461	2,087
Midas/Butterfield Creek	118	702	820
Willow Creek	0	997	997
Dry Creek	1,976	1,663	3,639
Bingham Creek	221	925	1,146
Total	**3,020**	**5,887**	**8,907**

[1] Natural flow from ungaged tributaries includes diffuse runoff.

[2] Stormwater includes runoff from catchment areas that drain directly into ungaged tributaries or into canals that drain into ungaged tributaries.

Based on these similarities, flows in Corner Canyon Creek were estimated using Fort Creek, located immediately to the south, as a reference watershed. All other ungaged tributaries on the east side of the Jordan River, including Willow Creek and Dry Creek, used Little Cottonwood Creek as a reference watershed. Ungaged tributaries on the west side of the Jordan River, including Bingham Creek, Midas/Butterfield Creek, and Rose Creek were compared to West Canyon Creek in Cedar Valley.

Flow estimates calculated with this method do not account for the influence of flow diversions for irrigation or municipal purposes or flow additions from stormwater. In order to account for flow diversions, monthly flow estimates for ungaged tributaries provided by Coon et al. (1982) were adjusted by assuming that all flows during the months of May through October were diverted for irrigation and did not reach the Jordan River.

The area-altitude method was used only for the upper sub-watersheds of Willow and Dry creeks because headwater flows in the canyons contributing to Willow Creek are diverted to Dry Creek by the Draper Irrigation Ditch near the canyon mouth of each tributary stream. It was assumed that estimated flows from the valley portion of Willow Creek and Dry Creek in these areas are minimal and do not significantly influence tributary stream flow to the Jordan River.

Groundwater inflow to each tributary stream is dependent upon long-term climatic trends as well as land cover and land use practices that influence groundwater hydrology. Years with high precipitation provide more groundwater recharge and subsequently more inflow to tributary channels. Land cover types vary considerably between urban and agricultural areas which subsequently influences runoff patterns, infiltration, and recharge to groundwater aquifers. In general, higher densities of urban development are found on the east side of the Jordan River while the majority of irrigated fields are located west of the Jordan River.

Bingham Creek has been monitored for water quality above the confluence at Station 4994180, Bingham Creek above the Jordan River confluence at 1300 West, during 1994–1995, 2000, and 2004. This data set is comprised of instantaneous flow measurements and provides monthly means that are substantially different than flow estimates provided by Coon et al. (1982). For purposes of consistency, it was not used in the water budget or load calculations. In general, tributary channels that are not instrumented with continuous flow gages are considered to support intermittent flow that is a combination of flows from natural and human sources.

2.3.4 PERMITTED DISCHARGE

Three UPDES point sources have been identified that discharge treated wastewater effluent to the Jordan River or tributaries. The South Valley Water Reclamation Facility (SVWRF) is 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. The SDWTP has a treatment capacity of 4 mgd. Discharge from the facility enters the Jordan River just downstream of the Cudahy Lane bridge.

Discharge Monitoring Report (DMR) documents are submitted to the Utah DWQ Permitting Section by each facility as part of UPDES requirements and include average daily discharge flows. Monthly flows typically vary less than 10 percent. Table 2.9 presents the flows from these sources.

Table 2.9. Average annual discharges to Jordan River from Permitted Discharge facilities.

Name	Permitted Discharge	Flow (ac-ft)
South Valley Water Reclamation Facility (1988–2005)	UT0024384 Effluent	28,061
Central Valley Water Reclamation Facility (1988–2005)	UT0024392 Effluent	61,041
South Davis South Wastewater Treatment Plant (2001–2005)	UT0021628 Effluent	2,599
Total		**91,701**

2.3.5 STORMWATER

Stormwater was defined as the amount of precipitation runoff captured in established, constructed stormwater catchment systems and was one of the more complex components to incorporate into the water budget. The term had to be defined, the amount calculated, and the various means of delivery to the Jordan River factored into the budget. Figure 2.1 diagrams the four methods that were used to route stormwater for the water budget and load calculations as described below:

- Discharge from catchments to gaged tributaries above stream gages via canal overflow or directly to stream channel. These amounts are automatically included in flows and loads at gage locations.
- Discharge from catchments directly to gaged tributaries below the gate 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 channel or via canal overflows.

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. The means of delivery can include direct discharge to the river from collection systems or drains, or indirect discharge via tributaries or canals. Runoff from areas outside of defined stormwater catchment systems is addressed as diffuse runoff (Section 2.3.6).

Stormwater catchments have been delineated by Salt Lake County and Salt Lake City. The boundaries used in this analysis were based on coverage developed in 1992. The location of all stormwater catchments in Salt Lake County are shown in Figure 2.3. 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.

The percent of impervious surface is greater in highly developed commercial or industrial areas in comparison to rural or low-intensity residential neighborhoods. Discharge volumes are also influenced by the percent of land area in a catchment basin that is serviced by runoff collection systems such as curbs, gutters, and drains. 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.

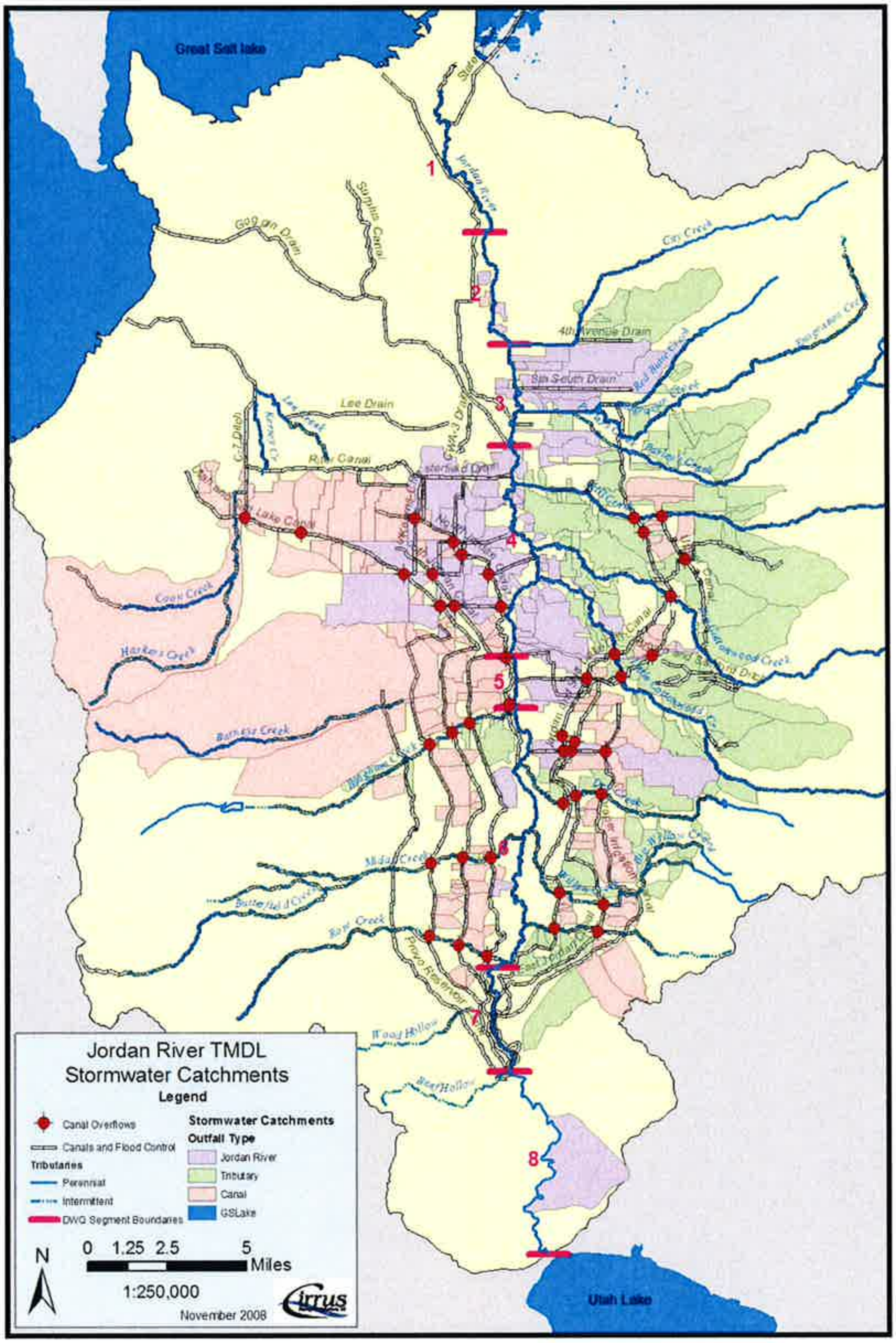


Figure 2.3. Stormwater catchments in the Jordan River watershed.

Development along the Wasatch Front continues to influence the composition of land cover types as well as the extent of stormwater collection systems. Land cover maps in Salt Lake County were updated in 2002 and indicated a decrease of low/medium density residential development and increases in heavy residential, commercial/industrial, and open space land cover types (Salt Lake County 2006).

Stormwater yields were calculated in a four-step process. Average monthly precipitation was based on 30-year averages of monthly precipitation values for the study area. A runoff correction factor of 0.9 was used to calculate the amount of precipitation that was available after evaporation for runoff. A second coefficient of 0.52 based on land cover types throughout the basin was developed and then applied to the calculated areas to yield the amount of stormwater transported to an outfall.

Table 2.10 shows the average annual amount of stormwater inflow to the Jordan River collected by catchment systems. Rain and snowmelt that is not collected in catchments is accounted for as diffuse runoff.

2.3.6 DIFFUSE RUNOFF

As in the case of stormwater 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 to enter in order to avoid overflow conditions.

Areas contributing diffuse runoff were calculated using computer GIS tools. A runoff correction factor of 0.9 was then applied to the average annual precipitation to account for surface depressions that do not produce runoff (Stantec 2006a). A runoff coefficient was also calculated for diffuse runoff areas using coefficients for stormwater runoff from catchments dominated by parks (0.20) and rural open space (0.10) (Stantec 2007). These land cover types were determined to more accurately represent conditions found in diffuse runoff areas. The average of these two values is equal to 0.15 and was used as a runoff coefficient for diffuse runoff areas. Monthly precipitation values were then multiplied by the runoff correction factor and runoff coefficient to determine diffuse runoff volumes for areas outside of the stormwater catchments.

Diffuse runoff listed separately in the final budget was 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 that tributary. Diffuse runoff to ungaged tributaries was considered part of the natural flow in the area-altitude models. Detailed results for diffuse runoff for the mainstem and gaged tributaries are presented in Table 2.11.

Table 2.10. Stormwater inflow to Jordan River from catchments.

	Annual Flow (ac-ft)
Stormwater Catchments Discharging into Gaged Tributaries Below the Gage	
Parley's Creek	1,915
Emigration Creek	1,011
Red Butte Creek	168
City Creek	2,181
Total	**5,275**
Stormwater Catchments Discharging Directly to Jordan River by Jurisdiction (including catchments that flow via drains or canals that empty into drains)	
Salt Lake County	1,864
Midvale	218
Murray	1,420
Riverton	72
Salt Lake City	3,964
Sandy	1,212
South Jordan	117
South Salt Lake	279
UDOT	232
West Valley	1,1,000
Lehi	2,038
Total	**12,416**

Stormwater Catchments Discharging into Ungaged Tributaries

Tributary	**Annual Direct Stormwater Discharge (ac-ft)**	**Annual Stormwater Discharge Via Canals (ac-ft)**	**Total Annual Flow to Ungaged Tributaries (ac-ft)**
Rose Creek	0	140	140
Corner Canyon	1,153	308	1,461
Midas/Butterfield Creek	15	688	702
Willow Creek	788	208	997
Dry Creek	873	790	1,663
Bingham Creek	384	541	925
Total	**3,212**	**2,675**	**5,887**

Table 2.11. Areas contributing diffuse runoff and annual flows for areas adjacent to the mainstem of the Jordan River and adjacent to gaged tributaries below the gages.

	Total Area (ac)	**Total Runoff (ac-ft/yr)**
Adjacent to Mainstem Jordan River	9,802	1,654
Parley's Creek below 10171600 and culvert	558	94
Emigration Creek below 10172000 gage and culvert	681	115
Red Butte Creek below 10172300 and culvert	236	40
City Creek	142	24
Total	**11,418**	**1,927**

2.3.7 IRRIGATION RETURN FLOW

Irrigation return flows are defined for this analysis as water volumes at the terminal end of canals. These result from irrigation water that does not penetrate the ground or water that is not actually used by the water right holder. Only diversions and return flows associated with the Jordan River are considered. Return flows from irrigation do not include stormwater discharge to canals. Stormwater flows are accounted for separately and transferred from canals to tributaries and drains through overflow structures.

Flows for irrigation are typically diverted from the Jordan River to canals during the months of May through 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.

In addition to irrigation demand, the practice used to apply irrigation water to fields can also influence the amount of return flows. Fields irrigated with pressurized systems (sprinklers) have essentially no runoff. In contrast, flood irrigation practices are inefficient with respect to the amount of water applied versus what is actually required to meet the consumptive demands of agricultural crops. Water right duty values (ac-ft of water used to irrigate each acre of land) in the Jordan River watershed range between 4-5 ft/ac (DWRi 2003). Efficiency of flood irrigation practices is generally considered to range from 40 percent to 50 percent. As a result, much of the water applied as flood irrigation in the project area does not infiltrate into fields and returns to canals as tailwater.

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 this analysis. However, shallow groundwater flow is collected from irrigated fields with drain tiles that subsequently discharge to canals, and these flows are included in return flow estimates.

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 based on time periods absent of storm events and do not include stormwater discharge. Monthly estimates of return flow were based on average monthly flow at the point of diversion, estimates provided by Salt Lake County and a correction factor derived from measured data.

These flows were added into the segments of the Jordan River where the canals eventually emptied. Flows from canals that discharge directly into the Great Salt Lake (e.g., the Utah and Salt Lake Canal) were not included in the budget.

Eight Jordan River diversion points serve 11 major canal systems, six of which return flows to the Jordan River. Table 2.12 presents irrigation return flows for these six canals.

Table 2.12. Irrigation return flows to Jordan River mainstem.

	Annual Diversion (ac-ft/yr)	Percent of Original Diversion Returning to Jordan River	Irrigation Tailwater (ac-ft/yr)	Point of Return (river mile)
Utah Lake Distributing Canal	26,135	20	5,227	42.3
Jacob-Welby Canal	28,051	10	2,805	42.3
East Jordan Canal	35,711	5	1,786	27.7
South Jordan Canal	24,464	20	4,893	27.4
North Jordan Canal	6,638	20	1,328	27.4
Jordan and Salt Lake City Canal	7,888	20	1,578	22.9
Total			**17,616**	

2.3.8 GROUNDWATER

Investigations have addressed groundwater flows to the Jordan River below Turner Dam, particularly the modeling documented in CH2M Hill (2005, Appendix K memo, Table 2). Most groundwater discharge estimates used in this water budget were taken from that analysis. Groundwater discharge to the Jordan River above Turner Dam was not included in the CH2M Hill analysis. As a result, these flows were calculated based on 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.

Table 2.13 summarizes these flows for the eight DWQ Segments of the Jordan River below Utah Lake.

Table 2.13. Annual ground water discharge flows to the Jordan River.

DWQ Segment	Annual Average Ground Water inflow volume (ac-ft/yr)
8	8,568
7	14,993
6	56,695
5	6,690
4	9,938
3	11,473
2	7,372
1	5,004
Total Flow	**120,733**

2.3.9 CANAL DIVERSIONS

The significant outflows from the Jordan River, other than evaporation, are diversions to canals transporting water for irrigation, flood control, or public water supply purposes. Irrigation diversions occur primarily in late spring through early fall. Diversions for flood control and public water supply occur year round. Flows for irrigation and public water supply are regulated by the DWRi which receives data either directly from flow gages in canals or as reported from water rights holders. Table 2.14 lists the canals diverting water from the Jordan River, the diversion points identified by river mile above Burton Dam, and the average annual diverted flow in ac-ft.

Table 2. 14. Outflows from Jordan River.

Canal	DWRi Identifier (and Water Right)	River Mile of Diversion	Average Annual Flow (ac-ft)
Utah Lake Distribution Canal and Jordan Valley Pump Station	04.01.04 Utah Lake Distribution Canal	41.9	26,135
Jacob-Welby Canal	05.01.07 Jordan Valley Water Conservancy Dist	41.9	28,051
East Jordan Canal	06.03.01 East Jordan Irrigation Company (57-7637)	41.8	35,711
Draper Irrigation Canal	06.04 Draper Irrigation Co. (57-23)	41.8	9,329
Salt Lake City County via East Jordan Canal	Salt Lake City Co. East Jordan Canal	41.8	12,608
Utah and Salt Lake Canal	06.02.01 Utah & Salt Lake Canal (59-3499)	41.8	42,495
Jordan and Salt Lake Canal	Salt Lake City Corp - Jordan & Salt Lake Canal	39.9	7,888
South Jordan Canal	07.02 South Jordan Canal	39.9	24,464
North Jordan Canal	10.01.01 North Jordan Irrigation Co. (59-3496)	28.8	6,638
Surplus Canal	10170500 - Surplus Canal at Salt Lake City, UT	16	466,533
State Canal	4990880 - Jordan R at State Canal Road crossing	1.7	51,612
Total			**711,465**

2.3.10 ANNUAL WATER BUDGET SUMMARY

Table 2.15 presents an average annual water budget for the Jordan River. Inflows and outflows described in this chapter 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.

Table 2.15. 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. 1982 (Coon et al.)	219
Corner Canyon Creek	Salt Lake Co. 1982 (Coon et al.)	2,087
Midas/Butterfield Creek	Salt Lake Co. 1982 (Coon et al.)	820
Willow Creek	Salt Lake Co. 1982 (Coon et al.)	997
Dry Creek	Salt Lake Co. 1982 (Coon et al.)	3,639
Stormwater	Stantec 2006a	3,481
Diffuse Runoff	Cirrus 2007	862
Irrigation Tailwater	Salt Lake Co. 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 2.15. (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. 1982 (Coon et al.)	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 Co. 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 2.15. (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 Co. 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 2.15. (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 Co. 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 Co. 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**

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.

2.4 FLOW MANAGEMENT

2.4.1 INTRODUCTION

This section describes the regulation of the Jordan River for water supply and flood control purposes and the implications of management on the water budget and minimum instream flows. The Jordan River is primarily regulated through the management of releases from Utah Lake, the diversion at the Surplus Canal and the diversions at the other primary irrigation canals. Each of these flow regulations is discussed in the following sections.

2.4.1.1 Utah Lake Management

The source of the Jordan River is Utah Lake, a natural freshwater lake that has been modified to be a flood control and water supply reservoir through the installation of an outlet gate structure and pumping station. Releases are managed by the Utah Lake and Jordan River Commissioner, appointed by the State Engineer through the DWR, pursuant to an agreement between Utah County, Salt Lake County, DWR, and other state and federal resource agencies.

The *1992 Utah Lake Water Distribution Management Plan* specifies the protocols for storage of water in the Provo River reservoirs and Utah Lake, and the distribution of water for primary and secondary storage water rights holders along the Jordan River (DWRi 1992).

Management of the outlet from Utah Lake for flood control purposes is specified in the *Compromise Agreement of 1985 (Civil No. 64770)*. According to the agreement, water must be released once the lake level exceeds the "compromise elevation," or the maximum legal storage elevation in Utah Lake, which was established in 1985 at approximately 4,489 feet above sea level (USGS datum). The control gates at the outlet to Utah Lake are fully opened at compromise elevation, with the restriction that the flow in the Jordan River measured at 2100 South is not to exceed 3,400 cfs (CH2M Hill 1984).

2.4.1.2 Surplus Canal Management

The Surplus Canal diversion structure is located on the Jordan River at approximately 2100 South. The Surplus Canal was constructed to route floodwaters from the Jordan River away from the densely populated downtown, Glendale, and Rose Park areas of Salt Lake City. The physical configuration of the diversion actually diverts the Jordan River off the Surplus Canal through three head gates and a radial gate. A check dam structure in the river raises the water surface and forces water to the east and into the Jordan River.

The operation of the diversion structure is mandated by the Operation and Maintenance criteria established by the United States Army Corps of Engineers for the Jordan River Project when the Surplus Canal was constructed (USACE 1985) and by the *Jordan River Flow Management Agreement* as an outcome of the mitigation negotiations for the construction of Little Dell Dam and Reservoir (Salt Lake County 1989).

The diversion structure is operated as follows:

- All excess flows will be diverted to the Jordan River unless:
    - The diversion interferes with satisfying any existing water rights;
    - The diversion is in excess of 300 cfs; and
    - The diversion would be in a period of threatening or actual rainstorms or that the diversion results in flooding during dry weather.
- The County will operate the structure when flows are greater than 600 cfs.
- The Lower Jordan River Commissioner will operate the structure when flows are less than 600 cfs.
- Mitigation flows will be reduced immediately if the River Commissioner determines excess flows are not present.

2.4.1.3 Water Rights

Water that is released from Utah Lake for downstream water users is diverted from the Jordan River into several canals (Table 2.16). The first diversion from the Jordan River, Jordan Valley Water Conservancy District Pump Station, is just above Turner Dam, approximately 9.6 miles downstream from the Utah Lake outlet. The Utah Lake releases get mixed with groundwater, springs, tributaries, and stormwater in the Jordan River before being diverted. The releases and diversions occur primarily during the irrigation season between April 15 and October 15, with the exception of the North Jordan Canal, which typically receives water throughout the year. The primary and secondary water storage rights in Utah Lake are summarized in Table 2.17 (Hooten undated).

Some of the oldest and most senior water rights are held by duck clubs in the Jordan River delta within the Great Salt Lake Shorelands. The duck clubs typically receive water from the Jordan River during April through January to maintain waterfowl habitat.

Water rights entitle the holder to a specified amount of depletion of the appropriated water, with the undepleted water returned to the hydrologic system either through seepage, drainage, or treated wastewater effluent. The amount of depletion allowed is dependent upon many factors, including the type of beneficial use, the distance from the diverted source, the type of conveyance, the type of crop or stock watering, the location within the state, the type of treatment, and the distance to the discharge point. For indoor domestic water use, the percentage of allowable consumption varies from 20 to 100 percent.

Table 2.16. Primary flow diversions from the Jordan River.

Diversion	River Mile	Purpose	Timing	Primary Water Rights Holders
Jordan Valley Pump Station	41.9			
Utah Lake Distributing Canal		Irrigation	Seasonal	Utah Lake Distributing Co.
Welby-Jacob Canal		Irrigation	Seasonal	JVWCD
Turner Dam	41.8			
East Jordan & Draper Canal		Irrigation	Seasonal	East Jordan Irrigation Company Draper Irrigation Company Salt Lake City
Utah and Salt Lake Canal		Irrigation	Seasonal	Utah and Salt Lake Canal Co. Kennecott Utah Copper
Joint Dam	40.0			
South Jordan Canal		Irrigation	Seasonal	South Jordan Canal Co.
Jordan & Salt Lake Canal		Irrigation	Seasonal	Salt Lake City
North Jordan Canal	28.8	Irrigation & Industrial	Year Round	North Jordan Irrigation Co. Kennecott Utah Copper
Brighton Canal	26.4	Irrigation	Seasonal	
Surplus Canal	16.0	Flood Control	Year Round	Duck Clubs
UP&L Diversion	12.2	Process	Year Round	Rocky Mountain Power
State Canal	1.7	Irrigation	Year Round	

Table 2.17. Primary and secondary storage rights in Utah Lake.

Entity	Primary Storage Rights	Secondary Storage Rights
Utah and Salt Lake Canal	35,319	
South Jordan Canal	24,355	
East Jordan Canal	40,465	
North Jordan Canal	5,350	
Salt Lake City	10,500	
JVWCD	34,174	5,439
CUWCD	25,000	50,739
Utah Lake Distributing Canal		39,727
Draper Irrigation Company		10,500
Total	175,558	112,739

Source: Utah Lake & Jordan River: Water Rights and Management Plan (Hooten undated).

2.4.1.4 Minimum Flows

No minimum flow requirements have been established for the Jordan River (DWR 1997); therefore, the river has the potential to be dewatered in certain segments at certain times of the year. In addition, the potential for dewatering is greater during drought years as there is not enough water to meet all of the water users' demands. Water rights holders can dictate the minimum flows in the river; however, there is no guarantee of minimum flows as water rights holders may only need water at certain times of the year. The minimum flows in the river are also largely dependent on groundwater accretion, irrigation return flows, and wastewater treatment plant effluent.

The segments of the Jordan River with the greatest potential for low or no flows are between Utah Lake and Turner Dam when flows are not being released from Utah Lake, immediately downstream of the Joint Dam during the irrigation season, and immediately downstream of the North Jordan Canal diversion. Groundwater and springs add flow to the Jordan River throughout these segments, so the extent of dewatering is both spatially and temporally limited.

2.4.2 IMPORTED WATER

This section summarizes current and proposed imports of water to the Jordan River basin. Import water for the purposes of this discussion is defined as water that is either diverted above Utah Lake within the Utah Lake/Jordan River Watershed or from another river basin and conveyed into Salt Lake County for water supply purposes.

In 2005, the amount of water imported into Salt Lake County for municipal, industrial, and agricultural water supply annually was 100,277 ac-ft (Salt Lake County 2009). The source of the import water is from the Provo River through the USBOR Provo River Project and the CUWCD Municipal and Industrial System.

The import water is delivered to the MWDSLS and the JVWCD, treated for potable use and then delivered to local water providers for municipal and industrial use.

By the year 2030, CUWCD plans to complete the Utah Lake Drainage Basin Water Delivery System (Utah Lake System), which will deliver water from the Diamond Fork and Spanish Fork Rivers to Salt Lake County. An additional 30,000 ac-ft of import water will be delivered to MWDSLS and JVWCD under the Utah Lake System (Salt Lake County 2009).

JVWCD has plans to develop additional water sources from the Bear River in the future. However, this is scheduled to be implemented in 2035, which is outside of the range of this water quality study.

Some of the import water is depleted by the end users for household, industrial, or irrigation purposes. The household and industrial water that is not depleted is either discharged to the sewer system for treatment at the wastewater treatment plants or ends up as return flow to groundwater and streams. Import water discharged to the sewer within the Salt Lake City Water Treatment Plant's and Magna Water Reclamation Facility's service area is not released to the Jordan River.

2.4.3 WATER REUSE

Water reuse is defined as the direct or indirect use of wastewater treatment plant effluent for a beneficial purpose (DWR 2005). This section summarizes the current and proposed water reuse projects that potentially affect the hydrology of the Jordan River.

In 2000, the CVWRF implemented a water reuse project. CVWRF provides approximately 672 ac-ft/year of treated effluent for irrigation of a public golf course and landscaped areas, and water for decorative ponds (DWR 2005).

The CUWCD is required by agreement with the USDOI to reuse a total of 18,000 ac-ft/year as part of the Utah Lake System (DWR 2005). The agreement requires water providers served by CUWCD to begin reusing 1,000 ac-ft/year by 2016, and an additional 1,000 ac-ft/year every year until 2033, for a total of 18,000 ac-ft/year. From the year 2033 until 2050, CUWCD must continue reusing 18,000 ac-ft/year, and for every year that CUWCD fails to fulfill this requirement, it must assess itself a surcharge as specified in the amendment. Under Section 207 of the Central Utah Project Completion Act, any surcharges collected are to be used by CUWCD to help fund water reuse projects that are created within its service area.

The *Jordan River Return Flow Study* (CH2M Hill 2005) estimated 6,088 ac-ft/year of water reuse at CVWRF and 6,048 ac-ft/year at SVWRF by the year 2030, for a total of 12,136 ac-ft/year. The remainder of the 18,000 ac-ft required by CUWCD was assumed to occur at the SLCWRP, which does not discharge to the Jordan River.

North Salt Lake City plans to reuse 463 ac-ft of treated effluent from the SDWTP in its secondary water system (DWR 2005).

Water Reuse in Utah (DWR 2005) discusses some of the considerations that will determine the amount of water reuse that is implemented in the future, including water rights, regulatory, environmental, economical and legal considerations. The demand for new water sources to meet a growing population combined with the limited availability of new water sources may improve the economics of water reuse in the future. This may result in additional water reuse beyond what is currently required through water provider agreements.

2.4.4 2030 WATER BUDGET

The import water, water reuse, and additional water development in the Wasatch Mountain and Oquirrh Mountain streams will affect the hydrology of the Jordan River. Most of the import water that is not consumed will be discharged to the Jordan River either through wastewater treatment effluent or irrigation return flow. Land use changes and population growth within the County will have significant impacts on the hydrology of the Jordan River as well.

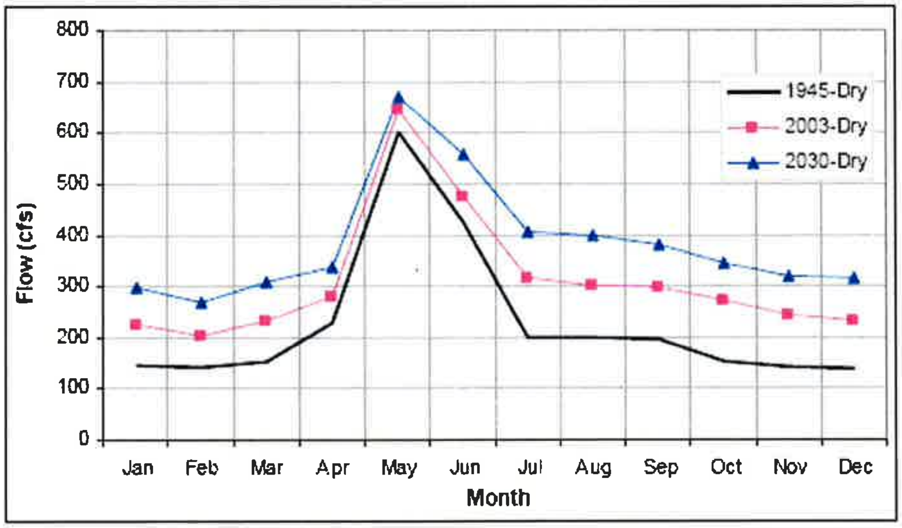
The *Jordan River Return Flow Study* (CH2M Hill 2005) projected flow conditions in the Jordan River in 2030 considering the proposed water development projects, future water demand and consumption, and with 18,000 ac-ft/year of water reuse. The study estimated the water budget for dry, average and wet hydrologic conditions in the years 2003 and 2030. The water balance estimate was made using CH2M Hill's VOYAGE water balance simulation tool, which was calibrated to 2003 conditions. VOYAGE considers inflows and outflows, municipal and industrial water demand and consumption, wastewater treatment plant discharges, water reuse, agricultural water demand and consumption, irrigation return flows, and groundwater for the water balance simulation.

The report concluded that annual flow volumes in the Jordan River are projected to increase in the future primarily due to an increase in import water which will more than compensate for the loss of flows resulting from proposed water reuse and water development projects (Table 2.18). The mean monthly flow rates were also projected to increase for 2030 (Figure 2.4).

Table 2.18. Jordan River flow volume balance summary under dry hydrologic conditions with water reuse.

Reach	2003 (ac-ft)	2030 (ac-ft)
Return flows (wastewater and irrigation)	165,200	211,300
Groundwater	44,700	44,700
Utah Lake releases	115,300	114,300
Tributaries including stormwater	81,000	78,300
Canal diversions	(147,400)	(138,800)
Outflow (Surplus Canal & Jordan at Cudahy Lane)	258,800	309,800

Source: *Jordan River Return Flow Study* (CH2M Hill 2005).



Source: *Jordan River Return Flow Study* (CH2M Hill 2005).

Figure 2.4. Simulated mean monthly flow in the Jordan River at 2100 South under dry hydrologic conditions with water reuse.

2.5 SUMMARY AND CONCLUSIONS

This analysis was necessary because no water budget existed that was sufficient to meet the needs of this TMDL process. As noted in the Introduction (Section 2.1), although the ultimate allocation in a TMDL is the load, or mass, of a pollutant, a water budget is important, because for many beneficial uses the most critical concern is concentration, which is a function of both mass and flow, and because some sources vary diurnally, seasonally, or annually, it is important to consider flow to calculate concentrations and loads.

This annual water budget was developed for the mainstem of the Jordan River utilizing all of the available data for seven categories of inflows and outflows that connect to the river at dozens of different places. The final budget summarized inflows and outflows for five sub-sections of the river bounded by Utah Lake, 9000 South, 2100 South, 500 North, Cudahy Lane, and Burton

Dam. The largest discrepancies found between calculated and measured flows were for the 12-mile section from 9000 South to 2100 South, but were relatively small on a percent per mile basis at less than 0.6 percent per mile. Some of the most important ramifications for water quality will be for the section below 2100 South, where the annual flows in the Jordan River are reduced by approximately 80 percent because of flood control diversions to the Surplus Canal (Chapter 4 Water Quality Linkages in the lower Jordan River). Recommendations for further studies and additional data collection with regards to specific components of the water budget are included in Appendix A.

3.0 POLLUTANT SOURCE CHARACTERIZATION

A number of water quality parameters, including TDS, TSS, BOD, NH_4, and Total P contribute to impairment of Jordan River water quality. The purpose of this section is to characterize the sources of these constituents in order to identify practical ways to address the impairments. Following an extensive review of published literature, monitoring data, and discussions with local agency personnel, a total of nine pollutant sources were identified that contribute pollutant loading to the Jordan River. These sources include the following:

- Utah Lake
- Mainstem Jordan River
- Tributaries
- UPDES Point Sources
- Stormwater
- Diffuse Runoff
- Return Flows from Irrigation Canals
- Groundwater
- Natural Background

The location of pollutant sources in the project area is shown in Figure 3.1 and includes specific geographic locations for each source, with the exception of Natural Background. Conditions and processes that contribute Natural Background loads are typically not limited to a specific geographic location. Additional information describing the methods used to characterize this source is included below.

A load, or mass of pollutant, has been calculated for each source as the product of flow and water quality. The location of monitoring stations used to collect flow and water quality measurements are shown in Figure 3.2. Descriptions of each station, responsible agency, and data type used (i.e. water quality or flow) in load calculations are shown in Table 3.1. Flow averages are based on records collected from 1980–2005 in order to account for longer periods of wet and dry cycles. Water quality data used for load calculations was generally limited to measurements collected during 1995–2005 in order to accurately characterize existing conditions that influence water chemistry. Load calculations at mainstem Jordan River monitoring sites are also presented at the end of this section, followed by an assessment of load duration curves. Annual loads are provided in the main body of the report. Monthly loads for each source were also calculated and archived in the appendix to this document.

3.1 UTAH LAKE

Utah Lake is located in northern Utah County and is one of the largest freshwater lakes in the western U.S. The lake covers approximately 145 square miles yet contains only 1 million ac-ft of water due to a shallow average depth of 9–10 feet (DWQ 1994). Utah Lake is the single largest flow contributor to the Jordan River and discharges to the river at its origin (Figure 2.2). Utah Lake discharge to the Jordan River is controlled according to guidelines contained in the Utah Lake Water Distribution Management Plan. The Jordan River receives the only surface discharge from Utah Lake and accounts for approximately 51 percent of outflow from the lake

(PSOMAS/SWCA 2007). The remaining outflow from the lake is partitioned between evaporation (42 percent) and groundwater seepage (7 percent).

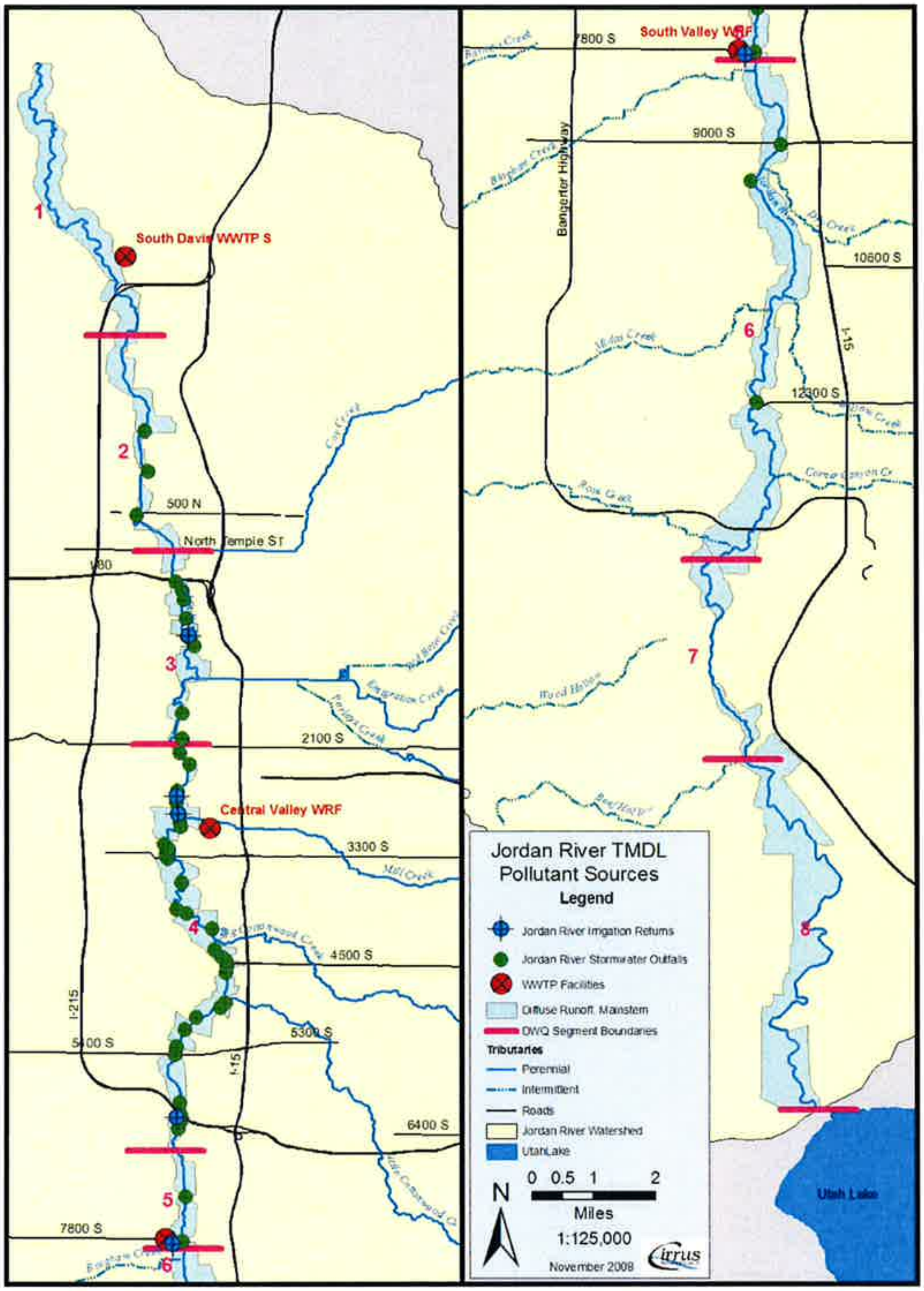


Figure 3.1. Jordan River Pollutant Sources.

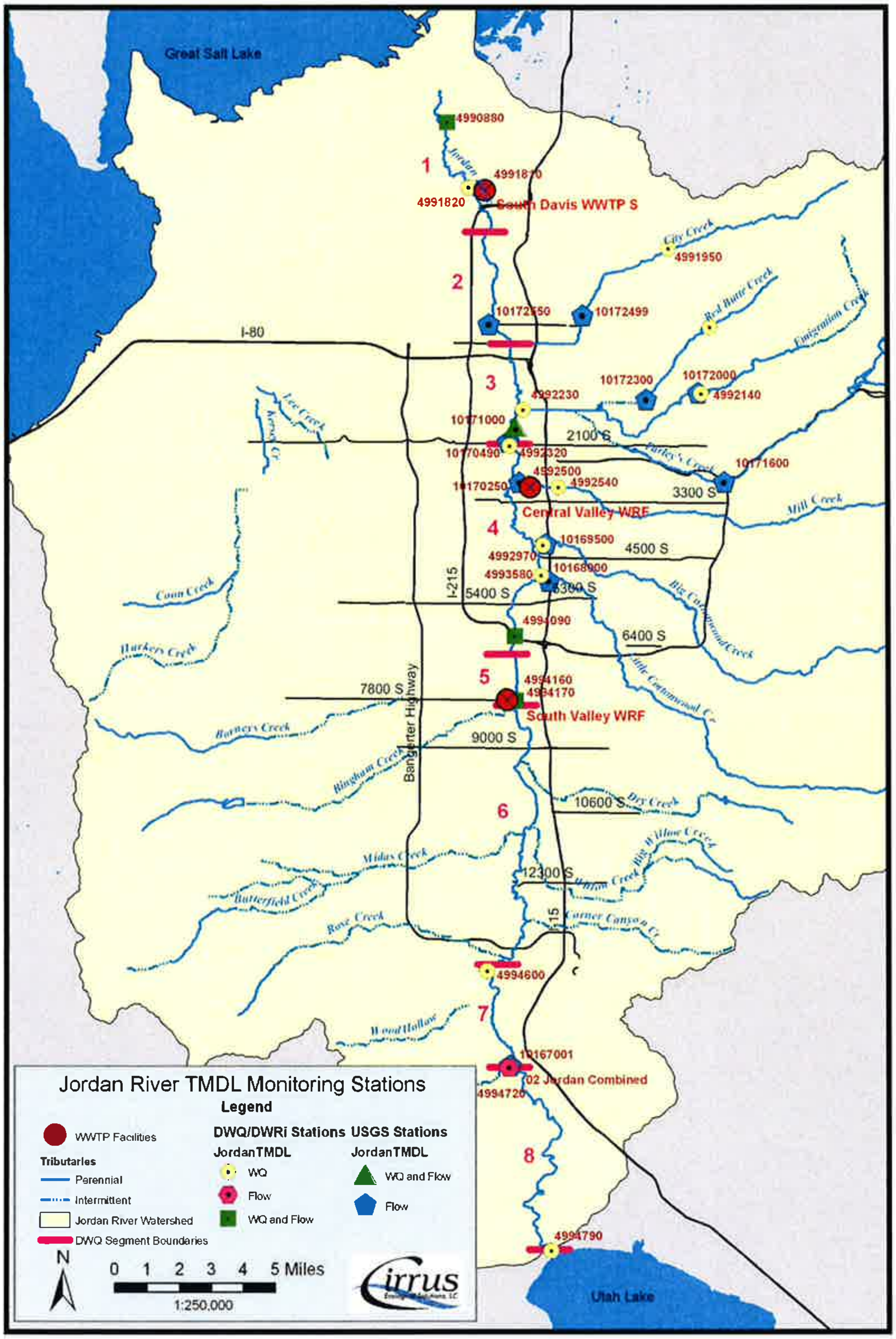


Figure 3.2. Flow and Water Quality Monitoring Stations used to calculate pollutant loads for the Jordan River TMDL.

Table 3.1. Flow and water quality stations used to calculate pollutant loads for the Jordan River TMDL.

Station Name	Description	Agency and Use
4990880	Jordan River at State Canal Road Crossing	DWQ/DWRi WQ and Flow
4991810	South Davis South WWTP	DWQ/DWRi WQ
4991820	Jordan River at Cudahy Lane above South Davis South WWTP	DWQ/DWRi WQ
4991950	City Creek above Filtration Plant	DWQ/DWRi WQ
4992140	Emigration Canyon Creek at Rotary Glen	DWQ/DWRi WQ
4992230	Parley's Canyon Creek at Mouth	DWQ/DWRi WQ
4992320	Jordan River 1100 West 2100 South	DWQ/DWRi WQ
4992500	Central Valley WTTP	DWQ/DWRi WQ
4992540	Mill Creek above Central Valley WWTP at 300 West	DWQ/DWRi WQ
4992970	Big Cottonwood Creek above Jordan River at 500 West 4200 South	DWQ/DWRi WQ
4993580	Little Cottonwood Creek 4900 South 600 West Salt Lake City	DWQ/DWRi WQ
4994090	Jordan River above 5400 South at Pedestrian Bridge	DWQ/DWRi WQ and Flow
4994160	South Valley WWTP	DWQ/DWRi WQ
4994170	Jordan River at 7800 South Crossing above South Valley WWTP	DWQ/DWRi WQ and Flow
4994600	Jordan River at Bluffdale Road Crossing	DWQ/DWRi WQ
4994720	Jordan River at Narrows - Pump Station	DWQ/DWRi WQ
4994790	Utah Lake Outlet	DWQ/DWRi WQ
02 Jordan Combined	Jordan River at Narrows (Turner Dam)	DWQ/DWRi Flow
10167001	Jordan River Station No 1. at Narrows, UT. (Adjusted to represent Jordan River at Bluffdale)	USGS Flow
10168000	Little Cottonwood Creek at Jordan River near Salt Lake City	USGS Flow
10169500	Big Cottonwood Creek at Jordan River near Salt Lake City, UT	USGS Flow
10170250	Mill Creek at Jordan River near Salt Lake City, UT	USGS Flow
10170490	Combined Flow Jordan River and Surplus Canal at Salt Lake City, UT	USGS Flow
10171000	Jordan River at 1700 South at Salt Lake City, UT	USGS WQ and Flow
10171600	Parley's Creek at Suicide Rock near Salt Lake City, UT	USGS Flow
10172000	Emigration Creek Near Salt Lake City, Utah	USGS Flow
10172300	Red Butte Creek at 1600 East at Salt Lake City, UT	USGS Flow
10172499	City Creek (Channel) Near Salt Lake City, UT	USGS Flow
10172550	Jordan River at 5th North at Salt Lake City, UT (Used to correlate flows between 500 North and DWRi gage "CUDAHY LANE (CFS)" for extended record of Jordan River at Cudahy Lane)	USGS Flow

Utah Lake has generally been considered to maintain poor water quality due to human caused pollutant sources as well as the turbidity of the lake (DWQ 1994). High turbidity levels are a response to resuspended bottom sediments (from wind action and fish feeding) as well as precipitation of calcium and bicarbonate ions.

Utah Lake is included on the 2006 303(d) List of impaired waters due to elevated levels of TDS and Total P. Although Utah DWQ does not currently associate numeric criteria with nutrient levels, Total P is known to contribute to processes that result in low DO concentrations. An assessment of TDS and Total P loading has recently been completed for Utah Lake and includes seasonal and annual loads for these constituents (PSOMAS/SWCA 2007). Pollutant loads were identified from a variety of sources including WWTPs, tributary streams, springs, groundwater, and diffuse runoff. Figure 3.3 indicates the distribution of TDS and Total P pollutant loads to Utah Lake based on 1980–2003 flow averages and water quality averages spanning the entire period of record. Annual Total P loads delivered from Utah Lake to the Jordan River were 81.7 tons/year. Annual TDS loads discharged from Utah Lake to the Jordan River were not included in the report.

No recent measurements of direct discharge from the outlet of Utah Lake have been identified (Section 2.3.2. Utah Lake). Calculations of daily and mean monthly discharge from Utah Lake are provided by Utah DWRi from water rights information or by other agencies using data from the gage at Turner Dam. Different discharge values from Utah Lake could reflect the period of record used to calculate average flows from gage data or possibly the use of different flow models. Due to the disparity that exists between these values, use of measured flow at the Turner Dam gage minus estimates of groundwater accretion, stormwater discharge, and diffuse runoff were determined to be the most accurate method for defining existing discharge from Utah Lake.

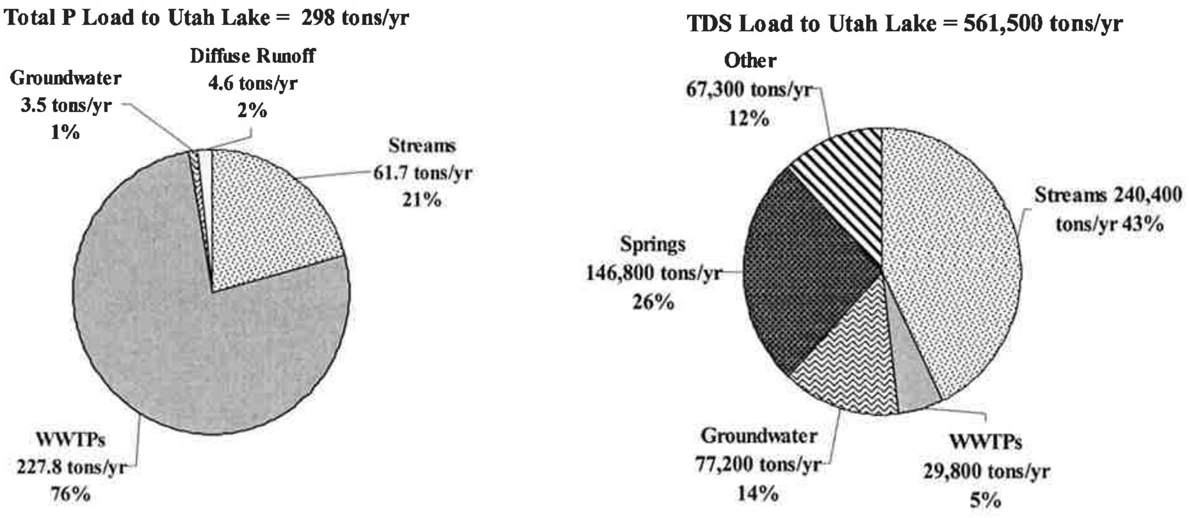


Figure 3.3. Annual Total P and TDS loading (tons/year) to Utah Lake as reported in the Utah Lake TMDL (PSOMAS/SWCA 2007).

Water quality data was obtained from samples collected at Station 4994790 - Jordan River at Utah Lake from 1995–2005. Samples at this station were collected just downstream of the lake outlet near the Saratoga Springs road crossing. All samples with concentrations below the detection limit were assigned a value of one-half that of the method detection limit associated with the test method used to measure a specific water quality parameter. These limits varied according to water quality parameter. Only EPA approved test methods were used to measure water quality parameters. Monthly loads for each pollutant of concern were determined from the product of monthly average flow and monthly average concentration. Annual loads for each pollutant of concern were summed from monthly loads and are shown in Table 3.2. Monthly loads for each pollutant of concern are included in Appendix B.

Table 3.2. Annual pollutant loads discharged from Utah Lake to the Jordan River.

	Annual Load (kg)	Annual Load (lbs)	Annual Load (tons)
Total Dissolved Solids	501,448,161	1,105,492,616	552,746
Total Suspended Solids	14,463,143	31,885,445	15,943
Total Ammonia	40,635	89,584	45
Total Phosphorus	43,019	94,840	47

3.2 TRIBUTARIES

Natural stream channels contributing to the Jordan River have been significantly impacted by agriculture and urban development. Substantial amounts of flow are diverted between the valley margin and the Jordan River from all streams that enter the Salt Lake Valley. Diverted water is used for municipal or agricultural purposes. As a result of these diversions, calculations of flows to the Jordan River are complicated, and portions of some stream channels are dewatered entirely during some or all of the year. Water quality in tributary streams is influenced through water-rights-exchange agreements that allow upstream diverted water to be replaced downstream with lower quality water from Utah Lake as well as discharge from stormwater outfalls and canal overflow structures. A detailed description of diversions and other structures that influence flow rates in the major tributaries between the canyon mouths and Jordan River is provided in the Salt Lake County Area Wide Water Study (Coon et al. 1982) and more recently in the *Salt Lake County Water Quality Stewardship Plan* (Salt Lake County 2009). Table 2.6 provides a brief description of hydrologic characteristics for selected stream channels in the project area including perennial and intermittent stream channels. Figure 3.1 indicates the location of perennial and intermittent tributary streams that discharge pollutant loads to the Jordan River.

Pollutant loads for each Jordan River tributary are provided in this section and account for all upstream loads discharged to the tributary stream channel above the point of confluence with the Jordan River. For the purposes of discussion, Jordan River tributaries can be organized into monitored and unmonitored streams. All perennial tributary stream channels on the east side of the Jordan River are instrumented for continuous flow measurement at locations that account for all sources of inflow including natural contributions and stormwater discharge. Water quality is routinely monitored near these same locations by federal, state, and local agencies.

With the exception of Bingham Creek, the remaining tributary channels on both east and west sides are considered to be intermittent. Monitoring data was collected from Bingham Creek at Station 4994180 (Bingham Creek above the Jordan River confluence at 1300 West) during 1994–1995, 2000, and 2004. This data set was not used to calculate monthly or annual pollutant loads due to the limited number of measurements. Loads for Bingham Creek were calculated in the same manner as other unmonitored tributaries.

Streamflow gages and water quality monitoring stations used to calculate loads from monitored tributaries were selected based on distance to the Jordan River as well as proximity to each other. In the case of Mill Creek, the flow and water quality monitoring stations are located upstream of a point-source discharge to Mill Creek from the CVWRF. The location and ID number for each streamflow gage and water quality monitoring station used to calculate Jordan River tributary loads is shown in Figure 3.2. Monthly average flow values from gaged tributaries were calculated as part of the water budget presented above in Chapter 2, and include all measurements of mean daily flow collected during 1980–2005. This period captures the full cycle of wet and dry years that are typically observed in Utah. Monthly average water quality concentrations were calculated for monitored tributaries using all available data collected from 1995–2005. This period represents current water quality conditions that contribute to impairment of DWQ Segments included on the 303(d) List for Utah during the recent past.

Monitoring stations on several east-side tributaries are located several miles upstream of the confluence with the Jordan River, including City Creek, Red Butte Creek, Emigration Creek and Parley's Creek. These stations were selected based on the amount of data available as well as proximity of each station with respect to the 1300 South conduit that transports flow from these streams through municipal areas and into the Jordan River. Additional pollutant loads from stormwater and diffuse runoff are discharged to tributaries below their respective monitoring stations. Loads from these sources were added to the total tributary load when this occurred. Additional information describing the methodology used to calculate these loads is presented below in Section 3.4 Stormwater and Section 3.5 Diffuse Runoff. The load contributed by each source to the total tributary load is included in the Appendix D.

Monthly average flows from ungaged tributaries were determined according to methods described in Chapter 2 which provide separate estimates of flows contributed by natural instream hydrology (including headwater flows, diffuse runoff, and groundwater inflow) and stormwater discharge. Water quality measurements collected from nearby monitored streams were used to represent monthly average pollutant concentrations for unmonitored tributaries. A review of GIS information depicting land cover, geology, and soil types in unmonitored and nearby monitored streams indicated that conditions in headwater canyons were similar. Monthly average concentrations from Station 4993660 - Little Cottonwood Creek above Murray City Water Intake were used to represent water quality from natural flows occurring in Dry Canyon Creek, Willow Creek, and Corner Canyon Creek, all of which are located on the east side of the Jordan River. In a similar manner, Station 4994440 - Butterfield Creek At Mouth of Canyon was used to represent water quality of natural flows for unmonitored tributaries on the west side of the Jordan River, including Bingham Creek, Midas/Butterfield Creek, and Rose Creek.

Stormwater loads from direct discharge or canal overflow into unmonitored Jordan River tributaries were calculated separately and added to the total tributary load. Stormwater load calculations were based on the methodology developed through the stormwater monitoring program supported by Salt Lake County. A summary of this methodology is provided below in Section 3.4 Stormwater and detailed in Stantec (2006a). The location of stormwater catchments and overflow structures that influence flow and water quality are also presented in Section 3.4 Stormwater, including those used to calculate stormwater loads from unmonitored tributaries.

Annual loads for pollutants of concern for each tributary stream to the Jordan River are shown in Table 3.3 and represent the total load from all sources that contribute flow to the stream channel.

The more detailed monthly loads for each tributary stream discharging to the Jordan River are presented in Appendix D.

Table 3.3. Annual pollutant loads (tons/year) for Jordan River tributary streams.

Tributary	Total Dissolved Solids	Total Suspended Solids	Biochemical Oxygen Demand	Total Ammonia	Total Phosphorus
Big Cottonwood Creek	23,350	2,517	N/A	1.7	3.3
Bingham Creek	443	205	21	0.5	0.9
City Creek	2,361	906	94	2.7	0.4
Corner Canyon Creek	582	307	33	0.9	1.4
Dry Creek	964	351	37	1.0	1.6
Emigration Creek	5,117	751	24	0.9	1.6
Little Cottonwood Creek	22,922	2,136	N/A	2.3	3.5
Midas/Butterfield Creek	298	153	16	0.4	0.7
Mill Creek	15,372	689	N/A	0.9	2.5
Parley's Creek	10,849	519	43	1.5	2.1
Red Butte Creek	1,654	332	4	0.2	0.4
Rose Creek	103	33	3	0.1	0.1
Willow Creek	290	209	22	0.6	0.9
TOTAL	84,305	9,108	296	13.7	19.4

3.3 PERMITTED DISCHARGE

Discharge of point-source pollution is regulated through the UPDES process. Three UPDES point sources have been identified that discharge treated wastewater effluent to the Jordan River or tributaries. The locations of these facilities are shown in Figure 3.1. This discussion is limited to these three permitted facilities and does not include all UPDES permittees previously identified in the Work Element 1 report. This is based on a review of additional information that characterized the infrequent nature and small amounts of discharge that occur from Holliday Water Company (UT0025429), Moog Aircraft (UTG790013), PacifiCorp-Gadsby (UT0000116), Rubber Engineering (UT0024767), and Weir Specialty Pumps (UT0025089). In addition, discharge from the Utah State Prison (UT0024082) to the Jordan River has been eliminated due to a recent design change in treatment of wastewater. As a result of this new information, no further assessment will be completed for these facilities. A brief description of the three facilities shown in Figure 3.1 is included in Section 2.3.4 Permitted Discharge.

DMR documentation is submitted to the Utah DWQ Permitting Section by each facility as part of UPDES requirements and includes measurements of flow and water quality required by the permit. Monthly average flow values used to calculate pollutant loads for UPDES point sources were based on DMR documentation. Flow measurements were collected 2001–2005 from CVWRF and SDWTP and 2000–2005 from SVWRF. In some instances, DMR water quality data does not include measurements of pollutants of concern. Measurements of permit parameters are also collected by Utah DWQ as a means of validating DMR data but include other water quality constituents of interest as well. Where possible, DMR water quality data was used to calculate loads for UPDES point sources. When DMR water quality data was not available, monitoring data collected by Utah DWQ was used.

Annual loads for pollutants of concern for each of these three primary UPDES point sources discharging to the Jordan River are shown in Table 3.4 and represent the sum total of monthly load calculations. Monthly loads for each point source are presented in Appendix E.

Table 3.4. Annual pollutant loads (tons/year) for Jordan River UPDES point sources.

Name	Total Dissolved Solids	Total Suspended Solids	Biochemical Oxygen Demand	Total Ammonia	Total Phosphorus
SVWRF	61,799[1]	418	246	6.1[1]	230.3
CVWRF	110,173[1]	798	427	192.6[1]	389.6[1]
SDWTP	7,985[1]	87	92	23.5	9.8[1]

[1] Based on water quality data collected by DWQ during routine monitoring at point of discharge.

3.4 STORMWATER

Stormwater discharge is regulated in Utah by the Utah DWQ according to requirements established by the EPA in accordance with amendments to the 1972 Clean Water Act. These requirements are incorporated into Phase 1 and Phase 2 stormwater permits and regulate stormwater systems of municipalities with populations greater or less than 100,000, respectively. Three Phase 1 permittees are currently located in the project area including Salt Lake County (both incorporated and unincorporated areas), Salt Lake City, and Utah Department of Transportation (UDOT). In addition, a total of 14 Phase 2 permittees are found in the project area including the following:

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

With the exception of Herriman, Holladay, and Taylorsville, each of these permittees discharges stormwater to the Jordan River.

Stormwater is collected during runoff events that occur on land managed by each permittee and is eventually discharged into receiving water bodies. As described in Section 2.3.5 Stormwater, stormwater flows can enter the Jordan River through direct discharge via stormwater outfalls or indirectly through flood control facilities that convey flows to the Jordan River from many sources including stormwater. Flood control facilities include both tributary stream channels and storm drains which collect stormwater along the length of a stormwater catchment. Stormwater can be discharged directly to tributaries or contributed to tributaries and storm drains through canal overflow structures. These structures provide a way to route stormwater flow collected by canals to flood control facilities. Excess canal flows accumulated from stormwater discharge are assumed to be removed by the nearest downstream overflow structure.

This assessment accounts for all stormwater discharge in the project area that enters the Jordan River. Stormwater loads delivered to monitored and unmonitored tributary streams have been included with those tributaries as described in Section 3.2 Tributaries. Therefore, stormwater loads presented at the end of this section are those delivered by outfalls that directly discharge to the Jordan River as well as additional loads delivered by canal overflows to storm drains that also discharge directly to the Jordan River. The following discussion outlines the process used to estimate stormwater loads for both tributaries and the Jordan River. The location of stormwater outfalls that discharge directly to the Jordan River are shown in Figure 3.1. 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 2.3.

Factors that influence the amount of stormwater flow were discussed in Section 2.3.5 Stormwater. Land cover type can likewise influence the quality of stormwater. For example, the highest concentrations of Total P, BOD, and TSS were observed in stormwater samples collected from residential areas of Salt Lake County (Stantec 2006a). Development along the Wasatch Front continues to influence the composition of land cover types as well as the extent of stormwater collection systems.

Stormwater has been monitored in the project area by Salt Lake County, Utah Department of Transportation (UDOT) Region 2, and Salt Lake City since 1992 as part of UPDES stormwater permitting (Stantec 2006a). Boundaries of stormwater catchments were delineated at that time and continue to be the basis for defining stormwater catchments in the project area. Land cover maps generated in 1992 for Salt Lake County were recently updated in 2002 (Stantec 2006a).

As of 2005, a total of 27 storm events have been sampled at Salt Lake County/UDOT outfalls and 29 storm events sampled at City outfall locations (Salt Lake County 2006). Measurements of water quality and flow are only collected from storm events that meet minimum criteria including at least 0.20 inches of precipitation that produces runoff. As a result, no snowmelt events were sampled during monitoring efforts. Stormwater discharge samples are currently collected during design storm events in the spring and fall of each year from eight reference stormwater catchments located in Salt Lake City (two stations) and Salt Lake County (six stations including one UDOT point of discharge). Each stormwater catchment represents a unique land cover type comprised of residential, industrial, commercial, and transportation uses. Where possible, three types of samples are collected from each design storm event including the following:

- Base grab samples before storm runoff begins.
- Rise grab samples collected within 30 minutes of the start of runoff.
- Storm composite samples (flow weighted) collected over a 6-hour period.

Roughly 30 water quality constituents were measured from each sample depending upon the volume of water collected. Water quality measurements from composite samples were first tested to remove outliers as outlined in the Salt Lake County Phase 1 permit. The remaining data set of composite sample measurements was used to calculate a load for each storm event. Loading for each sampled storm was summed and divided by total precipitation observed for all monitored storm events. This result was then divided by the area serviced by runoff collection systems and a runoff coefficient to produce an Event Mean Concentration (EMC) value. This method is defined by the equation below:

$$EMC = \frac{\sum L_x}{\sum P \bullet R_a \bullet A_s}$$

Where:
L_x = Storm event load.
P = Precipitation for the storm event.
R_a = Weighted average runoff coefficient based on land use of serviced area.
As = Serviced area of basin.

EMC values were calculated on an event basis for each monitored constituent and averaged to obtain the average valley-wide EMC for Salt Lake County and Salt Lake City. EMC values provided by Salt Lake County in the most recent stormwater monitoring report (Stantec 2006a) were used to represent water quality concentrations from stormwater discharge in the project area (Table 3.5).

Table 3.5. Valley-wide EMC values used to calculate stormwater loading (Stantec 2006a).

Constituent	Valley-wide EMC (mg/L)
Total Suspended Solids	154
Total Phosphorus	0.68
Biochemical Oxygen Demand	16.4
Total Dissolved Solids	214
Total Ammonia	0.425

Pollutant loads from stormwater catchments in the rest of the project area were calculated by applying the same methodology utilized by Salt Lake County (Stantec 2006a). Monthly pollutant loads were determined by solving the equation above for L_x. Annual stormwater runoff was estimated for 15 inches of annual valley rain with a correction factor of 0.9 to account for storms that produce no significant runoff. A mean runoff coefficient of 0.52 was used for all stormwater catchments in the project area and represents runoff generated by both rainfall and snowmelt events.

Annual pollutant loads from stormwater outfalls that discharge directly to the Jordan River are shown in Tables 3.6 and 3.7. Again, stormwater loads presented in this section include loading from outfalls that directly discharge to the Jordan River and canal overflows to storm drains that discharge to the river. Stormwater loading delivered to Jordan River tributary streams is accounted for in Section 3.2 Tributaries. Monthly details of stormwater loading by municipality and DWQ Segment are presented in Appendix F.

Table 3.6. Annual stormwater pollutant loads (tons/year) for each DWQ Segment from outfalls that discharge directly to the Jordan River.

Segment	TSS	Total P	BOD	TDS	NH_4
1	0	0.0	0	0	0.0
2	34	0.2	4	47	0.1
3	945	4.2	101	1,313	2.6
4	2,294	10.1	244	3,188	6.3
5	188	0.8	20	262	0.5
6	372	1.6	40	516	1.0
7	0	0.0	0	0	0.0
8	425	1.9	45	591	1.2
Grand Total	4,259	19	454	5,918	12

Table 3.7. Annual stormwater pollutant loads (tons/year) by municipality from outfalls that discharge directly to the Jordan River.

Jurisdiction	TSS	Total P	BOD	TDS	NH_4
Salt Lake County	583.4	2.6	62.1	810.7	1.6
Lehi	425.5	1.9	45.3	591.3	1.2
Midvale	45.5	0.2	4.8	63.2	0.1
Murray	296.6	1.3	31.6	412.1	0.8
Riverton	15.1	0.1	1.6	21.0	0.0
Salt Lake City	827.7	3.7	88.1	1,150.2	2.3
Sandy	462.5	2.0	49.3	642.7	1.3
South Jordan	24.4	0.1	2.6	33.9	0.1
South Salt Lake	58.3	0.3	6.2	81.0	0.2
UDOT	48.5	0.2	5.2	67.4	0.1
West Jordan	901.4	4.0	96.0	1,252.6	2.5
West Valley City	569.9	2.5	60.7	791.9	1.6
TOTAL	4,259	19	454	5,918	12

3.5 DIFFUSE RUNOFF

Diffuse runoff is defined as surface runoff from areas outside of stormwater catchments that flows directly to the mainstem Jordan River. Pollutant loads are transported to the Jordan River along with flow from these areas. Figure 3.1 identifies areas with potential to contribute direct surface runoff (diffuse runoff) to the Jordan River. As mentioned in Section 3.4 Stormwater, some unmonitored tributaries have areas that contribute diffuse runoff to the stream channel below the gage location. Pollutant loads from diffuse runoff were also calculated for these areas and contributed to the final load for each tributary stream where this occurs.

Section 2.3.6 Diffuse Runoff describes the method used to calculate flow from areas contributing diffuse runoff. Direct measurements of water quality from diffuse runoff do not exist for the project area, so estimates were made by correlating land cover types in diffuse runoff areas to monitored stormwater catchments where water quality measurements have been collected.

Determining pollutant loads from diffuse runoff involved a three step process that included defining areas that contribute diffuse runoff directly to the mainstem Jordan River, categorizing land cover types in each area, and selecting the appropriate EMC values to use in load calculations. Diffuse runoff boundaries were defined by first removing areas that contribute surface runoff to stormwater catchments or tributary streams. The remaining areas were assumed to contribute flow to the Jordan River through diffuse runoff. Canals or major roads that parallel the Jordan River were used to further define the upslope boundary for these areas.

The land areas assumed to contribute diffuse runoff to the Jordan River are summarized in Table 3.8. The greatest land areas with potential to contribute diffuse runoff loading are associated with DWQ Segments 1, 4, 6, and 8 where rural land cover types are more prevalent.

Table 3.8. Areas (ac) contributing diffuse runoff directly to the mainstem Jordan River.

Municipality	DWQ Segment								Grand 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

Land cover types in diffuse runoff areas were assessed as a means for selecting the appropriate EMC values used in load calculations. Land cover information used by Salt Lake County to assess stormwater catchments was also used for diffuse runoff areas. This information was available for all of Salt Lake County but not for project areas outside of Salt Lake County. Therefore, USGS National Land Cover Dataset, digital orthophotoquads, and 1:24000 topographic maps were used to define land cover types in DWQ Segment 1 (Davis County) and Segment 8 (Utah County) using the same categories included in the Salt Lake County land cover data. The average composition of land cover types that contribute diffuse runoff to the Jordan River was then compared to the valley-wide average composition for all stormwater catchments.

Land cover data for monitored stormwater catchments in Salt Lake County was also reviewed in order to identify a catchment that more closely represented areas contributing diffuse runoff directly to the mainstem of the Jordan River. The distribution of land cover in the monitored stormwater catchment discharging to outfall LIT-06 was similar to that found in areas contributing diffuse runoff to the Jordan River.

Land cover percentages are shown in Table 3.9 and indicate the average percent composition of land cover types for (1) all stormwater catchments in Salt Lake County, (2) areas contributing diffuse runoff to the mainstem of the Jordan River, and (3) the stormwater catchment above outfall LIT-06. This assessment determined that areas contributing diffuse runoff to the Jordan River had significant amounts of land cover types associated with Parks (57 percent) and Low Density Residential (11 percent). In comparison, the valley wide average composition of stormwater catchments had much greater percentages from Low Density Residential (37 percent) and Mountain (16 percent) land cover types as well as significant contributions from Industrial and Commercial land cover types. EMC values from stormwater outfall LIT-06 were selected to represent water quality of diffuse runoff. Table 3.10 shows EMC values for both the valley-wide average as well as LIT-06.

Table 3.9. Average composition (percent) of land cover types found in all Salt Lake County stormwater catchments, areas contributing diffuse runoff directly to DWQ Segment 1 (Davis county) or DWQ Segment 8 (Utah County), and the catchment discharging to Stormwater Outfall LIT-06 (Salt Lake County).

Land Cover Type	Salt Lake County Stormwater Catchments (%)	Jordan River diffuse runoff in Davis and Utah counties (%)	Stormwater Outfall LIT-06 (%)
Undefined	0.1	0.0	0.0
Commercial	4.2	0.8	0.0
Industrial - Heavy	2.6	0.0	0.0
Industrial - Light	1.4	5.0	0.0
Industrial	14.8	7.8	0.0
Mountain	16.0	0.0	0.0
Parks	13.0	56.5	2.9
Public	2.2	6.4	4.5
Residential High Density	1.4	1.3	0.0
Residential Low Density	37.5	11.0	92.6
Residential Medium Density	2.1	2.4	0.0
Residential Rural	4.0	6.5	0.0
Transportation	0.0	0.0	0.0
Utility	0.7	2.5	0.0
Grand Total	**100.00**	**100.0**	**100.0**

Table 3.10. EMC values for Valley-wide Average and Stormwater Outfall LIT-06.

Constituent	Valley-wide EMC (mg/L)	LIT-06 EMC (mg/L)
TSS	154	76
Total P	0.68	0.47
BOD	16.4	10.5
TDS	214	122
NH_4	0.43	0.45

Annual pollutant loads from areas contributing diffuse runoff directly to the Jordan River are shown by DWQ Segment and municipality in Tables 3.11 and 3.12 respectively. Monthly loads from diffuse runoff areas that discharge directly to the Jordan River or to unmonitored tributaries below the gage location are presented in Appendix G.

Table 3.11. Annual diffuse runoff pollutant loads (tons/year) by DWQ Segment from areas that flow directly to the Jordan River.

DWQ Segment	TSS	Total P	BOD	TDS	NH_4
1	22	0.14	3	35	0.13
2	11	0.07	2	18	0.07
3	9	0.06	1	15	0.05
4	25	0.15	3	40	0.15
5	5	0.03	1	9	0.03
6	48	0.30	7	78	0.29
7	9	0.06	1	15	0.05
8	41	0.25	6	65	0.24
Grand Total	**170**	**1**	**24**	**274**	**1**

Table 3.12. Annual diffuse runoff pollutant loads (tons/year) by municipal areas that contribute diffuse runoff directly to the Jordan River.

Municipality	TSS	Total P	BOD	TDS	NH_4
Bluffdale	17	0.11	2.3	27	0.10
Davis County	4	0.03	0.6	7	0.02
Draper City	8	0.05	1.2	14	0.05
Lehi	18	0.11	2.5	29	0.11
Midvale	6	0.04	0.8	9	0.03
Murray	8	0.05	1.2	14	0.05
North Salt Lake	7	0.05	1.0	12	0.04
Riverton	9	0.05	1.2	14	0.05
Salt Lake City	16	0.10	2.3	26	0.10
Salt Lake County	15	0.09	2.1	25	0.09
Sandy	1	0.00	0.1	1	0.00
Sandy City	2	0.02	0.3	4	0.01
Saratoga Springs	7	0.04	1.0	11	0.04
South Jordan	12	0.08	1.7	20	0.07
South Salt Lake	5	0.03	0.7	8	0.03
Taylorsville	6	0.03	0.8	9	0.03
Utah County	15	0.10	2.1	25	0.09
West Jordan	7	0.04	1.0	11	0.04
West Valley	5	0.03	0.7	8	0.03
Grand Total	**170**	**1.06**	**23.5**	**274**	**1.01**

3.6 RETURN FLOWS FROM IRRIGATION CANALS

Section 2.2.9 Canal Diversions , lists substantial diversions that occur from the Jordan River at eight locations to deliver water to 11 major canal systems for irrigation purposes. Section 2.3.7 Irrigation Return Flow describes six of these canals that return water to the Jordan River (Table 2.12). Flows are typically diverted from the Jordan River to canals during the months of May through October, although some variation is associated with the start and end date of the irrigation season based on the demand for irrigation water during any given year. Factors influencing the demand for irrigation water include total irrigated crop land, crop type, and annual precipitation levels. The method used to apply irrigation water also affects runoff amounts.

The general mechanics of the 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 of the farm itself, and (3) from the farm downstream to the receiving water body of interest. The water quality of return flows can be influenced by processes that are specific to each subsystem. This classification method was used to assess changes in water quality that affect return flows from irrigation and provide support to the assumptions made in load calculations for this source.

Water quality in the first and third subsystems is influenced by processes that either remove or add water to the canal. Removal of water through surface evaporation or transpiration by vegetation adjacent to the canal can concentrate salts or other constituents. Addition of water to canals through precipitation, groundwater seepage, and drainage from agricultural fields and pastures can either improve or degrade water quality in the canal depending on the quality of inflow. Based on the local climate and groundwater regime, precipitation and groundwater seepage likely have a minimal effect on water quality in Jordan River canal systems. Drainage from fields is addressed below in the discussion of the second subsystem.

Any canal flows that bypass diversions to farm fields are considered to be unchanged with respect to water quality from the original diversion point at the Jordan River. However, water quality in the third subsystem can continue to change somewhat as return flows from irrigated fields are mixed with canal flows and reapplied to fields further downstream.

Water quality impacts from the second subsystem are dependent upon farming practices such as fertilizer application, flood irrigation, and crop selection. The net effect of these practices is typically decreased water quality as return flows enter canals, although some parameters can show improvements. TSS concentrations are dependent upon whether the dynamics of irrigation water flows are sufficient to erode and transport sediment from cultivated fields. Phosphorus is typically immobile in the soil solution, and its influence on groundwater is low. However, concentrations of Total P in irrigation water can increase along with TSS due to adsorption of phosphorus to soil particles that move into the surface water as a result of erosion. BOD concentrations can likewise decrease or increase during irrigation based on opportunities for organic material to settle out of suspension or become detached from field soils and be transported by return flow. TDS concentrations typically increase as irrigation water is applied to fields and eventually discharged as surface or groundwater return flow. This is due to the presence of major cations and anions found in the soil matrix that are soluble and ultimately dissolved by irrigation water. NH_4 is highly soluble and quickly utilized by plants or adsorbed to soil particles. However, concentrations of Total N (of which ammonia is a component) can increase as irrigation water flows over fertilized soil.

Table 3.13 provides a summary of the resulting change in water quality based on studies that are applicable to the project area. Sperling (1975) has provided the most detailed study to date. A total of eight locations in Salt Lake County were monitored during the summer of 1973 to assess the quality of irrigation water in four canals and four points of return flow. All monitoring sites were located in canals that parallel the Jordan River on the west side of the Salt Lake Valley between the Narrows and 2100 South. Comparisons between canals and return flows indicated that return flow concentrations of BOD and Total Phosphate decreased while concentrations of TDS, Total N and major cations and anions increased. Templeton, Linke, and Alsup (1975) also estimated the quality of irrigation return flows in the Utah Lake-Jordan River basin with a combination of limited local sampling and previous studies completed in the western United States. Their results showed increased concentrations for all parameters and conflict somewhat with Sperling (1975). Discrepancies between the two studies are likely due to differences in sample size and location (including local sites and studies completed in other states).

Table 3.13. Incremental increases in pollutant concentration (mg/L) to Jordan River return flow following irrigation use.

	Templeton, Linke, and Alsup (1975)		**Sperling (1975)**
	Surface flow	**Shallow Groundwater[1]**	**Surface flow**
BOD	2.25	1.5	-5.4
TDS	250	850	800
Total N	3.2	8	1.8
Total PO_4	0.5	0.5	-0.1

[1] Collected in tile drains and discharged to canals.

Water quality measurements collected from canals in the project area reflect a combination of water quality from the Jordan River, irrigation return flows, and stormwater. Pollutant concentrations used to calculate loads for return flows from irrigation canals should represent a mixture of the first two sources only, as stormwater loading has been accounted for separately in this report. Therefore, the actual pollutant concentrations found in return flows from irrigation canals would likely range between the relatively lower concentrations measured in the Jordan River near irrigation diversions, and the higher concentrations measured in surface runoff as it leaves irrigated fields. A review of water quality measurements was completed for the Jordan River near irrigation diversions as well as published literature values for surface runoff from irrigated fields. The results of this review are shown in Table 3.14.

Annual pollutant loads delivered by return flows from irrigation canals are shown in Table 3.15. The detailed results for monthly loading by return flows from irrigation canals are in Appendix H.

Table 3.14. Water quality parameters used to support load calculations and selected concentrations for loads. Data sources include selected Jordan River stations, irrigation return flow samples, valley-wide average stormwater EMC values. Water quality parameters selected for load calculations are shown in the far right column.

	Station 4994600 Jordan River at Bluffdale Road	Station 4994720 Jordan River at Narrows	Irrigation Return Flow Sperling (1975)	Valley-wide average EMC (Stantec 2006a)	Concentrations used for load calculations
TDS	979	976	1,700	214	1,300
TSS	55	79		154	110
BOD	1	N/A	2.6	16.4	2
NH$_4$	0.06	0.09		0.425	0.15
Total P	0.08	0.08		0.68	0.35
N03^{-}			2		
P04^{-3}			0.2		

Table 3.15. Annual pollutant loads (tons/year) for return flows from irrigation canals by DWQ Segment.

DWQ Segment	TSS	Total P	BOD	TDS	NH$_4$
1	0	0	0	0	0
2	0	0	0	0	0
3	0	0	0	0	0
4	1,433	5	26	16,940	2
5	0	0	0	0	0
6	1,201	4	22	14,197	2
7	0	0	0	0	0
8	0	0	0	0	0
Grand Total	2,635	8	48	31,137	4

3.7 GROUNDWATER

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 primary source of groundwater flow to the Jordan River is the confined artesian aquifer with a smaller amount being contributed by the shallow unconfined aquifer. Estimates of groundwater discharge to the Jordan River are discussed in Section 2.3.8 Groundwater. Monthly distribution of groundwater flows are based on a USGS seven-layer groundwater model (Lambert 1995) that simulated flow to the Jordan River. An in-depth discussion of modeled groundwater flow is provided in CH2M Hill (2005).

Groundwater quality varies both horizontally and vertically and can be influenced by the chemistry of geologic strata that comprise groundwater aquifers. The principal aquifers in most of the project area consist of unconsolidated deposits of valley fill originating from inert parent material and do not exhibit characteristics that would degrade water quality. Temporal changes in historic groundwater quality are generally believed to be minimal, although indications of increasing TDS levels have been reported at some locations along the Jordan River. Groundwater quality is also influenced by surface activities and processes that interact with recharge volumes or directly through contamination of groundwater aquifers.

A review of previous groundwater quality studies was completed to assess potential sources of contamination (Cirrus 2007). Early studies completed by Richardson (1906), Taylor and Leggette (1949), and Hely et al. (1971) were primarily focused on TDS concentrations in groundwater as an indicator of potential for development and use as a culinary or agricultural water source. These studies identified large differences in TDS concentrations throughout the valley with generally higher concentrations found in areas northwest of the Jordan River and lower concentrations observed on the east bench.

More recently, Thiros (1995, 2000, and 2003) examined TDS concentrations in numerous public and private wells and found relatively low concentrations on the east side of the Salt Lake Valley, ranging from 100 to 500 mg/L, in comparison to concentrations on the west side that commonly ranged from 1,000 mg/L to 3,000 mg/L (Thiros 2003). Readings as high as 20,900 mg/L were documented in the northwest portion of the Salt Lake Valley, near the Great Salt Lake (Thiros 1995).

Seiler and Waddell (1984) identified pollutant sources contaminating groundwater including tailings areas, animal feeding sites, and urban neighborhoods. Tailings deposits are located at the Sharon Steel and Midvale Slag site (DWQ Segment 6 near 7800 South) and the Kennecott South Zone (adjacent to Bingham Creek and DWQ Segment 6 near 10600 South). A review of groundwater data collected from monitoring wells between the Jordan River and Sharon Steel-Midvale Slag sites did not identify TDS measurements or other parameters of interest. Other monitored parameters from these sites (e.g., lead and arsenic) were within acceptable limits.

Groundwater contamination has resulted from mining activities completed by Kennecott Utah Copper Corporation (KUCC) at the Kennecott South Zone (adjacent to Bingham Creek and DWQ Segment 6 near 10600 South). This contamination involves elevated concentrations of sulfate, metals, and acidic conditions that are spreading out laterally over 50 square miles and vertically downward in the primary aquifer. One of the contaminant plumes is located in South Jordan, adjacent to the Jordan River, and maintains sulfate concentrations ranging from 500 mg/L to 1,500 mg/L (DWQ 2004). Mean TDS concentrations near the downgradient edge of the plume range from 1,705 to 2,814 mg/L.

At present, KUCC is actively involved in remediation efforts to extract groundwater from contaminated plumes in the primary aquifer, treat it through reverse-osmosis, and deliver the treated, high-quality water to West Jordan, South Jordan, Riverton, and Herriman for municipal use. Since groundwater extraction began in 1997, the leading edge of the main sulfate plume has contracted substantially, and sulfate concentrations have decreased (KUCC 2005). Based on the review of monitoring data and positive effects of current mitigation activities, the contamination plume at this site does not substantially influence concentrations in DWQ Segments of the Jordan River currently listed as impaired for TDS. Furthermore, these efforts represent the most efficient Best Available Technology (BAT) practice to remediate groundwater in the area.

Other localized sources of groundwater contamination are known to exist in the project area, such as urban development (nutrients), confined livestock (nutrients), canal seepage (salts) and even geothermal water (arsenic). Based on the review of groundwater monitoring data discussed below, the total impact from these sources does not appear to contribute significantly to impairment of the Jordan River.

For this analysis, groundwater monitoring data from the study area was obtained from the USGS, Utah DWQ, KUCC, and data sets from published reports including Seiler and Waddell (1984), Thiros (1995) and Thiros (2003). Data collected from all wells located within 1.5 miles of each side of the Jordan River was selected for review. This review indicated that measurements were primarily limited to 1–3 samples per well that extended back as far as 1934. In order to assess the recent influence of groundwater contamination, the data set was further refined to only include 1980–2005 measurements. Data was then organized according to well location and DWQ Segment. Parameters of interest were reviewed to identify spatial patterns and compared with published maps defining groundwater quality contours. With the exception of TDS, no spatial patterns were noted in the data set that indicated changes in groundwater quality along the Jordan River corridor.

Based on the review of monitoring data, concentrations were selected that were representative of groundwater quality for each DWQ Segment including TDS, Dissolved P, and Dissolved NH_4. No measurements of Total P and Total NH_4 were identified in the data set. However, it was assumed that dissolved forms of phosphorus and ammonia comprise the total concentration of each parameter in a groundwater setting. No values were selected for TSS and BOD. These parameters were not identified in the data set and are not a significant component of groundwater quality. Suspended soil particles transported through an aquifer matrix are generally removed during the flow process. Organic matter that influences BOD is typically consumed by microorganisms that live in the soil matrix. Concentrations of TDS, Dissolved P, and Dissolved NH_4 selected for pollutant load calculations are shown in Table 3.16.

Annual pollutant loads delivered by groundwater to the Jordan River are displayed in Table 3.17. The results of monthly loading by groundwater flows are presented in Appendix I.

Table 3.16. Water quality concentrations (mg/L) selected for groundwater pollutant loads.

DWQ Segment	TDS Concentration (mg/L)	Dissolved P (mg/L)	Dissolved NH_4 (mg/L)
1	2,500	0.03	0.01
2	2,500	0.03	0.01
3	1,750	0.03	0.01
4	1,500	0.03	0.01
5	1,750	0.03	0.01
6	2,000	0.03	0.01
7	1,750	0.03	0.01
8	1,200	0.03	0.01

Table 3.17. Annual groundwater pollutant loads (tons/year) to the Jordan River.

DWQ Segment	TDS	Dissolved P	Dissolved NH_4
1	17,024	0.14	204.28
2	30,091	0.20	300.91
3	27,319	0.31	468.33
4	20,657	0.28	413.15
5	16,223	0.19	278.10
6	157,128	1.57	2,356.93
7	36,360	0.42	623.31
8	7,645	0.13	191.12
Grand Total	**312,447**	**3.22**	**4,836**

3.8 NATURAL BACKGROUND

This category comprises the pollutant load contributed by natural or non-anthropogenic sources not accounted for elsewhere in this analysis. Some of the sources that were considered during the assessment of natural background loading to the Jordan River include atmospheric deposition, wildlife, weathering and erosion of geologic formations, naturally occurring levels of soil erosion and stream channel dynamics. However, background loads can be associated with any natural process that is not enhanced or induced by human activity. Natural background loads are generally considered to be uncontrollable.

The Jordan River passes through an intensely developed urban area and receives most of its flow from Utah Lake, which is also influenced by human activities that result in impacts on water quality as well as flow. Natural levels of flow and water quality in tributaries to the Jordan River are likewise influenced by diversions for municipal and agricultural use and inflows from stormwater, diffuse runoff, and water rights exchanges that replace high quality water with lower quality water from Utah Lake. These influences on water quality and hydrology make it very difficult to define natural background loading for the pollutants of concern.

In order to approximate water quality concentrations for natural background loads, a review of monitoring data was completed for upper headwater streams and springs where human influences are known to be low. These concentrations are presented in Table 3.18 for selected Utah DWQ monitoring sites located on headwater segments of Jordan River tributaries. Additional information was obtained from a recent EPA ecoregion assessment of nutrients in headwater streams throughout the western U.S. including the Wasatch and Uintah Mountains ecoregion (U.S. EPA 2000).

Measurements from headwater streams provide a starting point for estimating natural background concentrations. It is generally accepted that water quality concentrations are dynamic, even in natural settings, and can be influenced by a number of factors including season, hydrology, soil type, geology and geographic region. Use of local monitoring data can help address some of this variation. Natural processes in some watersheds can also improve or degrade water quality as flows travel from upper elevations and combine with additional inflow from tributary streams and contributing upslope areas. In ecologically healthy settings, these processes are in balance and support good water quality and aquatic habitat, even in higher order streams such as the Jordan River. Supporting information describing soils, geology, and surface and groundwater processes in the project area was reviewed and discussed with local scientists and agency personnel. Based on this review, background loadings are not considered to be significant to the Jordan River and are not currently responsible for water quality impairment.

Following a review of the information sources described above, a concentration was selected for each pollutant of concern. These concentrations are assumed to represent water quality levels that are absent of human influence for streams and rivers in the project area. The selected concentrations and resulting annual loads for several Jordan River monitoring stations are shown in Table 3.19.

The loads shown in Table 3.19 are meant to provide an indication of the magnitude of human influence when compared to existing loads calculated at monitoring sites on the mainstem of the Jordan River.

Table 3.18. Water quality concentrations measured from headwater locations of tributary streams in the project area.

Station	BOD (mg/L)			NH_4 (mg/L)			Total P (mg/L)			TDS (mg/L)			TSS (mg/L)		
	Max	Min	Median	Max	Min	Median	Max	Min	Median	Max	Min	Median	Max	Min	Median
Station 4993400 - Big Cottonwood Creek above Silver Lake by Church	N/A	N/A	N/A	N/A	N/A	N/A	0.62	0.01	0.01	188	54	79	22	1	3
Station 4993340 - Big Cottonwood Creek at Guardsman Pass	1	1	1	N/A	N/A	N/A	0.08	0.01	0.01	623	42	140	26	0	2
Station 4993100 - Big Cottonwood Creek at USFS Boundary	1	0.5	1	0.7	0.002	0.025	37	0.0025	0.01	386	80	171	148	0	1.5
Station 4993370 - Big Cottonwood Creek below Silver Lake outlet at old gage.	N/A	N/A	N/A	N/A	N/A	N/A	0.03	0.01	0.02	234	38	122	17	1	4
Station 4993930 - Little Cottonwood Creek above Alta - below Grizzly Gulch - Under Sunnyside Ski Lift.	1	1	1	N/A	N/A	N/A	0.44	0.01	0.01	160	70	124	38	0	2
Station 4992700 - Mill Creek above Log Haven Restaurant pond inlet.	1	1	1	0.1	0.1	0.1	0.06	0.01	0.02	608	238	398	132	0	5
Station 4992640 - Mill Creek at USFS boundary.	1	1	1	0.305	0.002	0.025	1.36	0.005	0.021	574	126	384	500	0	2
Station 4992200 - Parleys Canyon Creek at U65 crossing above Mountain Dell Reservoir.	N/A	N/A	N/A	0.067	0.024	0.025	1.305	0.005	0.025	1866	118	460	122	0	2
Station 4992100 - Red Butte Creek above reservoir.	N/A	N/A	N/A	0.05	0.025	0.025	0.141	0.01	0.0271	508	268	389	64	0	2
Station 4992110 - Red Butte Creek at Junction of Parleys Fork.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	444	278	366	103	2	37
EPA Ecoregion II[1]	N/A	N/A	N/A	N/A	N/A	N/A	1.625	0.00025	0.02 – 0.03	N/A	N/A	N/A	N/A	N/A	N/A

[1] U.S. EPA 2000. Median values shown for Total P indicate range of seasonal medians.

Table 3.19. Estimated pollutant loads associated with natural background conditions. Note concentrations shown at top of table that were used to calculate loads for selected Jordan River stations.

	Natural background concentration (mg/L)				
	TDS	TSS	BOD	NH_4	Total P
	200	3	1	0.025	0.02
	Annual pollutant loads (tons/yr) at natural background concentrations				
Station	TDS	TSS	BOD	NH_4	Total P
Station 4994720 - Jordan River at Narrows - Pump Station	101,405	1,521	507	13	10
Station 4994600 - Jordan River at Bluffdale Road crossing	42,358	635	212	5	4
Station 4994170 - Jordan River at 7800 South crossing above South Valley WWTP	62,719	941	314	8	6
Station 4992320 - Jordan River at 1100 West 2100 South	156,061	2,341	780	20	16
Station 4991820 - Jordan River at Cudahy Lane above South Davis South WWTP	43,139	647	216	5	4

3.9 MAINSTEM JORDAN RIVER MONITORING

Pollutant loads for mainstem Jordan River monitoring sites were calculated using monthly average flow and water quality values. The same methodology was used for monitored tributaries and permitted discharge. The Work Element 1 Report (Cirrus 2007) provides an in-depth review of the data sets used for these load calculations.

Flows were calculated using daily average values recorded over long time periods by continuous flow gages. This continuous data better represents seasonal and year-to-year variability in streamflow because measurements are generally made at a much higher frequency than the available instantaneous flow measurements.

The process used to select Jordan River continuous flow gage stations for load calculations assessed the number of data records available, frequency of measurements, and time period when samples were collected in order to insure that both drought and high flow conditions were included as well as all seasons of the year. Where possible, monthly averages were generated from continuous flow records collected at USGS gage stations from 1980–2005 and Utah DWQ water quality measurements collected at or near the same location from 1995–2005. When continuous flow records were not available, instantaneous flow measurements at Utah DWQ stations from 1980–2005 were used if the data record was considered adequate to characterize a representative range of flows.

Water quality stations were selected based on proximity to continuous flow gages and the length and frequency of the data record. Water quality records at selected sites typically included two periods of intensive monitoring when stations were sampled every 2–6 weeks throughout an entire year. Additional data was collected outside of intensive monitoring for stations that are used for long-term monitoring by Utah DWQ or the USGS. All of the selected water quality stations are managed by Utah DWQ with the exception of the 1700 South station maintained by the USGS. All water quality measurements for each pollutant of concern were used during the period 1995–2005. Samples with concentrations below method detection limits were assigned a value equal to one-half the detection limit.

Flow and water quality stations that were used in this analysis are shown in Table 3.20 and mapped in Figure 3.2.

Annual pollutant loads were obtained as the sum of monthly loads. Annual loads for mainstem Jordan River monitoring stations are shown in Table 3.21. Note that no annual BOD loads are shown for the Narrows and 1700 South due to the lack of BOD measurements collected during 1995–2005. The results of monthly loading calculations at these stations are shown in the Appendix C. Pollutant loads at each station represent the total contribution from all pollutant sources located upstream of the station. Differences between stations are generally the result of additional loading or a pollutant loss.

Loss of pollutant loading can result from several processes including physical (diversions, deposition, adsorption), chemical (ionization), and biological (algal uptake, bacterial senescence). These processes affect pollutant loading in ways that are specific to a given water quality parameter. Differences in pollutant loading between stations can also result from different sample sizes (e.g. continuous vs. instantaneous measurements).

Calculations for all parameters indicate a reduction in loading immediately below the Narrows (Turner Dam) as well as below 2100 South. These reductions reflect diversions to irrigation canals that serve to remove flow and pollutant loads from the Jordan River. Loading below diversions shows increases that reflect additional load contributions from pollutant sources. A comparison of loads between the Narrows and 2100 South indicates an increase in annual loads of roughly 50 percent and 100 percent for TDS and NH_4, respectively. Annual loads of Total P increase by over 1,700 percent, resulting largely from loads contributed by permitted discharges. Total annual loads of TSS decrease between the Narrows and 2100 South. This loss indicates deposition of suspended material along this river segment.

3.9.1 POLLUTANT LOAD DURATION CURVES

3.9.1.1 Introduction

Load Duration Curves (LDCs) provide one perspective on when, and under what conditions, water quality problems occur. They help to determine whether water quality problems occur only at high, low, or average flows, or whether water quality is problematic at all flows. More specifically, LDCs:

- Provide a visual display and qualitative "feel" for the magnitude of the exceedances and flow conditions associated with them.
- Identify whether exceedances are limited to "extreme" flow events - very high or very low flows - or are distributed across a wide range of flow conditions.
- Differentiate between permitted relatively constant point sources that typically vary little in flow and concentration and unpermitted non-point sources that are problematic only at high flows.

- Compare when exceedances occur with the timing of those flow conditions to help trace problems specific to particular seasons.
- Compares patterns from different watersheds or monitoring points along a waterway to help focus solutions on particular segments of a river, and helps to identify when resolving an upstream source of pollution might lessen the burden on a downstream source.
- Helps to focus future monitoring efforts by identifying particular ranges of flows that exhibited problems in the past, and by ensuring that adequate data is gathered for flow patterns where little or no data has been collected before.
- Allows interpolating between daily loading points to reach a daily load expectation, keyed to flows expected on those days.
- Since actual loads and flows are used, LDCs also evaluate the magnitude of load exceedances.

LDCs graph allowable loads which are calculated by multiplying criterion concentrations of pollutants by the actual observed daily flows, ranked by daily flow. The x-axis is typically the percentage of days which had higher flows than the point being calculated. The y-axis is mass or weight (kilograms or pounds). Flow is usually one of the longest recorded data values, so the resulting load curve is representative of long-term conditions. Superimposed on this graph are loading points plotted from the product of the observed water quality measurements over time and the daily flow for that day.

Table 3.20. Flow and water quality stations used to calculate loads for all pollutants of concern measured at mainstem Jordan River stations.

Location	DWQ Segment	River Mile	Station Name	No. of samples (1980–2005)	Station Name	No. of samples (1995–2005)
Narrows (Turner Dam)	8	41.9	Jordan River 02 Combined Flow	9,279	4994720 – Jordan River at Narrows - Pump Station	20-26
Bluffdale Road	7	38.1	Jordan River 01 and USGS 10167001 Jordan River Station No. 1 at Narrows	7,693	4994600 – Jordan River at Bluffdale Road crossing	9-88
7800 South	5	26.4	Station 4994170 - Jordan River at 7800 South crossing above South Valley WWTP.	54	4994170 – Jordan River at 7800 South crossing above South Valley WWTP	27-48
5400 South	4	24.3	Station 4994090 - Jordan River above 5400 South at Pedestrian Bridge	35	4994090 – Jordan River above 5400 South at Pedestrian Bridge	36-55
2100 South	4	16.1	USGS 10170490 - Combined Flow Jordan River and Surplus Canal at SLC Ut.	8,309	4992320 – Jordan River 1100 West 2100 South	37-56
1700 South	3	15.2	Station 10171000 - Jordan River at 1700 South at Salt Lake City, UT	8,674	10171000 – Jordan River at 1700 South at Salt Lake City, UT	77-90
Cudahy Lane	1	5.2	USGS 10171000 - Jordan River at 500 North and UDWRi Jordan River at Cudahy Lane	7,002	Station 4991820 - Jordan River at Cudahy Lane above South Davis South WWTP	51-93

Table 3.21. Annual pollutant loads (tons/year) for mainstem Jordan River Stations.

Location	DWQ Segment	River Mile	TDS	TSS	BOD	NH_4	Total P
Narrows (Turner Dam)	8	41.9	503,400	41,161	N/A	60	41
Bluffdale Road	7	38.1	180,854	8,341	27	9	12
7800 South	5	26.4	364,739	15,711	641	20	27
5400 South	4	24.3	301,048	8,577	662	13	152
2100 South	4	16.1	714,602	25,353	2,301	145	727
1700 South	3	15.2	150,852	6,416	N/A	79	298
Cudahy Lane	1	5.2	197,294	8,697	773	70	148

3.9.1.2. Methodology Applied to Jordan River Monitoring Stations

Four sites on the Jordan River had adequate flow and water quality measurements made in reasonable proximity for meaningful LDCs. Table 3.22 shows the stations, number of measurements, and range of dates used in this analysis.

Table 3.22. Jordan River flow and water quality monitoring stations used for load duration curves.

Station: Flow / Water Quality		Narrows (Station 02 Combined / 4994720)	2100 South (10170490 / 4992320)	1700 South (10171000 / 4992270/4992290)	Cudahy Lane (DWRi Cudahy Lane / 4991820)
Location (river mile)		42.9	17.1	15.5	6.3
Flow	Number Samples	9163	8309	8695	2542
	Dates	1/1/1980 – 12/31/2005	1/2/1980 – 9/30/2003	1/2/1980 – 9/30/2003	1/1/1991 – 12/31/2004
Biochemical Oxygen Demand	Number Samples	0	94	91	44
	Dates	N/A	2/27/1980 – 7/29/2003	2/27/1980 – 2/18/1992	2/12/1991 – 11/4/2004
Total Dissolved Solids	Number Samples	83	35	12	68
	Dates	11/14/1989 – 1/27/2005	9/10/1986 – 6/7/2000	11/14/1989 – 6/11/1991	2/12/1991 – 12/8/2004
Total Suspended Solids	Number Samples	82	103	91	68
	Dates	11/14/1989 – 1/27/2005	2/27/1980 – 7/29/2003	2/27/1980 – 2/18/1992	2/12/1991 – 12/8/2004
Total Phosphorus	Number Samples	81	34	11	30
	Dates	11/14/1989 – 1/27/2005	9/10/1986 – 6/7/2000	11/14/1989 – 6/11/1991	2/12/1991 – 12/8/2004
Dissolved Phosphorus	Number Samples	53	27	7	38
	Dates	5/29/1992 – 1/27/2005	1/8/1991 – 6/7/2000	11/14/1989 – 6/11/1991	2/12/1991 – 12/6/1994

LDCs were created in several steps:

1. Data from flow and quality records for each station were merged, linking records by dates. Records were then ranked from high to low flow. As shown in Table 3.22 the period of record used to assess flow and water quality included all available measurements from 1980–2005.
2. A percentage of the number of flow records greater than each individual flow record was generated by dividing the rank of each measurement by the total number of measurements. (A record of high flow would have a low percentage value because few records would have higher flows.)

3. For each pollutant or indicator, the allowable load was calculated for each flow record by multiplying the water quality criterion (as a concentration) for that pollutant or indicator times the flow for that day.
4. The resulting "allowable loads by percentage flow percentages" function was plotted on a logarithmic scale.
5. Each record that also contained an actual water quality measurement was then treated similarly, by multiplying that day's flow by the concentration of the pollutant or indicator, and the result was plotted on the same graph as a point. Where points appear above the loads curve, the concentration for that pollutant at that flow is above the allowable or recommended limit. Where the points fall below the loads curve, the concentration for that flow is below the allowable limit and no further reduction would be required.

Table 3.23 shows the criterion for each pollutant or indicator used for the load duration curves that follow.

Table 3.23. Limits used for load duration curves.

Pollutant or Indicator	Allowable or Recommended Limit
Biochemical Oxygen Demand[1]	5 mg/L
Total Dissolved Solids [2]	1200 mg/L
Total Suspended Solids[3]	90 mg/L
Total Phosphorus[1]	0.05 mg/L
Dissolved Phosphorus[3]	0.05 mg/L

[1] Not a water quality standard but an indicator of water quality.
[2] Utah state water quality standard.
[3] Not a water quality standard but based on historical or parent standard.

This stage of the analysis was not intended to yield a TMDL, so no Margin of Safety (MOS) was applied before plotting the allowable load function. A TMDL for impaired segments of the Jordan River will need to include permissible loads and load reductions. The application of LDCs towards defining permissible loads and load reductions is one of many EPA-approved methods that can be used to support a TMDL. The Jordan River TMDL could ultimately utilize some information from LDCs but will also require other sources of data assessment that will accurately define linkages between pollutant sources and impaired water quality conditions.

A table was also created for each pollutant or indicator to present calculated loads observed at each station and the extent to which those loads exceeded recommended limits. The records of actual loadings were grouped in order to have enough points for reasonable calculations. Ranges for the groupings were:

- 0 to 10 per cent of loads exceeding the value
- 10 to 40 percent of loads exceeding the value
- 40 to 60 percent of flows exceeding the value
- 60 to 90 percent of loads exceeding the value, and
- Greater than 90 percent of loads exceeding the value.

These groupings were designed so that midpoints of the ranges yielded percentage load exceedances of 5 percent, 25 percent, 50 percent, 75 percent, and 95 percent, in order to be consistent with other presentations of distributions in this report. The actual concentrations yielding the loads within each grouping were averaged, and a group load was calculated using the mean concentration and median flow value for that group. The difference between the measured and allowable provides a place to start when considering recommended reductions for loading upstream of that site on the river for a given pollutant or indicator. Final recommendations should also take into account other factors, including a MOS, seasonal patterns and criteria for qualifying as "fully supporting."

3.9.1.3. Results by Parameter

3.9.1.3.1. Biochemical Oxygen Demand

The resulting LDCs for BOD are presented in Figures 3.4 through 3.6 (BOD was never measured at the Narrows). Excess BOD levels did not appear to be limited only to high or low flows. By the time the Jordan River reached 2100 South, BOD frequently exceeded the recommended loading at all flows. Just a short way downstream at 1700 South, the frequency of measurements above the recommended loading increased substantially and remained constant across all flows. By Cudahy Lane a smaller percentage of measurements exceeded the recommended load levels across nearly all flow levels.

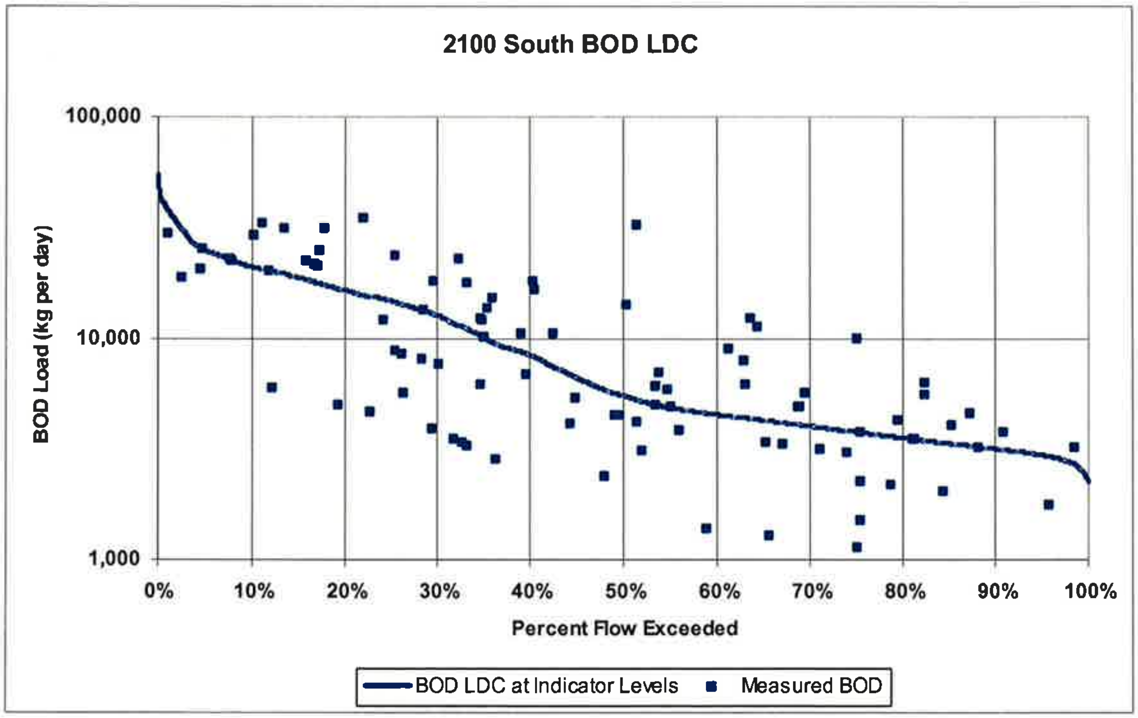


Figure 3.4. BOD load duration curve at 2100 South.

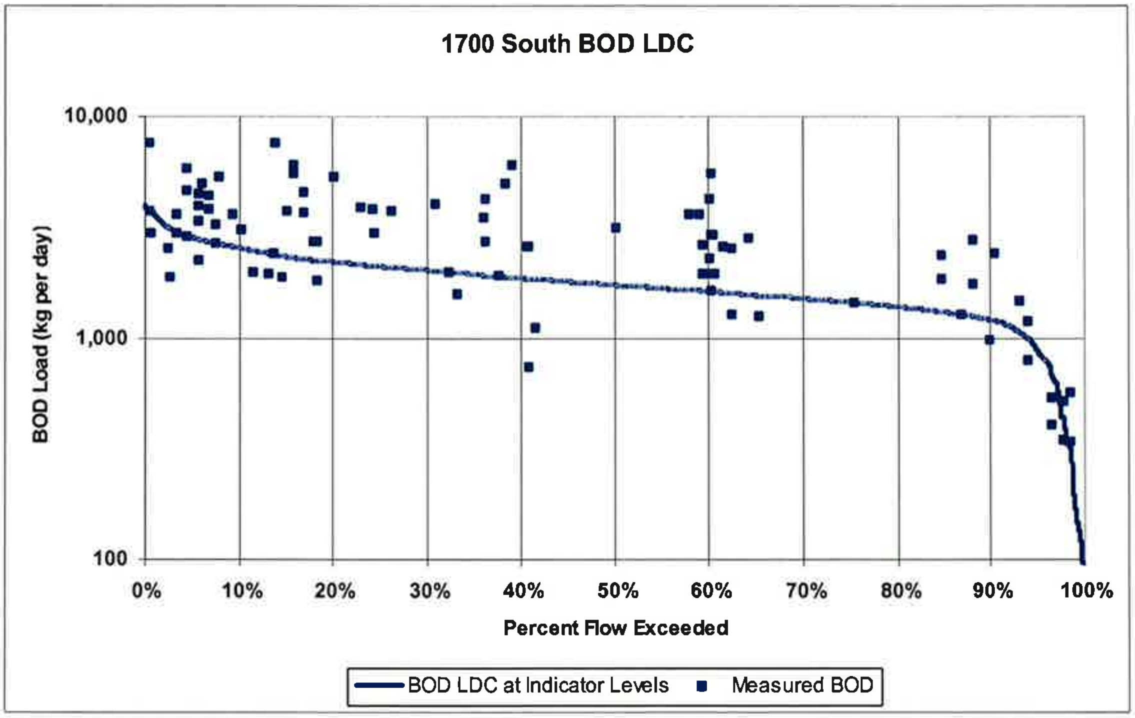


Figure 3.5. BOD load duration curve at 1700 South.

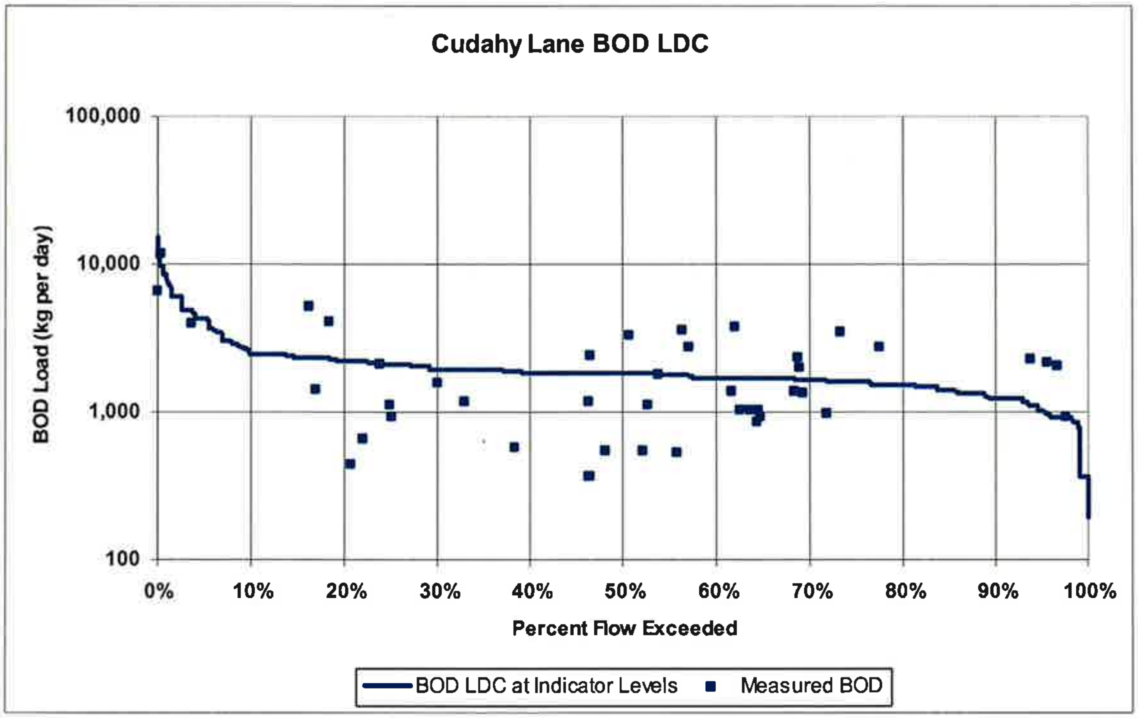


Figure 3.6. BOD load duration curve at Cudahy Lane.

Table 3.24 shows that BOD loads exceeded recommended levels at 2100 South, and increased substantially by 1700 South, as reflected in higher concentrations. Lowering BOD loads at 2100 South to the recommended levels would likewise help reduce exceedances at 1700 South. Large reductions at 1700 South in the mid to upper percentile range may also result in enough attenuation downstream to meet the needed reductions at Cudahy Lane. This assessment also illustrates the effect of different flow regimes above and below 2100 South. The flow regime below 2100 South has relatively narrow percentiles and minimal variance between median flow values in comparison to flows above 2100 South.

Table 3.24. BOD loads and estimated reductions needed to meet the BOD pollutant indicator level (5 mg/L) for all flows.

Flow Percentile Ranges	Samples	Mean BOD (mg/L)	Median Flow (cfs)	Load (kg/day)	Recommended at Median Flow (kg/day)	Estimated Reduction (%)	Estimated Reduction (kg/day)	Estimated Reduction (kg/yr)
2100 South								
0–10	6	4.3	2030	21522	24833	0.0%	0	0
10–40	37	5.0	1210	14882	14802	0.5%	80	8761
40–60	19	6.9	450	7562	5505	27.2%	2057	150165
60–90	29	6.2	309	4692	3780	19.4%	912	99908
90–100	4	4.1	243	2452	2973	0.0%	0	0
1700 South								
0–10	23	6.6	232	3751	2838	24.3%	913	33328
10–40	29	8.3	172	3483	2104	39.6%	1379	150948
40–60	9	7.1	142	2470	1737	29.7%	733	53540
60–90	20	7.7	119	2227	1456	34.6%	772	84482
90–100	10	6.0	72	1057	881	16.7%	176	6430
Cudahy Lane								
0–10	3	4.3	350	3711	4282	0.0%	0	0
10–40	11	4.0	170	1660	2080	0.0%	0	0
40–60	12	4.3	150	1569	1835	0.0%	0	0
60–90	14	5.2	130	1663	1590	4.4%	73	7960
90–100	4	9.3	85	1924	1040	45.9%	884	32260

3.9.1.3.2. TDS

The resulting LDCs for TDS are presented in Figures 3.7 through 3.9. Although the Jordan River is listed for TDS, the LDCs do not show that TDS loads were a severe problem at any of the monitoring points. TDS measurements were insufficient to develop a LDC at 1700 South, therefore the plot and results for this station are not included here.

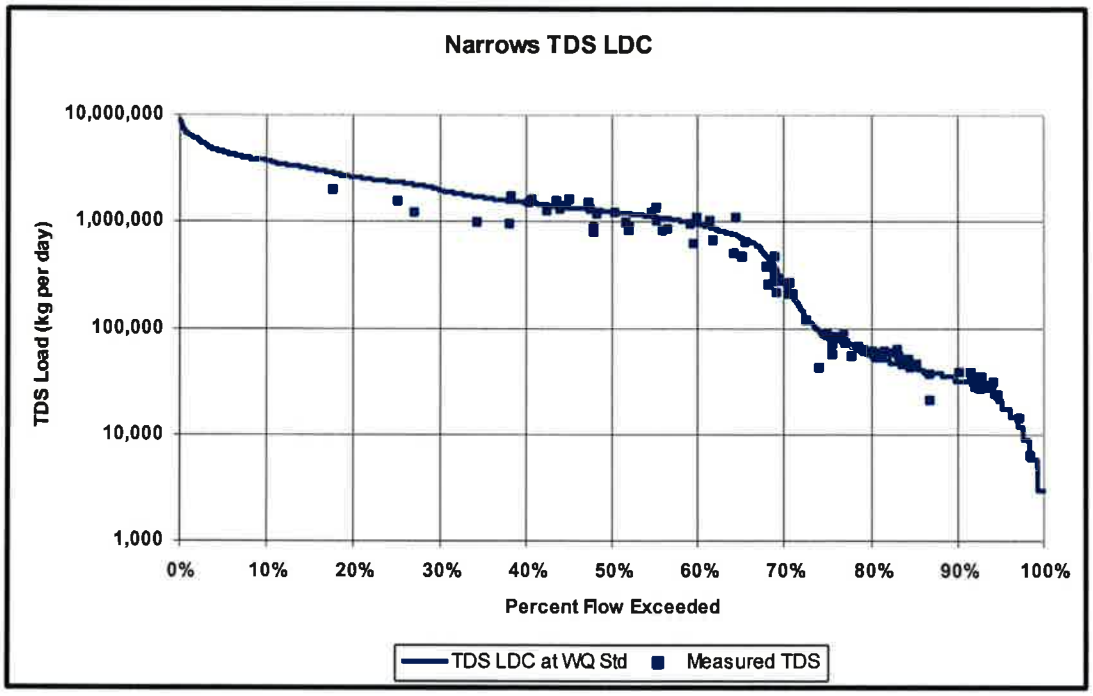


Figure 3.7. TDS load duration curve at the Narrows.

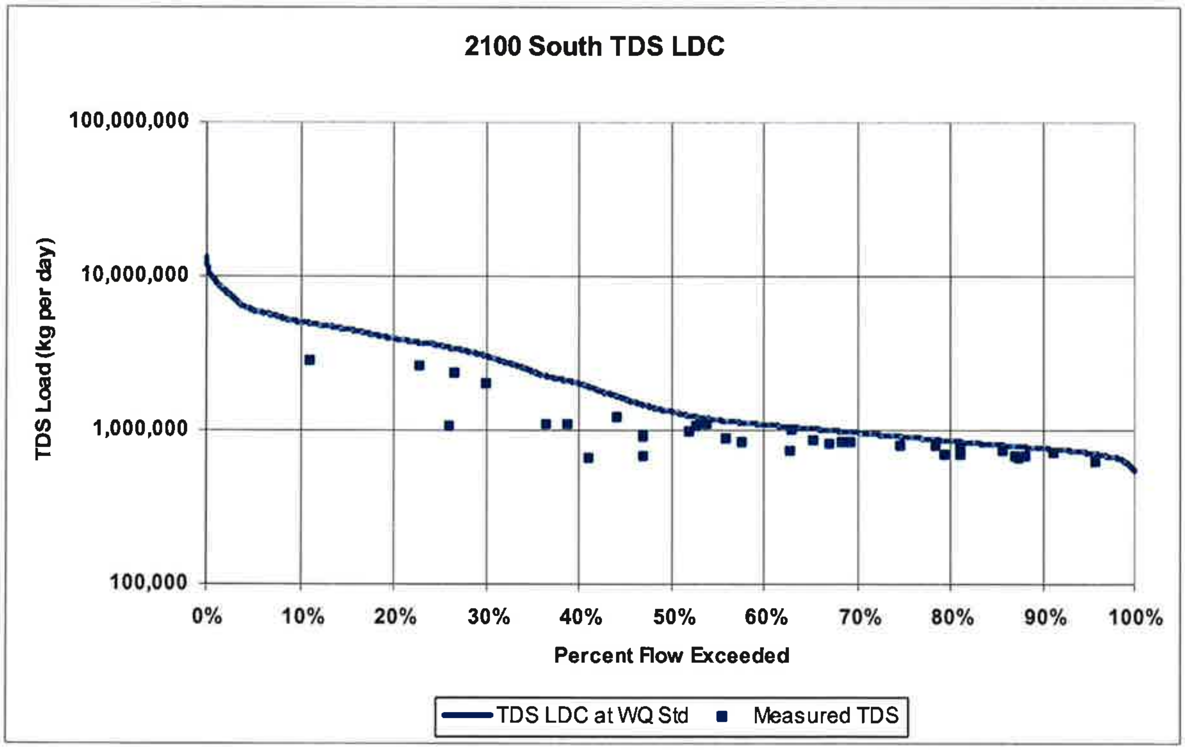


Figure 3.8. TDS load duration curve at 2100 South.

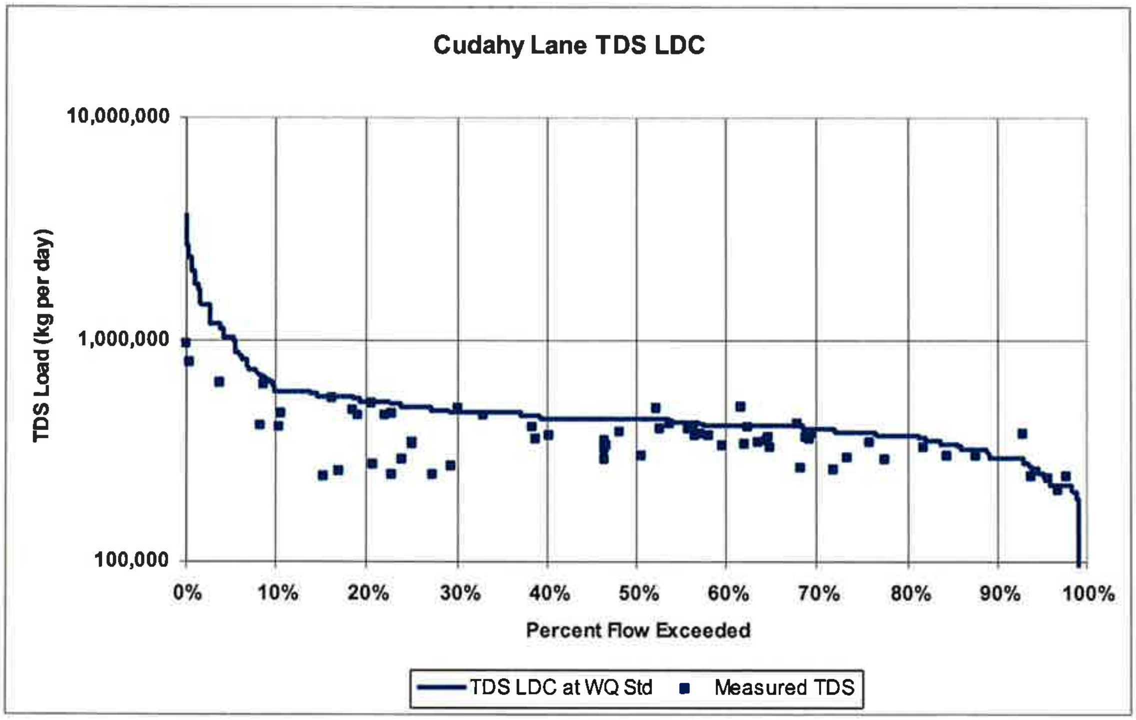


Figure 3.9. TDS load duration curve at Cudahy Lane.

Table 3.25 shows calculations for actual and allowable TDS loads at observed flows. The calculations are consistent with the LDCs, showing needed reductions only at very low flows at the Narrows and at Cudahy Lane. Exceedances during periods of base flow suggest pollutant loading from consistent flow sources such as point sources or groundwater. Point sources are a distant upstream source from Cudahy Lane but could still result in some influence to water quality conditions due to the size and consistent nature of the discharge. Groundwater loading does occur at both Cudahy Lane and the Narrows. Constant low flow releases from Utah Lake could also be an influence to base flow loading at the Narrows.

3.9.1.3.3. TSS

The resulting LDCs for TSS are presented in Figures 3.10 through 3.13. Some level of suspended sediment is essential to a healthy riverine ecosystem, providing a transport for nutrients supporting macroinvertebrates and benthic phytoplankton. High levels can indicate excessive erosion, sedimentation, or algal growth and result in gill irritation, covering of spawning beds, and excessive shading to benthic phytoplankton.

Utah currently has no standard for TSS on the Jordan River. In the past, Utah has used 58 mg/L as a daily maximum and 35 mg/L for 30-day average for cold water streams. Utah used 263 mg/L as a daily maximum and 90 mg/L for 30-day averages, respectively, for warm water streams. (U.S. EPA 2003) A value of 90 mg/L was used for the LDCs presented below. Based on this criterion, the LDCs indicate excess loads only at low and moderate flows at the Narrows, high flows at 2100 South and 1700 South, and little or no excess loading at Cudahy Lane.

Table 3.25. TDS loads and reductions.

Flow Percentile Ranges	Samples	Mean TDS (mg/L)	Median Flow (cfs)	Load (kg/day)	Allowable Load at Median Flow (kg/day)	Estimated Reduction (%)	Estimated Reduction (kg/day)	Estimated Reduction (kg/yr)
Narrows								
0–10	0	N/A	1555	N/A	4565310	N/A	N/A	N/A
10–40	6	832	797	1621684	2339905	0.0%	0	0
40–60	24	1115	424	1156211	1244818	0.0%	0	0
60–90	39	1160	28	79475	82205	0.0%	0	0
90–100	14	1285	7	21998	20551	6.6%	1447	52821
2100 South								
0–10	0	N/A	2030	N/A	5959858	N/A	N/A	N/A
10–40	7	671	1210	1986822	3552428	0.0%	0	0
40–60	10	822	450	904988	1321151	0.0%	0	0
60–90	16	1010	309	763741	907190	0.0%	0	0
90–100	2	1095	243	650997	713421	0.0%	0	0
Cudahy Lane								
0–10	5	658	350	563104	1027562	0.0%	0	0
10–40	21	885	170	368107	499101	0.0%	0	0
40–60	16	1026	150	376666	440384	0.0%	0	0
60–90	21	1051	130	334139	381666	0.0%	0	0
90–100	5	1269	85	263858	249551	5.4%	14308	522226

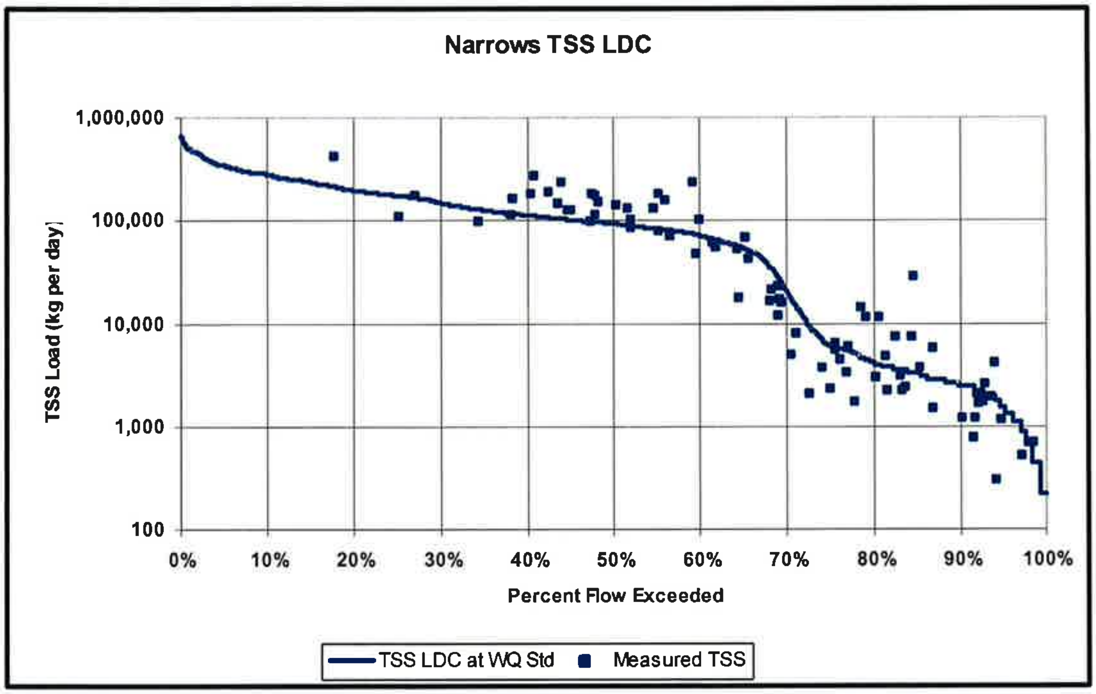


Figure 3.10. TSS load duration curve at the Narrows.

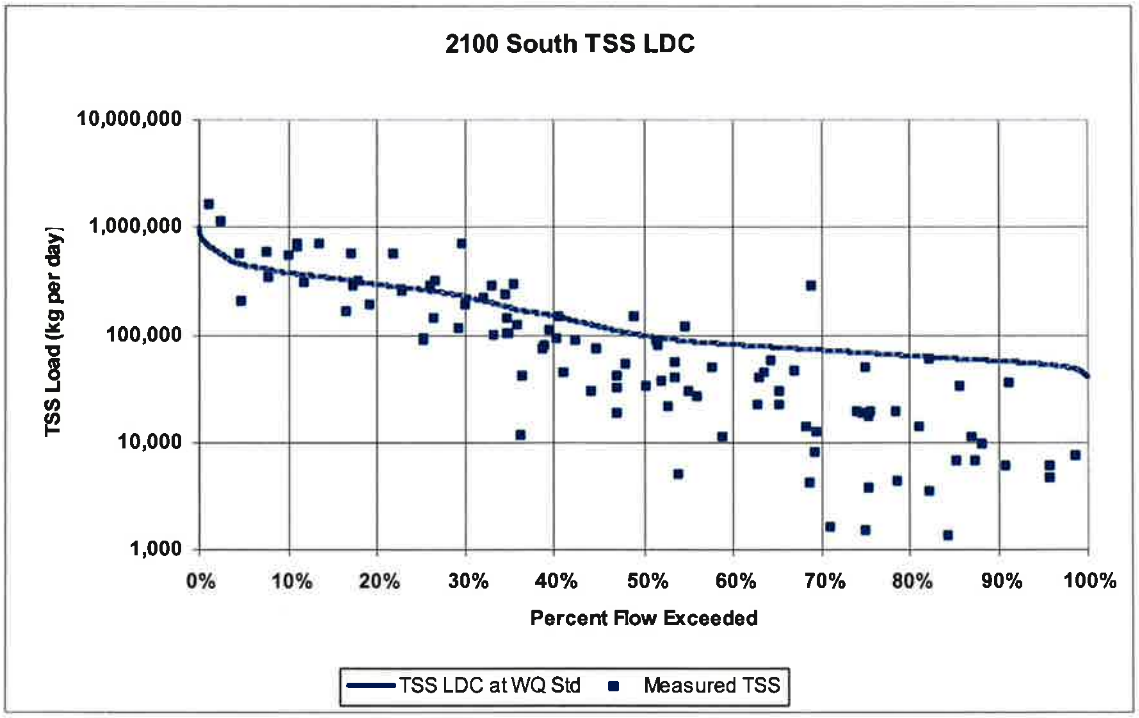


Figure 3.11. TSS load duration curve at 2100 South.

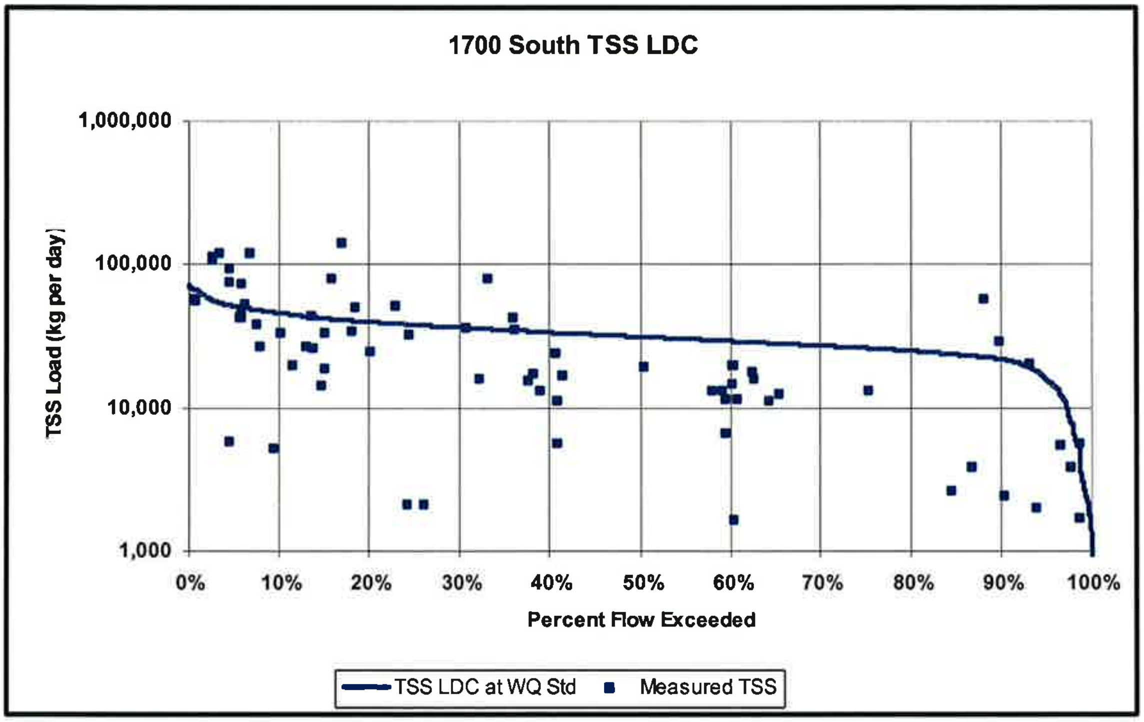


Figure 3.12. TSS load duration curve at 1700 South.

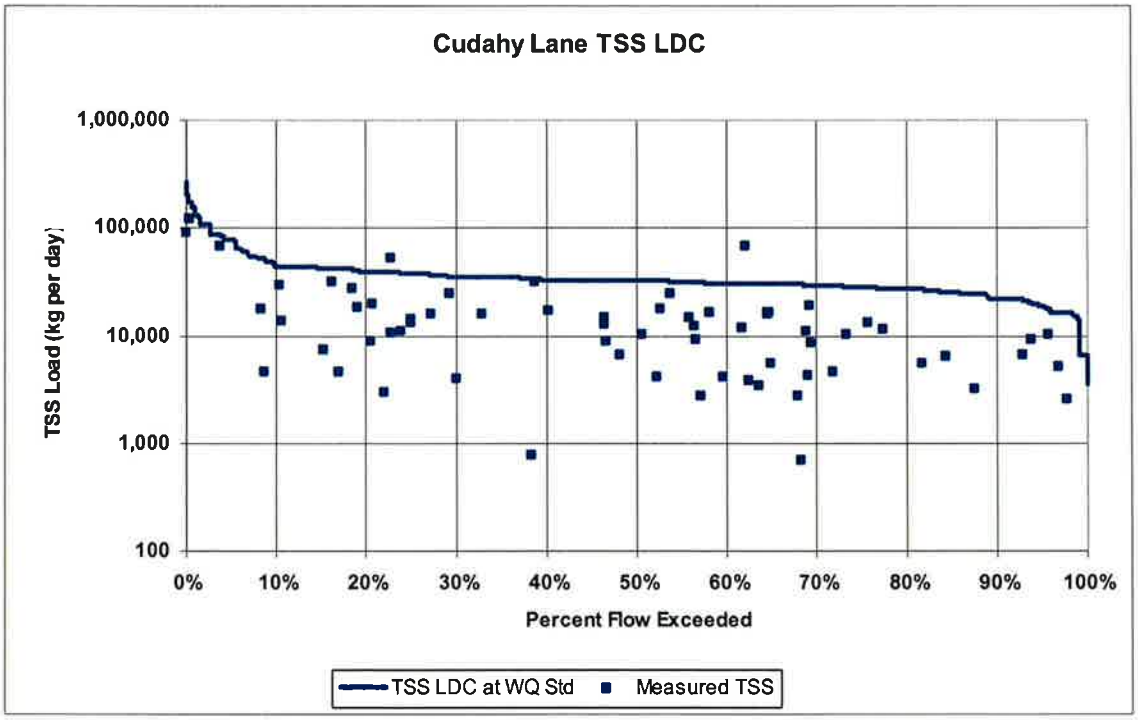


Figure 3.13. TSS load duration curve at Cudahy Lane.

Table 3.26 shows calculations for actual and recommended (90 mg/L) TSS loads at observed flows. The calculations are consistent with the LDCs, showing reductions needed to reach 90 mg/L only at moderate flows at the Narrows and higher flows at 2100 South and 1700 South. Note that recommended load reductions are based on a standard that is no longer used by Utah DWQ. LDCs for TSS are generated for informational purposes only.

Table 3.26. TSS loads and reductions.

Flow Percentile Ranges	Samples	Mean TSS (mg/L)	Median Flow (cfs)	Load (kg/day)	Recommended Load at Median Flow (kg/day)	Estimated Reduction (%)	Estimated Reduction (kg/day)	Estimated Reduction (kg/yr)
Narrows								
0–10	0	N/A	1555	N/A	342398	N/A	N/A	N/A
10–40	6	101	797	196032	175493	10.5%	20539	2249039
40–60	24	139	424	144127	93361	35.2%	50765	3705861
60–90	38	60	28	4142	6165	0.0%	0	0
90–100	14	34	7	575	1541	0.0%	0	0
2100 South								
0–10	6	126	2030	624957	446989	28.5%	177968	6495831
10–40	34	90	1210	266937	266432	0.2%	505	55298
40–60	24	48	450	52626	99086	0.0%	0	0
60–90	34	33	309	25210	68039	0.0%	0	0
90–100	5	20	243	11605	53507	0.0%	0	0

Table 3.26. (cont'd) TSS loads and reductions.

Flow Percentile Ranges	Samples	Mean TSS (mg/L)	Median Flow (cfs)	Load (kg/day)	Recommended Load at Median Flow (kg/day)	Estimated Reduction (%)	Estimated Reduction (kg/day)	Estimated Reduction (kg/yr)
1700 South								
0–10	23	109	232	62066	51084	17.7%	10982	400841
10–40	29	93	172	39179	37873	3.3%	1306	143003
40–60	9	38	142	13318	31267	0.0%	0	0
60–90	20	56	119	16158	26203	0.0%	0	0
90–100	10	43	72	7487	15854	0.0%	0	0
Cudahy Lane								
0–10	5	42	350	35965	77067	0.0%	0	0
10–40	21	40	170	16498	37433	0.0%	0	0
40–60	16	33	150	11934	33029	0.0%	0	0
60–90	21	35	130	11033	28625	0.0%	0	0
90–100	5	33	85	6779	18716	0.0%	0	0

3.9.1.3.4. Total Phosphorus

The resulting LDCs for Total P are presented in Figures 3.14 through 3.16. The Total P LDC shown in these figures is based upon the pollutant indicator level of 0.05 mg/L used by Utah DWQ which, if too high, can cause excessive algal growth. This can lead to low DO when bacteria decompose dying algae and during the night when algae rely primarily on respiration. These figures show that Total P exceeded recommended loads at all sites and all flows. Moreover, loads increased significantly from the Narrows to 2100 South. Total P measurements were insufficient to develop a LDC at 1700 South, therefore the plot and results for this station are not included in this section.

Table 3.27 shows calculations for actual and recommended Total P loads at observed flows. The calculations are consistent with the LDCs, showing substantial reductions necessary to reach recommended indicator levels. Although some reductions are necessary at the Narrows, the estimated reduction increases by an order of magnitude by 2100 South. Therefore additional intervention would be needed downstream of the Narrows in order to achieve recommended loads at 2100 South.

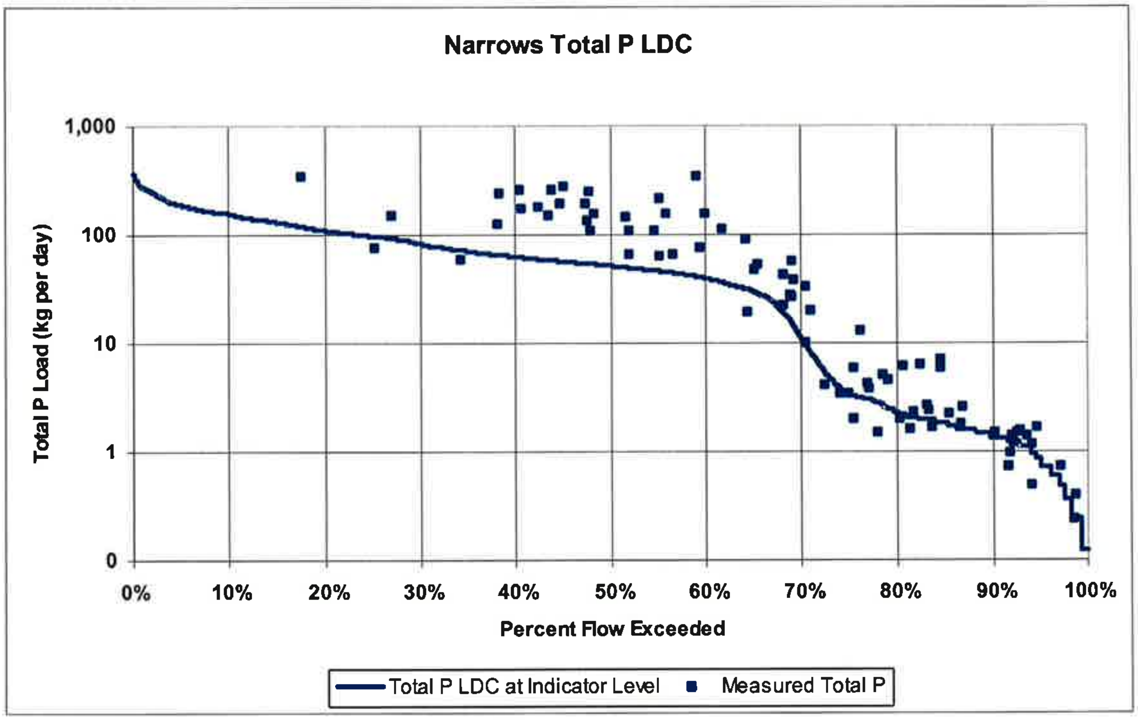


Figure 3.14. Total P load duration curve at the Narrows.

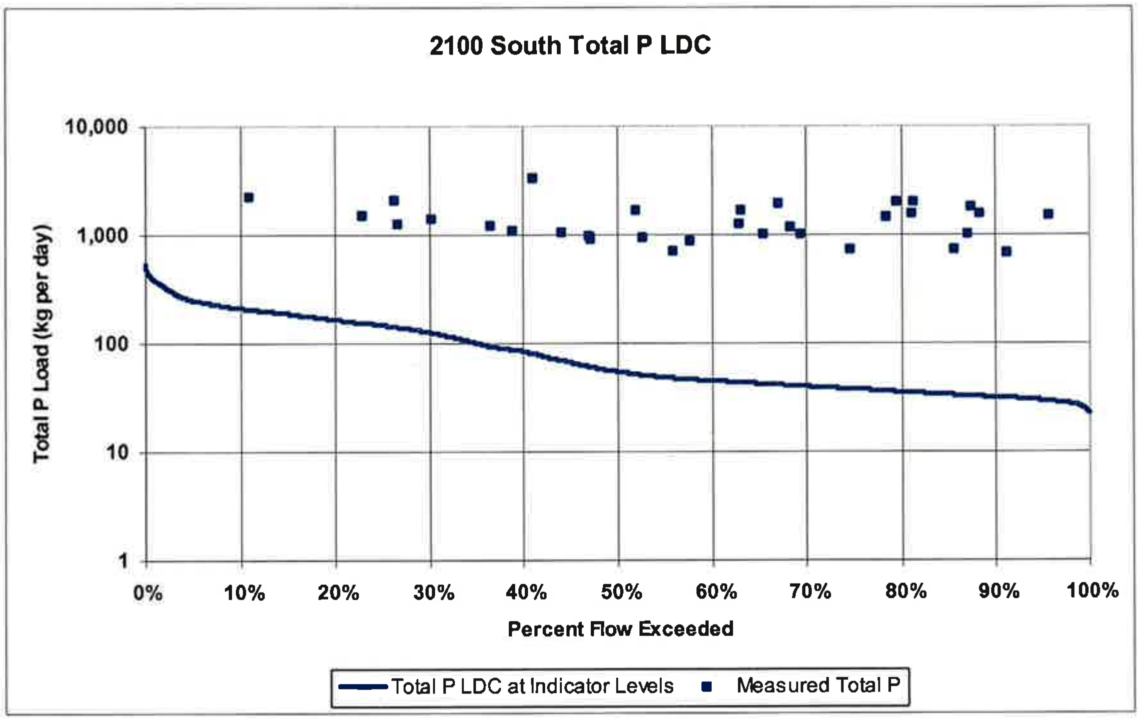


Figure 3.15. Total P load duration curve at 2100 South.

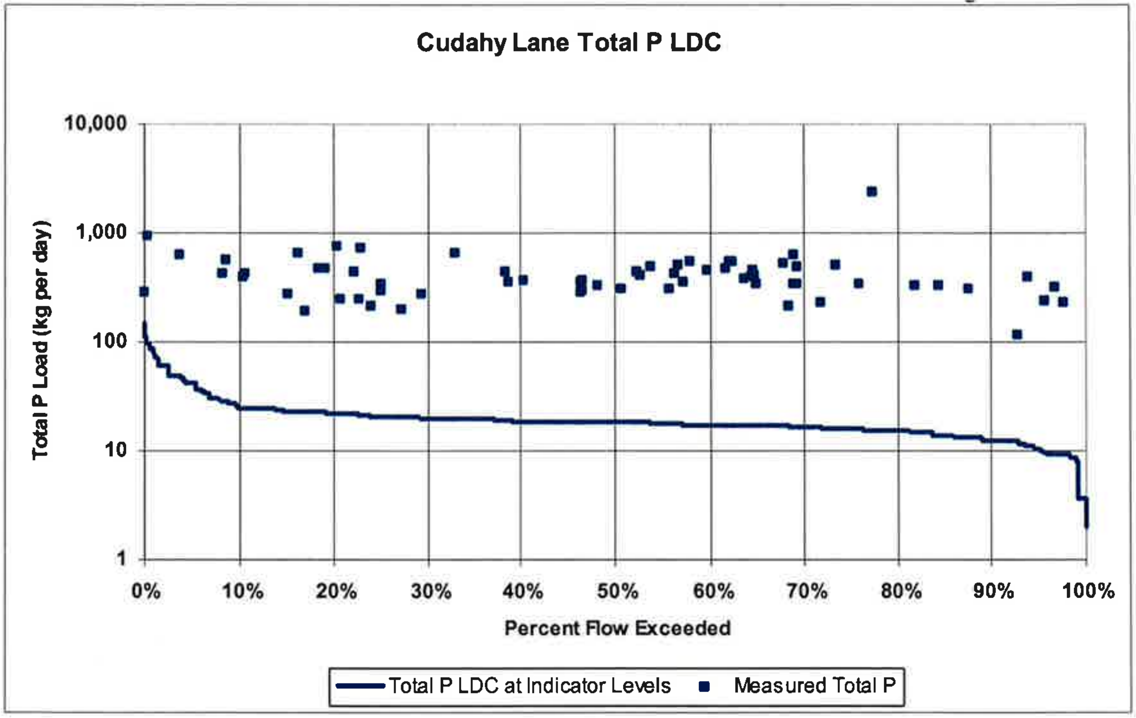


Figure 3.16. Total P load duration curve at Cudahy Lane.

Table 3.27. Total P loads and reductions.								
Flow Percentile Ranges	Samples	Mean Total P (mg/L)	Median Flow (cfs)	Load (kg/day)	Recommended Load at Median Flow (kg/day)	Estimated Reduction (%)	Estimated Reduction (kg/day)	Estimated Reduction (kg/yr)
Narrows								
0–10	0	N/A	1555	N/A	190	N/A	N/A	N/A
10–40	6	0.096	797	188	97	48.0%	90	9857
40–60	23	0.161	424	167	52	69.0%	115	8409
60–90	38	0.092	28	6	3	45.4%	3	312
90–100	14	0.058	7	1	1	13.5%	0	5
2100 South								
0–10	0	N/A	2030	N/A	248	N/A	N/A	N/A
10–40	7	0.570	1210	1687	148	91.2%	1539	168516
40–60	9	1.028	450	1132	55	95.1%	1077	78629
60–90	16	1.831	309	1384	38	97.3%	1346	147402
90–100	2	1.821	243	1082	30	97.3%	1053	38420
Cudahy Lane								
0–10	5	0.589	350	504	43	91.5%	461	16834
10–40	20	0.929	170	387	21	94.6%	366	40051
40–60	16	1.076	150	395	18	95.4%	376	27476
60–90	21	1.540	130	490	16	96.8%	474	51902
90–100	5	1.292	85	269	10	96.1%	258	9430

3.9.1.3.5. Dissolved Phosphorus

The resulting LDCs for Dissolved P are presented in Figures 3.17 through 3.19. Utah does not have a pollutant indicator value for Dissolved P. For the purposes of this analysis, the pollution indicator values for Total P (0.05 mg/L) are used. At the Narrows, Dissolved P was largely below the recommended loads, unlike Total P, perhaps because algae readily takes up the dissolved form and had already removed most of it. By 2100 South, however, levels were high once again, and remained high until below Cudahy Lane. Similar to Total P, Dissolved P measurements were insufficient to develop a LDC at 1700 South, therefore the plot and results for this station are not included below.

Table 3.28 shows calculations for actual and recommended Dissolved P loads at observed flows. The calculations are consistent with the LDCs, showing substantial reductions necessary to reach recommended indicator levels. Although data points were not available for all percentile ranges, reduction of loads between the Narrows and 2100 South may eliminate the need for reductions further downstream.

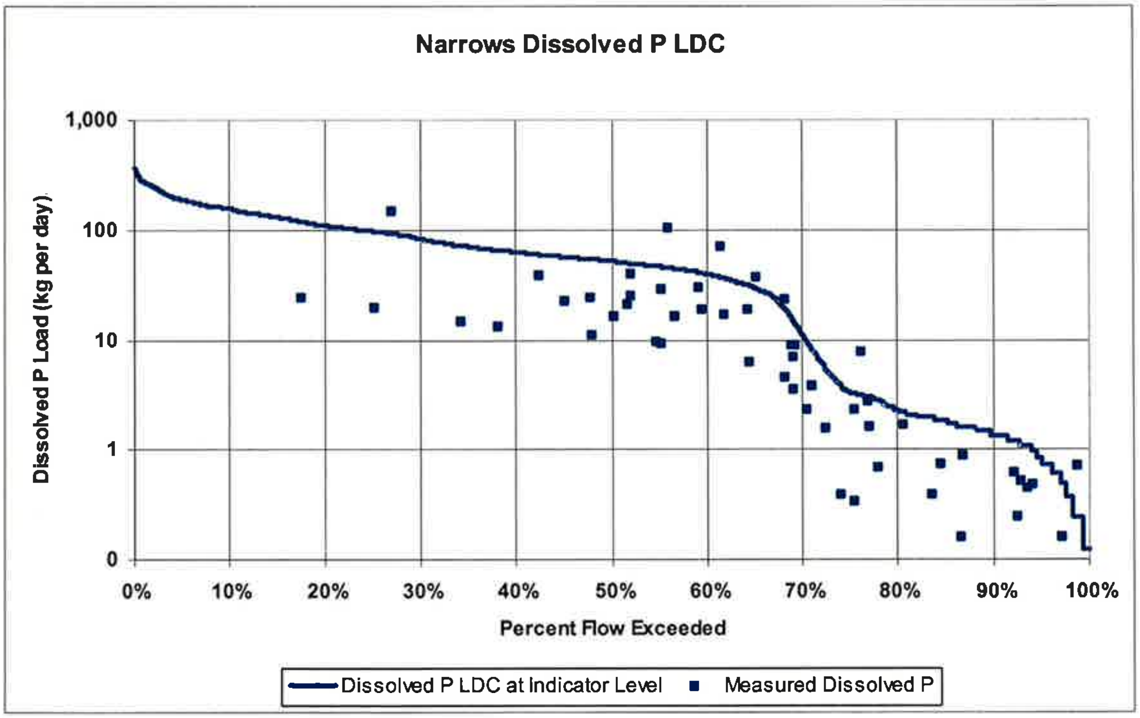


Figure 3.17. Dissolved P load duration curve at the Narrows.

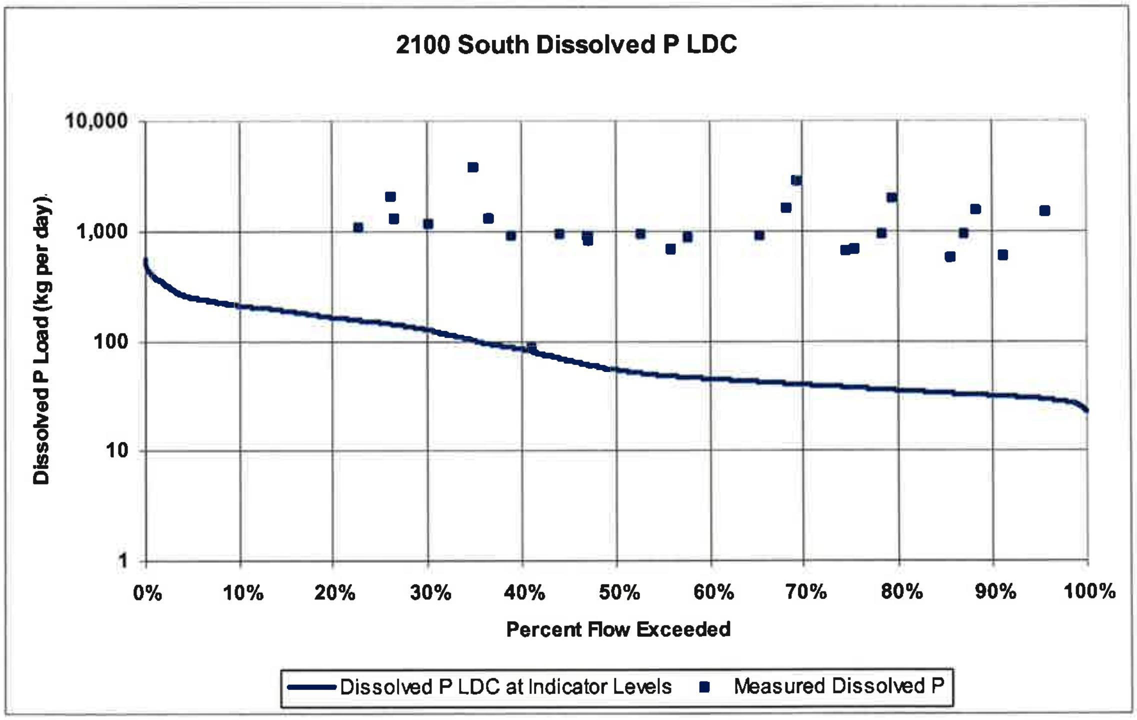


Figure 3.18. Dissolved P load duration curve at 2100 South.

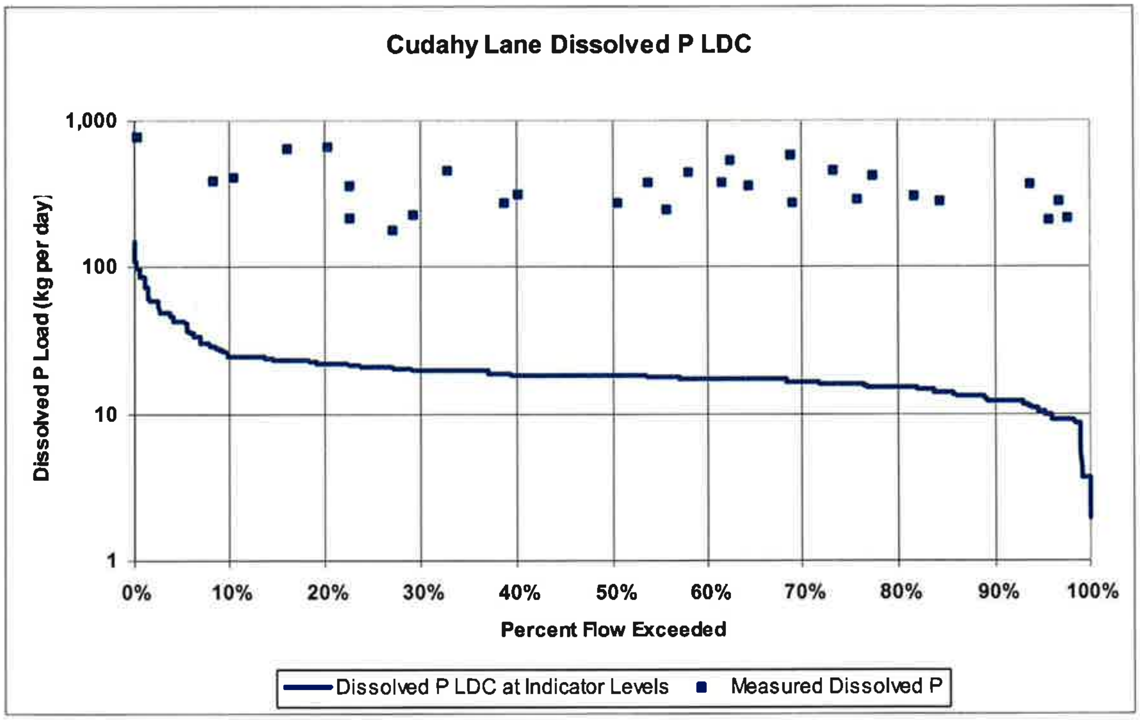


Figure 3.19. Dissolved P load duration curve at Cudahy Lane.

Table 3.28. Dissolved Phosphorus loads and reductions.

Flow Percentile Ranges	Samples	Mean Dissolved P (mg/L)	Median Flow (cfs)	Load (kg/day)	Recommended Load at Median Flow (kg/day)	Estimated Reduction (%)	Estimated Reduction (kg/day)	Estimated Reduction (kg/yr)
Narrows								
0–10	0	N/A	1555	N/A	190	N/A	N/A	N/A
10–40	5	0.024	797	47	97	0.0%	0	0
40–60	15	0.029	424	30	52	0.0%	0	0
60–90	26	0.030	28	2	3	0.0%	0	0
90–100	7	0.038	7	1	1	0.0%	0	0
2100 South								
0–10	0	N/A	2030	N/A	248	N/A	N/A	N/A
10–40	7	0.706	1210	2090	148	92.9%	1942	212648
40–60	8	0.675	450	743	55	92.6%	688	50201
60–90	10	1.687	309	1275	38	97.0%	1238	135521
90–100	2	1.745	243	1037	30	97.1%	1007	36770
Cudahy Lane								
0–10	2	0.529	350	453	43	90.5%	410	14971
10–40	9	0.875	170	364	21	94.3%	343	37573
40–60	5	0.919	150	337	18	94.6%	319	23270
60–90	10	1.190	130	379	16	95.8%	363	39717
90–100	4	1.341	85	279	10	96.3%	269	9801

3.9.1.4. Discussion

Load duration curves provide a way to graphically evaluate pollutant loads under a range of flows. As the TMDL process continues for the Jordan River, additional assessments of LDCs need to be considered and interpreted along with other analyses, including changes over time, and seasonal patterns. The results of this assessment indicate that in most instances, exceedance of allowable and recommended loads are fairly consistent over a wide range of flows for Total P. The level of exceedance increases with distance downstream from Utah Lake. Substantial reductions in Total P loading across a range of flows would be necessary to meet the recommended loads (developed from the indicator level of 0.05 mg/L Total P) at 2100 South and downstream. Reductions of more than 90 percent would be required of both point and non–point sources to reach recommended indicator levels in the lower Jordan River.

Development of LDCs can also provide an indication of monitoring locations that could be used to determine compliance with TMDL load reductions. Based on the review of data samples, it is likely that monitoring sites at the Narrows, 2100 South, and Cudahy Lane have sufficient data to adequately characterize existing loading patterns. Monitoring at 1700 South is limited in regards to the number of sample measurements for most parameters. Use of LDCs in the process of defining the Jordan River TMDL should be limited to only those locations where sufficient data exists to define the full range of flows and water quality dynamics. Three locations appear to have adequate data in this regard, including the Narrows, 2100 South, and Cudahy Lane.

3.10 SUMMARY

Chapter 3 of this report characterizes sources that contribute pollutant loads to the Jordan River. Loading from Utah Lake, seven monitored tributaries located east of the Jordan River, and three permitted discharges were calculated based on records of continuous flow and routine monitoring of water quality. Stormwater loads from outfalls that discharge directly to the Jordan River were computed from average annual precipitation, storm event monitoring of representative catchments (Stantec 2006a), and mapping information that defined specific outfall locations and boundaries of stormwater catchments.

Estimates of flow and water quality for the remaining pollutant sources (unmonitored tributaries, diffuse runoff, return flow from irrigation canals, and groundwater) were calculated using a combination of data and information collected from adjacent monitored tributaries, published literature, and GIS assessments.

Average annual and monthly loads for five pollutants of concern were defined for each source associated with all eight DWQ Segments. The total annual load to the Jordan River for each pollutant of concern to the Jordan River is presented. Monthly loads for each source are presented in the appendix to this document. Recommendations for further studies and additional data collection is included in Appendix A. This information will correct data gaps identified in the source characterization but will also support other areas of the TMDL process that will be used to complete a final TMDL for the Jordan River.

Monitoring data sets collected at mainstem Jordan River locations were reviewed and used to calculate loads between Utah Lake and Cudahy Lane. These loads indicated large decreases below canal diversions at Turner Dam, followed by gains from various pollutant sources downstream to 2100 South. A large decrease in loading was again observed below this point as flows and loads were diverted to the Surplus Canal.

Total annual contributions from each pollutant source to the Jordan River are displayed for each parameter in Figure 3.20 and Table 3.29. Annual loads in Figure 3.20 indicate that permitted discharges are a significant contributor to the total annual load for Total P, BOD, and NH_4. In a similar manner, Utah Lake makes a substantial contribution to the total annual load for TSS and TDS. As mentioned previously, stormwater loads described in this section are limited to surface runoff that enters the Jordan River through a constructed stormwater catchment that discharges directly to the mainstem or a drain that flows into the mainstem. Loads in surface runoff collected in catchments that enter the Jordan River via tributaries are accounted for in those tributary loads.

Table 3.29. Total annual pollutant loads (tons/yr) to the Jordan River.

	DWQ Segment								
Pollutant	1	2	3	4	5	6	7	8	Total
BOD	77	99	173	548	185	199	1	51	1,333
NH4	19	3	6	138	5	8	0	55	233
TDS	23,431	27,502	46,267	173,272	56,407	174,599	36,374	636,281	1,174,133
TP	8	1	9	274	155	13	0	59	520
TSS	92	952	2,556	9,607	472	2,879	9	18,947	35,514

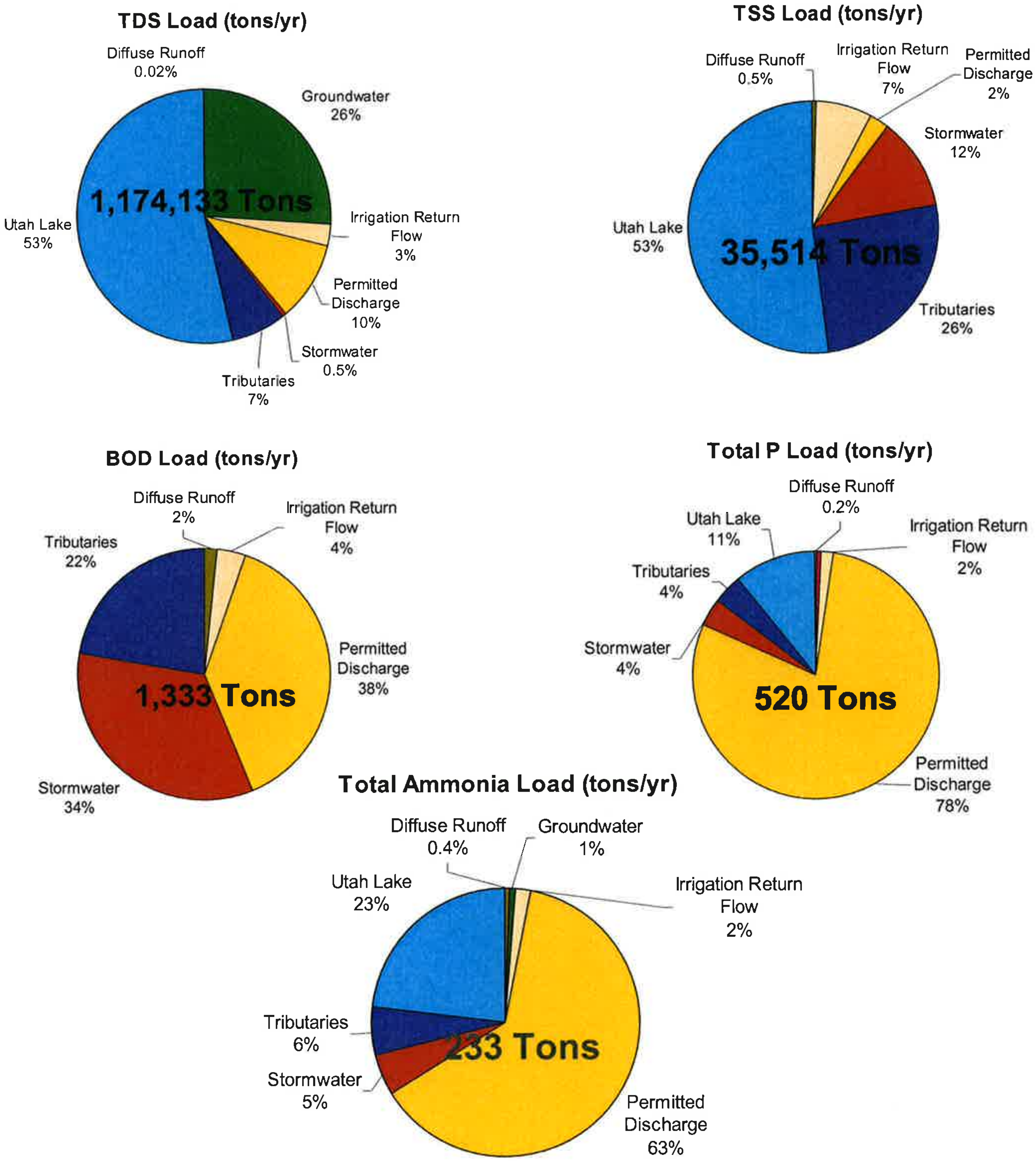


Figure 3.20. Distribution of annual pollutant loads (tons/year) to the Jordan River. Note the total annual load shown at the center of each plot. Loads shown here are the sum of all loads contributing to the Jordan River from Utah Lake downstream to Burton Dam. (Note that values for BOD do not include Utah Lake and tributaries for which there were no BOD measurements).

The accuracy of load calculations was evaluated with a mass balance assessment that compared the net balance of calculated incoming and outgoing loads for a segment of the Jordan River against a measured load at select mainstem monitoring locations. The results of this assessment are shown in Table 3.30. Additional detail for the mass balance assessment is included in Appendix J. Note that annual calculated loads shown in Table 3.30 and Appendix J are not modeled loads but the sum of monthly loads that were calculated for each pollutant source and shown previously in this chapter.

Table 3.30. Mass balance summary for pollutants of concern. All numbers indicate tons per year.

Source	Mile	Total Dissolved Solids	Total Suspended Solids	Biochemical Oxygen Demand	Total Ammonia	Total Phosphorus
DWQ Segment 8 - Jordan River from Utah Lake outlet (Mile 51.4) to Narrows (Mile 41.8)						
Utah Lake outlet	51.4	627,980	18,481	N/A	53	57
Incoming Loads		8,301	466	51	2	2
Outgoing Loads		(74,009)	(6,217)	N/A	(11)	(6)
Calculated Load		562,271	12,730	N/A	44	53
Measured Mainstem Load - Jordan River at Narrows (Turner Dam)	41.8	503,400	41,161	N/A	60	41
Difference as percent of Calculated Load		10%	(223%)	N/A	(35%)	24%
DWQ Segment 7 - Jordan River from Narrows (Mile 41.8) to Bluffdale Road crossing (Mile 38.1)						
Measured: Jordan River at Narrows (Turner Dam)	41.8	503,400	41,161	N/A	60	41
Incoming Loads		36,374	9	1	0	0
Outgoing Loads		(170,471)	(14,788)	N/A	(25)	(13)
Calculated Load		369,303	26,381	N/A	36	28
Measured Mainstem Load - Jordan River at Bluffdale Road crossing	38.1	180,854	8,341	N/A	9	12
Difference as percent of Calculated Load		51%	68%	N/A	76%	57%
DWQ Segment 6 - Jordan River from Bluffdale Road crossing (Mile 38.1) to 7800 South (Mile 26.4)						
Measured: Jordan River at Bluffdale Road crossing	38.1	180,854	8,341	NA	9	12
Incoming Loads		174,599	2,879	199	8	13
Outgoing Loads		(9,765)	(528)	(17)	(0)	(1)
Calculated Load		345,688	10,692	N/A	16	24
Measured Mainstem Load - Jordan River at 7800 South	26.3	364,739	15,711	641	20	27
Difference as percent of Calculated Load		(6%)	(47%)	N/A	(29%)	(11%)

Table 3.30. (cont'd) Mass balance summary for pollutants of concern. All numbers indicate tons per year.

Source	Mile	Total Dissolved Solids	Total Suspended Solids	Biochemical Oxygen Demand	Total Ammonia	Total Phosphorus
DWQ segment 5 - Jordan River from 7800 South (Mile 26.4) to 5400 South (Mile 24.3)						
Measured: Jordan River at 7800 South	26.3	364,739	15,711	641	20	27
Incoming Loads		56,408	472	185	5	155
Outgoing Loads		0	0	0	0	0
Calculated Load		421,147	16,184	826	25	182
Measured Mainstem Load - Jordan River at 5400 South	24.4	301,048	8,577	662	13	152
Difference as percent of Calculated Load		29%	47%	0	50%	17%
DWQ Segment 4 - Jordan River from 5400 South (Mile 24.3) to 2100 South (Mile 16.1)						
Measured: Jordan River at 5400 South	24.4	301,048	8,577	662	13	152
Incoming Loads		173,272	9,607	548	138	274
Outgoing Loads		0	0	0	0	0
Calculated Load		474,320	18,185	1,210	150	426
Measured Mainstem Load - Jordan River at 2100 South	16.1	714,602	25,353	2,301	145	727
Difference as percent of Calculated Load (5400S-2100 S)		(51%)	(39%)	(1)	4%	(71%)
Calculated Load (Narrows-2100 South)		763,817	38,812	1,374	185	470
Difference as percent of Calculated Load (Narrows-2100 South)		6%	35%	(67%)	22%	(55%)
DWQ Segment 3 through upper reach of DWQ Segment 1 - Jordan River from 2100 South (Mile 16.1) to Cudahy Lane (Mile 5.2)						
Measured: Jordan River at 2100 South	16.1	714,602	25,353	2,301	145	727
Incoming Loads		73,769	3,508	272	8	9
Outgoing Loads		(583,388)	(20,952)	(1,852)	(122)	(594)
Calculated Load		204,983	7,909	721	31	143
Measured Mainstem Load - Jordan River at Cudahy Lane	5.2	197,294	8,697	773	70	148
Difference as percent of Calculated Load		4%	(10%)	(0)	(124%)	(4%)
DWQ Segment 1 (mile 5.2 - mile 1.7) - Jordan River from Cudahy Lane to State Canal/Burnham Dam						
Measured: Jordan River at Cudahy Lane	5.2	197,294	8,697	773	70	148
Incoming Loads		23,431	92	77	19	8
Outgoing Loads		(65,220)	(3,161)	(276)	(18)	(56)
Calculated Load below diversion to State Canal and Burnham Dam		155,505	5,628	574	71	100

In general, the difference between calculated and measured loads is typically expected to be the greatest for pollutants such as NH_4, BOD, and Total P that are influenced by chemical and biological processes that influence concentrations. The mass balance approach does not account for these processes which can be significant even in short river segments. Pollutants such as TDS and TSS can be influenced by physical processes, although it is usually to a lesser degree. Poor characterization of pollutant sources can also contribute to differences between calculated and measured loads.

Large differences were noted between calculated and measured loads for many DWQ Segments, although most seemed to diminish with increasing size in river segment. Some of the greatest differences were noted between Utah Lake and 2100 South. With the exception of NH_4, differences between calculated and measured loads for all pollutants of concern decreased substantially below 2100 South. Significant improvements in the mass balance for TDS and Total P were noted between the Narrows and 2100 South when incoming and outgoing loads were totaled for DWQ Segments rather than assessing each segment individually.

This page is intentionally left blank.

4.0 WATER QUALITY LINKAGES IN THE LOWER JORDAN RIVER

[Editor's note: The substance of this chapter was presented and discussed at a 1-day Linkage Symposium held on April 20, 2009. This chapter was subsequently revised to incorporate input from that symposium, including the recommendations for additional information and data needs in Appendix A. (Cirrus 2009)]

4.1 INTRODUCTION

Water quality linkage is the relationship between a water quality impairment – low DO concentrations, for example – and those physical and biological factors that influence it.

Table 4.1 lists DWQ Segments of the Jordan River that do not meet DO criteria for their designated beneficial uses (DWQ 2008a). Additional information describing listing criteria is provided in Chapter 5.

Table 4.1. DWQ Segments of the Jordan River not supporting their designated beneficial use due to low DO.

DWQ Segment	Description	River Mileage	Water Quality Monitoring Stations (Number)
1	Jordan River from outlet at Farmington Bay to Davis County line	0–6.9	• Burnham Dam • Cudahy Lane (4991820)
2	Jordan River from Davis County line to North Temple Street	6.9–11.4	• Redwood Road (4991860) • 900 North (4991880) • 500 North (4991890)
3	Jordan River from North Temple to 2100 South	11.4–15.9	• 400 South (4991940) • 700 South (4992030) • 1300 South (4992270) • 1700 South (10171000)

As first mentioned above in Chapter 1, all three of these segments of the Jordan River have been assigned as protected for Class 3B – warm water game fish/aquatic life. To protect this beneficial use on the Jordan River the State of Utah requires (Utah Administrative Code, Rule R317-2 Standards of Quality for Waters of the State):

1. From May through July any 7-day average DO concentration shall be at least 5.5 mg/L and every instantaneous value shall be at least 4.5 mg/L in order to provide greater protection for more sensitive young organisms.

2. From August through April the instantaneous DO concentration shall be at least 4.0 mg/L;

3. The 30-day average concentration of DO shall always be greater than 5.5 mg/L;

As detailed in Chapter 5, these criteria are not currently being met, so a TMDL must be prepared to address the source(s) of the DO problem (DWQ 2008b).

4.2 EVIDENCE FOR DO IMPAIRMENT ON THE LOWER JORDAN RIVER

4.2.1 WATER QUALITY STATIONS ON THE LOWER JORDAN RIVER

The three segments comprising the lower Jordan River span 16 river miles and include several water quality monitoring stations, diversions, and inflows (Table 4.2). The lower Jordan River is defined here as beginning just below 2100 South after the Surplus Canal diverts most of the flow from the river. 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). The lower Jordan River therefore receives less than 20 percent of the total flow, with monthly mean flows relatively constant at 190–320 cfs. Details of the range of flows observed in lower Jordan River segments are discussed above in Chapter 2.

Table 4.2. Major water quality monitoring stations, diversions, and inflows in lower Jordan River (DWQ Segments 1, 2, and 3).

River Mile (approx.)	Water Quality Monitoring Station on Jordan River (Number)	Diversion	Other Inflow
16.1	2100 South (4992320)		
16.0		Surplus Canal diversion	
15	1700 South (10171000)		
14.2			1300 South Conduit (Parley's Creek, Emigration Creek, Red Butte Creek, Emigration Creek)
11.6			North Temple Conduit (includes City Creek)
10.3	500 North (4991890)		
5.2	Cudahy Lane (4991820)		
5.1			SDWTP
1.6		State Canal	
1.5	Burnham Dam		
0		Burton Dam, Great Salt Lake	

Monitoring stations in this lower section are located at 2100 South above the Surplus Canal diversion, at 1700 South below the Surplus Canal diversion, and at 500 North, Cudahy Lane, and Burnham Dam. Both water quality and flow measurements have been collected at these locations by Utah DWQ or the USGS. Significant inflows from tributaries include the 1300 South Conduit (from several mountain streams) and the North Temple Conduit (which includes City Creek). The discharge from the SDWTP is also monitored and flows into the lower Jordan River just below Cudahy Lane.

4.2.2 SEASONAL PATTERNS IN DIRECT DO MEASUREMENTS AND DO VIOLATIONS

Mean monthly DO concentrations from samples collected at four sites on the lower Jordan River from 1995 to 2005 are shown in Figure 4.1. 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 DO is 3–4 mg/L lower and percent violations are higher in late summer than in mid-winter. The rate of violations increases downstream of 1700 South at 500 North and Cudahy Lane.

Two important qualifiers to this summary are that the high percentage of violations for 2100 South in November was based on two measurements, only one of which exceeded the standard. Second, many measurements of DO in the past have been made during midday when algal photosynthesis increases DO. Night time concentrations of DO would have been lower and the number of violations significantly higher.

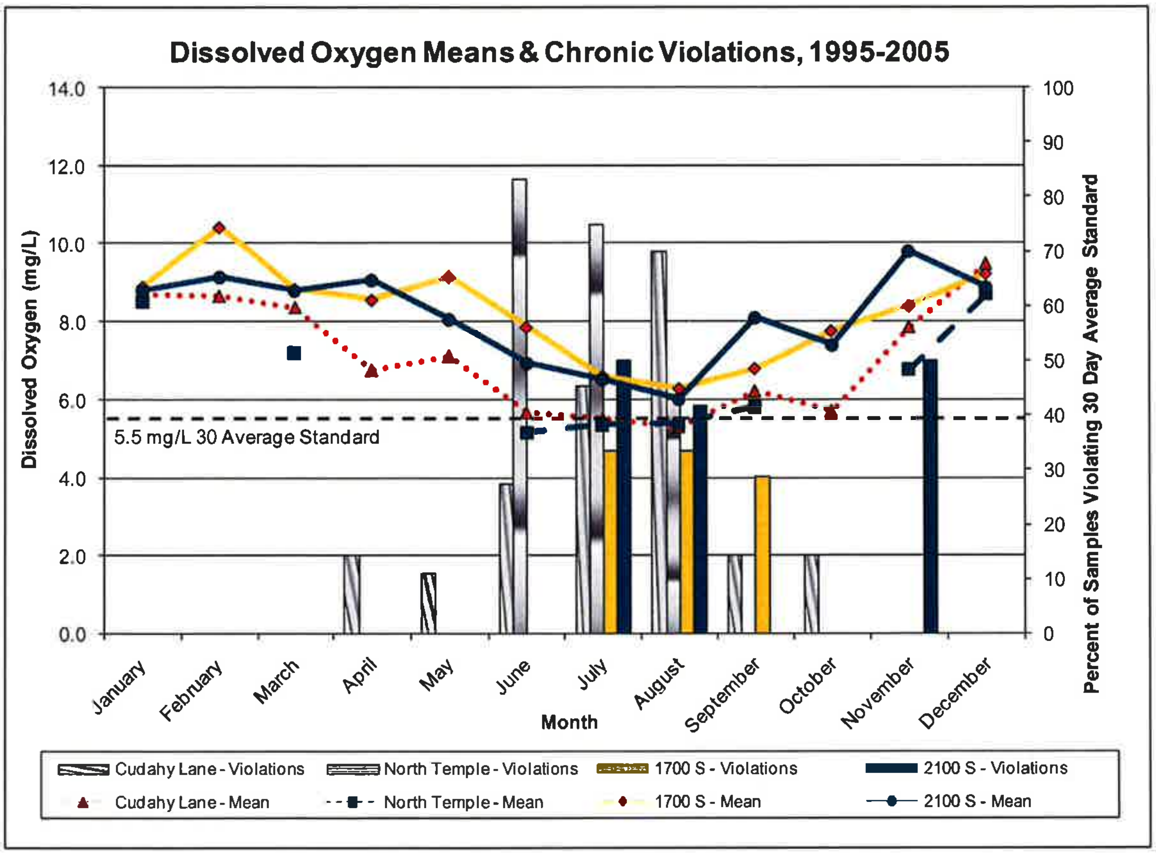


Figure 4.1. Mean monthly DO (lines, plotted on left axis) and percent of samples violating the 30-day average standard (bars, plotted on right axis).

Low DO in the lower Jordan River appears to be influenced by physical as well as biological conditions within this section of the river. No violations of the DO standard have been recorded in the Surplus Canal, which is also assigned a 3B warm water fishery beneficial use, and which is monitored at two Utah DWQ monitoring stations: 4991310-Surplus Canal at I-80 Crossing, and 4991290-Surplus Canal Northwest of Airport. Possible differences between these two water bodies that may help to explain the lack of violations of the DO standard in the Surplus Canal include:

1. Steeper slope and higher velocity of the Surplus Canal, which results in higher reaeration rates.

2. Higher flows and greater depth of the Surplus Canal resulting in lower macrophyte populations and lower water temperatures, which would both increase DO solubility and reduce oxygen demand from bacterial decomposition.

4.2.3 DO DEFICITS

Additional evidence of DO impairment in the lower Jordan River is that a DO deficit exists in all seasons and the deficit worsens downstream. A "DO deficit" is the difference between the measured concentration and the saturation concentration. Calculations of saturated DO concentrations can be made using standard formulas based on water temperature and altitude. The QUAL2K water quality model uses the following equation to calculate concentrations of oxygen saturation as a function of water temperature:

$$\ln o_s(T,0) = -139.34411 + \frac{1.575701\times10^5}{T_a} - \frac{6.642308\times10^7}{T_a^2} + \frac{1.243800\times10^{10}}{T_a^3} - \frac{8.621949\times10^{11}}{T_a^4}$$

where $o_s(T, 0)$ = the saturation concentration of DO in freshwater at 1 atm [mgO$_2$/L], and T_a = absolute temperature [K] where $T_a = T + 273.15$.

The effect of elevation is accounted for by

$$o_s(T, elev) = e^{\ln o_s(T,0)}(1 - 0.0001148 elev)$$

Figure 4.2 shows the results of this analysis for the lower Jordan River, using observed mean monthly DO concentrations, and the calculated saturation values. There is a DO deficit in the lower Jordan River in all seasons of the year, and the deficit increases in the summer and with distance downstream. The average monthly deficit for these three stations ranges from 0.8-1.7 mg/L.

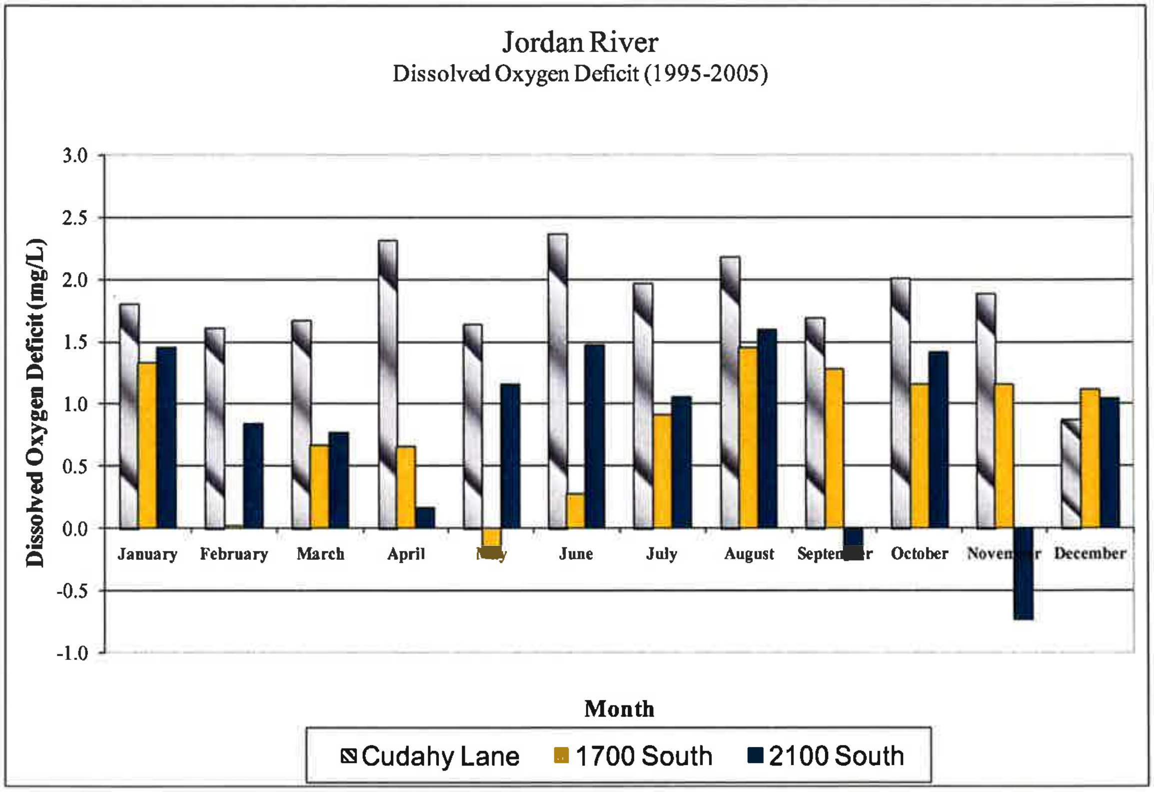


Figure 4.2. Monthly DO deficit in the lower Jordan River.

The processes contributing to low DO in the lower Jordan River are discussed in the next section.

4.3 FACTORS AFFECTING DO IN STREAMS AND RIVERS

The links between physical and biological processes and their effects on DO in a moving water body involve complex processes which are driven at different rates by similar factors, and even in opposite directions by some factors. For example, warmer water temperatures reduce DO solubility and increase rates of aerobic decomposition, which further reduces DO. Warmer water temperatures can also increase the rate of algal photosynthesis, which increases daytime DO concentrations. However, high rates of photosynthesis also mean increased algal growth that can result in “crashing” levels of DO in early mornings. This increased algal biomass will then inevitably die, generating more organic matter to be decomposed by bacteria, consuming yet more DO.

Out of this complexity emerge four major factors which influence the concentration of DO available to warm water fisheries of the lower Jordan River (U.S. EPA 2000). These are illustrated in Figure 4.3 with indicators, drivers, and possible solutions, and described as:

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

2. Aerobic decomposition of organic matter in the water column (measured as BOD).
3. Aerobic decomposition of organic matter and inorganic oxidation within the bottom sediments (measured as SOD).
4. Nighttime algal consumption of DO associated with the transition from plant photosynthesis to respiration.

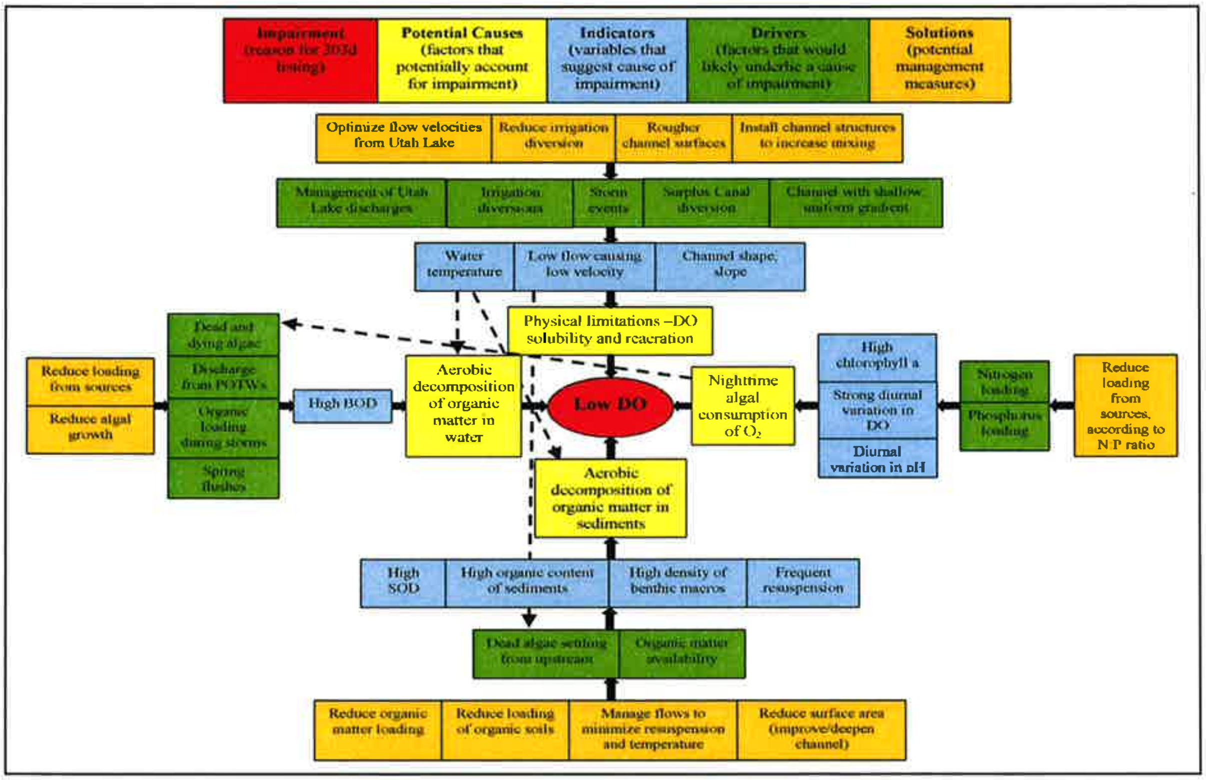


Figure 4.3. Factors potentially affecting DO in the lower Jordan River.

4.3.1 TEMPERATURE AND CHANNEL MORPHOLOGY

Temperature affects the solubility of oxygen in water; colder water has a higher solubility for oxygen than warmer water. The warmer water of summer has a saturated value almost 3.5 mg/L lower than in winter.

Water that is less than saturated in DO will absorb oxygen from the atmosphere, a process known as reaeration. Greater surface contact between air and water increases the rate of reaeration. Surface area is increased by turbulence which, given a constant slope and channel roughness, results from higher flows. Streams with similar flow but increased slope or channel roughness will have higher reaeration rates.

4.3.2 AEROBIC DECOMPOSITION IN WATER

Aerobic decomposition occurs when bacteria break down organic matter, consuming oxygen in the process. In the water column the demand on DO can be measured directly as BOD. The source of the organic matter may be external – for example, storm water drains, sewage treatment plants, and tributary streams – or internal – from dying aquatic plants and animals. Figure 4.4 shows that aerobic decomposition rates increase with warmer water temperatures, where "%BODult" is the percent of the ultimate BOD consumed at any one point in time.

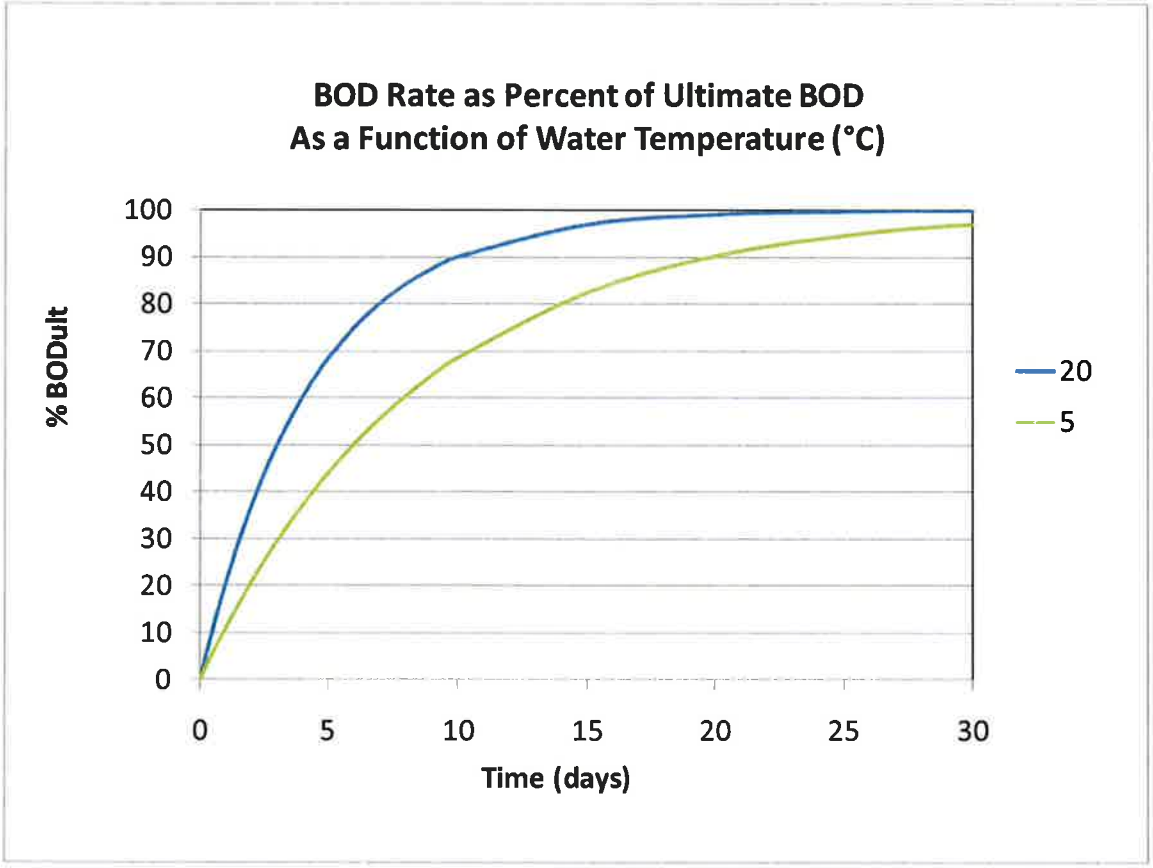


Figure 4.4. BOD rate as a function of water temperature.

4.3.3 AEROBIC DECOMPOSITION AND INORGANIC OXIDATION IN SEDIMENTS

Aerobic decomposition can also consume DO at the interface between the water column and the sediments, and is then referred to as SOD. Organic material that has settled to the bottom is decomposed by aerobic bacteria. As older sediments become buried by newer sediments, they are starved of oxygen and decomposition slows and is replaced by anaerobic processes. When these organic-rich sediments are disturbed, such as during storms or periods of high flow, the material is resuspended in the water column and the resulting aerobic decomposition places an increased demand for DO.

SOD also includes the effect of other, inorganic oxygen consuming processes occurring in the sediments. Documentation provided for the QUAL2K model succinctly explains these processes: "The sediments are divided into two layers: a thin (≅ 1 mm) surface aerobic layer underlain by a thicker (10 cm) lower anaerobic layer. Organic carbon, nitrogen and phosphorus are delivered to the anaerobic sediments via the settling of particulate organic matter (i.e., phytoplankton and detritus). There they are transformed by mineralization reactions into dissolved methane, ammonium and inorganic phosphorus. These constituents are then transported to the aerobic layer where some of the methane and ammonium are oxidized. The flux of oxygen from the water required for these oxidations is the sediment oxygen demand." (Chapra 2007, page 64) SOD is typically reported in units of $g/m^2/day$.

4.3.4 NIGHTTIME RESPIRATION

DO is also affected by plant photosynthesis, which occurs when autotrophic plants are exposed to solar radiation. These plants include algae (phytoplankton in the water column, growing in single cells, clumps or filamentous mats, or periphyton, dominated by algae growing on sands, cobbles, or other underwater structures) and macrophytes (rooted or floating aquatic plants large enough to be seen by the naked eye). The process of photosynthesis converts CO_2, phosphorus, nitrogen, and other basic nutrients into plant biomass. Photosynthesis releases oxygen, increasing DO concentrations in the water column. Temperature can increase the rate of plant metabolism but the magnitude of the resulting biomass is limited by availability of basic nutrients such as N or P. Different species of algae and macrophytes have different responses to temperature and ratios of N and P availability. Availability of light, nutrients, and warm conditions results in dense populations of plants, which can lead to supersaturated levels of DO during the day.

Increases in DO due to photosynthesis occur only during the day. At night plants stop photosynthesizing, relying only on a continuing respiratory process, which consumes DO and releases CO_2. High concentrations of photosynthetic plant biomass engaged in nighttime respiratory processes can result in "crashes" of DO, with concentrations well below those required by fish and macroinvertebrates.

The degree of nutrient richness in a water body is referred to as its trophic state: oligotrophy is nutrient poor, mesotrophy is an intermediate condition, eutrophy is nutrient rich, and hypereutrophy is excessively nutrient rich. In streams with excess nutrients, light- and nutrient-rich conditions (eutrophic or hypereutrophic) cause high rates of growth and consequently large diurnal swings in DO.

Plant growth in shallow streams is usually limited by the availability of nutrients (U.S. EPA 2000). In deep water, light can also be a limiting factor as a result of suspended material such as silt and phytoplankton. Reduced light also means reduced periphyton and, since some macroinvertebrates graze on periphyton, reduced populations and diversity of these macroinvertebrates results. This in turn reduces the available food supply for other aquatic wildlife, including fish and birds.

Diurnal swings of photosynthesis and respiration also cause diurnal swings of pH. Photosynthesis generates O_2 during the day which raises pH; plants rely only on respiration during the night, which generates CO_2 and lowers the pH. High pH can be disruptive to macroinvertebrates, which serve as a food source for fish. Low pH can irritate sensitive tissues of many aquatic animals, causing physiological stress or death, and can also trigger the release of heavy metals from sediments. Measurements of pH collected during routine and diurnal monitoring indicate that pH variability in the Jordan River appears to vary between 7.0 and 8.5 which is within the acceptable range of 6.5–9.0 established by Utah's water quality standards.

Fish, macroinvertebrates, and other aquatic animals also consume DO as part of their normal metabolism. There is insufficient data available on these populations in the lower Jordan River to directly quantify their impact on DO levels. However, previous surveys of fish and macroinvertebrate populations suggest it is unlikely that loss of DO through metabolic consumption contributes significantly to low DO levels in the Jordan River (Holden and Crist 1986, Holden and Crist 1989).

4.4 ANALYSIS OF EXISTING DATA ON FACTORS AFFECTING DO IN THE LOWER JORDAN RIVER

4.4.1 PHYSICAL LIMITATIONS – DO SOLUBILITY AND REAERATION

Seasonal differences in water temperature can account for seasonal differences in DO but cannot fully account for a deficit in DO year round. Oxygen is more soluble in cold water than in warm water, and Figure 4.5 shows the saturated DO concentrations as a function of average monthly water temperatures for the long-term record of 1980–2005 at Cudahy Lane, 1700 South, and 2100 South. Table 4.3 compares the actual mean monthly concentrations of DO for these same three monitoring stations on the lower Jordan River for the shorter period of record used in this report for assessing water quality measurements of 1995–2005 with calculated saturated DO concentrations at the observed mean monthly temperatures for that same period. There is a consistent deficit between saturated – the potential – and observed DO of 0.8-1.7 mg/L.

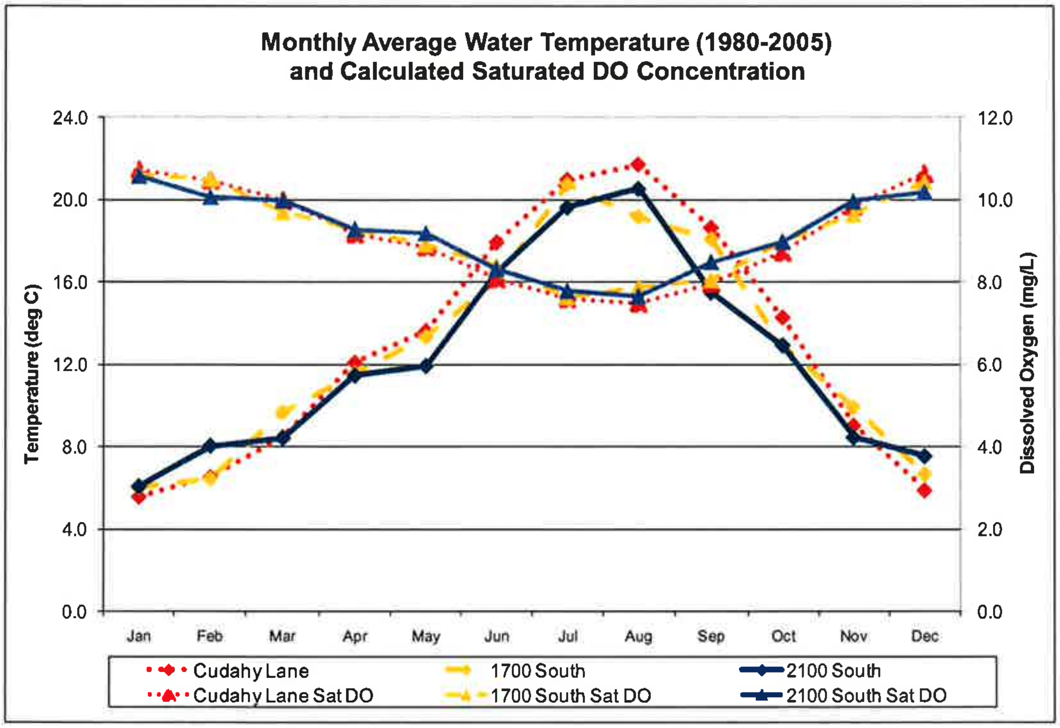


Figure 4.5. Monthly average water temperatures in the lower Jordan River.

Table 4.3. 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] (1995-2005).

Month	Mean Temp °C	Mean Observed DO Concentration (mg/L)	Mean Saturated DO Concentration (mg/L)	Deficit in DO (mg/L)
Jan	7.2	8.8	10.3	1.53
Feb	7.5	9.4	10.2	0.82
Mar	9.8	8.6	9.7	1.04
Apr	12.2	8.1	9.2	1.04
May	13.2	8.1	8.9	0.86
Jun	17.4	6.8	8.2	1.37
Jul	21.6	6.2	7.5	1.31
Aug	21.1	5.8	7.6	1.74
Sep	18.9	7.0	7.9	0.91
Oct	14.0	7.3	8.8	1.53
Nov	10.8	8.7	9.4	0.77
Dec	7.6	9.2	10.2	1.01

[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).

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, and doing so in all months of the year.

The potential for reaeration – the movement of the DO concentration in the water toward saturated values as a result of contact with the atmosphere – can be calculated using one of several formulas that take into account factors such as channel characteristics, flow, and depth (Figure 4.6). 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. Based on calculated transit times for water in the river, DO concentrations in the lower Jordan River should be increasing by approximately 0.8-1.6 mg/L in the reach between 2100 South and Cudahy Lane, and 1.7-3.4 mg/L between 2100 South and Burton Dam. Instead, as illustrated in Figure 2, DO concentrations are decreasing downstream of 2100 South.

Low flows decrease reaeration, although unsaturated DO conditions are not just associated with low flow. 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 flows (Table 4.4 and Table 4.5, respectively). Although the percentage of samples violating water quality criteria was greatest in the 40–70 flow percentile ranges, 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 4.7 shows channel elevations and Table 4.6 shows hydraulic characteristics of the river (Stantec 2006b). The lower velocities resulting from these shallower slopes also result in longer transit times which allows 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.

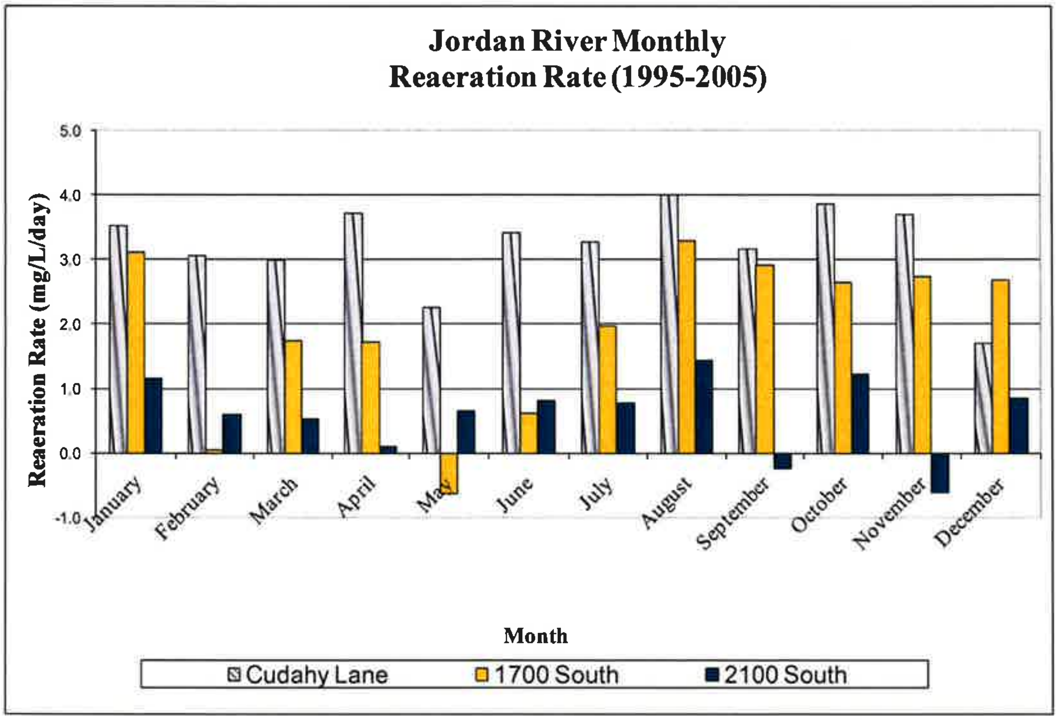


Figure 4.6. Reaeration rates in the lower Jordan River (Stantec 2006b).

Table 4.4. 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 4.5. 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.

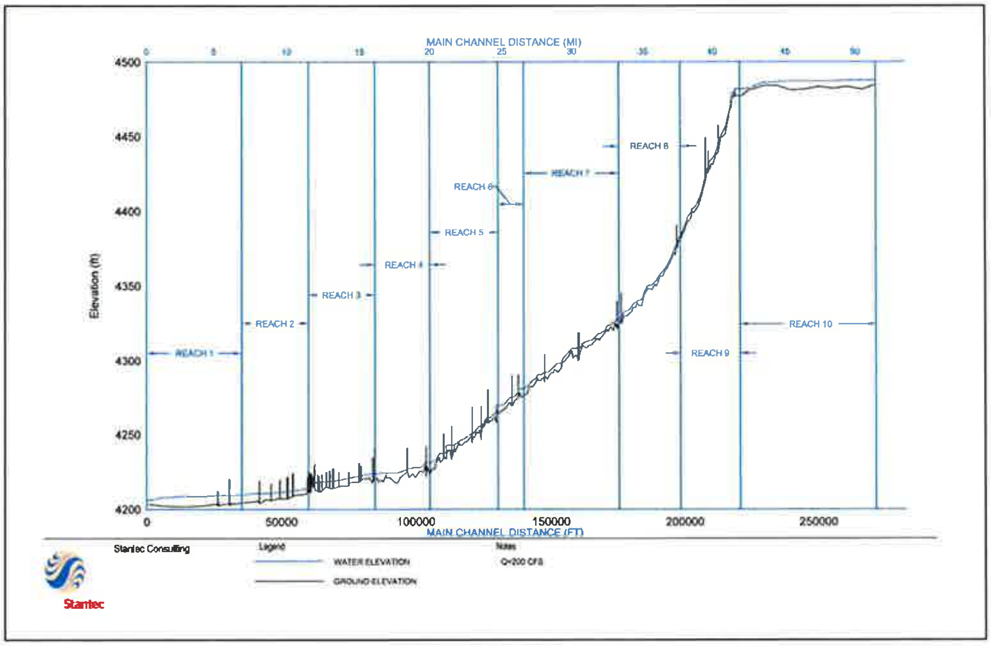


Figure 4.7. Jordan River elevations (DWQ Segments 1–3 are consistent with the lower Jordan River from Burton Dam upstream to 2100 South) (Reproduced from Figure 4-3 in Stantec 2006.)

Table 4.6. Velocities and transit times of DWQ Segments at 200 cfs.

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**

4.4.2 AEROBIC DECOMPOSITION OF ORGANIC MATTER IN THE WATER COLUMN

4.4.2.1 Biochemical Oxygen Demand

Since physical processes 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 restore it. One of these processes is the demand for DO that accompanies decomposition of organic matter in the water column.

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 from contributing DO) and at a constant 20°C temperature. The BOD_5 measurement can be made with or without nitrification inhibitors. If inhibitors are added, the decrease in DO is primarily due to aerobic bacterial decomposition of the organic matter that was in the sample. This is typically referred to as carbonaceous BOD_5, or $cBOD_5$. If inhibitors are not added, the DO loss results from both 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).

Even the simpler cBOD has its complexities, because all organic matter 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 – a "fast BOD" rate. Other materials, for example structural components of plants such as leaves and branches, are more resistant to decomposition, have a slower rate of decay, and produce a lower demand on DO – "slow BOD." These differences could be associated with different pollutant sources.

The measurements of BOD made prior to 2005 support a conclusion of significant DO demand due to organic matter. Figure 4.8 shows a bimodal distribution in monthly average BOD, peaking in early spring and late summer.

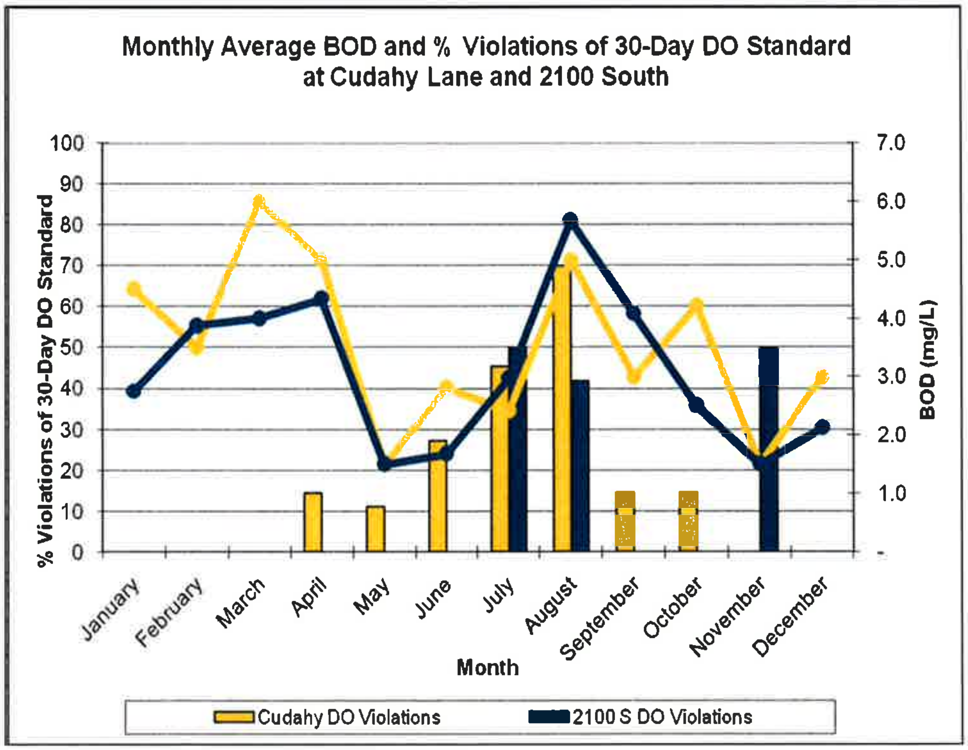


Figure 4.8. Monthly average BOD (lines, plotted on right axis) and percent violations of 30-day DO standard at Cudahy Lane and 2100 South (columns, plotted on left axis).

Note that DO violations in the river occur only in the warmer months of summer. This is consistent with potentially different sources of BOD – slowly decomposing plant detritus from flushing flows in the spring and decaying matter from plant growth in summer. Figure 4.4 shows that rates of BOD are strongly affected by temperature, which is also consistent with the fact that DO violations occur only in summer. It is worth mentioning at this point that SOD rates are also faster in warmer water, so would also contribute to low DO in summer.

4.4.2.2 Volatile Suspended Solids

Other direct evidence of organic matter in the water column is that a substantial portion of the suspended material in the water column is organic in nature. Figure 4.9 shows that the ratio of VSS:TSS ranged from 10–40 percent for sites along the Jordan River in August and October of 2006 and February of 2007. (No data was available for 2600 North in August 2006).

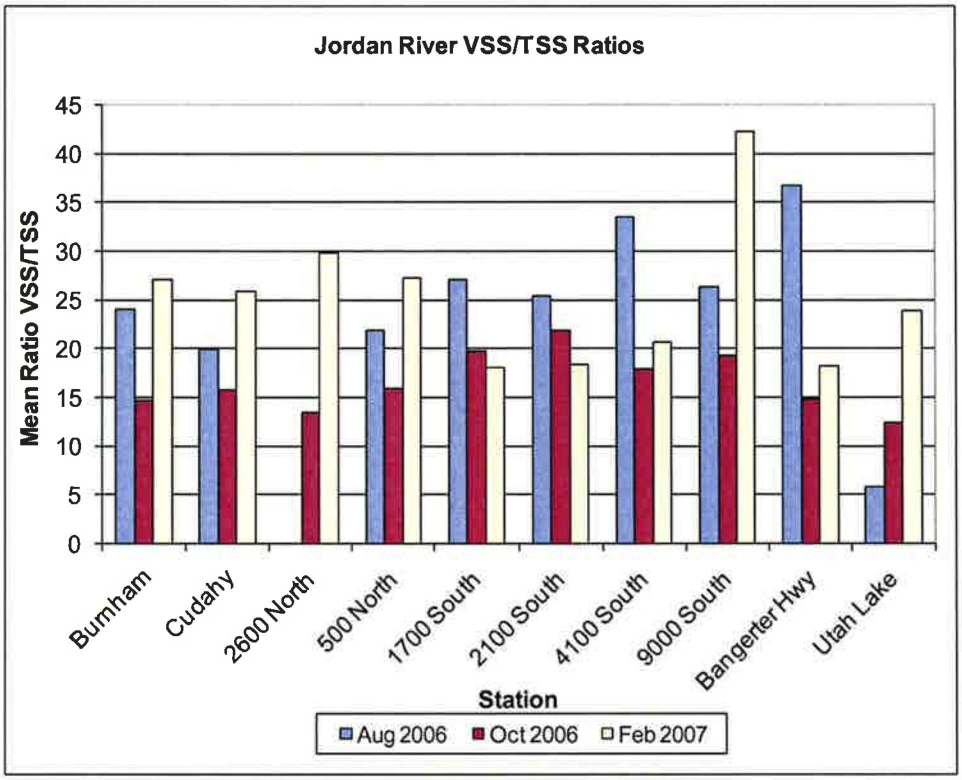


Figure 4.9. Ratio of VSS:TSS measured in the Jordan River.

Some of the organic matter comes from tributaries to the Jordan River. Figure 4.10 shows that Big Cottonwood Creek and Little Cottonwood Creek, both of which enter the Jordan River above 4100 South, carry ratios of VSS/TSS that are similar to the Jordan River. Mill Creek, which enters the Jordan River just above 2100 South, and City Creek, which enters the Jordan River above Cudahy Lane, carry significantly higher ratios of VSS/TSS, but contribute less than 5 percent of the flow to the Jordan River, so probably have little effect on the concentration of organic matter in the main stem of the river. All tributaries were sampled near the point of confluence with the Jordan River.

4.4.2.3 Overall Effect of Aerobic Decomposition on DO

A crude calculation of the effect of BOD 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) from 2100 South to 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.

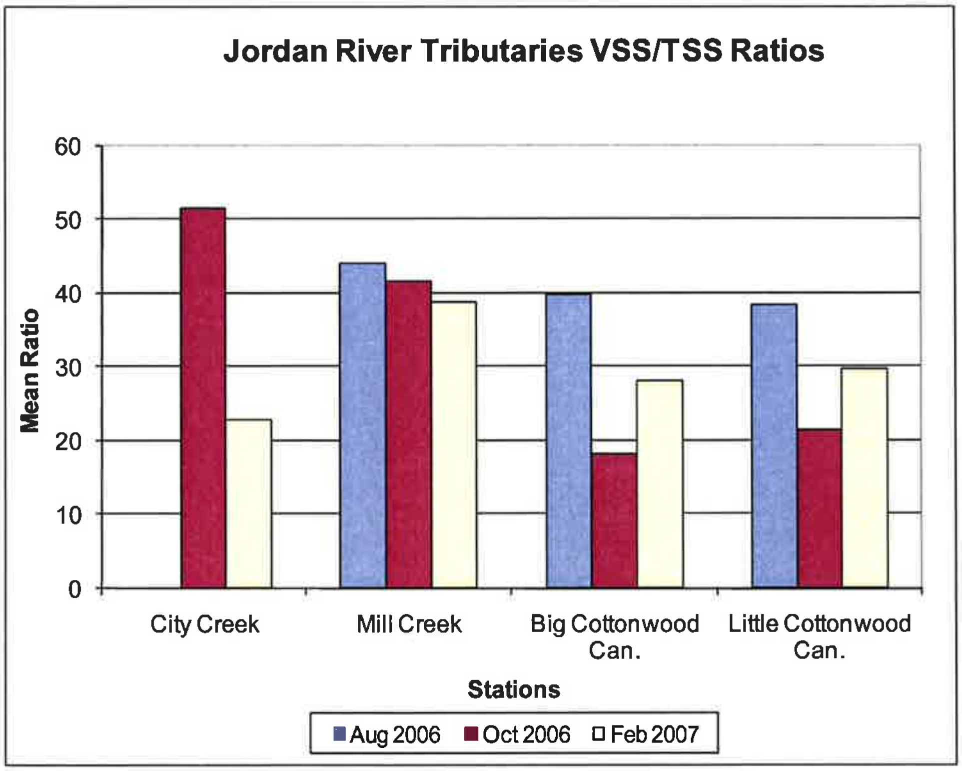


Figure 4.10. Ratio of VSS to TSS measured in Jordan River tributaries.

4.4.3 AEROBIC DECOMPOSITION OF ORGANIC MATTER 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 organic matter and the oxidation of inorganic compounds such as methane and ammonium and is expressed as 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 organic matter to methane and nitrogen to ammonium. As the methane diffuses into the aerobic layer above, some of it is oxidized into carbon dioxide and water. The diffusing ammonium is oxidized into nitrate and water, and then the nitrate combines with some of the methane and is further oxidized to produce nitrogen gas, carbon dioxide, and water (Chapra 1997).

Although benthic aerobic bacteria are much less active in deeper waters with very low DO concentrations (below 1–2 mg/L), and temperatures below 10° C, some authors regard SOD as the major cause of low DO concentrations in slow moving rivers or rivers with high levels of organic matter (Doyle and Lynch 2003). Organic matter 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, particularly those with sediments of coarser sands and gravels, SOD is much greater than the oxygen demand 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 is hard to seal a test chamber on the river bottom to measure DO without disturbing the sediments. As a result, SOD has only recently been measured in the Jordan River. DWQ reported recently at the 2008 Salt Lake Countywide Watershed Symposium on recent work by University of Utah scientists (Goel, 2009, personal communication) that measured SOD in the lower Jordan River of 2.073 $g/m^2/day$ (Arens and Harris 2008). (DWQ monitoring plans include measuring SOD in summer 2009.)

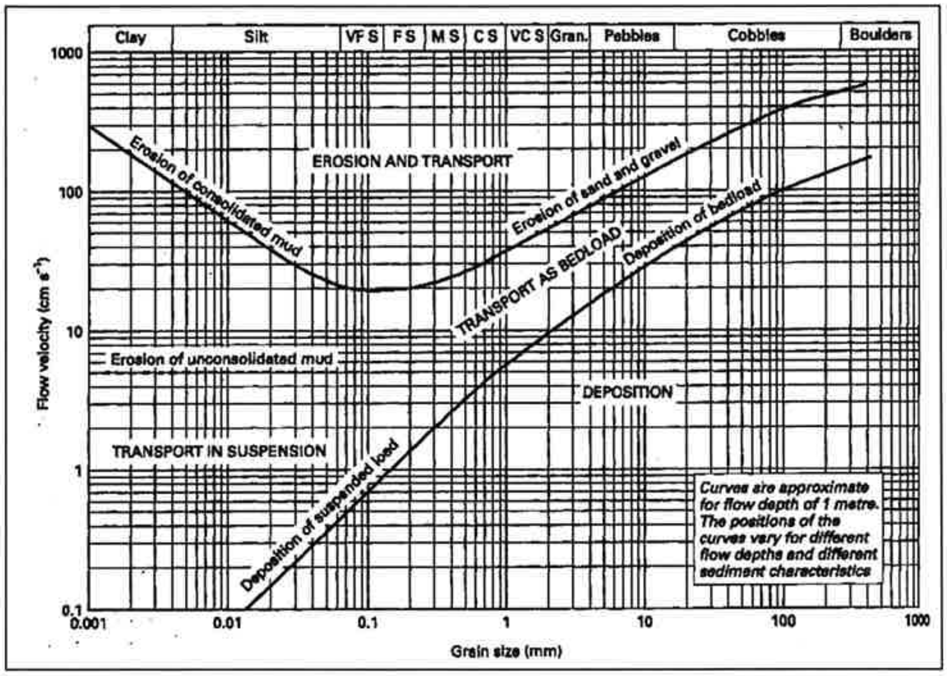
There is other supporting evidence of conditions that would result in a large SOD component contributing to low DO in the lower Jordan River. Settling out of organic matter is suggested by chlorophyll-a and diurnal DO studies that indicate a substantial amount of suspended algae upstream of the lower Jordan River section, and VSS/TSS ratios that demonstrate a substantial source of suspended organic matter even in the middle reaches of the river. The potential for settling of suspended matter is high due to the shallow slope of the river below 2100 South. Moreover, because the Surplus Canal diverts a significant proportion of the total flow at 2100 South, the lower Jordan River slows in velocity, which not only allows greater settling of suspended material but more time for bacteria to decompose suspended organic matter and consume DO. Past researchers have reported that bottom sediments are composed primarily of silts and fine sands that have a higher affinity for organic matter than coarser substrates (Bio-WEST 1987).

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 sq mi watershed (Jordan River watershed approximately 856 sq mi)
- 302,000 population (Salt Lake County 2005 approximately 970,000 (2009))
- 200 cfs summer (lower Jordan River mean monthly flows 190-320 cfs)
- Channel 50 ft wide, slope 1.3 ft/mile (lower Jordan River bottom width 35-45 ft)

SOD in the Tualatin was measured at 0.6-4.4 g/m2/day, with an average of 2.3 g/m2/day, very similar to that measured by Goel. Comparing the physical reaeration rates to these SOD values of approximately 0.8-1.6 mg/L between 2100 South and Cudahy Lane, and 1.7-3.4 mg/L between 2100 South and Burton Dam, finds 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. Figure 4.11 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.



Curves are approximate for flow depth of 1 metre. The positions of the curves vary for different flow depths and different sediment characteristics

Figure 4.11. Hjulstrøm's diagram showing flows necessary to transport different particle sizes.

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. These velocities would be capable of eroding a wide variety of particle sizes, from silts to coarse sands and, once disturbed, transporting particles ranging from clays to small pebbles.

There are, therefore, sources of organic matter, both upstream of, and from algal growth within, the lower Jordan River, some of which 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 increase the SOD in segments further downstream.

4.4.4 NIGHTTIME ALGAL CONSUMPTION OF DO

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

4.4.4.1 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 9 days in June 2006, 3.5 days in August 2006, 22 days in October 2006, and 10 days in February 2007. Table 4.7 shows the months when data was gathered at each site.

Table 4.7. Synoptic monitoring events.

	June 2006		August 2006		October 2006		February 2007	
Station	**Diurnal[1]**	**Wet[1]**	**Diurnal**	**Wet**	**Diurnal**	**Wet**	**Diurnal**	**Wet**
Main stem Jordan River								
Utah Lake	x	No data	x	x	x	x	x	x
Bangerter	x		x	x	x	x	x	x
2600 North						x		x
3900/4100 South[2]	x		x	x	x	x	x	x
2100 South	x		x	x		x	x	x
1700 South			x	x	x	x		x
North Temple						x		x
500 North	x		x	x	x	x	x	x
1800 North	x							
Cudahy	x		x	x	x	x	x	x
9000 South	x		x	x	x	x	x	x
Burnham			x	x	x	x	x	x
Tributaries								
LCC		No data		x		x		x
BCC				x		x		x
Mill Creek				x		x		x
1300 South				x		x		x
City Creek				x				
Wastewater Treatment Plant Discharges								
SVWRF				x				x
CVWRF				x				x
SDWTP				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] 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.

Hourly measurements of DO taken in June, August, and October 2006 and in February–March 2007 are shown in Figures 4.12–4.15 for sites on the lower Jordan River, and in Figures 4.16 and 4.17 for sites on the Upper Jordan River.

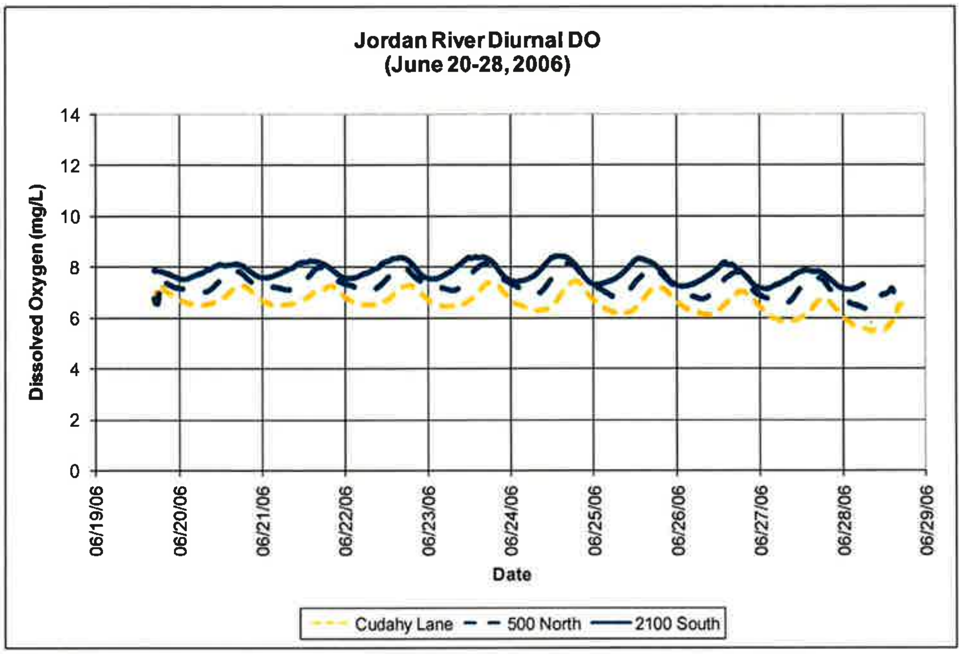


Figure 4.12. Diurnal DO concentrations in the lower Jordan River in June 2006 (dates indicate midnight of day beginning).

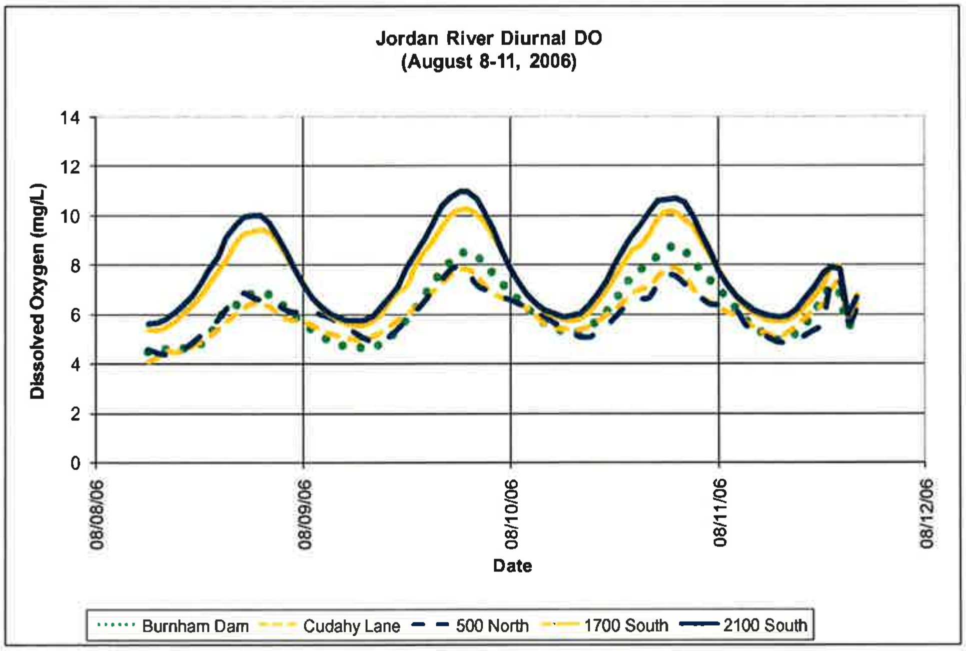


Figure 4.13. Diurnal DO concentrations in the lower Jordan River in August 2006 (dates indicate midnight of day beginning).

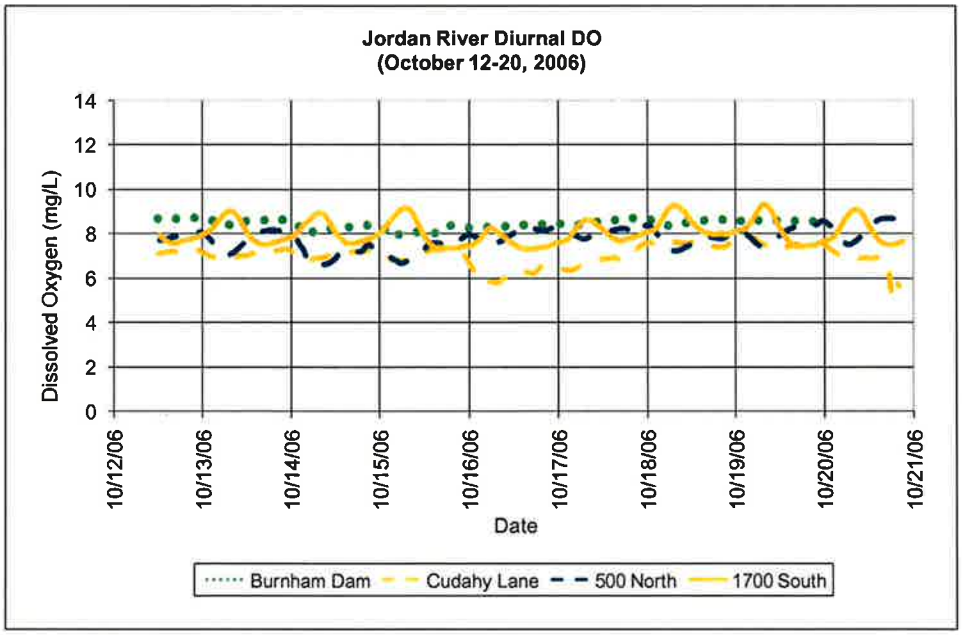


Figure 4.14. Diurnal DO concentrations in the lower Jordan River in October 2006 (dates indicate midnight of day beginning).

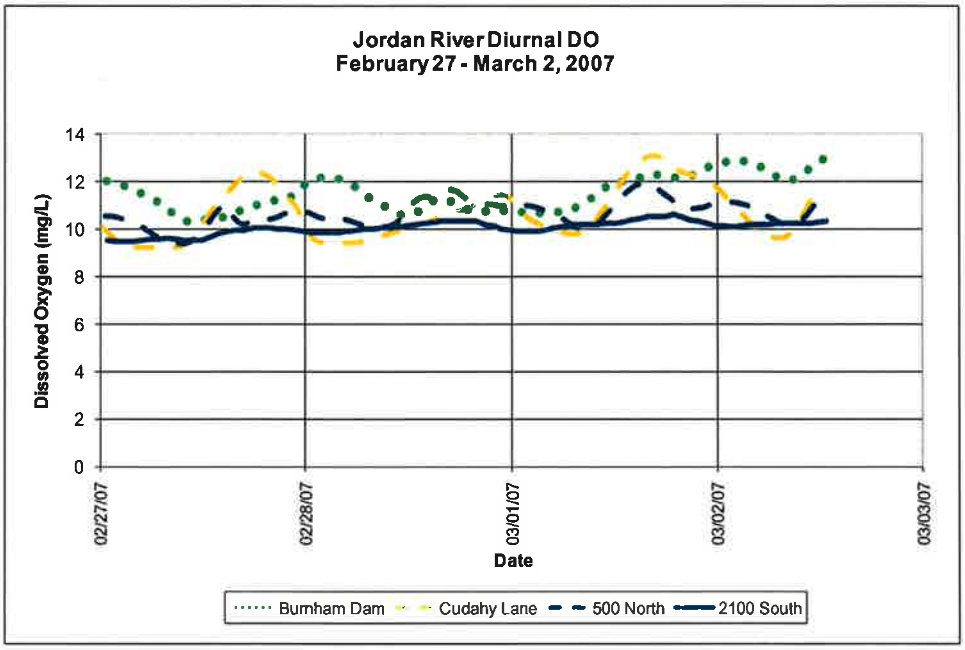


Figure 4.15. Diurnal DO Concentrations in the lower Jordan River in February–March 2007 (dates indicate midnight of day beginning).

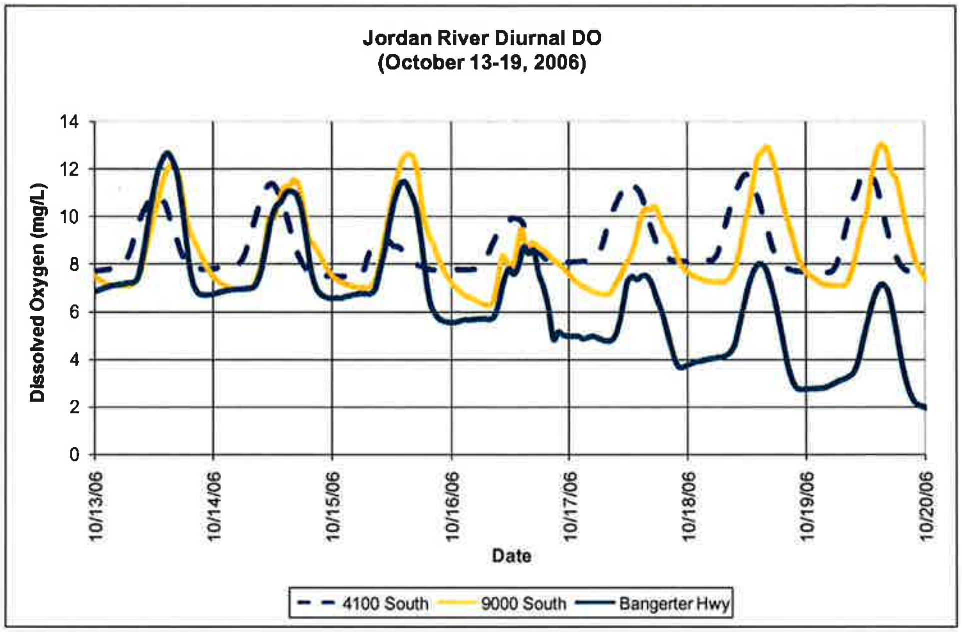


Figure 4.16. Diurnal DO concentrations in the upper Jordan River in October 2006 (dates indicate midnight of day beginning; drift at Bangerter Highway likely a probe malfunction, but still demonstrates a robust diurnal phenomenon).

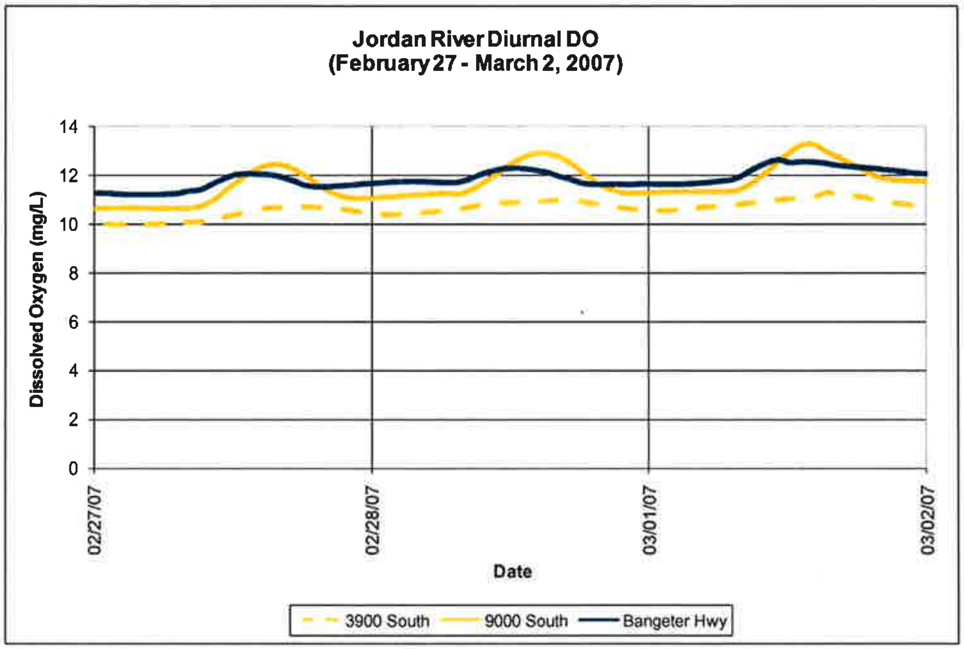


Figure 4.17. Diurnal DO concentrations in the upper Jordan River in February–March 2007 (dates indicate midnight of day beginning).

Diurnal patterns evident in these plots of DO concentrations provide compelling evidence of the effect of phytoplankton in the lower Jordan River (Figures 4.12 and 4.13). 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.

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

There are some interesting differences between upstream and downstream diurnal patterns. Within the lower Jordan River, the magnitude of the diurnal cycles between 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 4.8.

Table 4.8. 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)	Number	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.)

Figures 4.18 and 4.19 show DO and pH for several days in August at 500 North and Cudahy Lane and provide further evidence of algal activity. In each case, pH rises and falls synchronously with DO, consistent with the time when plants are taking up CO_2 from the water during the day - decreasing CO_2 makes water more basic - and using oxygen for respiration, releasing CO_2 at night – increasing CO_2 makes water more acidic. While pH swings provide evidence of photosynthetic activity, the magnitude of pH falls within accepted ranges (6.5–9.0) that protect the aquatic life uses of the Jordan River.

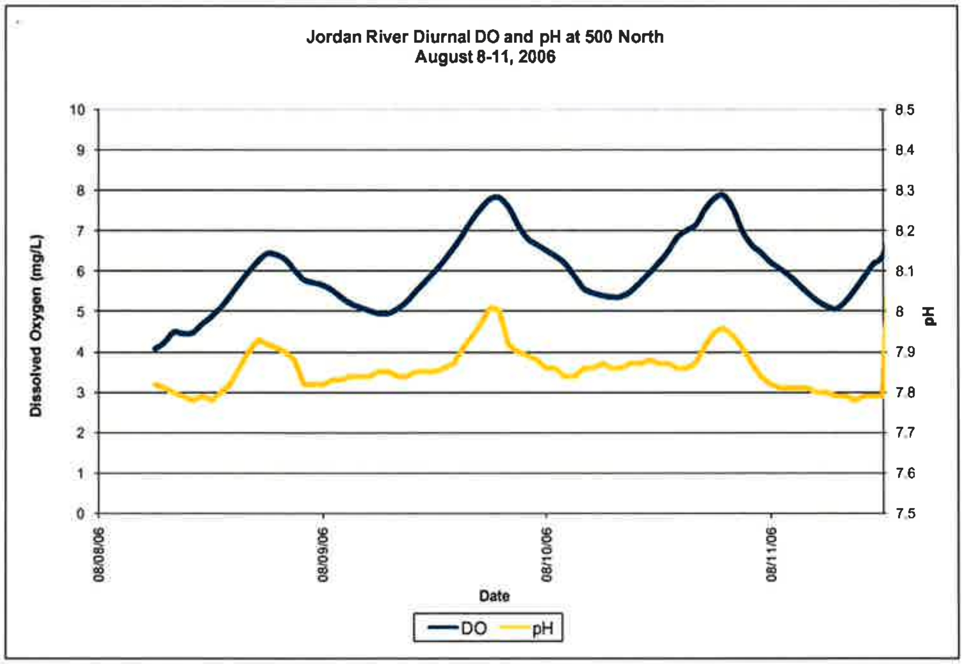


Figure 4.18. DO and pH at 500 North in August 2006.

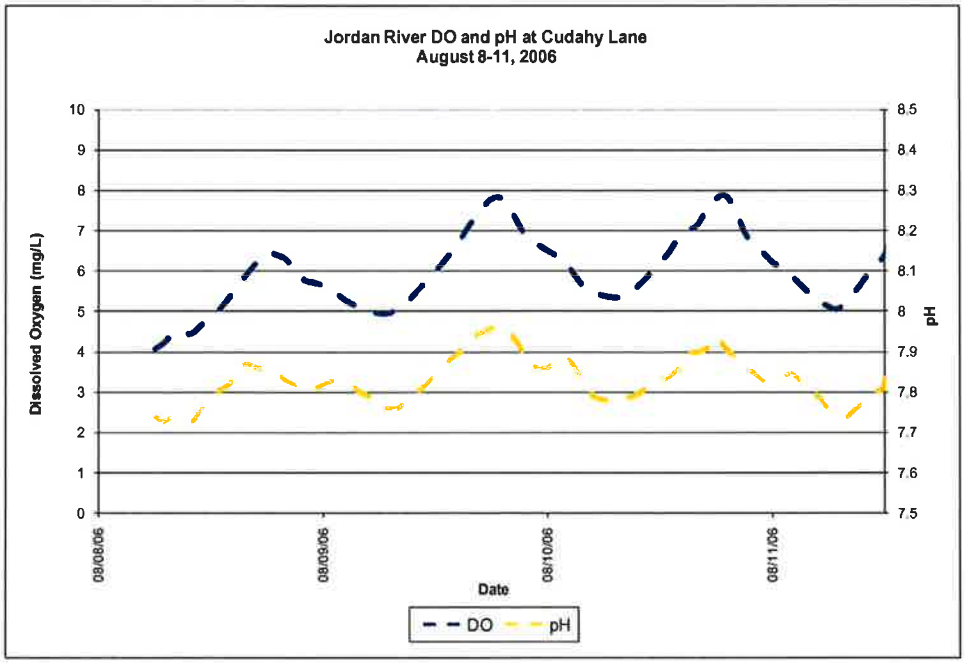


Figure 4.19. DO and pH at Cudahy Lane in August 2006.

4.4.4.2 Estimates of Algal Organic Matter

Fluctuations in diurnal DO concentrations establish that algal growth occurs throughout the Jordan River. Since algae have a relatively short life cycle, substantial portions of these algal populations die and contribute to suspended organic matter 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 are presented in Figure 4.20 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.

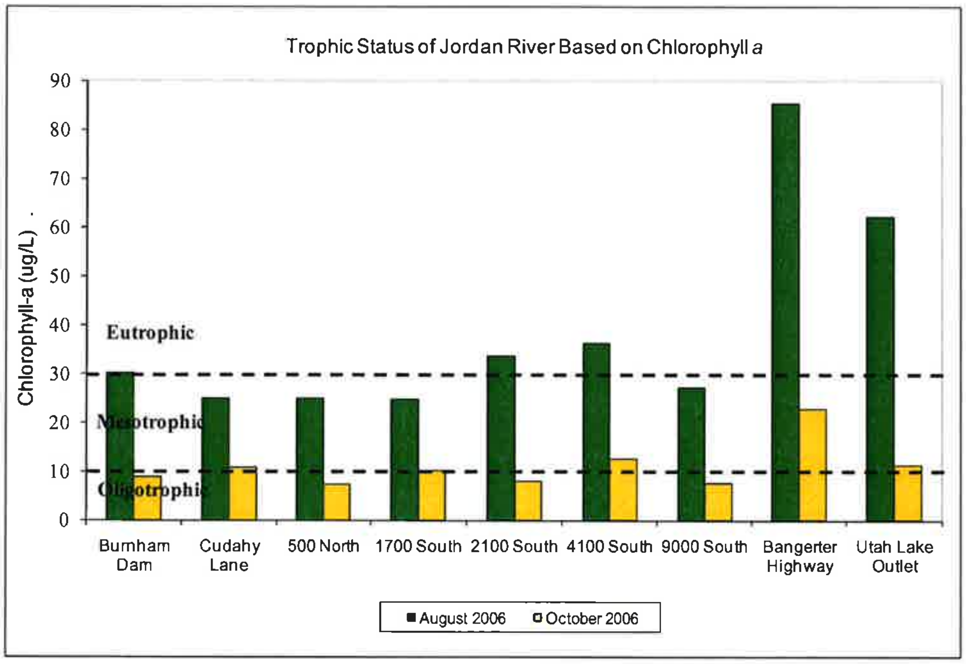


Figure 4.20. Trophic status (Dodds et al. 1998) of Jordan River based on synoptic measurements of Chlorophyll a collected during 2006.

Knowledge of the taxonomic characteristics of algae might also provide important insights. Species that thrive in Utah Lake do not thrive in riverine systems, which may help to account for the patterns of Chlorophyll-a illustrated in the previous section. The algae contributed by Utah

Lake may continue to grow in the segment between Utah Lake and the Narrows because waters are slow moving and similar to conditions in Utah Lake. Below the Narrows, however, the channel and hydraulic conditions change, which may result in a change in algal species. It would then take time for the "new" riverine species to grow.

It is interesting to note that although concentrations of suspended algae do not change dramatically below 2100 South, Figure 4.21 shows that Total P decreases from 2100 South to Cudahy Lane in almost every month. One explanation might be that the algae which continue to grow below 2100 South, consuming P as a nutrient, die and settle to the bottom before reaching Cudahy Lane but are not replaced by new growth because of limitations in other nutrients.

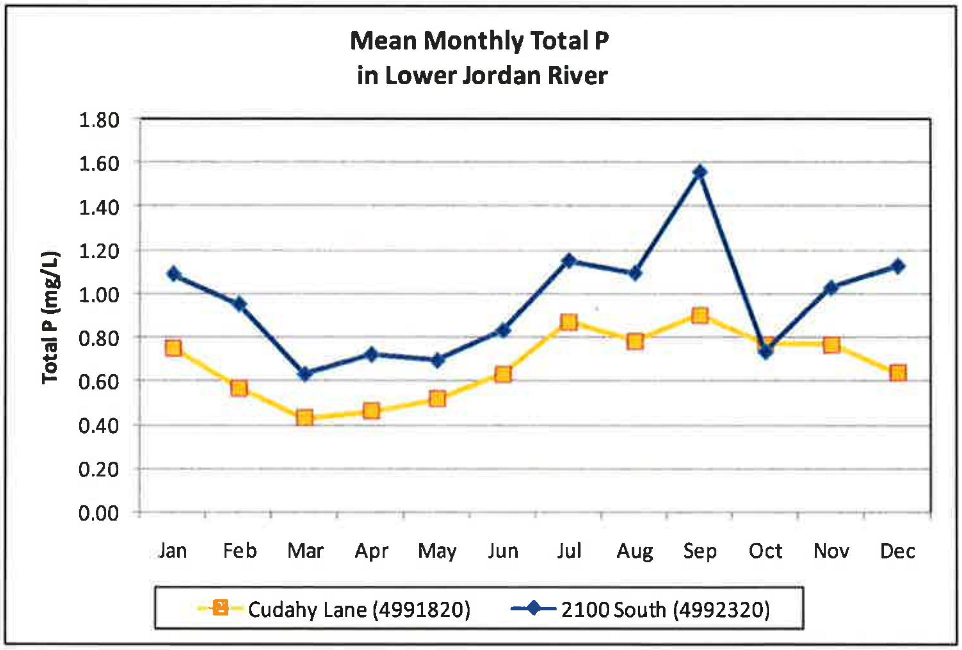


Figure 20. Total P in the lower Jordan River.

4.4.4.3 Limits on Algal Growth

It is possible to estimate Chlorophyll-a based on formulae from researchers (Van Nieuwenhuyse and Jones 1996) cited in U.S. EPA (2000) using Total P:

$$\log Chl = -1.65 + 1.99(\log TP) - 0.28(\log TP)2 \ (r2 = 0.67)$$

Where Chl is summer mean Chlorophyll-a and TP is Total P, both of which are expressed in mg/m^3 (equivalent to µg/L).

Figure 4.22 compares predictions of Chlorophyll-a from long-term Total P concentrations (summarized in Cirrus 2007) with actual measurements. If phosphorus was the limiting nutrient for algae, Chlorophyll-a concentrations should have been several times higher below 5400 South.

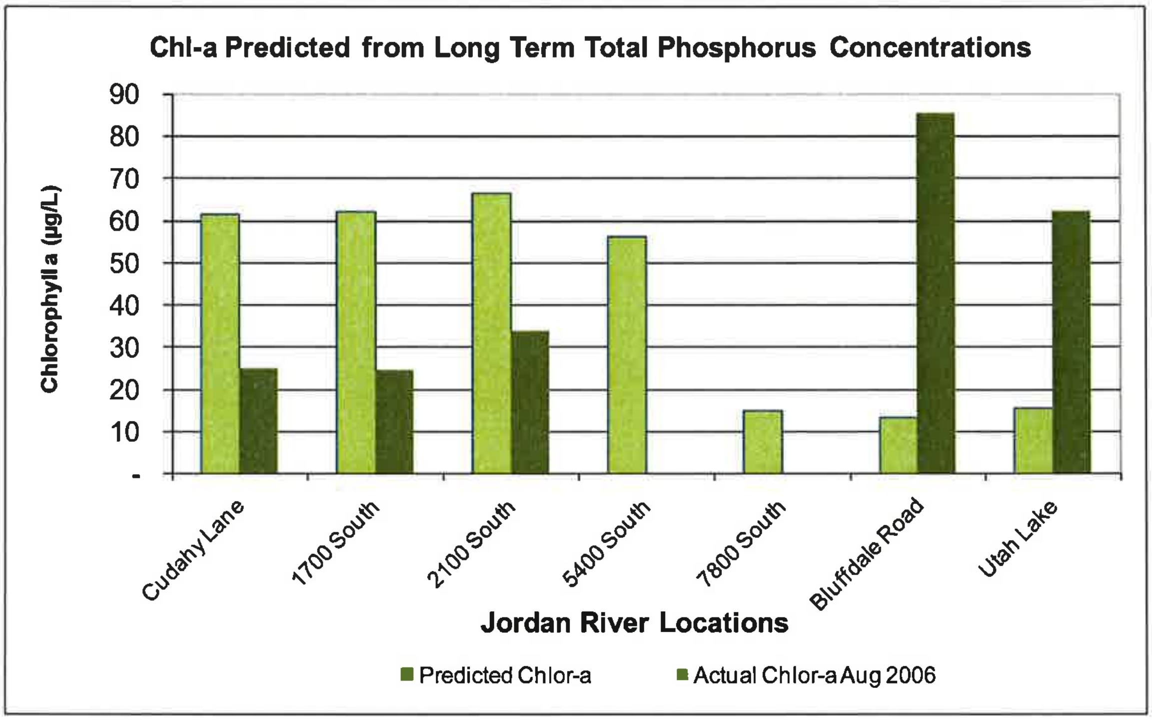


Figure 4.22. Chlorophyll-a predicted from long-term (1995–2005) Total P and observed.

Another 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 between 1978–2005 indicate low N:P ratios. Table 4.9 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 4.9. Average N:P ratios measured from 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

4.5 SUMMARY

The upper segments of the Jordan River constitute the primary “inflow” to the lower Jordan River, defined herein as the section of river below 2100 South. DO levels in the lower Jordan River do not meet water quality standards, as demonstrated in Section 4.2.2. This DO impairment is the result of both physical and biological factors. Available data suggest that warmer summertime water temperatures can account for seasonal reductions in DO. Year-round DO deficits in the lower Jordan River - despite positive reaeration rates of 2-4 mg/L/day (Figure 4.6) - mean that DO levels would meet numeric criteria if biological and inorganic processes weren’t consuming DO faster than it is being replenished. 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.

As illustrated in Figure 4.3, 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 3.0–5.5 mg/L over a five day period (Figure 4.8), 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 organic matter in suspended sediments (Figure 4.9).

SOD is probably also a major factor in low DO rates. Recent preliminary 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 could also consume over half of the DO provided through natural reaeration. Moreover, flows in the Jordan River are probably capable of resuspending much of these organic-rich bottom sediments (Figure 4.11), further contributing to both BOD and downstream SOD, and helping to explain why DO is lower, and DO violations are higher, 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 (Figure 4.13) – but when they die they contribute to the BOD and SOD load. Recommendations for further studies and additional data to better understand DO linkages is organized in Appendix A.

5.0 BENEFICIAL USE ASSESSMENT

The Utah 2008 303(d) List reports on streams and lakes identified as impaired for one or more of their designated beneficial uses due to pollutants that exceed their respective water quality criteria. Impaired waters are identified and prioritized through monitoring and assessment programs conducted by the DWQ. Figure 1.1 displays the impaired segments of the Jordan River, their beneficial uses and causes of impairment.

This Beneficial Use Assessment (BUA) of the Jordan River is intended to determine if water quality, coupled with other physical and biological factors, supports the beneficial uses established for each segment of the Jordan River and if the current chemical, biological and physical data support the 303(d) listings. Table 1.1 describes Utah's beneficial use designation for each class. Table 1.2 illustrates the impaired segments of the Jordan River and their corresponding beneficial use designation.

The following sections first address the beneficial uses for each DWQ Segment, and the various impairments within each of those segments. An assessment of whether it is attainable for each segment to support its designated beneficial use with its impairment will be determined during the final load allocation and implementation stage of the TMDL process. Recommendations for further studies and additional data collection to support a better understanding of Jordan River beneficial uses are included in Appendix A.

While there is a number of water quality impairments associated with different beneficial uses for each river segment, only the parameter of concern for each beneficial use is discussed in this document. For example, while a segment may be impaired for dissolved oxygen, this impairment does not affect a class 2B designation for recreational usage, and is therefore not discussed for that segment. Dissolved oxygen does affect a class 3B designation, and is discussed for that usage instead.

5.1 BENEFICIAL USE: CLASS 2B RECREATION

From Utah Administrative Code R317-2-6, Use Designations.
Class 2 -- Protected for recreational use and aesthetics.
Class 2A -- Protected for primary contact recreation such as swimming.
Class 2B -- Protected for secondary contact recreation such as boating, wading, or similar uses.

The Jordan River corridor currently contains a number of recreational facilities, including trails, parks, and golf courses, used for activities such as hiking, camping, bird watching, and fishing. A survey on attitudes about the Salt Lake County Watershed conducted by Dan Jones and Associates (2007) asked respondents about recreational priorities. The survey found that 10 percent of respondents selected "recreation opportunities" as the most valuable function of the watershed. The most popular recreational activities in the watershed included hiking/walking and camping/picnicking. Over 80 percent of respondents stated that they participate in these activities one to two times per year. Other popular recreational activities were biking and nature or bird watching, in which about half of respondents said they participated (Dan Jones and Associates 2007).

The Jordan River Parkway is envisioned as a paved trail extending the entire length of the river, from Utah Lake to the Great Salt Lake. Substantial portions of it have been completed in recent years through various grants and funding. Over seven miles of paved walking and cycling paths have been built along the Parkway in Salt Lake County, which also features horse trails, parking areas, and pedestrian bridges. There are also six golf courses and numerous parks along the river, including the Utah State Fair Park (Salt Lake County Parks and Recreation 2007). Utah County contains an additional nine miles of Jordan River Parkway trails for bicycling, horseback riding, jogging, and walking. Several parks in Utah County are located on the river, including Inlet, Wetlands, Willow, and Indian Ford parks, and the privately developed Thanksgiving Point (Utah County 2007).

In addition to paved trails, the Jordan River Trail Master Plan has the vision of providing increased public access for boating and recreation on the Jordan River. The goal of the plan is to develop designated launches and portages in protected, safe, locations that are accessible by a variety of boaters with differing skill levels. Boating and swimming are considered recreational options on the Jordan River, but according to those who participated in the initial survey for the Jordan River Trail Master Plan, there is not enough information available for those who want to boat on the Jordan River, but have never done it before.

5.1.1 WATER QUALITY DATA RELATING TO CLASS 2B WATERS

5.1.1.1 E. coli

An assessment based on measured levels of E. coli was performed to determine if a class 2B classification is supportable with the existing water quality data. Total and Fecal Coliform were used by DWQ as class 2B criteria until 2004. In 2005, E. coli replaced Fecal and Total Coliform as the parameter used to assess recreational use of waters of Utah because E. coli is a relatively reliable indicator of the amount of fecal contamination in water, is more closely correlated with swimming-related gastroenteritis, and is generally safe to work with in the lab (DWQ 2005a).

High presence of pathogenic bacteria, including E. coli, can cause illness in humans who come in contact with contaminated waters. E. coli bacteria are generally indicative of human or animal waste sources in a watershed, originating from stormwater outfalls, septic tanks and/or graywater facilities and seepage pits (DWQ 2005b). Ingestion of contaminated water can cause diarrhea, cramps, nausea, headaches, and other symptoms.

Harmful forms of E. coli produce a toxin called Shiga toxin. Bacteria that make this toxin are identified as "Shiga toxin-producing" E. coli, or STEC which commonly reside in the digestive tracts of ruminant animals and are harmful only to humans (CDC 2009a). Symptoms of STEC infection include stomach cramps, diarrhea, vomiting and mild fever. Most cases recover within 5–7 days although some cases are severe. Severe STEC infection can result in permanent damage to kidneys or other vital organs and even death. People of any age can be infected, although young children, pregnant women, older adults, and individuals with compromised immune systems are more susceptible.

Other pathogenic diseases transmitted through water contaminated by fecal material include giardia, cryptosporidium, and toxoplasmosis. Symptoms can include stomach cramps, nausea, fever, weight loss, and dehydration. Severe toxoplasmosis can result in damage to the brain, eyes, or other organs, and can cross the placental barrier to cause birth defects or symptoms later in life (CDC 2009b).

Since the Jordan River is classified as class 2B for secondary contact recreation, ingestion of river water is less likely, although incidental or accidental ingestion of river water is possible during activities such as boating and fishing.

5.1.1.2. E. coli Data

The E. coli sample maximum standard is 940 colonies/100 ml and a 30-day geometric mean standard of 206 colonies/100 ml for a minimum of five samples collected within a 30-day period. The 2008 303(d) List shows that DWQ Segments 2, 3, and 5 as non-supporting of the class 2B beneficial use due to E. coli.

All available monitoring data that met the minimum sampling requirements for a 30-day period was collected in June and July of 2004 from monitoring stations located between Cudahy Lane upstream to the Bluffdale Road crossing. Table 5.1 shows the sampling locations and DWQ Segments where measurements exceeded the standard according to the water quality data from the 303(d) List. A numeric percentage is included to indicate how significantly each location exceeds the allowable standard. The geometric mean for E. coli exceeded the criterion in DWQ Segments 1, 3 and 4, and the sample maximum criterion was exceeded in DWQ Segments 1 to 4. The geometric mean standard was exceeded 100 percent of the time at Cudahy Lane, North Temple, and 1300 South. The maximum standard was exceeded 11 to 22 percent of the time in DWQ Segments 1 to 4.

5.1.1.3. High E.Coli Implications

The 2008 303(d) List assigns non-support of the E. coli standard if water quality fails to meet either criterion. DWQ Segments 1 and 4 were not included on the 303(d) List for E. coli, but both experienced exceedances of both criteria, meeting the requirements for listing as impaired. Although no E. coli samples were collected from DWQ Segment 5, the monitoring station at 5400 South is located near the boundary between DWQ Segments 4 and 5 and represents upstream conditions in the 1.7 miles that comprise all of DWQ Segment 5. The monitoring data reviewed in this assessment concur with segments included on the 2008 303(d) List. Based on the available measurements of E. coli, DWQ Segments 6 – 8 are supporting the assigned beneficial use classification for recreational use, but DWQ Segments 1 – 5 are not supporting their designated beneficial use.

Table 5.1. Assessment of E. coli samples collected during 2004 including percent of samples in violation of numeric criterion.

Monitoring Station	DWQ Segment	30-day Sample Maximum Criterion	30-day Geometric Mean Criterion	n	% Exceed Sample Max Criterion	Range of 30-day Geometric Means	% Exceed Geo. Mean Criterion
Cudahy Lane - 4991820	1	940	206	9	22	290–359	100
Redwood Road - 4991860	2	940	206	9	22	10–113	0
North Temple - 4991910	3	940	206	9	11	290– 64	100
400 South - 4991940	3	940	206	9	11	170– 80	60
700 South - 4992030	3	940	206	9	11	86–458	60
1300 South - 4992270	3	940	206	9	11	270–365	100
2100 South - 4992320	4	940	206	9	11	64–355	60
5400 South - 4994090	4	940	206	9	11	71–150	0
Bluffdale Road - 4994600	7	940	206	9	0	25–128	0

Results shown in this table are based on minimum requirements for sample size within a 30-day period.

5.1.2. PHYSICAL FACTORS RELATING TO CLASS 2B WATERS

While physical factors are not considered in the assessment of recreational beneficial use support they are an important component in the public's perception and use of the river and are briefly discussed below.

The floodplain of the Jordan River has been profoundly altered in several locations along its length. Channelization and altered flow levels have affected the recreational use of the river. Straightening and channelization of the Jordan River has increased bank erosion and undercutting, creating safety hazards for people who approach the edge of the river to fish, wade or launch boats (Jensen 1996). Peak flows present safety problems at trail underpasses, forcing closure of trail sections (Salt Lake County Parks and Recreation 2007). These high flows are associated with the snow melt and occur in May and June (CH2M Hill 1992). The flows are lowest in October, at the end of the irrigation season. Besides snow melt and irrigation, flow in the Jordan is also dependent on the levels of Utah Lake. Figure 5.1 shows outflow from Utah Lake 1950 – 2006 (DWRi 2007).

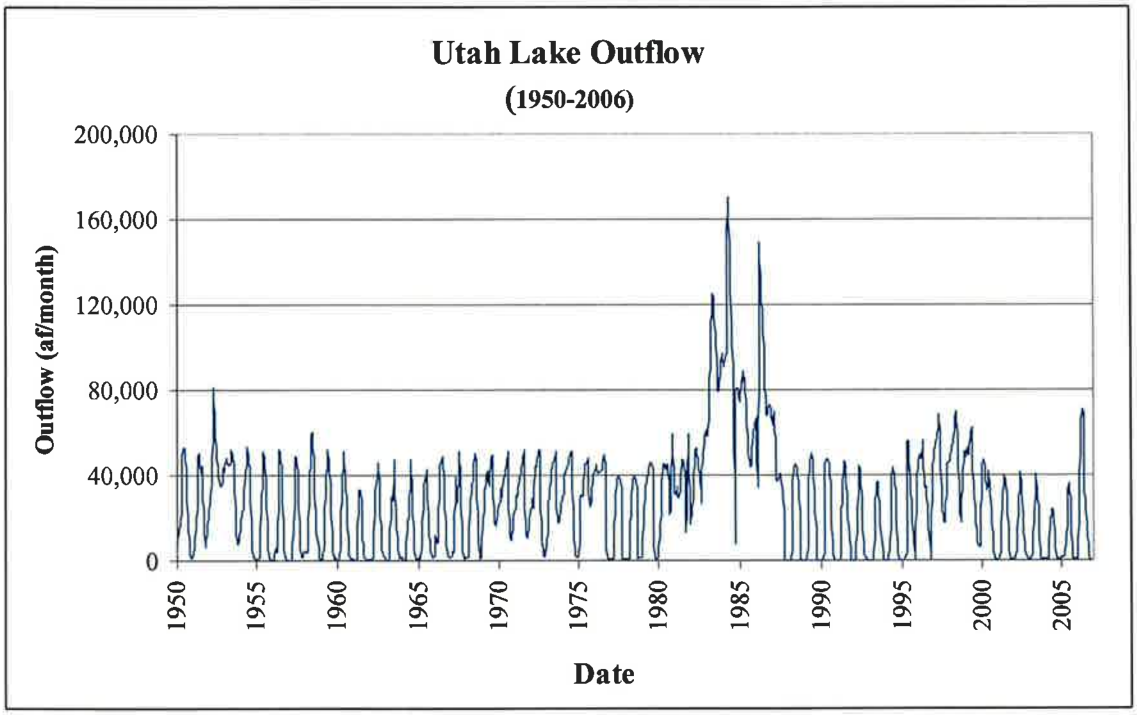


Figure 5.1. Calculated outflow from Utah Lake based on data provided by Jordan River Commission (DWRi 2007).

Illegal dumping and discharges of dredged and fill material have added to these impacts on river ecology and aesthetics to further impair recreational uses of the Jordan River corridor (Jensen 1995). The Jordan River Shared Use Area Management Plan (2002) states that the river contained large amounts of trash within the northern section of the parkway, between the 1800 North Redwood Road bridge and the I-215 bridge. Garbage often enters the river through storm drains from city streets and forms floating mats of refuse, clogging the channel. Over 300 shopping carts have been pulled out of the river since 2000 (Vellasenor 2006). This waste in and along the river, and particularly in the vicinity of recreation sites, creates the impression that the corridor is a dumping ground which deters visitors and impairs recreational usage.

5.1.3 SUMMARY – CLASS 2 RECREATION

Water quality data on E. coli substantiates the "non-supporting" designation for 2B beneficial uses in the 2008 303(d) listing for DWQ Segments 2, 3, and 5 as not supporting the 2B beneficial use is accurate. The data also indicates DWQ Segment 1 and 4 exceed the established criteria for secondary contact recreation as well.

This water quality impairment in itself is likely not a significant constraint on recreational use of the Jordan River, but it is one of several basic factors that diminish the overall appeal of the river and its corridor. These include physical changes to the natural setting (e.g., channelization of the river and deposition of trash and other waste material). Other changes, specifically high flow volumes, channelization, and bank erosion, affect the safety of recreationists in some locations.

Collectively, these changes decrease the appeal of the river and corridor to recreationists and thus limit progress toward achieving the river's recreational potential. Some of these constraints are associated with water quality but most are not. The Class 2B designation remains appropriate, though impairment in terms of water quality and physical factors exists.

5.2 BENEFICIAL USE: CLASS 3A AND 3B AQUATIC WILDLIFE

From Utah Administrative Code R317-2-6, Use Designations.
Class 3 -- Protected for use by aquatic wildlife.
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.

DO and temperature are the relevant water quality parameters associated with the Class 3 aquatic wildlife beneficial use. Fish and the biota on which they depend require appropriate oxygen and temperature conditions to thrive. These requirements vary by species, but cold-water game fish generally have more stringent requirements than warm-water and non-game species. State of Utah water quality standards and impairments discussed in this analysis are shown in Table 1.1.

5.2.1 WATER QUALITY DATA RELATING TO CLASS 3A AND 3B WATERS

5.2.1.1 Class 3A: High Temperature

The Utah DWQ has identified DWQ Segments 5, 6, and 7 as impaired for the Class 3A beneficial use due to high water temperatures. Aquatic organisms have limited temperature ranges within which they can exist. Increasing temperatures are generally associated with a loss of biodiversity in aquatic systems. As temperatures move beyond those ideal ranges, organisms are subject to increased disease and mortality.

One source of stress is related to available DO. Colder water has a higher solubility for oxygen than warmer water. Reaeration occurs as oxygen is absorbed from the atmosphere into the water column and can only occur if the water is not already saturated. Warmer waters also reduce the rate at which reaeration occurs.

Unnaturally high in-stream temperatures can result from both natural and human activities. For example, decreased riparian vegetation reduces shading and increases temperature; artificial impervious surfaces such as parking lots collect solar radiation and warm surface runoff, leading to increased temperatures when the runoff reaches the stream.

5.2.1.1.1 Temperature Data

The number of monitoring stations is limited for the temperature-impaired DWQ Segments. No monitoring stations are located on DWQ Segment 6 although stations are located above and below this segment. The 7800 South and Bluffdale Road stations are located at the boundaries of DWQ Segments 5/6 and 6/7, respectively. Another station is located in the Narrows, in DWQ Segment 8 just above Segment 7. Table 5.2 shows mean temperatures and percent exceedances for their assigned temperature standard for four stations that bound these impaired segments. Based on the closest available monitoring station, these data indicate percent exceedances for DWQ Segments 5, 6, and 7 of 12.2 percent, 7.9 percent, and 16.7 percent, respectively. DWQ Segment 8 is not impaired, in part because the temperature standard is higher.

Table 5.2. Percent of temperature measurements exceeding criteria in DWQ Segments 5, 6, 7, and 8 that are considered to be impaired due to high temperature levels, 1980–2005.

	5400 South (Upper portion of DWQ Segment 4)	**7800 South (DWQ Segment 5/6 boundary)**	**Bluffdale Road (DWQ Segment 6/7 boundary)**	**Narrows (DWQ Segment 8)**
Temperature Criteria	20°C	20°C	20°C	27°C
Mean (°C)	14.1	12.3	12.1	11.9
n	98	151	257	97
Exceedance (%)	12.2%	7.9%	16.7%	0.0%

Note: 7800 South and Bluffdale Road are located on the downstream and upstream boundary of DWQ Segment 6, respectively.

Figure 5.2 shows monthly average temperatures for these four stations and the temperature criteria. Compared to the lower stations, water temperatures in the Narrows are warmer in summer and colder in winter. This may be due to the stabilizing influence on temperature of higher groundwater flows just below Turner Dam where DWQ Segment 7 begins.

Figure 5.3 shows all of the data values for these four stations from 1980–2005. The large percentage of temperatures exceeding the 20°C criterion at Bluffdale, 7800 South, and 5400 South is apparent, as is the substantial cooling in temperatures from the Narrows to Bluffdale during June and July. No values exceeded the higher 27°C standard at the Narrows.

Diurnal temperature data was collected in June, August, and October of 2006, and February of 2007 in impaired DWQ Segments 5 and 6 (Figure 5.4 and Figure 5.5, respectively). The number of hours per day that the 20°C 3A standard was exceeded varied from 0 hours to 17 hours in impaired DWQ Segments 5 and 6 (no diurnal data exists for impaired DWQ Segment 7). At 7800 South (DWQ Segment 5), the temperature standard was exceeded an average of 10 hours per day in June (no data exists for August, October, or February). At 9000 South (DWQ Segment 6), the temperature standard was exceeded in both June and August. It was not exceeded in October or February.

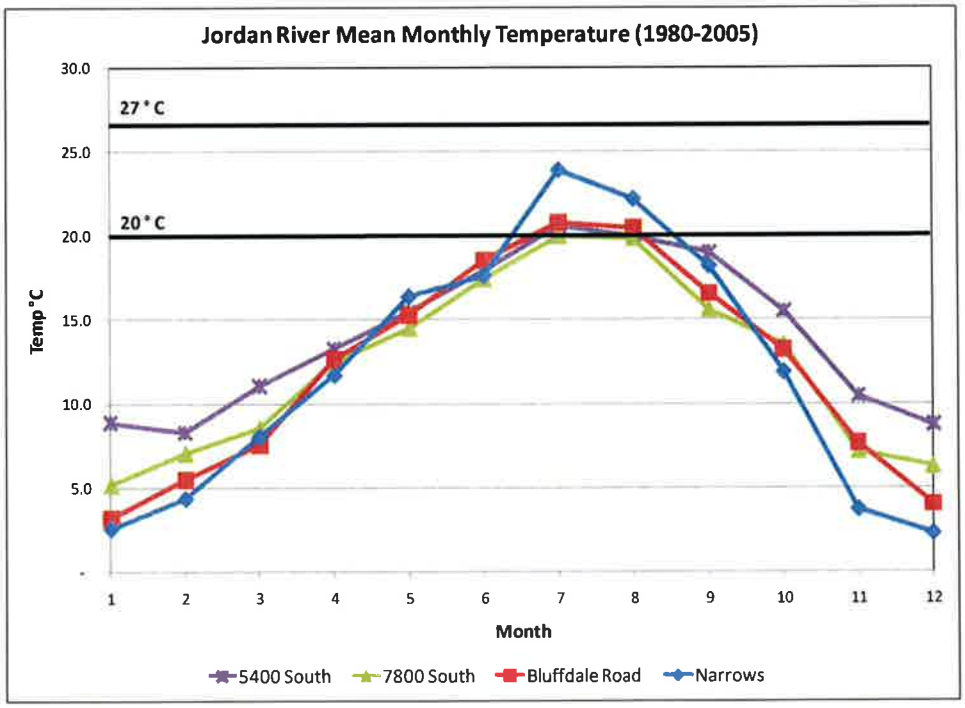


Figure 5.2. Monthly average water temperatures in the upper Jordan River.

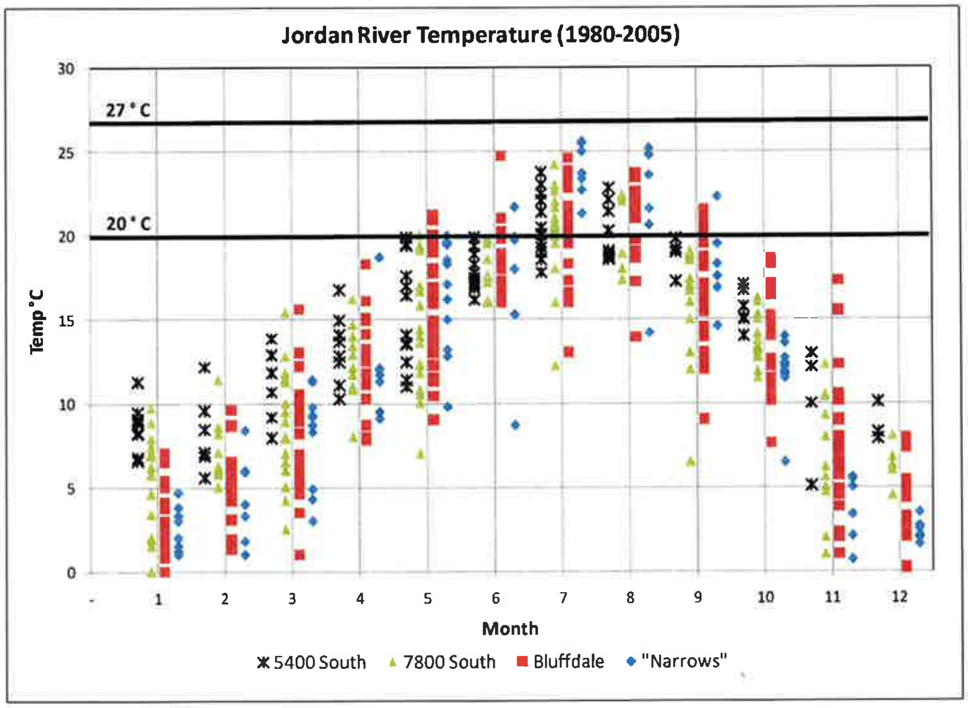


Figure 5.3. Water temperature distributions at stations bounding DWQ Segments 5, 6, and 7 in the upper Jordan River.

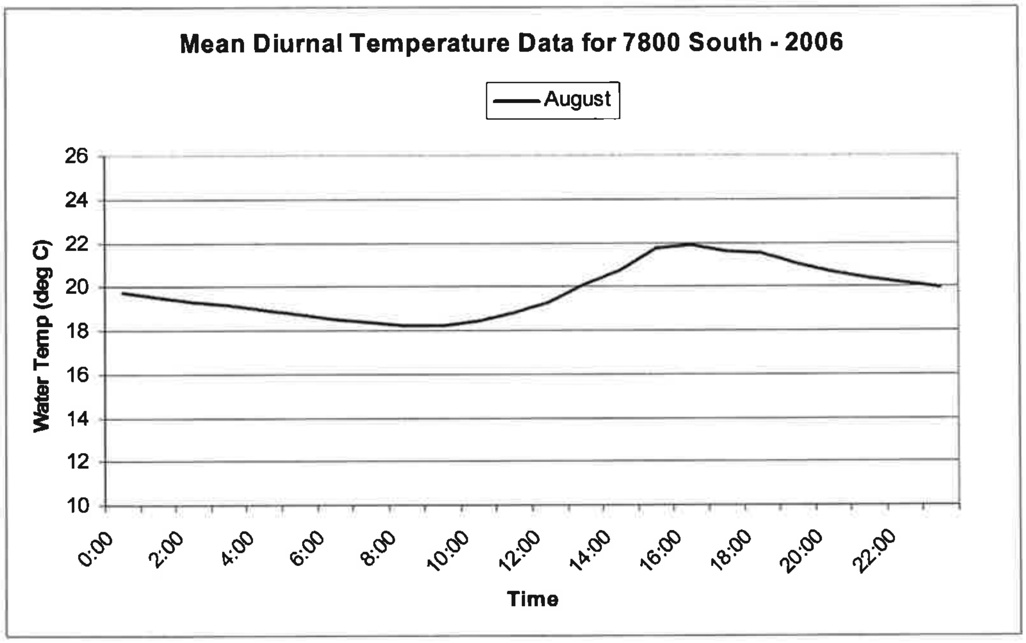


Figure 5.4. Mean diurnal temperature data for 7800 South, collected in 2006.

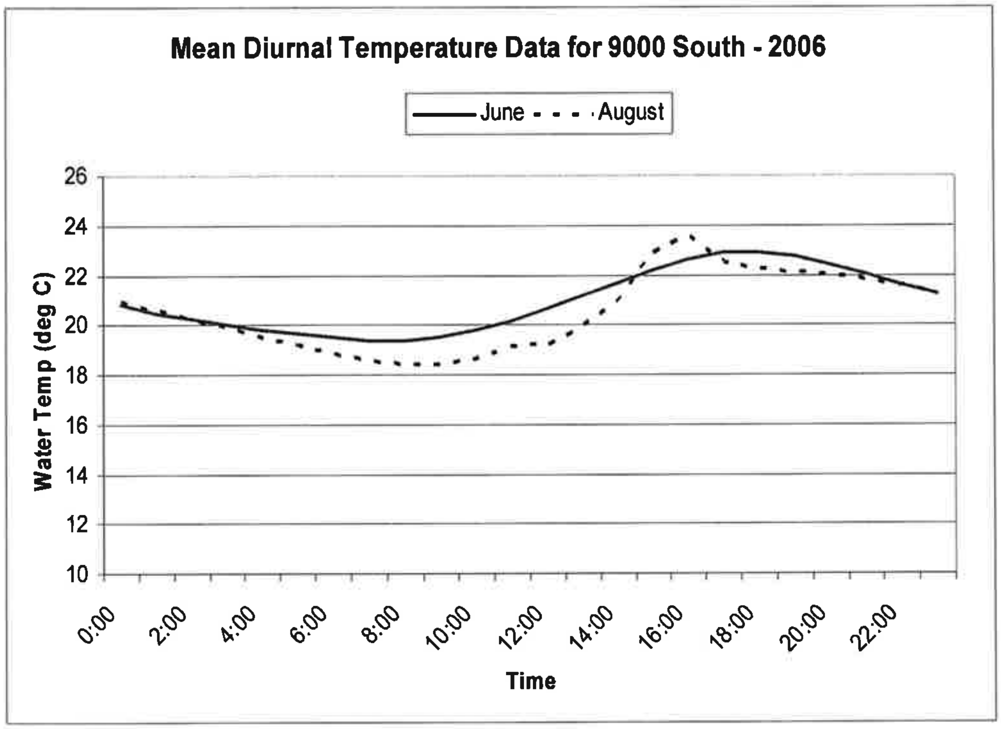


Figure 5.5. Mean diurnal temperature data for 9000 South, collected in 2006.

5.2.1.1.2 High Temperature Implications

Warm water species, in addition to being more tolerant of warmer temperatures, have different physical habitat requirements than cold water species. Many warm water species are more tolerant of low structure, fine substrate, and less riparian vegetation. Cold water species generally require meandering stream channels with well defined pools and riffle sections, sufficient vegetation to provide the shade necessary to keep water temperatures cooler and an assortment of stream bed materials, including sand, gravel and cobble (Community Stream Steward Program 2008).

Fish species vary in their tolerance of high temperatures. For the segments designated as protected for cold water aquatic wildlife (3A), cutthroat and rainbow trout are the most temperature-sensitive, with optimum temperature ranges for adult fish of about 12° to 15°C and 12° to 18°C, respectively (Table 5.3). Brown trout have a somewhat higher optimum range (18.3° to 22.2°C). Therefore, water temperatures above 20°C in these segments pose fairly severe constraints on the potential of a cutthroat trout population, although in DWQ Segments 5 and 6, the data indicates that most of the daily temperatures are close enough to meeting the requirements of adult rainbows populations at some level and are within the optimum range for brown trout adults.

The 27°C temperature standard is above the optimum range for warm water species such as walleye, white bass, and yellow perch. These species are also generally more tolerant of other water quality impairments, such as low oxygen conditions, but high temperatures may adversely affect their reproduction (Bartenhagen et al. 2008). Optimum temperatures for spawning are considerably lower than for adult fish, making a fishery dependent on natural reproduction less likely to succeed than a fishery based on stocking of hatchery-raised fish.

Table 5.3. Summary of habitat needs of Jordan River fish.

Species	Optimum Temperatures (deg C) Egg	Adult	Spawning	DO Requirements (mg/L)*	Habitat Type	Diet	Spawning Season	Substrate
Black Bullhead	22.2 to 23.9	21–24	18.9–22.2	Optimum > 7, Lethal <3 (summer), 0.3 (winter)	50–80% of total stream area with low velocity pools or backwaters and also riffle-run areas.	Omnivores, mainly crustaceans	Late spring–summer	Silt
Black Crappie	16.7	23.9–30.6	14.4–17.8	Optimum >5, Lethal <1.4	Large, warm, clear lakes and ponds.	Adults eat fish and insects, young eat plankton and insect larvae	Early spring	Sandy to muddy
Bluegill	20.0	15–25	19.4–20.0	Optimum >5, Lethal <1	Weedy, shallow, clear, warm water.	Adults eat insects, small fishes, frogs, crayfish, and snails; young eat plankton	Spring	Sand or gravel
Brown Trout	6.6–12.8	18.3–22.2	7.2–10.0	Optimum >9, Lethal <3	Clear, cool to cold water with 50–70% pool to 30–50% run-riffle habitat, and areas with slow deep water, often in the fertile downstream region.	Adults carnivorous, young eat plankton and insects	Late fall	Silt-free, rocky
Common Carp		18–27	14.4–19.4	Optimum >6, Lethal <0.5	Wide range, from large lakes, rivers, and reservoirs to small farm ponds.	Invertebrates, mainly insects	Spring	
Channel Catfish	26.7	High 20's to low 30's	21.7–23.9	Optimum >7, Lethal <1	Warm waters of deep pools and backwaters of rivers and lakes.	Adults carnivorous, young eat plankton and insects	Spring–early summer	Boulders, gravel, sand

Table 5.3. (cont'd) Summary of habitat needs of Jordan River fish.

Species	Optimum Temperatures (deg C)			DO Requirements (mg/L)*	Habitat Type	Diet	Spawning Season	Substrate
	Egg	Adult	Spawning					
Cutthroat Trout	10.0	12–15	5.5–8.9	Optimum >9	Clear, cold lakes and streams.	Adults carnivorous, young eat plankton and insects	Early spring	Silt-free, rocky
Fathead Minnow	25		17.7		Sluggish streams, lakes, bogs, and ponds.	Algae, plankton, insect larvae	Spring	
Green Sunfish	23.3	18–32	18.9–27.7	Optimum >5, Lethal <1.5	Small, warm, streams, ponds, and shallow areas of lakes.	Insects, mollusks, and small fish	Spring	
Largemouth Bass	16.7–18.3	26.7	14.4–15.0	Optimum >8, Lethal <1	Small, shallow lakes and ponds and large, slow rivers.	Adults eat fish and small mammals; young eat plankton, insects, and fish	Spring	
Longnose Dace	15.6	11.7–21.1	>11.7		Swift-flowing, steep gradient, headwater streams.	Aquatic insect larvae, invertebrates	Spring	Boulder-strewn, with gravel and rock beds
Mountain Sucker		12.8–21.1	10	1–2	Cold, clear riffles of streams and rivers.	Periphyton, plants, invertebrates	Spring	Gravel, rubble, sand, or boulders
Rainbow Trout	>5.6	12–18	10	Optimum >9, Lethal <3	Clear, cold lakes and streams with 1:1 pool:riffle ratio.	Fish, invertebrates, algae, vascular plants	Early spring	Silt-free rocky substrate
Smallmouth Bass	23.9	20.0–26.1	16.1–18.3	Optimum >6, Lethal <1	Medium to large lakes and streams.	Fish, crayfish, insects	Late spring-early summer	Rocky or sandy, silt-free

Table 5.3. (cont'd) Summary of habitat needs of Jordan River fish.

Species	Optimum Temperatures (deg C) Egg	Adult	Spawning	DO Requirements (mg/L)*	Habitat Type	Diet	Spawning Season	Substrate
Utah Chub	19.6	Wide range	11–20		They prosper in such diverse habitats as irrigation ditches, reservoirs, ponds, sloughs, creeks, large rivers, and large lakes.	Omnivores	Late spring–summer	Clay, mud, sand, gravel, peat, rubble, or marl.
Utah Sucker		Wide range	15.5	1–2	Wide range of habitats from large, deep, cold lakes to shallow warm lakes to small warm streams.	Omnivores, especially algae	Spring	Mud, clay, sand, and gravel bottom
Walleye	13.9	20.6–23.2	3.3–6.7	Optimum >5, Lethal <1	Cool, mesotrophic waters of rivers and lakes.	Adults eat fish and invertebrates, young eat plankton and insects	Early spring	Clean, rocky
White Bass	16.7	Wide range	14.4–18.9	Optimum >5, Lethal <2	Warm waters of larger rivers, lakes, and reservoirs.	Fish, insects, crustaceans	Spring	Sand, gravel, rubble.
Yellow Perch	10.0–16.7	17.6–25.0	6.7–11.1	Optimum >5, Lethal <3	Large lakes and reservoirs or quiet rivers.	Insects, invertebrates, fish	Early spring	Wide range

*The term "optimum" can be misleading, as some species can survive DO levels well below their optimum, while others are more sensitive. When considered with the lethal limit, this information provides an indication of the relative ranges of requirements across species.

Sources: Petrovsky and Magnuson 1973, Eklov et al. 1999, Matthews and Berg 1997, Stuber et al. 1982a, Edwards et al. 1983, Edwards and Twomey 1982, Hickman and Raleigh 1982, Stuber et al. 1982b, McMahon et al. 1984, Hamilton and Nelson 1984, Edwards et al. 1982, Sigler and Sigler 1996, Krieger et al. 1983.

5.2.1.2 Class 3A and 3B: Low Dissolved Oxygen

Relative to 3B criteria, the Utah DWQ has identified DWQ Segments 1 – 3 as impaired for low DO concentrations. State of Utah water quality standards and impairments discussed in this analysis are shown in Table 1.1.

DO concentrations in the Jordan River increase with distance downstream from the Utah Lake outlet to DWQ Segment 5 at 7800 South. Concentrations then begin to decline through DWQ Segment 3 at North Temple, increasing again through DWQ Segments 2 and 1 (Figure 5.6). The percentages of samples violating the chronic class 3B criterion during the 2004 to 2005 intensive monitoring were: DWQ Segment 1 (39 percent of samples), DWQ Segment 2 (33 percent), DWQ Segment 3 (50 to 87 percent), DWQ Segment 4 (33 percent), and DWQ Segment 7 (30 percent). (Note that 36 percent of samples at the Utah Lake outlet also violated the criterion, but that station was not considered representative of DWQ Segment 8 given its location.)

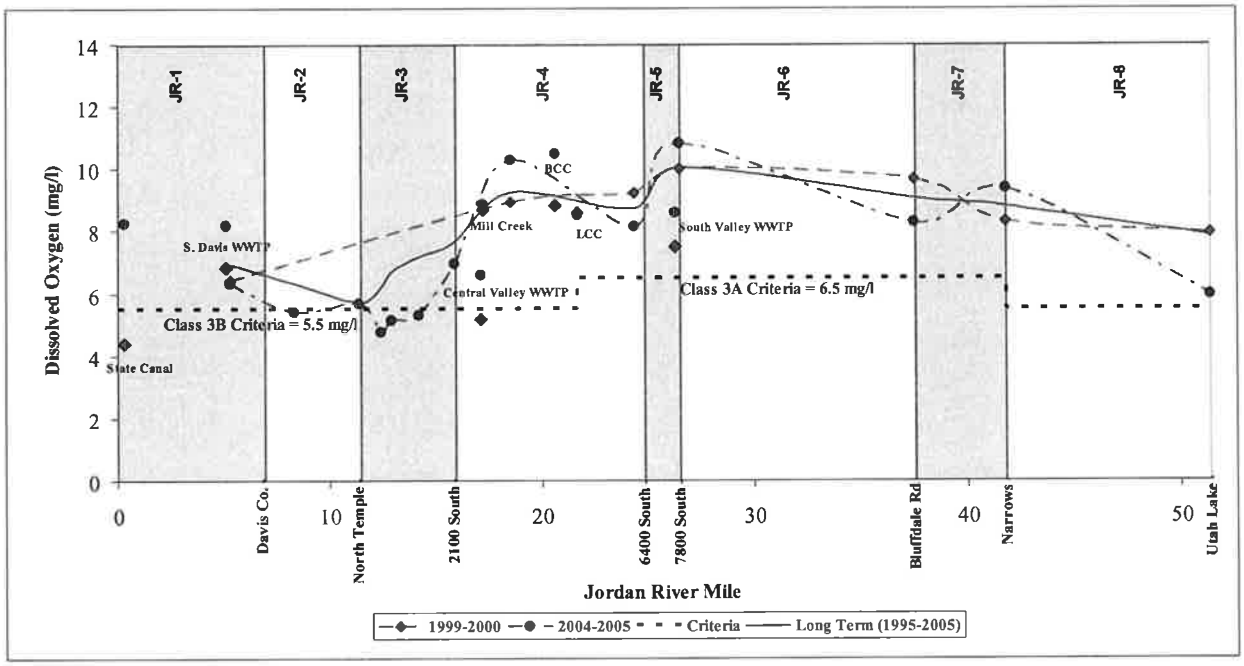


Figure 5.6. Dissolved oxygen concentrations on the Jordan River from sampling years 1999 to 2000, 2004 to 2005 and long term data from 1995 to 2005.

A review of data between 1995 and 2005 from the more data-rich stations provides a long term view with broader seasonal coverage. Figure 5.7 shows monthly DO means and violations of the chronic criterion at the seven most data-rich Jordan River stations. Typically, exceedances were highest in the summer months. July and August monthly means were below the 3B chronic, 30-day average DO criterion at Cudahy Lane and the Utah Lake outlet (DWQ Segment 8).

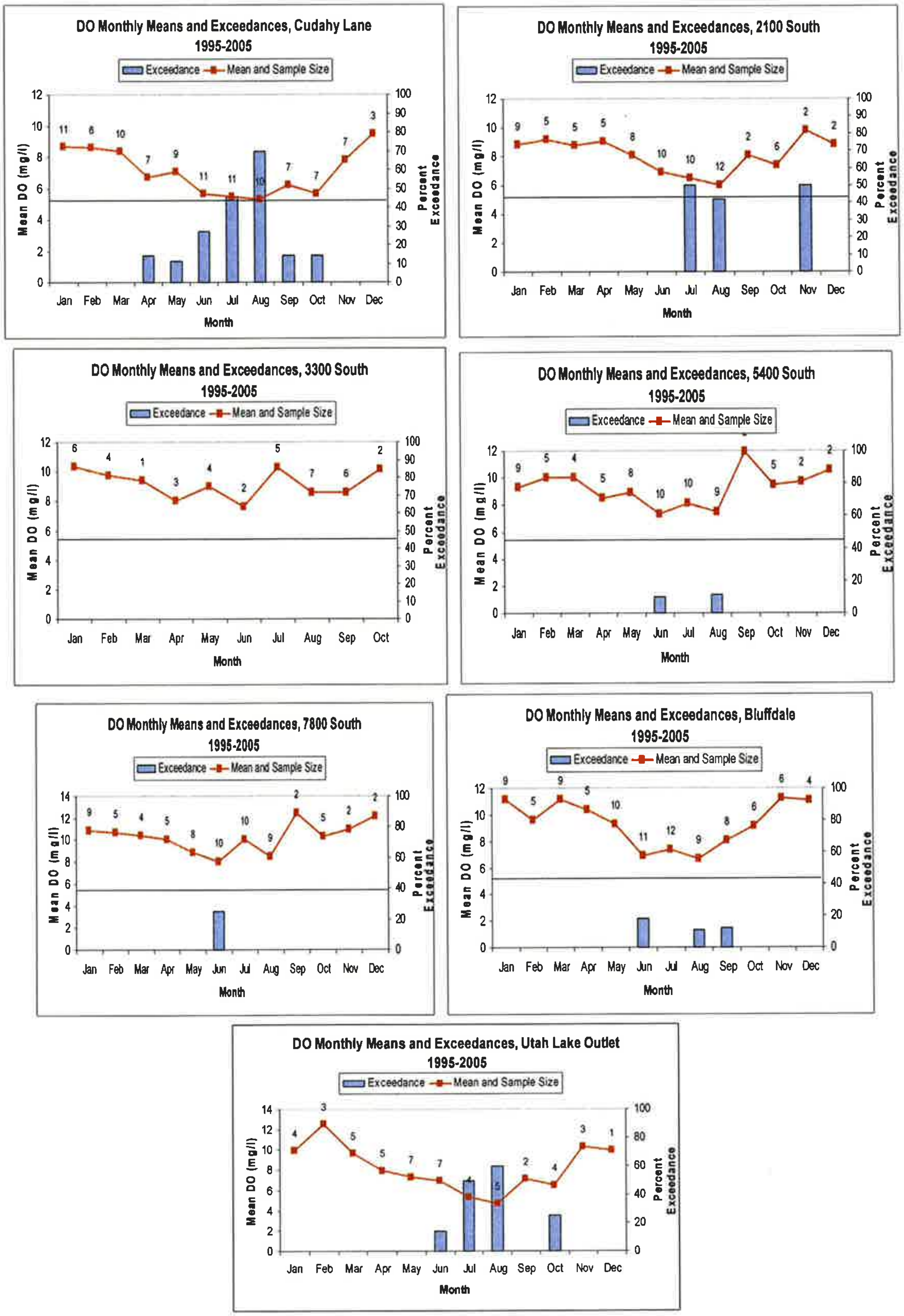


Figure 5.7. Monthly DO means and violations at selected stations on the Jordan River, 1995 to 2005. Numbers above mean line indicate number of samples.

To better represent DO dynamics in the lower Jordan River, the DWQ established site-specific acute criteria for the reach between Burnham Dam and the confluence with Little Cottonwood Creek. To protect designated uses on the Jordan River, the State of Utah requires that:

4. The 30-day average concentration of DO shall always be greater than 5.5 mg/L;
5. From August to April the instantaneous concentration shall be at least 4.0 mg/L;
   From May to July any 7-day average is to be at least 5.5 mg/L and any instantaneous value is to be at least 4.5 mg/L in order to provide greater protection for more sensitive young organisms.

Diurnal measurements of DO provide a clear picture of how DO concentrations change at a given location and indicate if and when violations of criteria occur. Hourly DO measurements were collected at multiple locations on the Jordan River for several days in June, August, and October, 2006, and February, 2007. No individual diurnal DO measurements in the lower portion of the river, including the impaired DWQ Segments 1 and 2, were below the site specific, seasonal instantaneous criteria for DO. However, some August measurements were below 4.5 mg/L for approximately 2–3 hours on the first day the probes were deployed. In general, the lowest readings (approaching the 4 mg/L criterion) occurred in the early morning hours (from 6:00 a.m. to 9:00 a.m.) in August at Burnham Dam, Cudahy Lane, and 500 North, in DWQ Segments 1 and 2. Diurnal DO data from these and other Jordan River segments are shown above in Figures 4.12 through 4.17 of Chapter 4.

A review of all instantaneous DO measurements (grab samples) collected during 1980–2005 from routinely sampled locations on the Jordan River identified 38 measurements falling below the 4.0 mg/L criterion, with values ranging from 0.1–3.98 mg/L. All but three of these samples were collected at or downstream of 2100 South. Many of these measurements were collected between 9:00 a.m. and 12:00 p.m. during the summer months, so it is likely that the minimum diurnal DO levels were even lower on these dates in early morning just before daylight, based on the shape and timing of August diurnal cycles shown in Figure 4.13.

5.2.1.2.1 Class 3A and 3B: Low Dissolved Oxygen Data

The State's 3A acute criteria, 4 mg/L for adult fish and 8 mg/L for juveniles, apply to most of the upper portion of the river, DWQ Segments 4 to 7 (DWQ Segment 4 is classified as 3B below Little Cottonwood Creek, as is DWQ Segment 8). The 2006 to 2007 diurnal monitoring data do not show any violations of the 4 mg/L instantaneous criterion. However, the diurnal data indicate that violations of the 8 mg/L criterion for juvenile fish occur on a daily basis (generally lowest in the early morning) during the summer and fall diurnal monitoring. Violations do not occur in winter and early spring, when the magnitude of diurnal fluctuation is less and concentrations generally remain above 10 mg/L.

5.2.1.2.2 Low Dissolved Oxygen Implications

In terms of the practical implications of these DO conditions, review of the literature on aquatic species' habitat requirements indicates that the State criteria provide a reasonable level of protection for both warm water and cold water fish species occurring or potentially occurring in the Jordan River, as shown in Table 5.3. Looking first at the segments classified as 3B, the 5.5 mg/L chronic criteria for warm species approximates the lower limits of the optimal range for many of the species considered. Those with higher optimal levels can survive 5.5 mg/L with minimal physiological effects. The noted violations of this criterion during summer months in DWQ Segments 1, 2, and 3 and at the Utah Lake outlet limit the potential for healthy populations of the more DO sensitive warm water species such as bass (largemouth and smallmouth) and channel catfish in these reaches. The 4 and 4.5 mg/L seasonal acute criteria for 3B segments, while not violated in these reaches according to this review, are approached during August mornings.

Widespread summer and fall violations of the 8 mg/L acute criterion for juvenile fish could limit population health. While adequate spawning could occur in tributaries, these DO conditions could limit recruitment in the mainstem population, making a fishery based on stocking more likely to succeed than one depending on natural reproduction.

It should also be noted that the species that are most sensitive to very low DO (below 3 mg/L), such as Black Bullhead, Brown Trout, Rainbow Trout and the Yellow Perch, have only rarely seen DO concentrations in the Jordan River approach this low level, and only at the Utah Lake outlet station and at the Cudahy Lane station (for example, only 2 percent of samples in the entire 1995 to 2005 data set at each station). Based on this data, it is understandable why there have been no reported fish kills due to low DO.

5.2.2 BIOLOGICAL AND PHYSICAL FACTORS RELATING TO CLASS 3A AND 3B WATERS

5.2.2.1 Class 3 Aquatic Wildlife Biological Factors

The Jordan River has historically been home to warm and cold water fish, amphibians, and macroinvertebrates, as well as provided important habitat to migratory and shore birds.

5.2.2.1.1 Fish

Fish survey data are considered in this review primarily to support conclusions based on water quality and physical habitat. The data also indicate potential for increases in species composition and abundance. Table 5.4 shows the results of Jordan River fish surveys from the past 30 years. The surveys used varying units to measure fish numbers, including fish/m^2 and fish/minute. Fish were classified into non-game, warm water, and cold water species, and the total number of species identified is provided. According to the survey results, non-game species dominate the river, with species such as carp and Utah sucker thriving despite reduced water quality. Cutthroat trout, common in the river up to the era of intensive Mormon settlement in the mid 19th century, have been replaced by warm water species such as walleye and white bass.

The Jordan River is regularly stocked with rainbow trout and channel catfish by the Utah DWR. However, these fish are intended to be caught the same year they are stocked rather than left to establish sustainable populations (Audubon Society 2000). The dominant established fish populations in the Jordan River are common carp and the Utah sucker, although channel catfish, rainbow trout, white bass and walleye have also been collected. Larger numbers of rainbow trout and brown trout are present from 14600 South downstream to 9000 South as well as some bluegill sunfish, common carp, black bullhead, mountain sucker, Utah sucker, and fathead minnow. Between 9000 south and 2100 South, common carp, Utah sucker, and few rainbow trout have been collected. Common carp, Utah sucker, and Utah chub have been found between 2100 South and the Great Salt Lake. Previous studies have noted 11 other species of fish in the Jordan River within the past 30 years, including: cutthroat trout, rainbow-cutthroat trout crosses, green sunfish, black crappie, yellow perch, largemouth bass, mosquitofish, longnose dace, goldfish, and mottled sculpin.

Table 5.4. Fish survey results on the Jordan River.

Year	Location	DWQ Segment	Fish numbers			Units	Total number of species
			Non-game	Warm water	Cold water		
2004	Little Cottonwood Creek	4	2	2	N/A	#fish/m^2	3
2003	Little Cottonwood Creek	4	20	8	N/A	#fish/m^2	6
2002	Little Cottonwood Creek	4	20	1	N/A	#fish/m^2	8
2000	1700 South	3	8	N/A	N/A	#fish/m^2	3
1999	Little Cottonwood Creek	4	43	5	3	#fish/m^2	8
1991	Above Mill Creek	4	2.4	N/A	N/A	#fish/min	6
1991	Below Mill Creek	3–4	1.7	N/A	N/A	#fish/min	6
1991	1700 South	3	2.1	N/A	N/A	#fish/min	8
1991	1000 North	2	0.8	N/A	N/A	#fish/min	2
1991	Surplus Canal	N/A	0.7	N/A	N/A	#fish/min	8
1988	Above Mill Creek	4	108	1.2	N/A	#fish/1000 sec	11
1988	Below Mill Creek	3–4	86	3.3	0.2	#fish/1000 sec	13
1988	1700 South	3	180	1.1	0.2	#fish/m^2	14
1988	1000 North	2	88	0.1	N/A	#fish/m^2	10
1988	Surplus Canal	N/A	121	1.4	N/A	#fish/m^2	8
1976	1700 South	3	13	N/A	N/A	#fish/m^2	2
1976	4100 South	4	98	N/A	2	#fish/m^2	3
1976	12300 South	6	70	N/A	3	#fish/min	4
1976	14600 South	6	25	124	N/A	#fish/min	6

5.2.2.1.2 Macroinvertebrates

Macroinvertebrates are of particular interest in this review for two primary reasons. First, macroinvertebrates are specific in their habitat preferences, especially in their tolerance to pollutants, making them a useful barometer of aquatic habitat health. Second, they are a key component of the aquatic food chain, supporting the full range of aquatic and riparian species at some point in their life cycles.

The Jordan River's macroinvertebrate community is substantial and diverse in upper river segments and is dominated by diptera, oligochaeta, coleoptera, isopoda, ephemeroptera, and trichoptera. Many of these species are intolerant of pollution and indicate good water quality. Higher macroinvertebrate densities are found in the Riverton and Bluffdale areas, while lower densities are observed downstream of these locations (Nabrotzky 1986). In contrast, macroinvertebrate populations in lower Jordan River segments, including those found below 2100 South, are dominated by pollutant tolerant species, including oligochaeta and chironomidae, which is consistent with relatively lower water quality (Holden and Crist 1986).

Water quality may not be the only factor influencing species composition. Macroinvertebrates generally favor cobble/gravel substrates. These substrates are more common upstream of Mill Creek, while sand/silt/gravel substrates are predominant below Mill Creek (Jensen 1996). Table 5.7 shows substrates identified in a 1987 study. Gravel and cobble were the primary upstream substrates, turning to clay-silt and then sand further downstream. Jensen (1995) lists gravel as the substrate material throughout the river except for a sandy segment between the Brighton Diversion and Mill Creek. Jensen and Fillmore (1997) also list mostly gravel substrates, with the exception of the area between Brighton Diversion and 2100 South, which are described as having sandy substrates. Salt Lake County (1978) described substrates in the lower, mid, and upper reaches of the river as having poor, fair, and good substrates for invertebrates. Thus, substrate must be considered along with water quality in interpreting the results of macroinvertebrate surveys.

The Family Level Biotic Index (FBI) (Hilsenhoff 1988) is an index of organic pollution and is based on the response of a community to the combination of high organic loading and decreased DO levels. Pollution tolerance values are assigned to the family level of each of the organisms identified. Lower values represent pollution intolerant families, so the presence of these species suggests high water quality. Table 5.5 gives a summary of FBI ratings on the Jordan River. Areas with FBI levels above 6.5 are considered to have "poor" water quality and those above 7.25 are considered to have "very poor" water quality. Only the station at 1700 South had an average FBI lower than 6.5. While the findings of the cited macroinvertebrate surveys are not entirely consistent, they cumulatively suggest a high level of organic pollution in the Jordan River that generally increases from upstream to downstream segments.

Table 5.5. Summary of FBI ratings at monitoring sites located on the Jordan River, 1995 to 2003.

Station Name	Station ID	Average FBI
Jordan River at State Canal Road Crossing	4990880	12.5
Jordan River at 1700 South at SLC	10171000	6.3
Jordan River below 12300 South	4994500	9.7
Little Cottonwood Creek at Jordan River near SLC	10168000	7.0
Jordan River at 7800 South Crossing above South Valley WWTP	4994170	7.2
Jordan River at Bluffdale Road Crossing	4994600	7.4

As part of the Utah Comprehensive Assessment of Stream Ecosystems monitoring process, DWQ has chosen to use the RIVPACS (River Invertebrate Prediction and Classification System) model approach (Wright 1995) to quantify biological integrity. RIVPACS-based methods for conducting biological assessments were initially developed in Great Britain (Wright 1995) and have subsequently been used in numerous biological assessment programs worldwide. To quantify biological condition, RIVPACS models compare the list of taxa (the lowest practical taxonomic resolution to which taxonomic groups are identified) that are observed (O) at a site to the list of taxa expected (E) in the absence of human-caused stress. Predictions of E are obtained empirically from reference sites that together are assumed to encompass the range of ecological variability observed among streams in the region where the model was developed. In practice, these data are expressed as the ratio O/E, the index of biological integrity.

Interpretation of RIVPACS models requires an understanding of the O/E ratio. In essence, O/E quantifies loss of biodiversity. It is not a measure of raw taxa richness since O is constrained to include only those taxa that the model predicted to occur at a site. The fact that O/E only measures losses of native taxa is an important distinction because the stream ecological template changes in response to human-caused disturbance and taxa richness can actually increase as conditions become more advantageous to taxa that are more tolerant of the degraded condition. Despite the mathematical complexities of model development, O/E is easily interpreted as it simply represents the extent to which taxa have become locally extinct as a result of human activities. For example, an O/E ratio of 0.40 implies that, on average, 60% of the taxa have become locally extinct as a result of human-caused alterations to the stream.

O/E has some very useful properties as an index of biological condition. First, it has an intuitive biological meaning. Species diversity is considered the ecological capital on which ecosystem processes depend; thus, O/E can be easily interpreted by researchers, managers, and the public and policy makers. Second, O/E means the same thing everywhere, which allows direct and meaningful comparisons throughout the state. This is particularly important for Utah, where streams vary considerably from high-altitude mountain environments to the arid desert regions of the state. Third, its derivation and interpretation does not require knowledge of stressors in the region. Finally, the value of O/E provides a quantitative measure of biological condition (DWQ 2008c).

5.2.2.2 Class 3 Aquatic Wildlife Physical Factors

While water quality is a key component of a productive and sustainable fishery, physical characteristics including water flows, depths, and velocities, channel bank, bed stability, and streambank vegetation are also important factors. Additionally, in-channel habitat features, such as the ratio of riffles to pools, sinuosity, in-stream structure, coarse woody debris, and channel substrate contribute to the beneficial environment for fish production. These factors provide the physical habitat necessary for shelter, protection from predators, thermoregulation, feeding, and reproducing.

Similar to many rivers in heavily urbanized watersheds, the Jordan River's physical habitat has been radically altered from its natural or pre-settlement state. Since the pioneers arrived in 1847, the river has been heavily impacted by grazing, channel modification, and encroachment by development. Poor grazing practices have destabilized and broken down banks, changed channel patterns, increased sediment, reduced streambank vegetation, and reduced aquatic habitat value. Dredging and channelization for flood control purposes have led to a monotypic, trapezoidal channel configuration in many areas, and much of the river's floodplain has been taken over by development. Reduced sinuosity from channelization has resulted in accelerated bed and bank erosion. Table 5.6 summarizes some of the key changes evident in the river's current habitat conditions.

Table 5.6. Comparison of historic (1937–1950) and current features observed for the Jordan River.

River Reach	Entrenchment ratio		Width:Depth ratio		Sinuosity		Slope (ft/ft)		Substrate		Floodplain		Rosgen Type*	
	Historic[1]	Current[2]	Historic[3]	Current[2]	Historic[2]	Current[2]	Historic[2]	Current[2]	Historic[3]	Current[2]	Historic[1]	Current[1]	Historic[1]	Current[1]
Turner Dam-Joint Diversion	Slight	1.5 (moderate)	~25	19	1.3	1.2	.00757	.00682	gravel	gravel	yes	Yes	C4	B4c
Joint Diversion-1460 South		1.6 (moderate)		14	1.2	1.2	.00379	.00527				No	C4	B4c
14600 South-12600 South		2.6 (slight)		24	1.5	1.1	.00253	.00264				Yes	C4	C4
12600 South-10600 South		2.5 (slight)		23	1.6	1.0	.00154	.00144				Yes	C4	C4
10600 South-N. Jordan Diversion		2.8 (slight)		16	1.4	1.0	.00271	.00061				Yes	C4	C4
N Jordan Diversion-6400 South		2.0 (moderate)		14	1.5	1.0	.00161	.00143				little	C4	B4c
6400 South-Brighton Diversion		2.0 (moderate)		21	1.6	1.0	.00107	.00308				No	C4	B4c
Brighton Diversion-Mill Creek		3.0 (slight)		15	1.6	1.4	.00050	.00310	sand	sand		Yes	C5	C5
Mill Creek-2100 South		1.4 (entrenched)		25	1.7	1.1	.00034	.00008				No	C5	F5

[1] Jensen and Fillmore, 1997.
[2] CH2M Hill, 1992.
[3] USF&W Sharon Steel Conceptual Plan, 1995.

The Rosgen classification system was devised to reduce the complexity resulting from the number of variables involved, and it has become a widely-used method for classifying streams and rivers based on common patterns of channel morphology. While it is normally applied to more natural systems, the Rosgen types shown in Table 5.6 help summarize the habitat changes due to human actions.

Most segments were given a historic rating of C4. A "C" rating denotes streams that have a well-developed floodplain and are relatively sinuous (meandering), with a channel slope of less than 2 percent. Channel aggradation/degradation processes are active. The number 4 denotes a gravel substrate. These characteristics are what one would expect for the Jordan River without human influences. Current ratings reclassify most previously C4 sections to B4c. "B" stream types are moderately entrenched, display a low channel sinuosity, and have a channel slope between 2 and 4 percent. Bedform morphology typically produces scour pools (pocket water) and characteristic rapids. The "c" designation in B4c denotes a channel slope shallower than expected for a B-type stream. F5 classification indicates high levels of entrenchment and bank erosion. These changes reflect primarily the historic and ongoing efforts to straighten, channelize, and dredge the river.

5.2.2.2.1 Vegetation

Loss of vegetated streambanks has led to increased erosion and high turbidity. Streambank vegetation, which provides shading and reduces water temperature, has largely been removed (CVWRB 1992). Additionally, wetlands have been cut off from the river by channelization, reducing their ability to improve water quality and provide young fish habitat (Audubon Society 2000).

In addition to improving water quality and aquatic habitat, wetlands provide important habitat to waterfowl and shorebirds along the Jordan River. The American white pelican, Columbia spotted frog, and western toad are listed on the Utah Sensitive Species List as threatened (DNR 2006). Historically, Jordan River wetlands have been comprised of willow and cottonwood trees, marshes, oxbows, and sloughs. Such habitats are vital for shelter, feeding, and breeding use by many species. Unfortunately, much of the wetlands ecosystems have been damaged or lost due to overgrazing, channelization, dredging, and urban encroachment. Up to 30 percent of Jordan River floodplain wetlands were estimated as lost between 1974 and 1986, and wetland acreage has decreased from 6,240 acres to 2,690 acres, a 43 percent drop, since the first European settlers arrived (Audubon Society 2000).

Following removal of wetlands species, many of the riparian species have been replaced by other, less desirable vegetation, particularly invasive species. Russian olive and tamarisk are two exotic species that have replaced the upper canopy of the riparian habitat, and xeric grass and forb meadows have taken over the understory. Riparian vegetation is more abundant in downstream segments, but throughout much of the corridor grasses dominate over trees, shrubs, and forbs. Channelization has prevented the river from accessing the floodplain in many segments, reducing the potential for native riparian vegetation to be re-established (Audubon Society 2000).

5.2.2.2.2 Channelization and Dredging

A major river straightening project took place in the 1950s to increase channel conveyance for flood control purposes. This project involved channel straightening and slope increases. Subsequent projects included localized dredging, levee construction, and meander cutoffs. In addition, the river channel was relocated and straightened between 6400 South and 9000 South.

Dredging has, in fact, been common everywhere except the upstream sections of the river, around Bluffdale and Riverton. The river was dredged in the mid-1980s in the area below 12600 South. Dredging downstream of Mill Creek takes place under an agreement with the U.S. Army Corps of Engineers. Dredging may also be responsible for elevation decreases in the lower part of the river around the North Jordan Diversion to 2100 South. Other localized dredging has occurred protect structures or control flood levels (CH2M Hill 1992).

A comparison of channel bed elevations from 1950 to 1990 levels found that all reaches of the Jordan River except the area from Turner Dam to Joint Diversion have experienced long-term scour or degradation, resulting in decreases in elevation (CH2M Hill 1992). Some of these elevation changes may be due to dredging rather than geomorphic processes. The areas from 12600 South to 10600 South and from Brighton Diversion to Mill Creek have been most affected. The Brighton Diversion has experienced elevation decreases of over two feet, and the Mill Creek area has experienced decreases up to seven feet.

BioWest (1987) evaluated the habitat and fishery characteristics of the river, and the results are shown in Table 5.7. The results illustrate that the vast majority of the river is "run habitat," providing flood conveyance, but is not habitat well suited to fish species that prefer more pool and riffle habitat. Lack of suitable physical habitat has been cited as the main reason for the lack of game fish species in the Jordan River, particularly the lower portion (BioWest 1987, Holden and Crist 1989, Jensen 1995). The substrate is primarily gravel and cobble, with clay and silt in some areas.

Table 5.7. Summary of Jordan River habitat (BioWest 1987).

Location	Substrate	Riparian Vegetation	Major Habitat Type	Recent Dredging	Other
Bluffdale	Large and small cobble.	58 percent.	Fast run (64%).	Never been dredged.	Upper portion braided, right bank diked.
Riverton	Fine and coarse gravel.	Sparse or nonexistent.	Run (92%).	Never been dredged, except for short section near Hwy. 71 bridge.	Fast current.
4500 South	Cobbles and gravels.	90% rip-rapped.	Run (77%).	1983 – 84	Recent channelization and bank stabilization.
Above Mill Creek	Firm clay-silt/gravel.	Fair to good; 49% grass.	Run (95%).	1983	Deepest area recorded (>12 feet).
Below Mill Creek	Firm clay-silt or gravel.	95% grass, some willows.	Run (95%).	1983–84	Channel very uniform.
Above Surplus Canal	Firm clay-silt, some gravel.	Banks stable; vegetation almost all grasses.	Run (98%).	1983–84	Channel very uniform.

Table 5.7. (cont'd) Summary of Jordan River habitat (BioWest 1987).

Location	Substrate	Riparian Vegetation	Major Habitat Type	Recent Dredging	Other
1700 South	Soft silt and sand underlain by gravel.	Good but variable; 76% grasses.	Run (79%).	Annually in early 1980s	Slow current, low flows.
1000 North	Sand, occasional soft silt.	Good to excellent; 92% grasses.	Run (99%).	1981–1982	Slow and shallow.

5.2.3 SUMMARY – CLASS 3 AQUATIC WILDLIFE

In terms of verifying the 303(d) List, DWQ Segments 5–7 are listed for exceeding the 3A temperature criterion (<20°C), and the data review supports this listing. DWQ Segments 1–3 are currently listed as not supporting Class 3B beneficial use based on the DO criterion, and the data review indicates that DWQ Segments 4 and 7 also do not support this use.

Examination of the combined water quality, physical habitat, and biological factors indicates that the Jordan River's overall support of the assigned 3A and 3B beneficial uses is marginal. The interactions among these limiting factors are complex, but some generalities emerge in regard to each classification.

First, the 3A cold water fishery classification of the upper portion of DWQ Segment 4 and DWQ Segments 4–7 is poorly supported, as evidenced by the preponderance of rough fish and warm water species, coupled with the scarcity of trout. Widespread exceedance of the acute DO criterion for juvenile fish coupled with summer temperatures unfavorable for spawning and eggs make a naturally-reproducing trout population unlikely. Damage to physical habitat both exacerbates the water quality constraints and adds new ones. DWQ Segment 7 is in the triple bind of concurrent DO and temperature impairments in the summer with low-quality physical habitat. The upper portion of DWQ Segment 4 and Segments 5 and 6 have somewhat higher potential.

The 3B segments face similar constraints. DO is more limiting than temperature, but both play a role in limiting the species diversity and productivity of DWQ Segments 1–4 (below Little Cottonwood Creek). Further, physical habitat degradation, particularly channelization and dredging, has been severe. Again, the dominance of carp and suckers and scarcity of warm water game species indicate the impaired condition of the fishery. The lower portions of DWQ Segments 4 and 8 have somewhat higher potential.

Overall, the respective 3A and 3B beneficial use designations remain appropriate, though impairments of water quality, physical, and biological factors limit the level of support for these uses.

5.3 BENEFICIAL USE: CLASS 4-AGRICULTURE

From Utah Administrative Code R317-2-6, Use Designations.
Class 4 -- Protected for agricultural uses including irrigation of crops and stock watering.

There are about 20,000 acres of irrigated agriculture in the Jordan River watershed on which forage, grain, orchards, vegetables, and other crops are grown. Irrigation water is delivered by a series of canals, most diverting water directly from the Jordan River. The main irrigation diversions from the river take place in the upstream part of the river below its outlet from Utah Lake, at Turner Dam and the Joint Diversion.

This irrigation water, and the infrastructure built to deliver it, has helped to support a thriving agricultural industry since settlement period 150 years ago. As the Jordan River watershed has developed, croplands have steadily been converted to residential, commercial, and industrial development. Irrigated croplands and pastures, as part of the overall agricultural land use, have been reduced. Even though agricultural demand for irrigation water has fallen, however, diversion rates have been generally maintained.

Agriculture, including irrigated crops and livestock, has been dramatically reduced in scale but remain an important component of the local economy. The value of livestock and crops produced in Salt Lake County in 2002, the year of the last agricultural census, was $19.3 million.

This section assesses the water quality, biological, and physical factors that affect agriculture, especially regarding TDS.

5.3.1 WATER QUALITY DATA RELATING TO CLASS 4 WATERS

5.3.1.1 Total Dissolved Solids

TDS is a measurement of the concentration of mineral salts in water, derived from water passing over and through the landscape, dissolving salts found naturally in soils, or added by humans such as de-icing road salt. Elevated TDS levels can adversely affect both livestock and agricultural crops. High concentrations in stock water can cause illness and reduce milk production. In irrigation water, high concentrations can damage crops and decrease productivity. The State of Utah standard for TDS is 1,200 mg/L, and was listed as a pollutant of concern in the 2008 303(d) List for DWQ Segments 1, 2, 5, 7 and 8, as shown in Table 1.1.

5.3.1.2 TDS Data

To determine whether the data support listing of these sections, the results of the 2004 to 2005 intensive monitoring were compared to the State class 4 TDS criterion. The results are shown in Table 5.8. Non-support of beneficial use occurs if more than 10 percent of samples exceed the criterion. Based on these results, the current 303(d) listings are supported, with the exception of DWQ Segment 4, which appears to warrant listing above Little Cottonwood Creek.

Table 5.8. Mean TDS concentrations and percent of samples in violation of numeric criteria for DWQ Segments of the Jordan River, 2004–2005.

Station	DWQ Segment	Criteria	Mean	n	% Exceedance
Cudahy Lane	1	1,200	998	18	11.1
Redwood Road	2	1,200	895	9	0
North Temple	3	1,200	992	15	0
1300 South	3	1,200	945	9	0
2100 South	4	1,200	1,019	15	0
Big Cottonwood Creek	4	1,200	843	6	0
Little Cottonwood Creek	4	1,200	1,039	6	33.3
5400 South	4	1,200	1,290	15	93.3
7800 South	5	1,200	1,473	6	100
Bluffdale Road	7	1,200	1,236	18	72.2
Narrows	8	1,200	1,334	6	66.7
Utah Lake	8	1,200	1,214	11	54.5

Note: 7800 South and Bluffdale Road are located on the downstream and upstream boundary of DWQ Segment 6, respectively.

In general, the percentage of TDS exceedances decreases substantially below the confluence of major tributaries with the Jordan River due to dilution from tributaries with relatively low TDS. The decrease in percent exceedances between 5400 South, upstream of the Little Cottonwood Creek and the Big Cottonwood Creek stations, is evidence of this, as shown in Table 5.8.

Table 5.9 reviews the long-term data set by month from 1995–2005 and provides data on seasonal TDS dynamics. Stations were selected for review based on the amount of data available at each station. Although limited monitoring occurred in DWQ Segment 2 (Redwood Road) during 2004 it is insufficient to compare to the 1995–2005 data record collected at other stations. TDS measurements collected at the Narrows indicate concentrations at the upstream boundary of DWQ Segment 7.

Lower Jordan stations show exceedances of less than 50 percent only 1 to 3 months per year, normally in winter. Upper Jordan stations show exceedances of up to 100 percent 5 months or more per year, with this number increasing downstream to the confluence with major tributaries.

5.3.1.3 High TDS Implications

The highest mean monthly TDS value at the Jordan Narrows was 1,730 mg/L, which occurred in September. This correlates to an Electrical Conductivity of the extract (EC_e) of 3.15 dS/m. This would cause less than a 10 percent yield reduction in alfalfa or corn, and more than a 10 percent yield loss in common forage grasses (Kotuby-Amacher et al. 2007). These numbers suggest that production of several of the major crops grown in the Salt Lake Valley is being reduced by existing TDS levels in Jordan River irrigation water.

Table 5.9. Months during which TDS exceedances occurred at selected Jordan River stations, 1995–2005.

Station	DWQ Segment	Month	n	Mean (mg/L)	Percent Exceedance
Cudahy Lane	1	1	10	1,121.0	40.0
		3	9	910.0	11.1
		11	7	1,192.6	14.3
5400 South	4	1	3	1,528.0	66.7
		2	2	1,127.0	50.0
		3	3	1,133.3	66.7
		4	3	1,046.7	33.3
		6	8	1,162.0	62.5
		7	5	1,232.0	80.0
		8	2	1,165.0	50.0
		9	1	1,408.0	100.0
		11	1	1,334.0	100.0
		12	2	1,261.0	100.0
7800 South	5–6 boundary	1	3	1,208.0	66.7
		2	2	1,166.0	50.0
		3	3	1,196.7	66.7
		4	3	1,099.3	66.7
		7	2	1,144.0	50.0
		8	2	1,318.0	50.0
		9	1	1,592.0	100.0
		11	1	1,550.0	100.0
		12	2	1,458.0	100.0
Bluffdale Road	6–7 boundary	1	9	1,056.0	11.1
		2	5	1,032.4	20.0
		3	9	986.7	22.2
		6	12	1,026.2	33.3
		7	10	1,110.6	50.0
		8	5	1,045.2	40.0
		9	4	1,166.5	50.0
		10	8	907.0	12.5
		12	4	959.5	25.0
Narrows	7–8 boundary	1	3	1,193.3	33.3
		7	2	980.0	50.0
		8	2	1,099.0	50.0
		9	1	1,730.0	100.0
		12	2	1,223.0	50.0

As the acreage of irrigated cropland has decreased and culinary demands have risen, some of the water diverted for irrigation has been used for secondary water systems. Using this canal water for landscape irrigation reduces the demand on culinary systems. Secondary irrigation is not considered a traditional agricultural use under Class 4. However, it has been estimated that secondary irrigation comprises 20 percent of irrigation water delivered by canals from the Jordan River (DWQ 2007). While other uses for excess canal water are being considered by the canal companies, allocation to secondary systems will likely increase. Therefore, it is important to consider how these TDS concentrations affect water use for landscape irrigation.

Many common garden vegetables, besides onions and tomatoes, are also sensitive to salinity. The mean September TDS value at the Jordan Narrows (1,730 mg/L) would result in over 25 percent yield reductions in onions and carrots, and more than 10 percent yield reductions in potatoes, radishes, peas, and sweet corn (Kotuby-Amacher et al. 2007). Bluegrass, a common Utah turf grass, is affected by salinity levels of less than 1.0 dS/m, or 550 mg/L (Camberato et al. 2006), so the performance of bluegrass lawns would be affected by irrigation with water from these canals. Perennial ryegrass, another common turf grass, has a threshold value of 5.6 dS/m, or 3,080 mg/L (Kotuby-Amacher et al. 2007), making it tolerant of the highest Jordan River TDS levels.

5.3.2 BIOLOGICAL AND PHYSICAL FACTORS RELATING TO CLASS 4 WATERS

5.3.2.1 Biological Factors

In terms of the practical implications of current TDS concentrations on agriculture, soil salinity adversely affects crops by causing nutrient imbalances and reducing water infiltration. Salinity in livestock water can also be a problem, although most livestock tolerance levels are greater than 2,000 mg/L (ANZECC 2000), which is well above levels normally recorded in the Jordan River. For this reason, effects of salinity on livestock will not be discussed further.

Measurements of EC_e are used to assess soil salinity, and the units of measure are decisiemens per meter (dS/m). Suggested conversion factors from EC_e (in µS/cm) to TDS vary from about 0.5 to 0.625. The TDS thresholds shown in Table 5.10 were based on a conversion factor of 0.55. Using this conversion, the TDS criteria of 1,200 mg/L is equivalent to an EC_e of 2.2. Thus, any crop with an EC_e above that value will be affected when the TDS criterion is exceeded.

Table 5.10. Calculated TDS thresholds of selected Utah crops and pasture grasses.

Crop/Grass	EC_e threshold (dS/m)	Equivalent TDS (mg/L)
Alfalfa	2.0	1,100
Smooth Brome	2.5	1,375
Orchardgrass	1.5	825
Bermuda grass	6.9	3,795
Corn	2.7	1,485
Wheat	4.7	2,585
Rye	5.9	3,245
Onions	1.2	660

EC_e multiplied by 550 to convert to TDS.
Source: Kotuby-Amacher et al. 2007.

Salinity tolerance varies by crop species. Among forage crops, alfalfa is the most common irrigated crop in the area, comprising 41.6 percent of irrigated land in Salt Lake County, and 35.9 percent of the crop in Utah County, as seen in Table 5.11. Alfalfa is sensitive to salinity, with a threshold EC_e of 2.0 dS/m, or about 1,100 mg/L. An average tolerance threshold for plants is in the 4 to 8 dS/m range. Most common forages grown in Utah have low salinity tolerances (1 to 4 dS/m), including clovers, smooth brome, and orchard grass. Some higher-tolerance forage species (>5.5 dS/m) are Bermuda grass, perennial ryegrass, and tall wheatgrass. These forage species are likely to be found in irrigated pastures in the project area (Kotuby-Amacher et al. 2007).

Among field crops, corn is the fourth most common irrigated crop in Salt Lake County, comprising 3.7 percent of acreage and Utah County, covering 5.0 percent. Corn has a low salinity tolerance of 2.7 dS/m. Other types of grain (wheat, oats, rye), as well as sorghum, generally have tolerances at or above 4 dS/m. Onions and tomatoes, the two most common vegetable crops, also have low tolerances of 1.2 and 2.5 dS/m, respectively (Kotuby-Amacher et al. 2007).

Table 5.11. Acreage of irrigated crops in Jordan River TMDL project area, 2002.

	Salt Lake County		**Utah County**	
Crop	**Acres**	**Percent**	**Acres**	**Percent**
Alfalfa	5,653.6	41.6	2,499.1	35.9
Pasture	4,329.1	31.9	2,430.4	34.9
Grain	1,183.1	8.7	1,114.7	16.0
Idle	999.0	7.4		
Corn	507.5	3.7	346.4	5.0
Grass/Turf	279.0	2.1	35.2	0.5
Other Vegetables	233.7	1.7		
Fallow	196.5	1.5		
Grass Hay	106.7	0.8	532.8	7.7
Orchard	43.1	0.3	2.1	0.03
Sorghum	38.8	0.3		
Onions	6.6	0.05		
Tomatoes	5.7	0.04		
Total	**13,582.4**	**100**	**6,960.7**	**100**

5.3.2.2 Physical Factors

A substantial physical constraint to agriculture in the Jordan River watershed is the loss of agricultural land. Farm acreage has decreased dramatically in Salt Lake County, particularly over the past 20 years. As seen in Table 5.12, total farm acreage has decreased by almost 50 percent, from 155,398 acres in 1987 to 82,267 acres in 2002, and total cropland has decreased 26 percent, from 39,582 acres in 1987 to 29,303 acres in 2002 (USDA 1999, 2004). Accordingly, acreages devoted to hay, wheat, barley, and oats have also decreased.

In spite of the physical loss of agricultural land, water quality must be preserved in order to protect beneficial use of water for the remaining irrigated lands, including an increasing amount of use for landscape and garden areas. Water resources in Utah will continue to remain in high demand, particularly in heavily developed areas such as Salt Lake County. Allocation of higher quality waters will be more effective if Jordan River water meets all criteria for irrigation purposes as well as other beneficial uses.

Table 5.12. Changes in Salt Lake County crop acreage, 1987 – 2002.

Crop	1987 acres	2002 acres	Percent Change
Land in Farms	155,398	82,267	-47.1
Total Cropland	39,582	29,303	-26.0
Hay	8,481	4,295	-49.4
Wheat	7,148	6,350	-11.2
Barley	2,184	63	-97.1
Oats	164	67	-59.1

Source: U.S. Census of Agriculture, 1997 and 2002.

5.3.3 SUMMARY - CLASS 4 AGRICULTURE

The reviewed TDS data indicates non-support of the Class 4 criteria in DWQ Segment 1, 4, 5, 7, and 8. This is consistent with the 2008 303(d) List, with the exception of DWQ Segment 2, which is on the list but should not be, based on this data, and DWQ Segment 4, which is not on the list but should be, according to this review.

These elevated TDS levels adversely affect vegetable, forage, and hay crop production in the Jordan River valley. While vegetables are grown on limited acreages in the valley, pasture and forage are the most common uses of irrigated land. Even TDS levels below the 1,200 mg/L criterion can affect these crops. Small grains such as wheat and rye are more tolerant to salinity and should not be affected by TDS from irrigation water.

These TDS levels also adversely affect the productivity of bluegrass lawns and garden vegetables when canal water is used in secondary systems for landscape irrigation.

The amount of land used for agriculture in Salt Lake County is declining, as development increases to meet the needs of the area's growing population. Therefore, although TDS levels are high in the upper segments of the river where irrigation water is diverted, other factors play a greater role in determining the future of the agriculture in Salt Lake County. At this point, the Class 4 designation remains appropriate, with water quality impairment among the factors that increasingly limit local agriculture.

REFERENCES

Arens, H. and J. Harris. 2008. Jordan River TMDL Study; What have we learned so far? Salt Lake Countywide Watershed Symposium, Salt Lake City, UT, October 29th, 2008. See http://www.waterresources.slco.org/html/events/watsymp08_present.html.

Audubon Society. 2000. The Jordan River Natural Conservation Corridor Report. Submitted to the US Fish and Wildlife Service.

Australian and New Zealand Environment and Conservation Council (ANZECC). 2000. National Water Quality Strategy. Paper No. 4. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Chapter 4 Primary Industries, Section 4.3 Livestock Drinking Water Quality.

Bartenhagen, K. A., Marjut T., and D. L. Osmond. 2008. NCSU Water Quality Group. See <http://www.water.ncsu.edu/watershedss/about.html.>. Accessed November 3, 2008.

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

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.

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.

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

Camberato, J. J, Peterson, P. D., and Martin, S. B. 2006. Salinity and salinity tolerance alter rapid blight in Kentucky bluegrass, perennial ryegrass, and slender creeping red fescue. Applied Turfgrass Science. See <http://www.plantmanagementnetwork.org/pub/ats/research/2006/salinity/>. Accessed January 16, 2008.

Center for Disease Control (CDC). 2009a. Disease Listing: Escherichia coli General Information. See <http://www.cdc.gov> Accessed January 2009.

Center for Disease Control (CDC). 2009b. Toxoplasmosis: Fact Sheet. See <http://www.cdc.gov> Accessed January 2009.

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.

Central Valley Water Reclamation Board (CVWRB). 1992. Fishery Investigations of the Lower Jordan River, Utah – Final Report 1988–1991, TR-291-1. Submitted by Randall Filbert and Paul Holden, BIO/WEST, Inc. Submitted to Central Valley Water Reclamation Board. February 5, 1992.

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

CH2M Hill. 1984. Utah Lake Jordan River Flood Management Program. Salt Lake County and Utah County.

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

Chapra, S.C. 1997. Surface Water Quality Modeling. McGraw-Hill Companies, Inc. Boston, MA.

Chapra, S.C., G. J. Pelletier, and H Tao. 2007. QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality, Version 2.09: Documentation and Users Manual. Civil and Environmental Engineering Dept., Tufts University, Medford, MA.

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

Cirrus (Cirrus Ecological Solutions, LC). 2009. Jordan River TMDL Do Linkage Symposium April 20, 2009 – A Synopsis.

Community Stream Steward Program. 2008. Trout Habitat Enhancement. See <http://www.ofah.org/Stream/Downloads/FactSheets/TroutHabitatEnhancement.pdf>. Accessed November 2008.

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.

Dan Jones and Associates. 2007. A Study of Attitudes About the Salt Lake County Watershed. Conducted for Stantec Consulting/Salt Lake County.

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 Lynch, D. D.. 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.

Edwards, E.A., D.A. Krieger, M. Bacteller, and O.E. Maughan. 1982. Habitat suitability index models: Black crappie. U.S. Department of Interior Fish and Wildlife Service FWS/OBS-82/10.6.

Edwards, E.A., and K.A. Twomey. 1982. Habitat suitability index models: Common carp. U.S. Department of Interior Fish and Wildlife Service FWS/OBS-82/10.12.

Edwards, E.A., G Gebhart, and O.E. Maughan. 1983. Habitat suitability information: Smallmouth bass. U.S. Department of Interior Fish and Wildlife Service FWS/OBS-82/10.36.

Eklöv, A.G.; L. A. Greenberg; C. Brönmark; P. Larsson; and O. Berglund. 1999. Influence of water quality, habitat and species richness on brown trout populations. Journal of Fish Biology 54 (1).

Glenne, Bard, Dr. 1977. Water Supply and Use, Status and Outlook in Salt Lake County. July 1977, as cited in Coon et. al. 1982.

Hamilton, K., and P.C. Nelson. 1984. Habitat suitability index models and instream flow suitability index curves: White Bass. U.S. Department of Interior Fish and Wildlife Service Biology Report 82 (10.89).

Hansen, Roger D., et.al. Historical and Projected Municipal and Industrial Water Usage in Utah 1960/2020. Utah Water Research Laboratory. Utah State University. February, 1979, as cited in Coon et. al. 1982.

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.

Hickman, T., and R.F. Raleigh. 1982. Habitat suitability index models: Cutthroat trout. U.S. Department of Interior Fish and Wildlife Service FWS/OBS-82/10.5

Hilsenhoff, W.L., 1988. Rapid field assessment of organic pollution with a family-level biotic index. Journal of the North American Benthological Society 7:65–68.

Holden, P.B. and L.W. Crist 1986. Fishery and Macroinvertebrate Studies of the Jordan River in Salt Lake County. Submitted to the Central Valley Water Reclamation Facility Board.

Holden, P.B. and L.W. Crist. 1989. Annual Summary Report – 1988 Fishery Investigation of the Lower Jordan River PR 166. Prepared for Central Valley Water Reclamation Board. Prepared by BIO/WEST, Inc.

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.

Jensen, S.F. and R. Fillmore 1997. Level II Stream Morphology Classification of the Jordan River in Support of the Jordan River Channel Restoration Project. Submitted to the Board of Salt Lake County Commissioners.

Jensen, S.F. 1995. Jordan River Nonpoint Source Management Plan for Hydrologic Modifications. Board of Salt Lake County Commissioners.

Jensen, S.F. 1996. Final Draft Environmental Statement: Jordan River Bank Assessment. Submitted to Board of Salt Lake County Commissioners.

Kennecott Utah Copper Corporation (KUCC). 2005. South facilities groundwater remedial action progress report, 2002-2004.

Kotuby-Amacher, J., R. Koenig, and B. Kitchen. 2007. Salinity and Plant Tolerance. Utah State University Extension AG-SO-03.

Krieger, D.A., Terrell, J.W., and Nelson, P.C. 1983. Habitat Suitability Information: Yellow perch. Dec 1983. U.S. Department of Interior Fish and Wildlife Service FWS/OBS-82/10.55.

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.

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

Matthews, K.R. and N. H. Berg 1997. Rainbow trout responses to water temperature and dissolved oxygen stress in two southern California stream pools. Journal of Fish Biology 50 (1).

McMahon, T.E., J.W. Terrell, and P.C. Nelson. 1984. Habitat suitability information: Walleye. U.S. Department of Interior Fish and Wildlife Service FWS/OBS-82/10.56.

Nabrotzky, F. 1986. Jordan River Wetlands: Macroinvertebrates and Water Quality. Submitted to the Salt Lake City-County Health Department.

Petrosky, B.R. and J. J. Magnuson. 1973. Behavioral Responses of Northern Pike, Yellow Perch and Bluegill to Oxygen Concentrations under Simulated Winterkill Conditions. *Copeia*, Vol. 1973, No. 1.

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. Water Supply and Irrigation Paper No. 157. Department of the Interior, United States Geological Survey.

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

Salt Lake County Parks and Recreation 2007. Park Facilities - Jordan River Parkway. See <http://www.recreation.slco.org/parks/html/jordan.html >. Accessed December 2007.

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. 1989. Jordan River Flow Management Agreement, Little Dell Dam Project Mitigation Agreement. U.S. Fish and Wildlife Service, State of Utah, Salt Lake County. Salt Lake County Contract No. PV9054C89.

Salt Lake County. 2006. Salt Lake County UPDES Municipal Stormwater Permit No. UTS000001 2005 Annual Report. 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.

Seiler, R.L. and K.M. Waddell. 1984. Reconnaissance of the Shallow-Unconfined Aquifer in Salt Lake Valley, Utah. Water Resources Investigations Report 83-4272. United States Geological Survey. Prepared in cooperation with the Salt Lake County Water Conservancy District and the Salt Lake County Division of Flood Control and Water Quality.

Sigler, W.F. and J.W. Sigler. 1996. Fishes of Utah: A Natural History. University of Utah Press.

Sperling, R.A. 1975. Irrigation Return Flow to the Jordan River. Masters thesis submitted to Department of Civil Engineering, University of Utah, Salt Lake City, UT. Submitted December 1975.

Stantec Consulting, Inc. (Stantec). 2006a. 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 Consulting, Inc. (Stantec). 2006b. 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 Consulting, Inc. (Stantec). 2007. Unpublished data assessing runoff volumes and land cover types measured from monitored stormwater catchments in Salt Lake County. Data included in Jordan TMDL administrative record. Data submitted May 2007 to DWQ.

Stuber, R.J., G. Gebhart, and O.E. Maughan. 1982a. Habitat suitability index models: Largemouth bass. U.S. Department of Interior Fish and Wildlife Service FWS/OBS-82/10.16.

Stuber, R.J., G. Gebhart, and O.E. Maughan. 1982b. Habitat suitability index models: Green sunfish. U.S. Department of Interior Fish and Wildlife Service FWS/OBS-82/10.15.

Taylor, G.H. and R.M. Leggette. 1949. Ground Water in the Jordan Valley Utah. Geological Survey Water Supply Paper 1029. United States Geological Survey. Prepared in cooperation with Salt Lake City.

Templeton, Linke and Alsup. 1975. Report of Utah Lake – Jordan River Hydrologic Basins Water Quality Management Planning Study. Prepared for the Department of Social Services, Utah State Division of Health Environmental Health Services, Bureau of Water Quality. Prepared by Templeton, Linke and Alsup, Salt Lake City, and Engineering-Science, Inc., Berkeley, CA.

Thiros, S.A. 1995. Chemical Composition of Ground Water Hydrologic Properties of Basin-Fill Material, and Ground-Water Movement in Salt Lake Valley, Utah. State of Utah, Department of Natural Resources, Technical Publication No. 110-A.

Thiros, S.A. 2000. Analysis of Nitrate and Volatile Organic Compound Data for Ground Water in the Great Salt Lake Basins, Utah, Idaho, and Wyoming, 1980-98. U.S. Geological Survey, Water Resources Investigations Report 00-4043.

Thiros, S.A. 2003. Quality and sources of shallow ground water in areas of recent residential development in Salt Lake Valley, Salt Lake County, Utah. USGS Water Resources Investigation Report 03-4028.

United States Army Corps of Engineers (USACE). 1985. Operation and Maintenance Manual for Jordan River Project, Salt Lake County, Utah, Flood Control Project. U.S. Army Corps of Engineers, Sacramento District.

U.S. Environmental Protection Agency (U.S. EPA). 1999. Protocol for Developing Nutrient TMDLs, First Edition. Office of Water. EPA-841-B-99-007.

U.S. Environmental Protection Agency (U.S. EPA). 2000. Nutrient Criteria Technical Guidance Manual Rivers and Streams, Office of Water, EPA-822-B-00-002.

U.S. EPA. 2003. Developing Water Quality Criteria For Suspended and Bedded Sediments (SABS), DRAFT, Potential Approaches, A U.S. EPA Science Advisory Board Consultation. U.S. EPA Office of Water, Office of Science and Technology, August 2003.

United States Department of Agriculture (USDA). 1999. 1997 U.S. Census of Agriculture. National Agricultural Statistics Service. See <http://www.agcensus.usda.gov/Publications/2002/index.asp >. Accessed January 2008.

United States Department of Agriculture (USDA). 2004. 2002 U.S. Census of Agriculture. National Agricultural Statistics Service. See <http://www.agcensus.usda.gov/Publications/2002/index.asp >. Accessed January 2008.

United States Department of Fish and Wildlife (USF&W), K. DuBois and B. Gutermuth. 1995. Sharon Steel Damage Settlement: A Conceptual Restoration Plan. USF7W Service Lincoln Plaza, Suite 404, 145 E. 1300 S., Salt Lake City, Utah, 84115.

Utah County. 2007. Utah County Park Detail. See <http://www.co.utah.ut.us/Dept/PubWrks/Parks/ParkDetails.asp?IDNO=10 >. Accessed December 2007.

Utah Department of Natural Resources (DNR). 2006. Utah's State Listed Species by County. Updated October 20, 2006. See <http://dwrcdc.nr.utah.gov/ucdc/ViewReports/sscounty_20061020.pdf >. Accessed November 2007.

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

Utah Division of Water Quality (DWQ). 2004. State of Utah Natural Resource Damage Trustee Southwest Jordan Valley Groundwater Cleanup – Report to the Public. Utah Department of Environmental Quality, Utah Division of Water Quality. June 2004.

Utah Division of Water Quality (DWQ). 2005a. Standards of quality for waters of the State, R317-2, Utah Administrative Code, Utah Department of Environmental Quality, Utah Division of Water Quality. 62 pp.

Utah Division of Water Quality (DWQ). 2005b. Jordan River Water Quality Total Maximum Daily Load Assessment. See <http://www.waterresources.slco.org/pdf/wqJrTMDL.pdf >. Accessed December 11, 2007.

Utah Division of Water Quality (DWQ). 2007. Utah Lake TMDL: Pollutant Loading Assessment & Designated Beneficial Use Impairment Assessment. See <http://www.waterquality.utah.gov/TMDL/Final%20Draft_Task2_Task3_Memo%20_08-01-07.pdf >. Accessed January 2008.

Utah Division of Water Quality (DWQ). 2008a. Utah's 2008 Integrated Report Part 3 - 303(d) List of Impaired Waters. Table 3.1. Category 5 - Stream Assessment Units Needing Total Maximum Daily Analysis, pp 3.24-25.

Utah Division of Water Quality (DWQ). 2008b. Utah 2008 Integrated Report Part 1 - Water Quality Assessment Guidance. Section 7.2.

Utah Division of Water Quality (DWQ). 2008c. Utah's 2008 Integrated Report Part 2 – 305(b) Assessment Report. Chapter 2.15 Biological Beneficial Use Support Assessment Procedure.

Utah Division of Water Rights (DWRi). 1992. 1992 Utah Lake Water Distribution Management Plan. State of Utah Department of Natural Resources, Division of Water Rights, Salt Lake City, UT.

Utah Division of Water Rights (DWRi). 2003. Division of Water Rights Duty Value Map. Revised November 2003. See <http://www.waterrights.utah.gov/wrinfo/policy/duty.asp >. Accessed June 2008.

Utah Division of Water Rights (DWRi). 2007. Calculations of outflow from Utah Lake during 1950-2006. Data provided by Jordan River Commission and archived on UDWRi website. See <http://www.waterrights.utah.gov/distinfo/distribution_systems.asp >. Accessed June 2008.

Utah Division of Water Resources (DWR) 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 Division of Water Resources (DWR). 2005. Water Reuse in Utah. State of Utah Department of Natural Resources, Division of Water Resources, Salt Lake City, UT.

Vellasenor, Maria. 2006. Nonprofit clears trash – and shopping carts – from river. *Salt Lake Tribune*, August 28, 2006. See <http://www.westminstercollege.edu/features/index.cfm?parent=515&detail=6317&content=6483.> Accessed December 2007.

Wright, J.F. 1995. Development and use of a system for predicting the macroinvertebrate fauna in flowing waters. Australian Journal of Ecology 20: 181-197.