JORDAN RIVER TMDL
DO LINKAGE SYMPOSIUM
APRIL 20, 2009 – A SYNOPSIS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

The recent "Jordan River TMDL: Public Draft Work Element 2 – Pollutant Identification and Loading" report established that low concentrations of dissolved oxygen (DO) constitute a serious impairment in the Jordan River below 2100 South. Chapter 4 of the report demonstrated that the DO impairment occurs almost exclusively in the warm months of summer and analyzed the linkage between DO and four processes: (1) physical characteristics related to reaeration, (2) aerobic bacterial decomposition of organic material in the water column, (3) bacterial decomposition of organic material and inorganic reactions occurring at the boundary between sediments and the water column, and (4) the diurnal and long-term effects of algal growth and senescence. The cited report concluded with an analysis of the linkages among these four processes.

To help build a consensus on this vital component of the Jordan River TMDL process, the Division of Water Quality (DWQ) convened a symposium of agency personnel, scientists, and key stakeholders to review the conclusions of the linkage analysis and recommend additional data that would help clarify questions regarding these water processes. Thirty people participated in a daylong meeting where each of the four processes above was discussed in detail. Attendees were given materials to review in advance, and scientists actively engaged in research on these processes were asked to critique the linkage analysis and contribute their own perspectives and knowledge. At the end of the symposium, the participants developed a summary of data needs and priorities that would help to better understand the causes of DO impairments.

This report describes the symposium (Section 1), provides an overview of the linkage analysis (Section 2), describes in detail the discussion associated with each process (Sections 3 – 6), and outlines issues and data collection needs to address in furthering our understanding of the four processes and their interactions. It focuses on the discussion that occurred on the four processes, the interactions among them, and the identified information needs.

In regard to the first process, reaeration associated with physical characteristics, a DO deficit exists in the lower Jordan River in all seasons. Reaeration from physical processes would logically be increasing DO concentrations toward saturated values – even at the low flows typical of the lower Jordan River – but instead the deficit increases downstream. Warm water temperatures reduce saturated concentrations in the lower Jordan River, and more frequent measurements of temperature, both temporally and spatially, may help to explain why DO is not impaired elsewhere in the Jordan River. Symposium participants suggested several possible ways to lower water temperatures in the lower Jordan River, including increasing shading, decreasing the temperature of water from tributaries, and increasing the depth of the lower Jordan River, either physically or with higher flows. Necessary provisions for flood control and downstream senior water rights limit the range of alternatives, but there may still be some innovative options available. It was noted that sudden increases in flows can re-suspend sediments that might result in higher DO demands in the water column from bacterial decomposition, nitrification, or oxidation of other substances (ferrous oxidation was mentioned in particular). One commenter noted that NH_4 oxidation could be as significant as organic decomposition, and suggestions were made for future data collection that might elucidate this factor. In the end, however, the participants recognized that some process(es) must be consuming DO faster than reaeration can restore it.

Demand on DO by bacterial decomposition of organic matter is one contributing factor. Biological oxygen demand (BOD) analyses are used to estimate organic matter in the water column and the demand for DO that results. Based on the limited BOD data, typical travel times, and summertime water temperatures, it appears that the decomposition of organic matter in the water column could account for half of the DO that might be provided by physical reaeration. Indirect evidence on the volatile portion of total suspended solids confirms the presence of significant organic material in the water column.

BOD is an abstraction – the result of processes that have been active upstream of where the water sample was taken – and the ultimate BOD is only part of the story. It is also important to characterize the rate of BOD, which is affected by the types of organic material in the water column. The more “digestible” the organic matter is, the faster DO will be consumed and the larger the effect of bacterial decomposition will be.

Looking more closely at temporal patterns of DO helped to reveal that water at the beginning of the lower Jordan River (2100 South) may be dominated by autotrophic organisms (those that produce DO as part of photosynthesis) while organisms downstream at Cudahy Lane appear to be more heterotrophic, and oxygen-demanding. The ramifications of this include cautions related to autotrophic processes – specifically that they may now be limited by nutrients but very sensitive to additional N and P.

It is also important to know what form of BOD is being measured by whom. During the symposium, it was revealed that the water reclamation facilities are reporting carbonaceous 5-day BOD while the state is measuring total 5-day BOD, which includes both carbonaceous and nitrogenous BOD.

There may also be unexpected, significant impacts on DO from stormwater drains and irrigation return flows. Although a small input in terms of flow, piped water has little exposure to the atmosphere, so physical reaeration is very limited. As a result, these flows may contain very low DO and have a disproportionate effect on the Jordan River.

At the bottom of the river bed, both organic and inorganic processes demand DO. As in the water column, aerobic bacteria work to decompose settling organic matter. Other, anaerobic processes below the surface of the sediments produce methane and ammonium, which can be transported to the surface of the sediments and be further oxidized. The total demand at this sediment interface is referred to as sediment oxygen demand (SOD). SOD is difficult to measure, but preliminary work on the lower Jordan River has found a demand on DO that, similar to decomposition of the suspended organic matter, may consume over half of the DO potentially provided by physical reaeration. Moreover, the few assessments of bottom sediments have found particle sizes that may be easily suspended by changes in water velocities thought to be typical of the lower Jordan River. This in turn can result in additional demand for DO as additional organic material becomes available for aerobic decomposition. Additional research is scheduled for the summer of 2009 to measure additional sites along the Jordan River to yield better estimates of the contribution of SOD to low DO.

Algae also have a profound effect on DO beginning where they are introduced to the Jordan River at its source from Utah Lake. Diurnal measurements of DO during the summer show a daily cycle of peak concentrations in late afternoon and minimum values just before dawn, consistent with diurnal patterns of photosynthesis. Daily swings of 4–5 mg/L in DO are not uncommon in summer. In phase with this diurnal change in DO, pH also fluctuates in a diurnal cycle, consistent with changes in CO_2 concentrations as a result of daylight and photosynthetic activity. These effects are reduced somewhat in fall and winter. Measurements of Chlorophyll-a, a pigment of photosynthesis that reliably indicates the presence and approximate mass of algae, indicate that suspended algal mass in the Jordan River increases in the upper 15 miles of the Jordan River. Summertime concentrations then drop markedly below Bangerter Highway and remain at upper mesotrophic values (Chlorophyll-a values of 25–35 µg/L) all the way to Burnham Dam.

The reduction in algae may well be due to a change in species, as lacustrine species do not survive well in riverine environments, and it takes some time for the riverine species to replace them. Interestingly, one formula used to predict algal biomass from Total P concentrations predicts much more Chlorophyll-a in the lower Jordan River than has been found. One explanation is that the river may be nutrient-limited by N. Measurements of Total N and P are few, but they indicate a ratio at the low end of the ideal range for algal growth. As above, a warning is appropriate because any consequent increase in N may trigger a disproportionate increase in algal growth.

Future work to characterize the effects of algae should include identifying the species throughout the river's length and additional synoptic measurements of Chlorophyll-a concentrations, as well as direct measurements of both suspended and benthic algal populations.

At the end of the symposium, the participants helped to articulate and prioritize concerns and data needs for the near future. These are presented in Section 7 of this report. The DWQ offered to assist in gathering much of this information as soon as possible, so as to improve the modeling effort for DO scheduled for fall 2009 as part of the TMDL process.

The objectives set forth for the symposium were met. In most cases a consensus was achieved on the influence of various processes on DO in the lower Jordan River, and there was wide agreement on the additional research needed to further our understanding of the nature of the impairment.

1.0 INTRODUCTION

1.1 PURPOSE

Dissolved oxygen (DO) in any river is affected by a very complex set of interrelated processes, and it is hard to discuss one without understanding others. It is also true that all of the data is simply not available on all of these processes for the Jordan River, either because it has not been collected, it has been collected at different times at different places, or it has not been collected in fine enough resolution or for a long enough period. Indeed, it would have been impossible to efficiently and cost effectively collect all the relevant data because we are still trying to understand the nature of the impairment.

The Linkage Symposium described in this report was held at the Utah Department of Environmental Quality in Salt Lake City on April 20, 2009. It added an extra step in the conventional TMDL process to seek a broad consensus regarding the causes of low DO and additional data needed to understand it. An ongoing reminder during the symposium was the need to "understand the problem (of low DO) in order to discover the solution" and this reminder was printed on a stainless steel water bottle provided to each attendee.

The stated objectives of the symposium were:

- To achieve a consensus among key individuals in scientific and regulatory roles on the factors resulting in low DO in the lower Jordan River, their interrelationships, and their relative importance.

- To identify where consensus is not currently possible and where additional data might help achieve that consensus.

Both of these objectives were achieved during the course of the one-day meeting. This report summarizes the discussions, questions, and future direction suggested by those attending the symposium.

1.2 FORMAT AND ATTENDEES

The symposium was not an attempt to formulate a solution to the DO impairment; there was challenge enough for one day just to understand the processes. It also did not involve everyone who might be knowledgeable about the Jordan River. Although many perspectives exist, each with something to offer, it would have been very difficult to carry on a productive discussion with more than 20-30 people. The individuals invited to participate were therefore chosen for specific reasons. DWQ personnel were invited because it is their responsibility to ensure that waters of the state meet water quality standards. An EPA representative was invited because ultimately EPA must review and approve the State's analysis and plans. Consultants participated because they have extensive experience with the data, they have provided analysis and conclusions in written form, and were actively seeking feedback from a wider and more penetrating review. Research scientists were invited from the field of water quality to provide current insight to the scientific debate. Finally, several individuals particularly knowledgeable about the nuances of pollutant source loading were asked to participate.

A symposium format was chosen because new ideas often emerge when hearing discussion by others. A list of attendees who participated in the symposium is provided in Appendix A. The schedule for the day is reproduced as Appendix B.

To start the discussion, Cirrus and Stantec provided an overview of the DO impairment in the lower Jordan River (downstream of 2100 South) and an explanation of how, after calibration by this summer's data, the QUAL2K model will provide quantitative insights. Following this introduction, four 1-hour periods were devoted to more in-depth discussions on the main processes affecting DO. Each hour began with a 10-minute presentation from one of the consultants responsible for the "Jordan River TMDL: Public Draft Work Element 2 – Pollutant Identification and Loading" report (herein referred to as the "Pollutant Loading Report") that provided an analysis of impairments and sources of pollution. A scientist knowledgeable in that field was then asked to present 10-15 minutes of critique, alternative explanations, and insights. The remainder of the hour was devoted to a discussion of the process in more depth, seeking new insights. Renette Anderson, Director of Planning and Public Affairs for the Utah Department of Environmental Quality, facilitated the discussion. The consultants took notes and provided real-time access to data and maps, as necessary.

An audio recording of the meeting was created, not to provide a complete transcript, but to make sure the nuances of individual contributions were accurately captured. People were asked to speak one at a time, and leave a respectful amount of time after the previous speaker finished to let everyone else digest what was said. It was more important that everyone – together – understand most of the material than to move too fast through the subject. Portions of the recordings were reviewed for this report.

1.3 This Report

Presenters included personnel from Cirrus and Stantec, consultants for the Jordan River TMDL, and four scientists: Dr. Michelle Baker (Utah State University), Dr. Ramesh Goel (University of Utah), Dr. Bethany Neilson (Utah State Water Laboratory), and Dr. Sam Rushforth (Utah Valley University). Each presenter used presentations in Microsoft PowerPoint format, which are available from the Division of Water Quality website:

http://www.waterquality.utah.gov/TMDL/Jordan_TMDL.htm

Rather than reproduce all of the graphics in the presentations, this report concentrates on summarizing the major points from the presenters and the discussions that followed. These summaries of the presentations by the four scientists are from the perspective of Cirrus and not the presenters themselves.

Following a synopsis of the overview is a review of each of the four major processes affecting DO in the lower Jordan River:

- Physical Processes - Reaeration
- Aerobic Decomposition of Organic Matter in the Water Column – Measured as BOD
- Aerobic Decomposition of Organic Matter and Inorganic Oxidation in Sediments – Measured as SOD
- Algal Effects on DO

At the end of the day, an hour was devoted to a session wherein the group articulated priorities for additional understanding of DO in the lower Jordan River. Those priorities are reproduced in the final section of this report.

2. OVERVIEW

2.1 TMDL Process

Figure 1 shows a map of the lower Jordan River with landmarks and locations of water quality stations. The lower Jordan River includes Segments 1, 2, and 3, designated by DWQ, downstream (and north) of 2100 South, below where the Surplus Canal diverts approximately 80 percent of the annual average flow of the river.

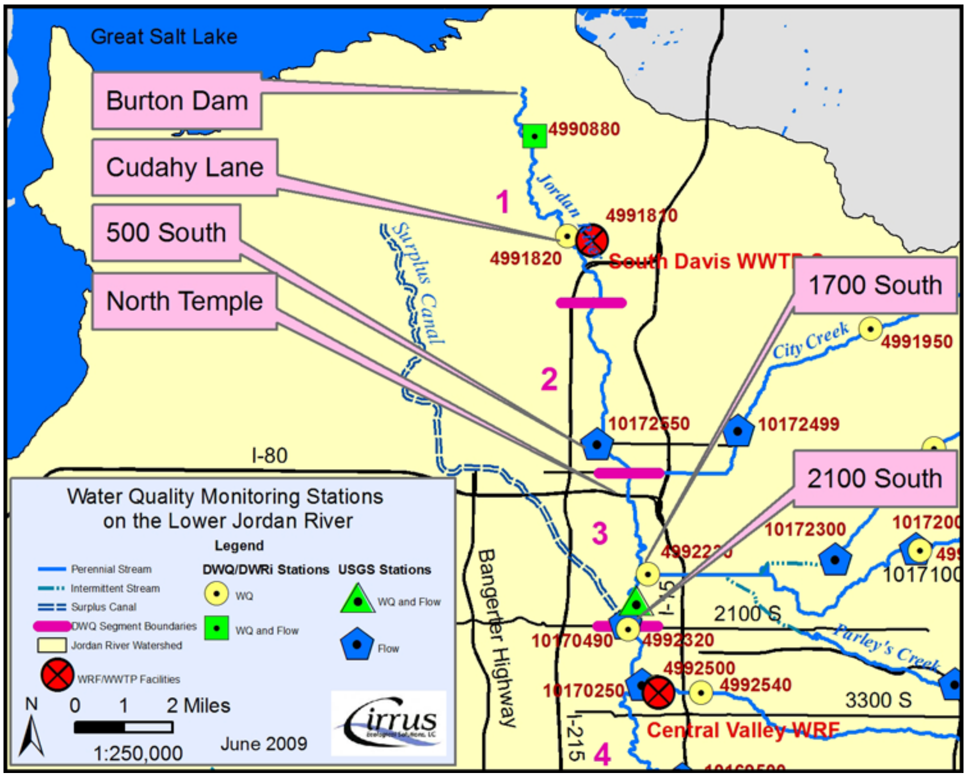

Figure 1. Water quality monitoring stations and prominent landmarks on the lower Jordan River.

The TMDL process for the Jordan River is defined by three major components: beneficial use classifications, assessment of monitoring data, and the determination of allowable pollutant loads. First, the State originally designated classes of "beneficial uses" for each segment of the Jordan River and established numeric and narrative water quality criteria that would help ensure support for those designated beneficial uses. For the lower Jordan River, these uses include secondary contact recreation such as boating, wading, or similar activities (Class 2B), warm water species of game fish and other warm water aquatic life, including the necessary aquatic organisms in their food chain (Class 3B), and agricultural uses including irrigation of crops and stock watering (Class 4). DO is one parameter of critical importance for aquatic organisms. Table 1 lists criteria for DO set by the state of Utah for this use specific to the Jordan River:

Table 1. Water Quality Standards for DO for aquatic organisms in the Jordan River.
30-Day average (Chronic): • 5.5 mg/L year-round • Typically used for inclusion on 303(d) list
May – July: • 7-Day average for juvenile aquatic species = 5.5 mg/L • Instantaneous (Acute) = 4.5 mg/L
August – April: • Instantaneous (Acute) = 4.0 mg/L

Second, the State collects data on the critical water quality parameters to determine whether the designated beneficial uses are being "fully supported" or whether the water quality is "impaired." Where water quality was assessed to be impaired for those designated beneficial uses, the State contracted with Cirrus to analyze the available data and determine the pollutant loads associated with the impairment. Cirrus assessed the sources of pollutant loads and analyzed the "linkage" between these pollutants and the observed impairments. The analysis for DO was provided in Chapter 4 of the Pollutant Loading Report released for public comment in February 2009 (Cirrus 2009). Figure 2 shows that violations of the DO standard in the lower Jordan River occurred primarily in summer.

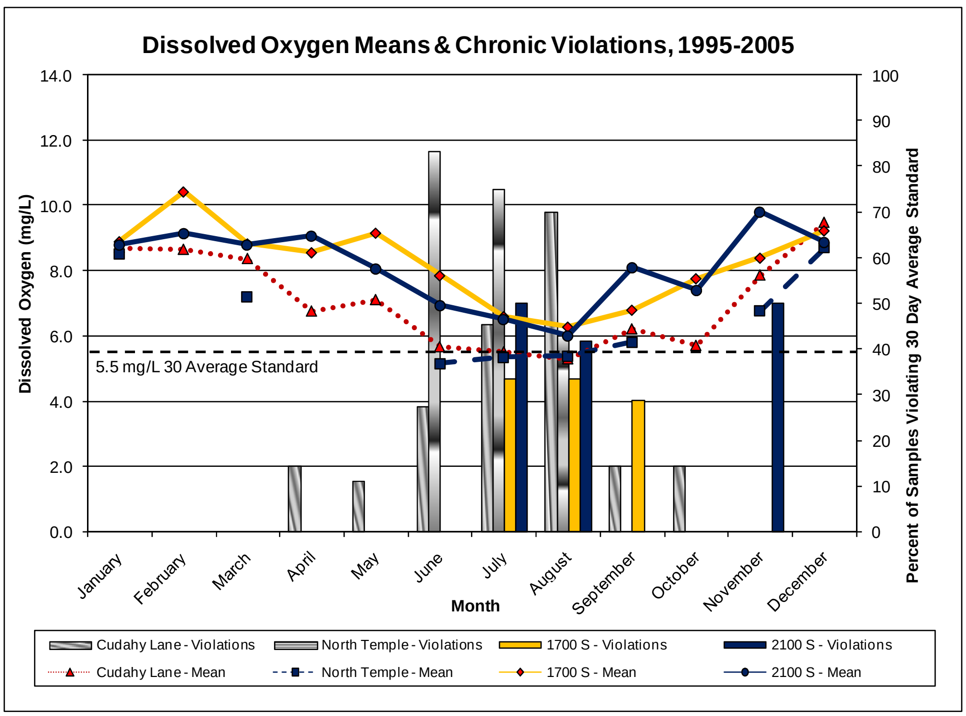

Figure 2. Seasonal patterns of DO concentrations and water quality violations in the lower Jordan River 1995-2005 (Cirrus 2009 Figure 4.1).

Third, the State has contracted with Cirrus to determine the maximum allowable loads for pollutants causing low DO in the lower Jordan River. This will guide strategies to reduce those loads in order that the river may again meet DO criteria and support its designated beneficial uses.

This third step is just beginning, which is why it is now opportune to better understand those factors that cause low DO and whether additional data is needed to determine the principal causes. Where more data is needed to understand those factors, collection can begin this year to improve the final TMDL allocation step. A recommended reduction in pollutant loads will be proposed in early 2010.

2.2 DO Linkage

The Pollutant Loading Report identified four major processes that affect DO in the lower Jordan River, illustrated in Figure 3.

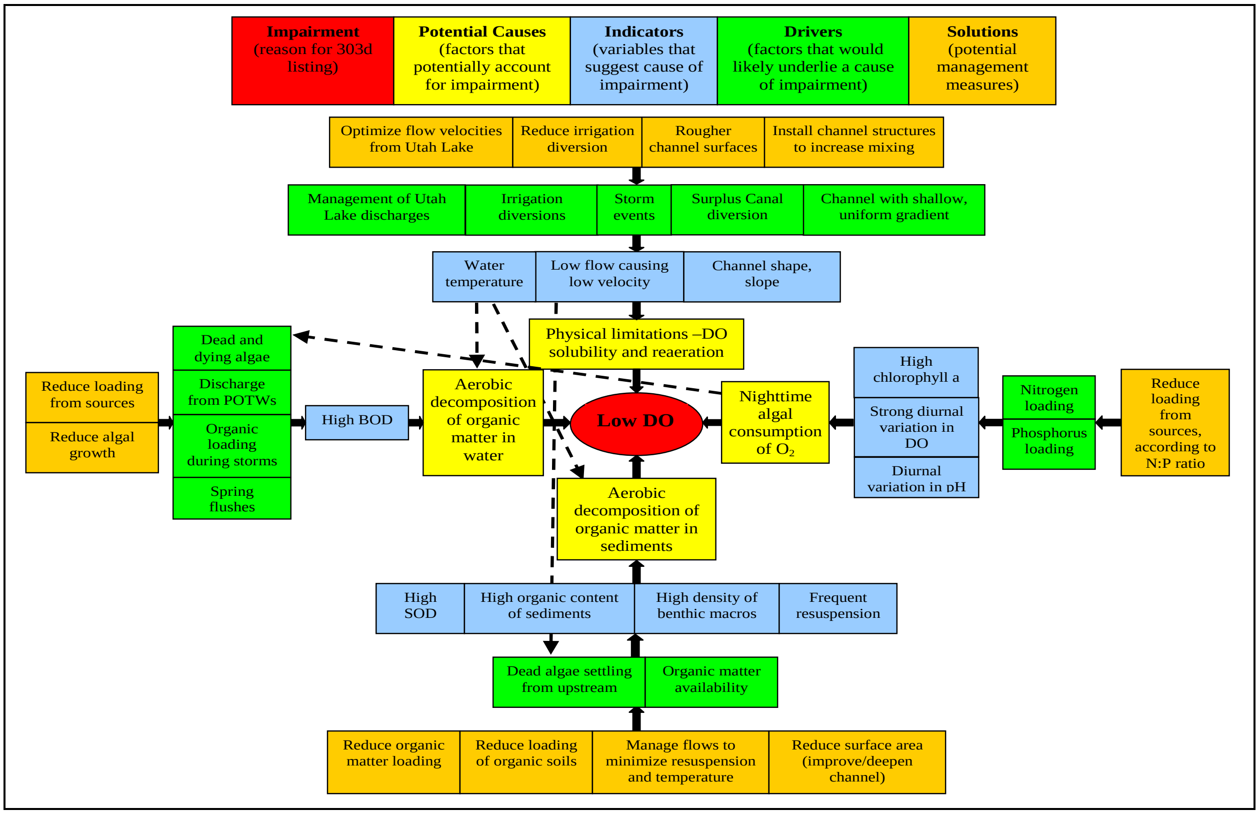

Figure 3. Factors potentially affecting DO in the lower Jordan River (Cirrus 2009 Figure 4.3).

The existing dataset for the Jordan River is comprehensive enough to provide an understanding of the key factors associated with the low DO impairment. Specifically:

- DO impairments occur almost exclusively in summer.
- Processes affecting DO are complex and interacting.

- Conclusions from the TMDL study warrant specific actions to reduce the effect of these factors.
- Continued monitoring is also appropriate to evaluate the impacts of these factors as well as other ongoing changes throughout the Jordan River watershed.

The balance of this report documents the discussions on these processes that took place during the Linkage Symposium.

2.3 QUAL2K

In order to understand in quantitative terms the complex interactions of these processes, a water quality model is being developed and calibrated to predict the effects of changes in pollutant loadings on the lower Jordan River. A model is used because it can integrate the effects of complex physical, chemical and biological processes through empirically based mathematical equations. Once calibrated, it can serve as a decision tool for the State and Jordan River stakeholders to use in developing pollutant load allocation alternatives. The QUAL2K model was selected for use in the lower Jordan River because:

- It was specifically developed to simulate DO conditions in river systems.
- It is capable of simulating the four DO processes:
  - Physical: channel hydraulics, temperature and reaeration.
  - Organic decomposition in the water column: BOD.
  - Organic decomposition and inorganic processes in the sediment interface: SOD (proscribed or DiToro diagenesis model).
  - Algal growth: diurnal time scale, nutrient cycle, free-floating and benthic algae.
- It can also estimate other water quality kinetics, including: total suspended solids (TSS), conductivity (TDS), and pathogens.

The QUAL2K model was initially calibrated to July 2004 conditions and then was validated to January 2004 observations. Calibration constituents include: flow and travel time, temperature, conductivity, carbonaceous Biochemical Oxygen Demand (cBOD), DO, Total Phosphorus (Total P), TSS, *E. coli*, alkalinity and pH.

It was not possible to calibrate plant growth kinetics and SOD for the QUAL2K model due to a lack of available data on nitrogen speciation (nitrate, ammonia, dissolved organic), phosphorus speciation (inorganic, dissolved organic), particulate organic matter, free floating plants (phytoplankton), fixed plants (periphyton and benthic algae), and sediment oxygen demand (SOD). To address these needs, 3-day seasonal synoptic sampling was undertaken on the Jordan River and its primary inflows in August 2006, October 2006, and February-March 2007. In addition, the State has contracted for a SOD research study, periphyton sampling, reaeration measurements, and a stream shading study to be completed during summer 2009. Stantec conducted a sensitivity analysis on model parameters in 2008 that helped to validate the methodologies used in the model.

Next steps for using the QUAL2K model require completing data collection in summer 2009 and a recalibration of the model in fall 2009. Model parameters will be adjusted and evaluated for each season, and best-fit values will be selected for all seasons. The model will then be ready for use as a decision-making tool to assess the likely outcomes of various loading scenarios.

2.4 Participant Discussion

One participant asked about the time periods covered by the data. The Pollutant Loading Report used flow data from 1980-2005 which represents a long term average that includes both drought and high precipitation years. Water quality data collected from 1995-2005 was used to represent conditions resulting from recent changes in population growth and urban development patterns. Since 2005, the State has increased the frequency of water quality measurements and this data is just now becoming available. It will be incorporated where possible in the upcoming analyses that forecast future loads.

Debris in the river was mentioned not only as a visual pollutant but also as an obstruction that might significantly affect flow rates. There have been recent efforts to remove much of this debris as low as 2300 South.

Water quality patterns have not yet been analyzed with respect to drought and non-drought years. This will have an impact on average concentrations resulting from different kinds of sources. Water Reclamation Facilities (WRFs) have relatively constant flows and water quality, but outfalls from stormwater collection systems may contribute dramatically higher concentrations during drought years when fewer storms occur to flush out the systems.

3. PHYSICAL PROCESSES – REAERATION

3.1 Pollutant Loading Report Analysis

The first of the four processes discussed during the symposium involved how physical characteristics and processes affect the capacity of water to hold or reabsorb oxygen from the atmosphere.

Cirrus began by summarizing the analysis in the Pollutant Loading Report on physical processes. Figure 2 (above) illustrated that the lowest DO concentrations and the most violations of the DO standard occur almost exclusively in the summer. The warmer water temperatures of summer are partly responsible for lower DO concentrations due to the lower solubility of oxygen in water as temperature rises. Figure 4 compares monthly average water temperatures and the saturated DO concentration for that water temperature in the lower Jordan River (corrected for atmospheric pressure at that elevation and observed salinity).

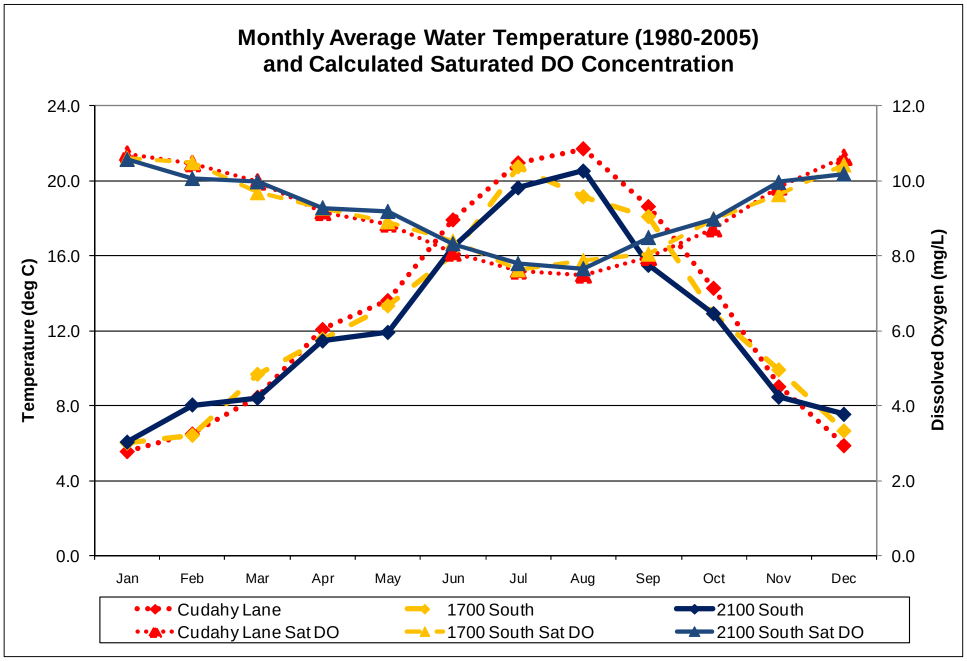

Figure 4. Seasonal water temperature and saturated DO concentrations in the lower Jordan River (Cirrus 2009 Figure 4.5).

The difference between actual and saturated DO concentrations is referred to as the DO deficit. Figure 5, illustrates that a deficit occurs almost every month at the three main water quality stations in the lower Jordan River, and the average deficit for these three stations ranges from 0.8—1.7 mg/L.

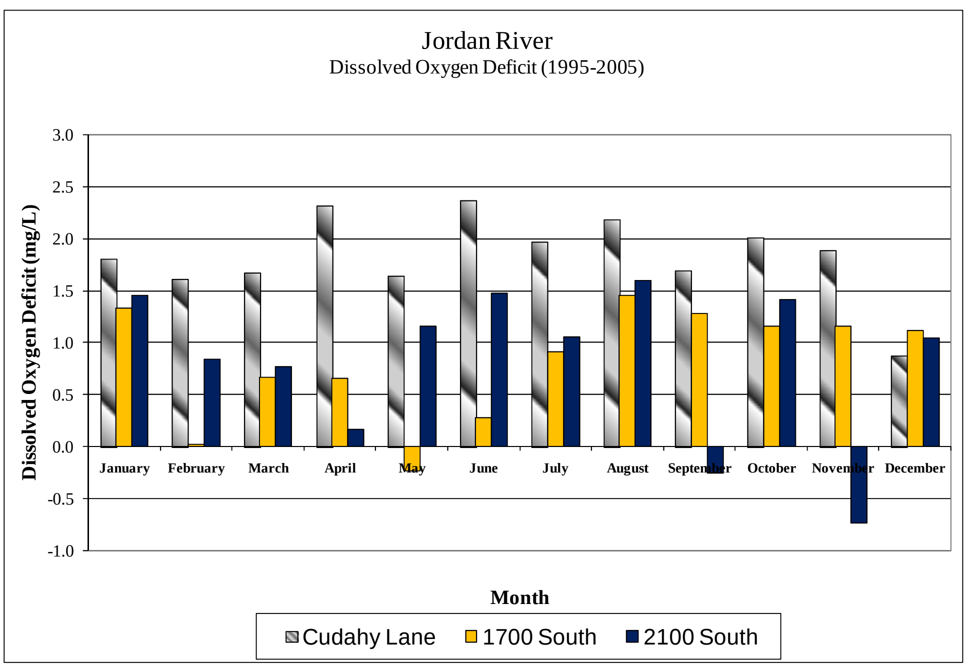

Figure 5. Monthly DO deficits in the lower Jordan River (Figure 4.2 from Cirrus 2009).

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 6). Using the formulas found by Stantec 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.

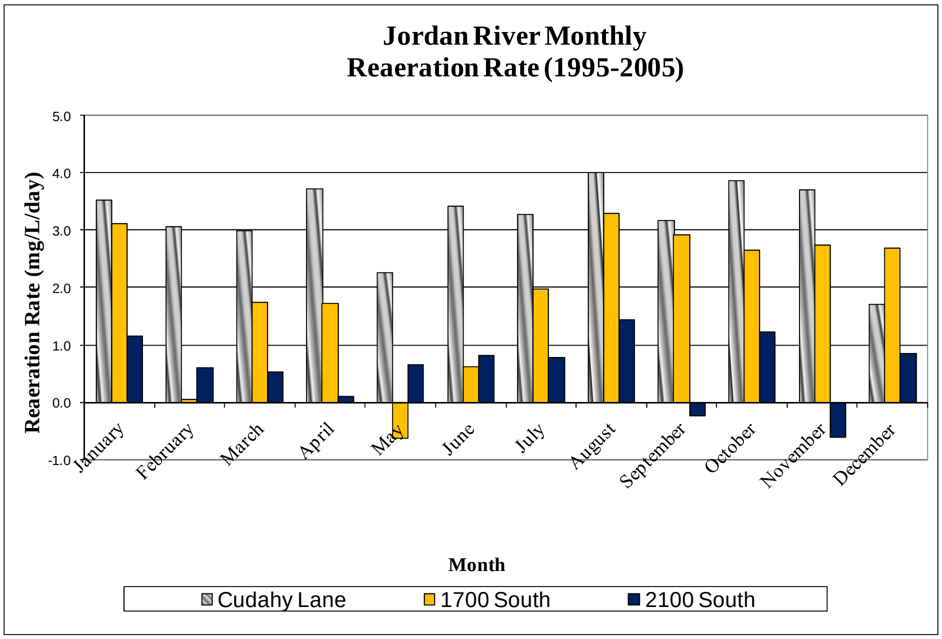

Figure 6. Reaeration rates in the lower Jordan River (Cirrus 2009 Figure 4.6).

The conclusion from this analysis was summarized as follows: DO is not usually saturated in the lower Jordan River (although some supersaturated measurements do occur in summer when photosynthesis is at its peak) – i.e., there is a DO deficit in all seasons. Reaeration should be increasing DO concentrations toward saturated values – even at the low flows typical of the lower Jordan River – but instead, the deficit increases downstream. Therefore, some process(es) must be consuming DO faster than reaeration can restore it.

3.2 Contribution by Dr. Bethany Neilson

The dominant physical factors affecting reaeration of water are depth, velocity, travel time, and temperature. Shallower depth increases the surface area of water exposed to the atmosphere but allows greater warming from solar radiation. Longer travel time gives the water more time to absorb oxygen. Higher temperatures reduce saturation values making it more difficult to reach higher DO concentrations. In turn, depth and velocity influence travel times, settling, scour, reaeration rates, and temperatures. Greater flows produce greater depths, but also greater velocities. The greater depth reduces the relative surface area, but the greater velocity increases turbulence which exposes more of the water to the atmosphere. The greater turbulence from higher velocities also reduces settling and increases scour.

The fact that DO violations are not recorded in the Surplus Canal may be partially explained if the Surplus Canal is significantly deeper than the lower Jordan River, for deeper waters are less influenced by solar radiation and as a result, tend to be cooler and have higher DO saturation concentrations.

Temperature affects reaeration rates in more ways than just saturated concentration. Higher temperatures increase all reaction rates – including reaeration – but perhaps more importantly, processes such as nitrification, denitrification, hydrolysis, and algal growth and decomposition rates.

It is not adequate only to analyze monthly average temperatures. Figure 7 shows the complexity of diurnal swings in temperature during one synoptic monitoring period. Though small, the 1.5-3.0°C swing during a diurnal cycle could be significant in terms of reaeration rates, although these effects may be offset by reaeration due to biological processes such as photosynthesis. Also of interest is that temperatures downstream of 2100 South are consistently higher throughout the day.

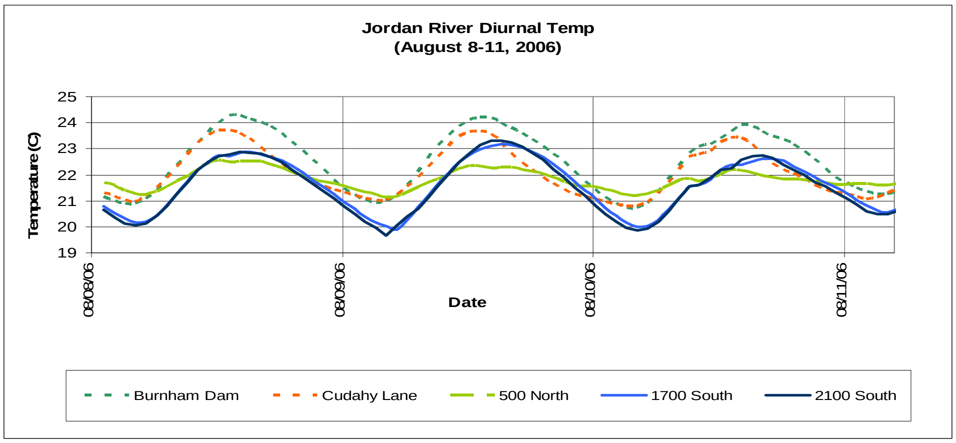

Figure 7. Diurnal temperature fluctuations in the lower Jordan River (from B. Neilson presentation).

Table 2 shows that the details of diurnal variation may also help to explain DO differences along the Jordan River. While maximum temperatures vary irregularly and differ less than 2°C from Bangerter Highway to Burnham Dam, the minimums increase steadily and vary more than 3.5°C. The cooler water, and higher saturated DO concentrations, in the upper river segments may allow higher reaeration rates at night when nighttime algal respiration is placing its biggest net demand on DO, which helps to explain why waters in the upper Jordan River do not violate the DO standards.

Table 2. Diurnal temperature variation in Jordan River.

Jordan River 8/8/2006 - 8/11/2006			
	Average Temperatures	**Minimum Temperatures**	**Maximum Temperatures**
Bangerter Hwy	20.94	17.07	24.76
9000 South	20.34	17.53	22.83
4100 South	20.59	17.47	22.92
2100 South	21.48	19.65	23.31
1700 South	21.55	19.20	23.18
500 North	21.77	19.79	22.53
Cudahy Lane	22.05	20.66	23.71
Burnham Dam	22.49	20.71	24.26

3.3 PARTICIPANT DISCUSSION

As noted by the presenters, temperature affects reaeration in many ways, and in both directions. Higher temperatures increase the rates of all bio-chemical reactions, including the rate at which oxygen is dissolved, rates of nitrification and denitrification, hydrolysis, and algae growth and decay rates. However, higher temperatures also reduce saturation concentrations. It appears, however, that the net effect of higher temperatures is to reduce DO concentrations. This suggests that efforts to lower temperatures in the lower Jordan River, by increasing shading, decreasing temperature of water from tributaries, or increasing the depth of the lower Jordan River, either physically or with higher flows – even by a couple of degrees – might have a significant positive effect on DO concentrations.

Flows in the lower Jordan River are managed at a relatively constant level, driven by the need to provide room for flood flows and responsibilities to provide water for senior downstream rights. One suggestion is to allow higher flows when water is available and weather conditions do not threaten large storm flows. It would be important to involve downstream duck clubs and other water rights owners in the planning. Reshaping the channel cross-section to allow a narrow, deeper channel for low flows, but a broader channel to accommodate flood flows would allow deeper water and lower temperatures for a greater percentage of the time. These approaches might mean higher management costs, but could help DO significantly. A caution, also discussed later, is that sudden increases in flows can resuspend sediments that might result in higher DO demands in the water column from bacterial decomposition, nitrification, or oxidation of other substances (ferrous oxidation was mentioned in particular).

Instead of limiting the analysis to modeling, it may be possible to actually measure reaeration in order to compare measured with calculated values. One researcher said that a protocol and equipment for direct measurements already exist and will be incorporated into this summer’s research agenda.

Temperature probes are relatively inexpensive, so it should also be possible to measure water temperatures at fine temporal and spatial resolutions. Shading will be evaluated this summer for the QUAL2K model, complete with GIS modeling and ground-truthing of the overhanging canopy with a densiometer.

Local reaeration can be affected dramatically by channel characteristics such as drop structures. The QUAL2K model can incorporate many of these kinds of site-specific characteristics if better data is available on the location and types of such structures.

Other practices that might help reaeration include more riparian plantings. Not only would these provide more shade, but they could also increase channel roughness and turbulence.

4. AEROBIC DECOMPOSITION OF ORGANIC MATTER IN THE WATER COLUMN - BOD

4.1 POLLUTANT LOADING REPORT ANALYSIS

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 taken from a river. 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 8 shows bimodal distributions in monthly average BOD, peaking in spring and summer.

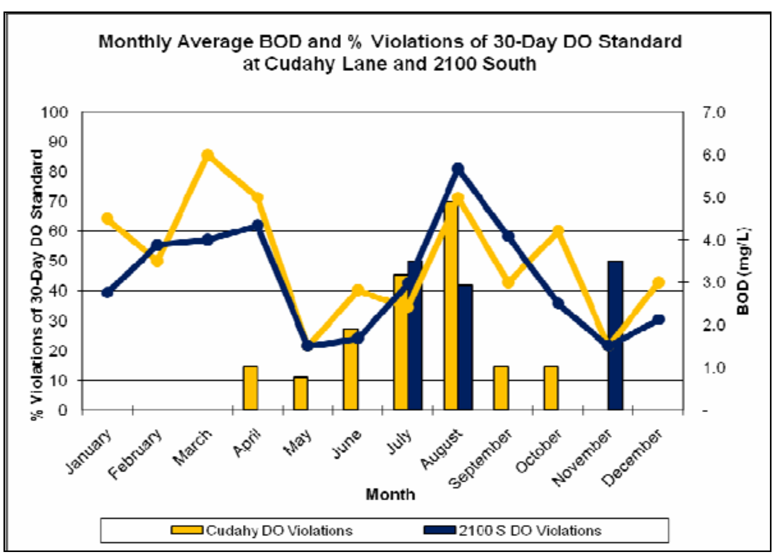

Figure 8. Seasonal differences in BOD and DO violations (Cirrus 2009 Figure 4.8).

Note that DO violations in the river occur only in the warmer months of summer. This would be consistent with different sources of BOD – slowly decomposing plant detritus from flushing flows in the spring and decaying matter from growth in summer. Figure 9 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.

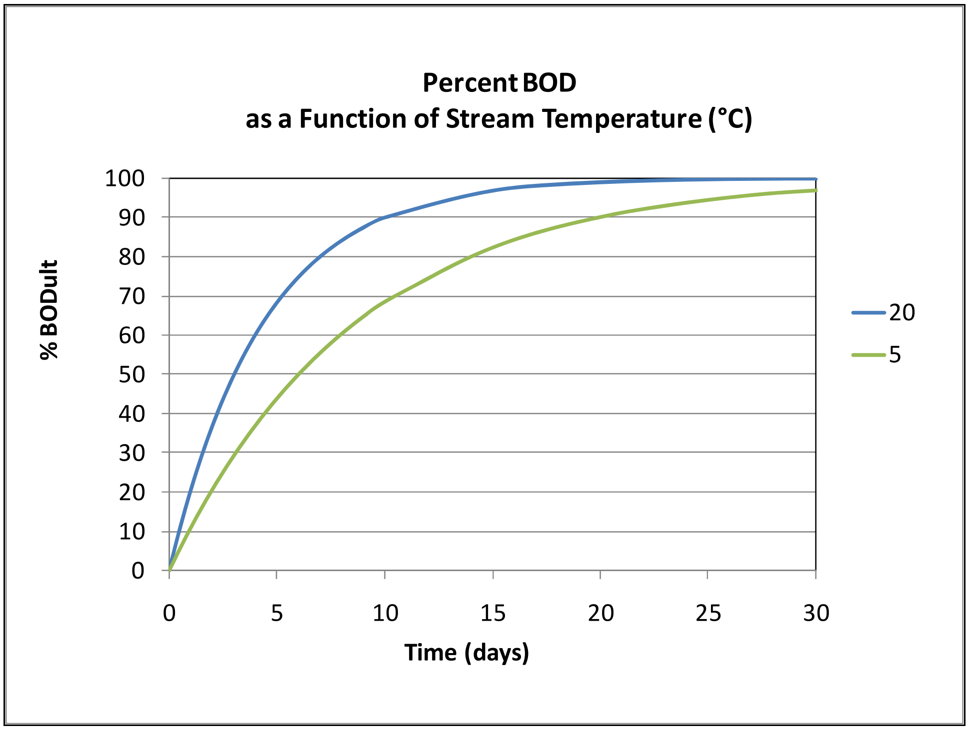

Figure 9. BOD rates increase as a function of temperature.

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 replace 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 replace 1.7-3.4 mg/L in this time.)

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

Indirect evidence supporting the findings that significant quantities of organic matter are available for decomposition also comes from the fact that a substantial portion of the total suspended solids (TSS) in the Jordan River are organic. This is reflected in the ratio of volatile suspended solids (VSS) to TSS. (See Figures 4.9 and 4.10 in the Pollutant Loading Report).

4.2 Contribution by Dr. Michelle Baker

Dr. Baker began with a reminder that DO measured at one location is the result of both biotic and abiotic processes that occur upstream of that location. BOD, the measurement typically used to assess biological components of water quality, is an abstraction; a laboratory analysis of the dynamic and complex processes that are ongoing in the river itself. Not taking into account all of the major processes – such as inorganic processes – may not give the stakeholders a correct understanding of influences on DO.

The analysis in Chapter 4 of the Pollutant Loading Report may overly simplify the processes which affect DO in the Jordan River. Instead of presenting BOD as a simple mass demand (mg/L) for example, it might be more useful to analyze it in terms of decay rates (which would require interim DO measurements during the 5-day BOD protocol).

The biological component of BOD measurements is assessing the action of heterotrophic bacteria – those that cannot manufacture their own food. Autotrophs, on the other hand, need only simple nutrients and sunlight with which to make the fundamental sugars necessary for life. The latter may, in fact, be net contributors to DO as their photosynthesis may produce more DO than they consume in respiration. The former, on the other hand, are always only consuming DO. Figure 10 shows these two processes.

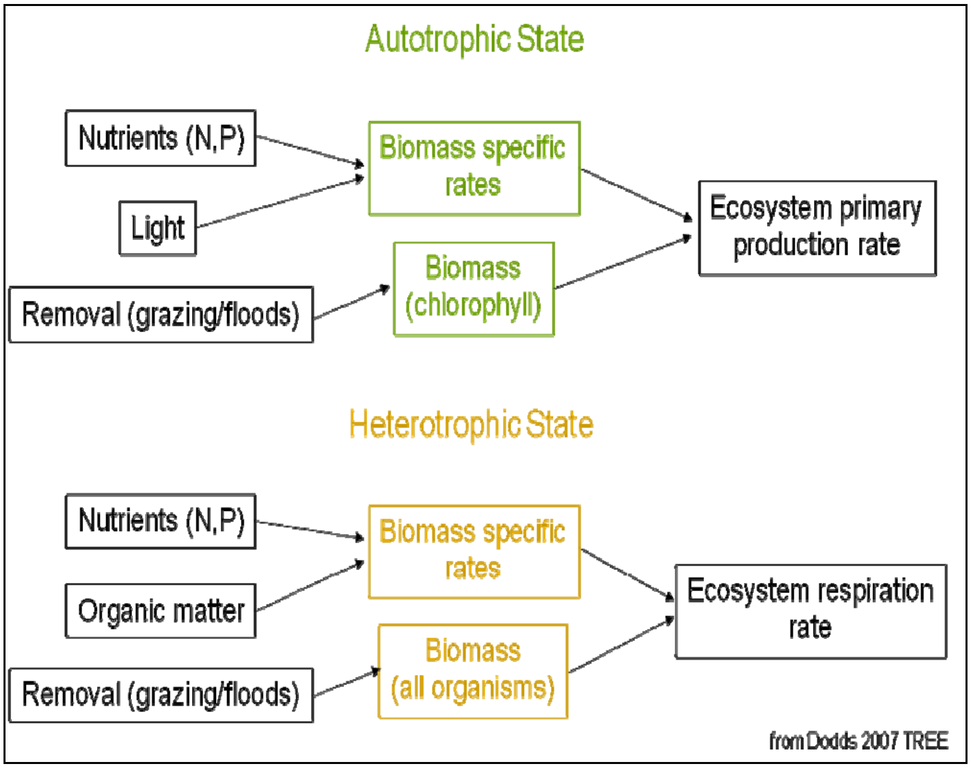

Figure 10. Autotrophic and heterotrophic processes (from M. Baker presentation).

Further, a look at diurnal patterns helps to understand some of the differences between the Jordan River upstream and downstream of 2100 South. Figure 11 compares the summertime diurnal fluctuation in DO with the saturated DO concentration at that temperature at 2100 South and Cudahy Lane. Note that DO concentrations at 2100 South are usually above saturated DO concentrations, indicating a predominantly autotrophic, and net DO-producing, condition. At Cudahy Lane, by contrast, DO concentrations are usually below saturated DO concentrations, indicating a predominantly heterotrophic, and net DO-consuming, condition.

The fact that 2100 South may be predominately autotrophic also sounds a warning. Autotrophic conditions may be thought of as limited by one or another nutrient (typically N or P), but if both nutrients are increased the trophic state may increase by more than the sum of the effects of either one.

In conclusion, Dr. Baker noted that new data on nBOD versus cBOD, organic matter standing stocks and fluxes, and analysis of the light-limiting effects of turbidity may help significantly to explain DO patterns in the lower Jordan River. It may also help to analyze diurnal data with respect to some of the potential drivers of DO. Finally, more measurements of other factors, such as Total P and Total N as well as temperature may help explain some of the effects.

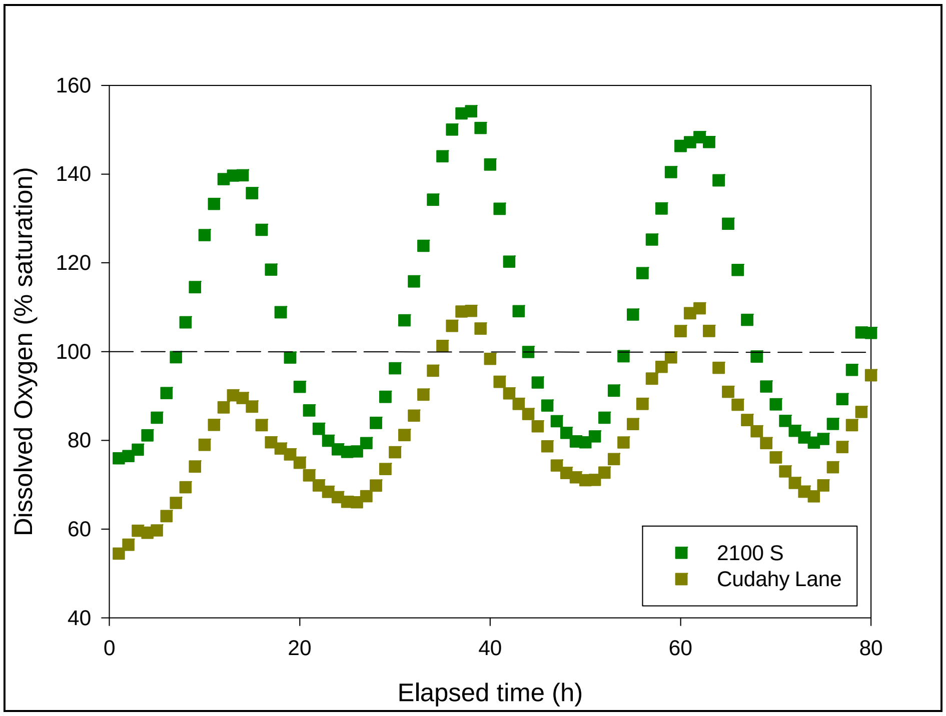

Figure 11. Diurnal fluctuation at 2100 South and Cudahy Lane and saturated DO (from M. Baker presentation).

4.3 Participant Discussion

Questions from other participants regarded the range of data included in the Pollutant Loading Report (generally 1980-2005 for flow and 1995-2005 for water quality), locations of sampling sites with respect to locations of WRF outfalls, and whether DO water quality measurements were assessed using in-situ or grab sample methods (except for diurnal studies, grab samples were used for assessing whether waters met water quality standards).

There are also some differences in which BOD measurement is reported. DWQ does not use a nitrification inhibitor, resulting in total BOD_5 (cBOD + nBOD). CVWRF reports cBOD only. This discrepancy needs to be resolved in load calculations and more uniform reporting in the future. It may be possible to assess some of the impacts of N by measuring NH_4, and perhaps establish some relationship between combining cBOD and NH_4 and comparing it to total BOD in order to evaluate past data.

Another aspect of BOD is whether the organic matter decomposes slowly or more quickly. It is unknown what percentage of the BOD in the lower Jordan is slow versus fast, but it could make a significant difference in how much DO is consumed by decomposition in the 0.4-0.85 days of transit time from 2100 South to Burton Dam.

Based on summertime diurnal DO patterns from 2100 South and Cudahy Lane that were superimposed on the saturated concentration of DO (Figure 11) it appears that most of the time DO is above saturated values at 2100 South, indicating a primarily autotrophic state. By contrast, at Cudahy Lane most of the time DO is below the saturated concentration, indicating a more heterotrophic state. This is consistent with higher DO demand and consequently lower average DO and more DO violations downstream at Cudahy Lane. This pattern is also consistent with a robust algal community at 2100 South and proportionately more bacterial decomposition occurring at Cudahy Lane.

Some studies have shown that when both N and P are added to surface water, productivity rates often increase more than the sum of increases due to one or the other. Hence, absolute nutrient concentrations are just as important as nutrient ratios.

Some discussion regarded what the water quality probes were actually measuring and where the QUAL2K analysis will be applied. The Jordan River TMDL process considered all water quality stations from Utah Lake to Burton Dam and QUAL2K will be used to model this same length. This helps to assess the status and water quality dynamics of water coming into the lower Jordan River at 2100 South. Conceptually, stationary probes are measuring an average of the processes occurring upstream, equivalent to the length of river that passes across the probe between measurement scans. If one wishes to know what is going on in a particular place, an alternative procedure would be to place two probes somewhat closer together (~100 m) and evaluate the differences between their measurements.

Although irrigation return flows from canals and storm water from drains are a small contributor to flow in the Jordan River, they may have an impact out of proportion to their flows. Water carried in pipes is exposed to less atmosphere so has much lower reaeration potential while in the pipe. As a result, it may be have a much lower DO concentration than the water in the Jordan River. Canals may carry more BOD and nutrients from fields than might be supposed. Measurements of water quality have not been made in most canals. However, storm water has been evaluated based on EMC (event mean concentration) measurements dating to 1992. Still, pollutant concentrations may be very different at different places and times. Another participant noted that only the section of the lower Jordan River from 2100 South to North Temple has any inputs from stormwater outfalls and tributaries; there are none below that. There is already much data on the location of stormwater inputs, but less data on the quality of that inflow.

One commenter noted that NH_4 oxidation could be as significant as BOD, but it was not mentioned in the Pollutant Loading Report - Chapter 4 Linkage Analysis. The principal reason for this was the lack of NH_4 data – a linkage analysis is intended to first relate the existing data to existing conditions.

Data on DO demand by NH_4 (nitrification to NO_2 and NO_3) isn't available. One recent source found by a participant estimated that this process alone could place a 1 mg/L per hour demand on DO in the water column.

5. AEROBIC DECOMPOSITION OF ORGANIC MATTER AND INORGANIC OXIDATION IN SEDIMENTS - SOD

5.1 POLLUTANT LOADING REPORT ANALYSIS

Physical processes should be moving DO toward saturated values, but instead DO is actually decreasing downstream. Decomposition of organic matter in the water column (BOD) may account for half of the physical reaeration and there is evidence for suspended organic matter and some quantification of its demand on DO in BOD measurements. Given the low velocities and shallow slope of the lower Jordan River some of this organic matter should settle out for decomposition. This, in turn, generates an additional oxygen demand at the interface of the water column and the sediments and also within the sediments.

In addition to decomposition of organic matter by bacteria at the surface of the sediments, there are also inorganic processes consuming DO. Figure 12, reproduced from the documentation for the QUAL2K model (Chapra 2007), shows some of the reactions that occur in the sediments. Aerobic processes dominate in surface layers of the sediments, while anaerobic processes dominate in the deeper sediments.

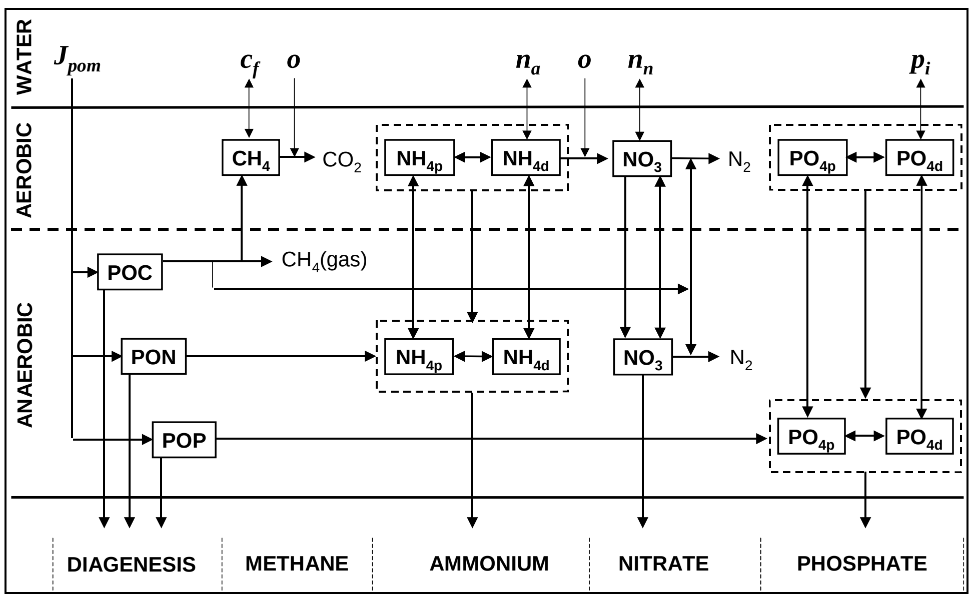

Figure 12. Nutrient flux in sediments. (from Chapra 2007).

Documentation provided for the QUAL2K model explains the diagram succinctly: "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 $g/m^2/day$.

SOD is very difficult to measure. Challenges include inserting the measurement chambers without disturbing the sediments being measured and then distinguishing between SOD and the DO demanded by aerobic decomposition in the water column. Actual measurements of SOD in the lower Jordan River have only recently been made in preliminary experiments by Dr. Ramesh Goel (Goel, personal communication, 2008). He found average SOD rates of 2.073 g/m^2/day. If this value is used for the lower Jordan River where typical depths are 1 m, then total SOD from 2100 South to Cudahy Lane would be approximately 0.8 mg/L, and from 2100 South to Burton Dam would be 1.7 mg/L.

These measurements of SOD 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, WaQSP 2008)
- 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, means that SOD alone could account for over half of the potential physical reaeration.

Resuspension of sediments has the potential for additional DO demand from aerobic bacterial decomposition. Figure 13 reproduces Hjulstrom's diagram and shows the potential for resuspension and transport of sediments based on water velocity and particle size. Stantec (2006) calculated water velocities in the lower Jordan River at 30-45 cm/s. Bio-WEST (1987) found bottom conditions in the lower Jordan River to consist of soft sands and silts. The intersections of these variables are plotted as the blue dot on the diagram, showing that typical sediments in the lower Jordan River can not only be resuspended by typical flows but, once resuspended, would be transported in the water column, exposing them to further aerobic bacterial decomposition.

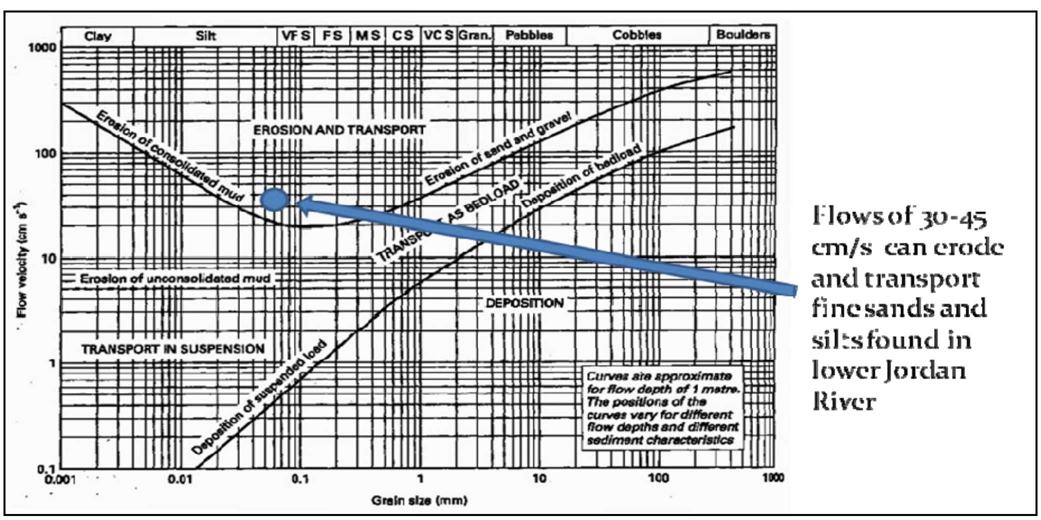

Figure 13. Hjulstrom's diagram for resuspension potential, with typical values for the lower Jordan River (Cirrus 2009 Figure 4.11).

Thus, preliminary results indicate that SOD could be a very significant contributor to low DO conditions in the lower Jordan River.

5.2 Contribution by Dr. Ramesh Goel

Dr. Goel reiterated the concepts of SOD, diagrammatically reproduced in Figure 14.

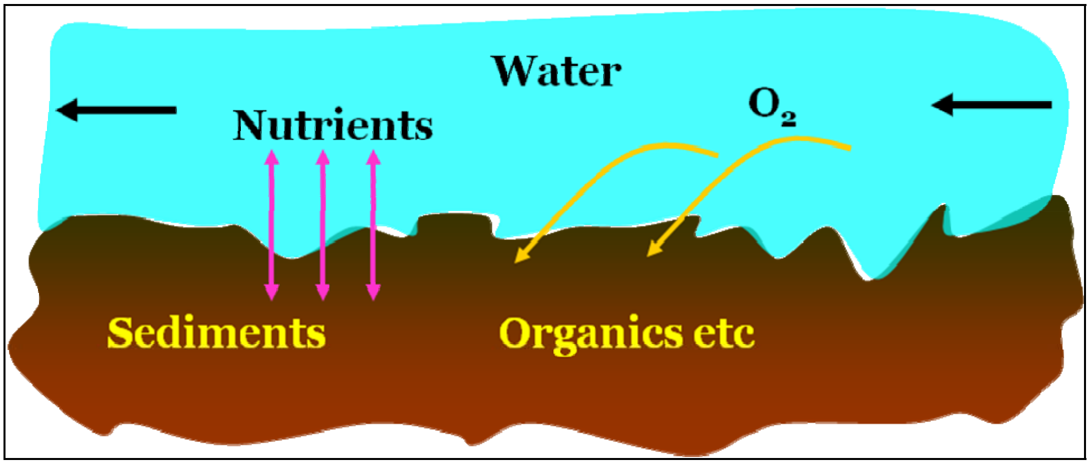

Figure 14. Conceptual diagram of SOD DO (from R. Goel presentation).

Measured SOD is dominated by "biological decomposition of organic material and microbially facilitated nitrification of ammonia." Techniques for measuring SOD are illustrated in Figures 15 and 16. A chamber is pushed gently into the sediments to seal a sample of the river bottom from the rest of the water column. DO measurements are made while a pump mixes the water within the chamber without disturbing the sediment layers. A control chamber, open to the water column but sealed from the sediment layers, provides a control for DO demand by suspended organic matter in the water column. The difference between the two measurements is the SOD.

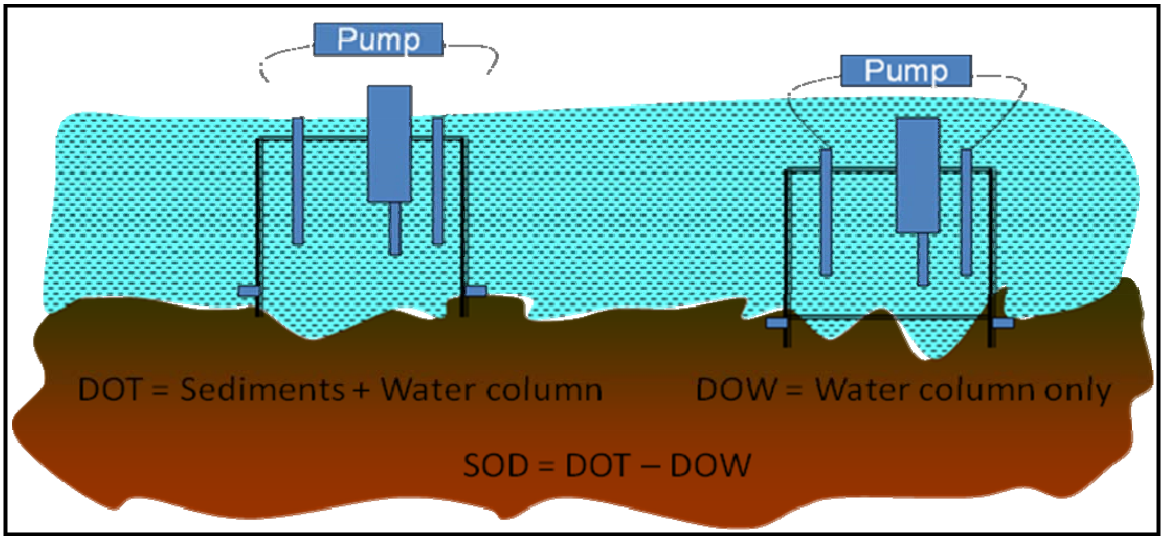

Figure 15. Measurement of SOD and control (from R. Goel presentation).

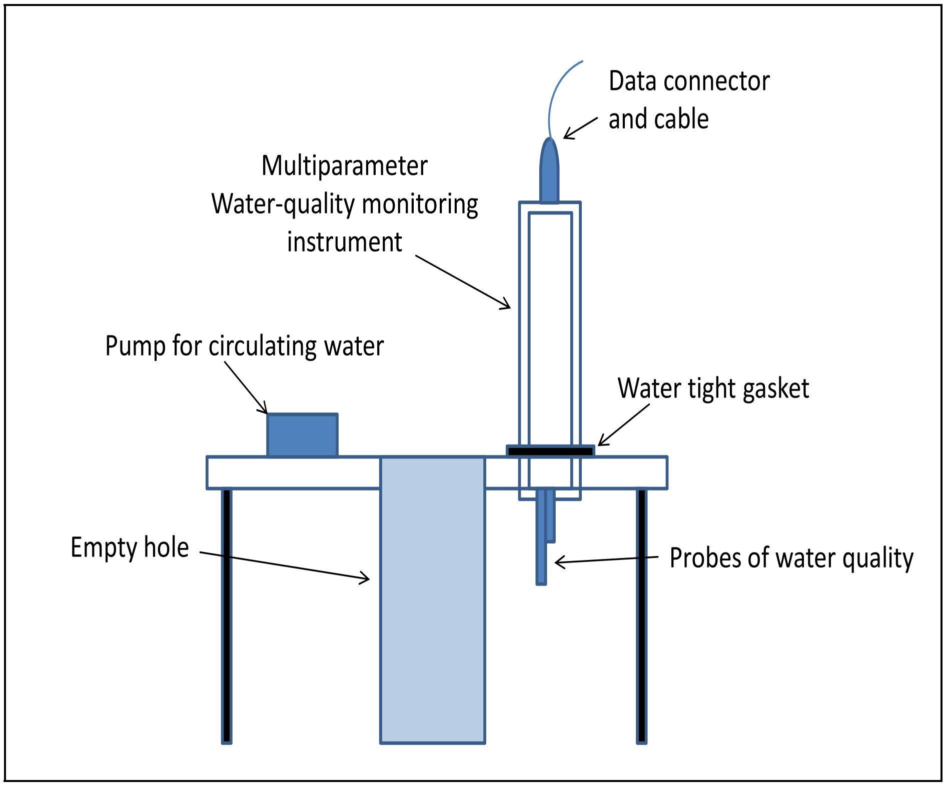

Figure 16. SOD chamber (from R. Goel presentation).

The rate of SOD changes over time as organic matter is decomposed. As a result, only the initial slopes of DO demand change are used. Figure 17 shows calculations for determining SOD; Figure 18 shows results from a preliminary measurement.

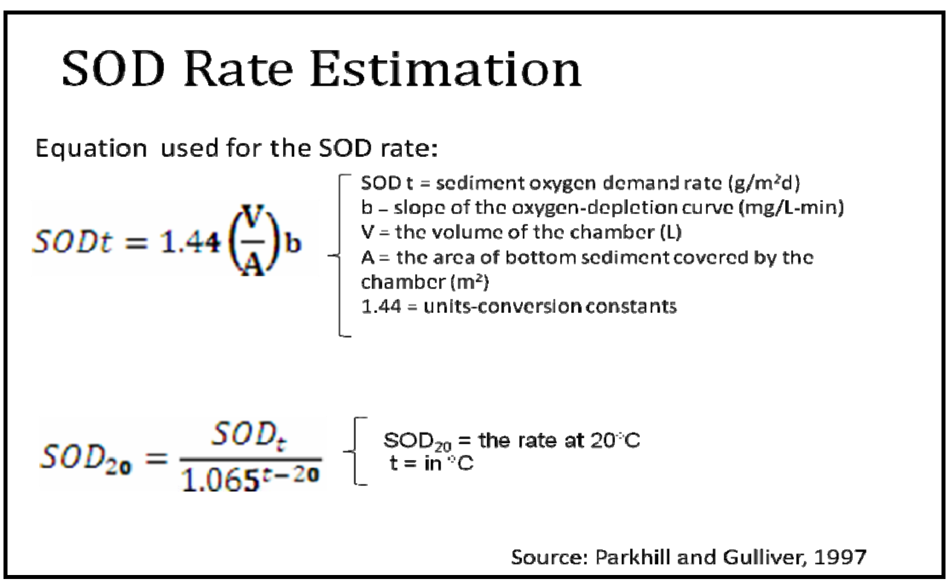

Figure 17. SOD rate calculations (from R. Goel presentation).

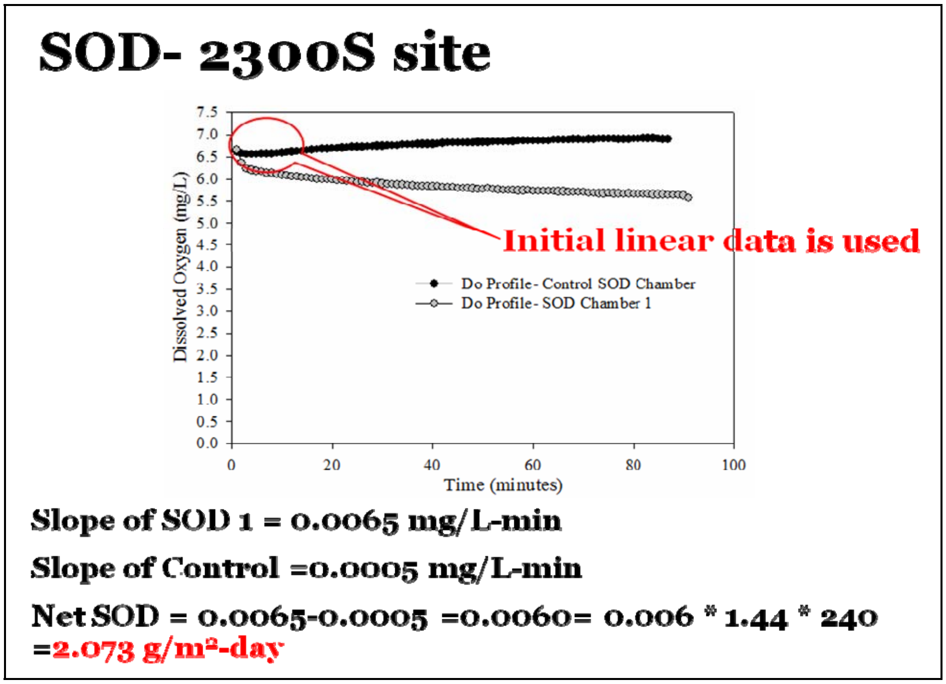

Figure 18. Measurement of SOD in the Jordan River at 2300 South (from R. Goel presentation).

Difficulties in measuring SOD include: 1) “bed-sediment heterogeneities” – finding a representative sample of the river bed and getting a good seal through the sediments to prevent interference from water column effects; and 2) measurement errors resulting from disturbances during chamber placements, sampling errors, and control chamber data fluctuations.

5.3 Participant Discussion

Some concern was expressed about whether measurements could be duplicated and whether one control was adequate. Dr. Goel responded that the control chambers seem to be very reliable; one control per measurement has been found to be adequate.

Location of the sample chambers could affect the interpretation of the measurements. If placed near the banks of the river the chambers may not measure the effect of deeper sediments in mid-channel. One difference between shallow and deeper placements is that, in deeper waters, light effects on the benthic periphyton are reduced, reducing the effects of photosynthesis that offset some of the SOD. Placement is limited for practical purposes to waters less than 2 m in depth because researchers must wade into the river to place and monitor the chambers.

Inorganic reactions could have a significant contribution, involving NO_3, NO_2, NH_4, SO_4, Fe, or CH_4. Power for the pump has been limited in the past to 6 hours, so longer term reactions have not been measured. Better power supplies and methods for securing the chamber to the river bottom could provide longer term measurements that would incorporate some of these inorganic reactions.

It was noted that bubbles can be seen rising from disturbed sediments in places with calm water and deep silts, e.g., behind the diversions at 9400 South and 4800 South. Two pipelines act as dams that could also trap silts and generate high SOD - at 4800 South and 950 South. This could indicate gases coming from the inorganic processes.

In response to a question about whether QUAL2K could predict some of the inorganic oxidation reactions, Stantec replied that QUAL2K does not model reactions of sulfides or iron.

Extrapolating from the rate of 0.0005 mg/L/min in the first few minutes of the water column control to a rate for an entire day yields a value of 0.72 mg/L/day. This compares favorably to a first day's DO consumption of 0.92-1.64 mg/L, which would be the DO consumed by aerobic decomposition in the first day of a sample with a BOD_5 of 3.0-5.5 mg/L, assuming a BOD rate of 0.23/day, similar to that of effluent from a WRF.

It was noted that the control chamber DO measurements actually went up over time, as if material was photosynthesizing, even though the sample was in the dark. One explanation might be a continuing DO release for the first few minutes, even in the dark, if the algae had stored energy from photosynthesizing that it used in the process of metabolism that creates oxygen. The effect had been repeated, but more measurements will be made at that site again this summer to confirm the effect. If true, this means the SOD measurements had been partially offset by these oxygen-producing processes, which suggests that the real SOD was even greater.

6. ALGAL EFFECTS ON DO

6.1 POLLUTANT LOADING REPORT ANALYSIS

As noted earlier, physical processes do not alone account for low DO – reaeration should be increasing DO, but DO decreases downstream. Previous sessions presented direct and indirect evidence for organic matter decomposition in the water column demanding DO as well as direct and indirect evidence for organic matter and inorganic processes in sediments demanding DO for decomposition and nitrification. The fourth process discussed during the symposium was the role of algae.

Suspended and benthic algae and macrophytes are autotrophic, generating DO during daytime photosynthesis, although resulting in a net consumption of DO as respiration continues without photosynthesis at night. Eventually, algae senesce and contribute to the organic decomposition reflected in BOD and SOD. Algae's diurnal impact on DO appears as a peak in DO concentration in late afternoon, followed by a sag in early morning before dawn. As expected, larger swings in DO occur during longer days. Ultimately, however, algal growth is limited by nutrients and light availability.

Diurnal DO has been measured hourly by the State over four seasonal test periods using Troll 9000 probes. The probes measured DO, pH, and temperature. The probes were left in place for periods of 9 days in June 2006, 3.5 days in August 2006, 22 days in October 2006, and 10 days in February 2007.

Figure 19 shows a diurnal DO pattern in June with regular but low amplitude fluctuations, decreasing downstream from 2100 South. Figure 20 shows a higher amplitude – approximately 5 mg/L – swing in August, and again decreasing in amplitude downstream. Figure 21 shows that by October, the amplitude is smaller and irregular downstream. In February, Figure 22 shows an irregular pattern, but increasing slightly in amplitude downstream. These effects are consistent with patterns of photosynthesis changes with day length, decreasing from August to October and February.

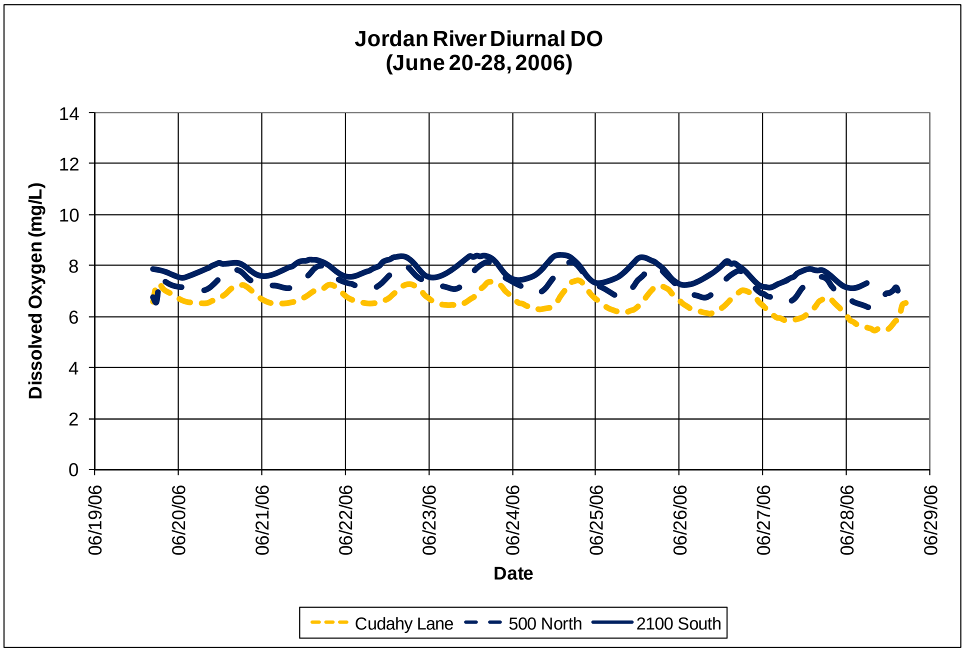

Figure 19. Diurnal DO in June 2006 (Cirrus 2009 Figure 4.12).

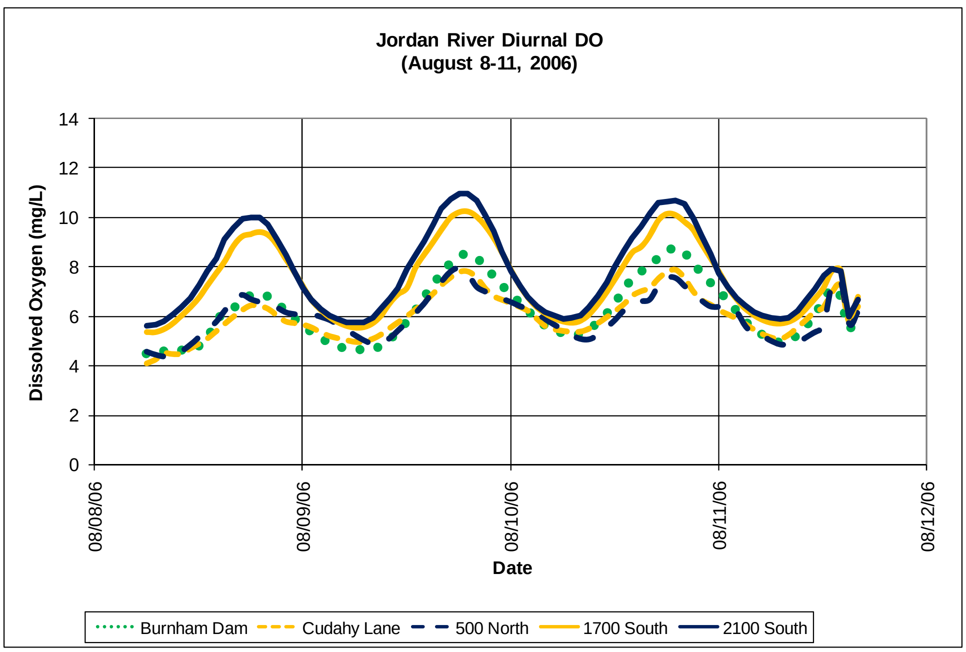

Figure 20. Diurnal pattern in August 2006 (Cirrus 2009 Figure 4.13).

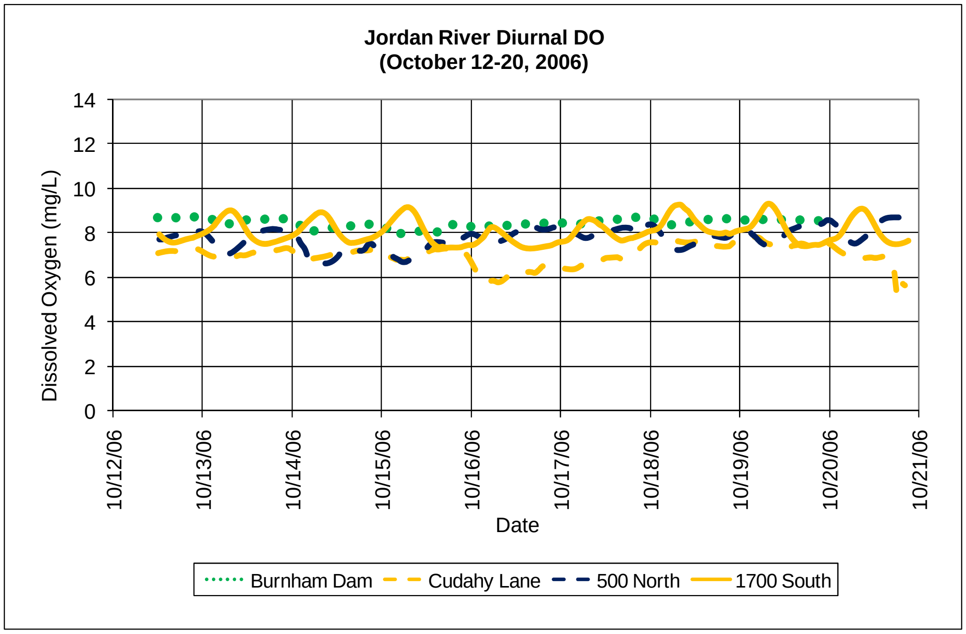

Figure 21. Diurnal pattern in October 2006 (Cirrus 2009 Figure 4.14).

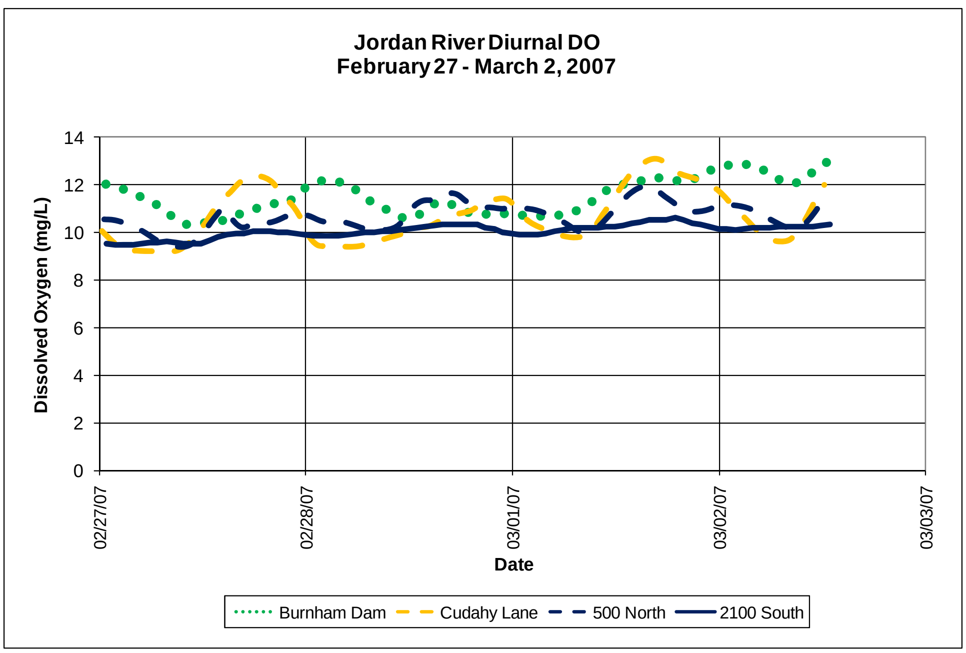

Figure 22. Diurnal pattern in February 2007 (Cirrus 2009 Figure 4.15).

Diurnal patterns of pH offer additional, albeit indirect, evidence of photosynthesis. Figures 23 and 24 show diurnal changes in pH during August 2006 at 500 North and Cudahy Lane. As photosynthesis consumes CO_2 and produces DO, the pH increases, as photosynthesis decreases and CO_2 production dominates, pH decreases. Despite the diurnal changes, however, pH remains within acceptable limits throughout the period.

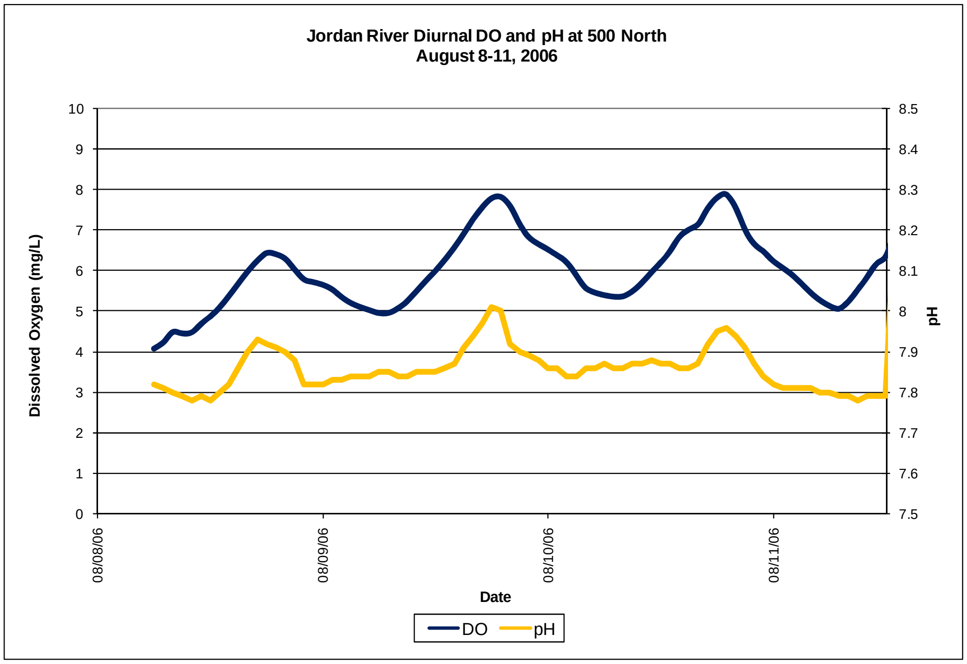

Figure 23. Diurnal changes in pH at 500 North (Cirrus 2009 Figure 4.18).

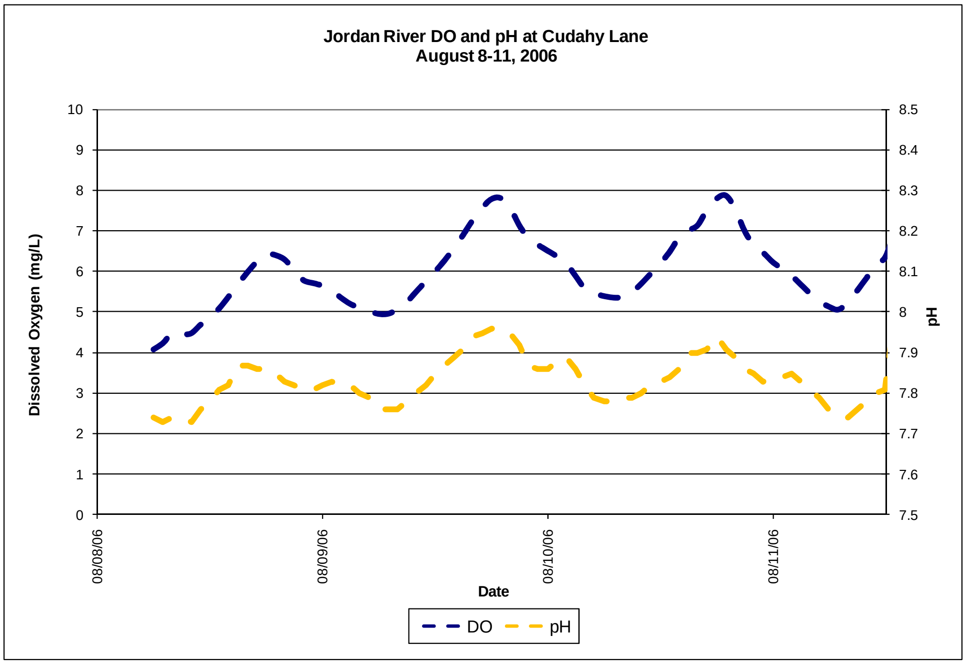

Figure 24. Diurnal changes in pH at Cudahy Lane (Cirrus 2009 Figure 4.19).

Additional evidence of algal effects on DO comes from measurements of Chlorophyll-a. Figure 25 shows that Chlorophyll-a increases from Utah Lake to Bangerter Highway, but then declines rapidly to a relatively steady state all the way to Burnham Dam, in both August and October 2006.

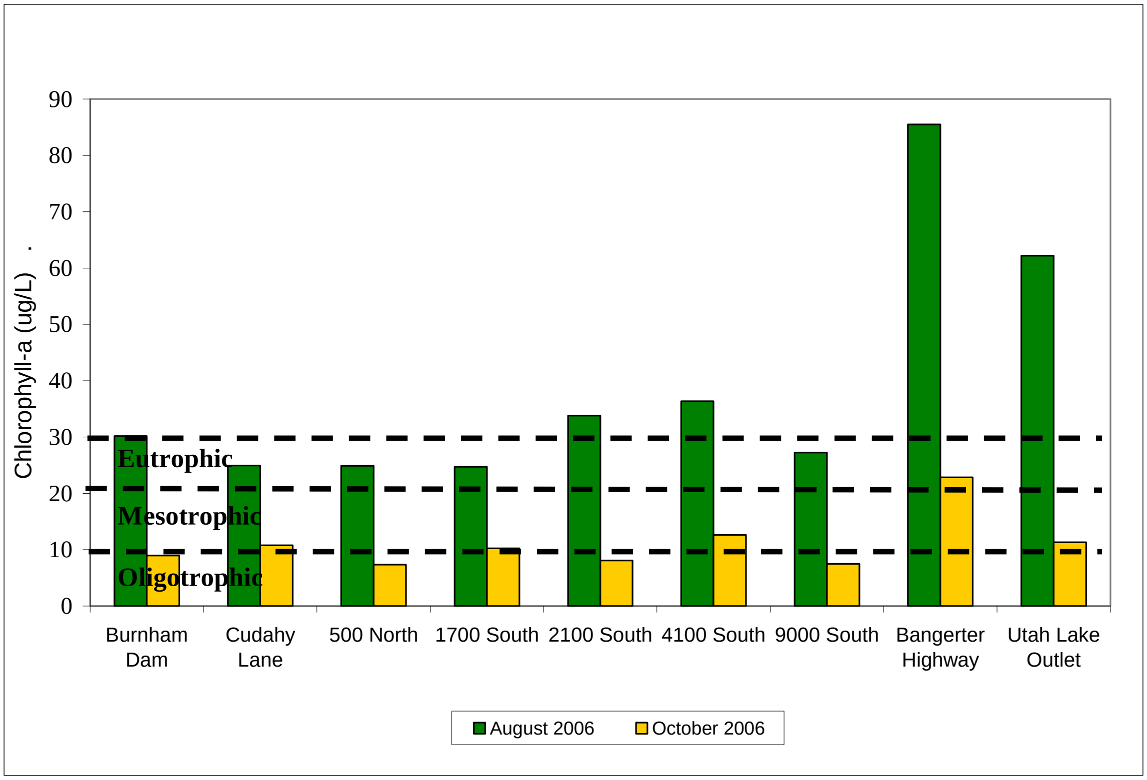

Figure 25. Chlorophyll-a and trophic status in the Jordan River (Cirrus 2009 Figure 4.20).

It is interesting to note that although concentrations of suspended algae do not change dramatically below 2100 South, Figure 26 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.

Consistent with this hypothesis is that the mass of algae in the lower Jordan River is less than would be predicted. Figure 27 shows the difference between Chlorophyll-a measurements and concentrations predicted from Total P using regressions developed by Van Nieuwenhuyse and Jones (1996) (cited in U.S. EPA 2000).

Plant growth may be faster or slower depending on light and temperature, but it is ultimately limited by nutrients, particularly N and P. According to Chapra (1997) N:P ratios less than 7.2:1 suggest that N would be a limiting factor. The few Total N measurements available for the Jordan River are consistent with limitations on algal growth below 2100 South by available N. Table 3 gives the ratios of N and P from historic data in the lower Jordan River. All ratios are below the 7.2:1 ratio, consistent with N-limited conditions.

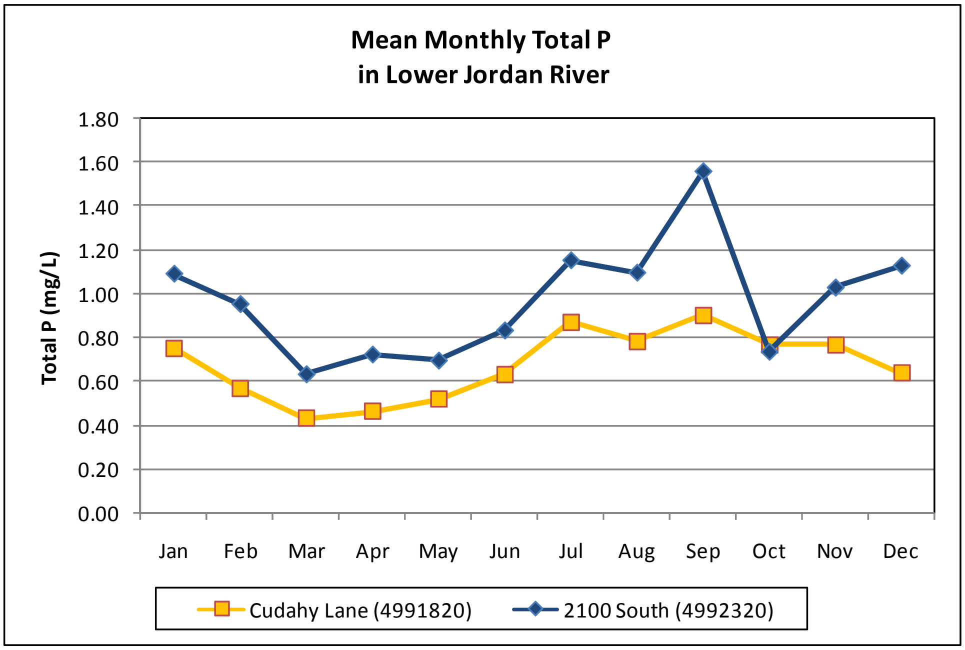

Figure 26. Total P in the lower Jordan River.

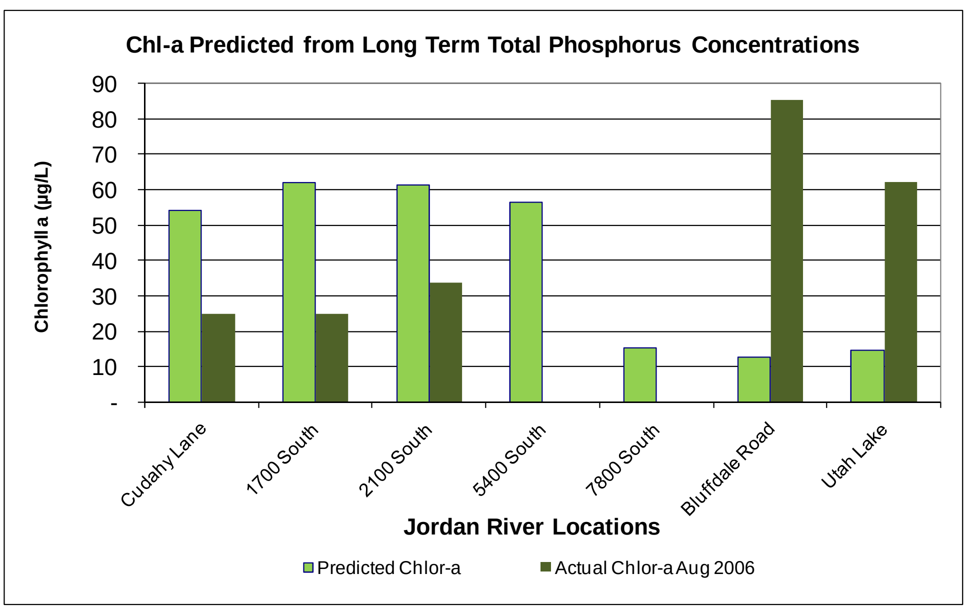

Figure 27. Actual and predicted Chlorophyll-a concentrations in the Jordan River (Cirrus 2009 Figure 4.21).

Table 3. Average N:P ratios measured from locations on the lower Jordan River (1978–2005). (Cirrus 2009 Table 4.9)

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

In conclusion, the influence of algae on DO is indicated by strong diurnal fluctuations in DO in August, with peaks in late afternoon and sags in DO at night, and weaker diurnal patterns in winter. Chlorophyll-a data shows a major source of algae from Utah Lake (senescent algae having already settled in lake), but additional algal growth below Utah Lake to 9000 South. Below 2100 South, algal growth may be limited by availability of N. Algal growth and senescence can be relatively rapid, doubling and dying within 24 hours, and contributing to very significant effects on a local scale. Senescing algae also provide a source of organic matter for aerobic decomposition, appearing as BOD and VSS in the water column and SOD at the sediment interface.

6.2 Contribution by Dr. Sam Rushforth

Dr. Rushforth reiterated that algae lead to a decrease in DO in the lower Jordan River in three ways: nighttime use of DO following net daytime production of DO during photosynthesis, bacterial decomposition of algae in the water column, and bacterial decomposition when algae senesce and settle to the bottom sediments.

The effects of these processes are summarized in Figures 28-30. Figure 28 shows that the time of day when the sample is taken can be extremely critical (it is important to note that DWQ has changed their DO sampling protocol to avoid taking samples during afternoon periods).

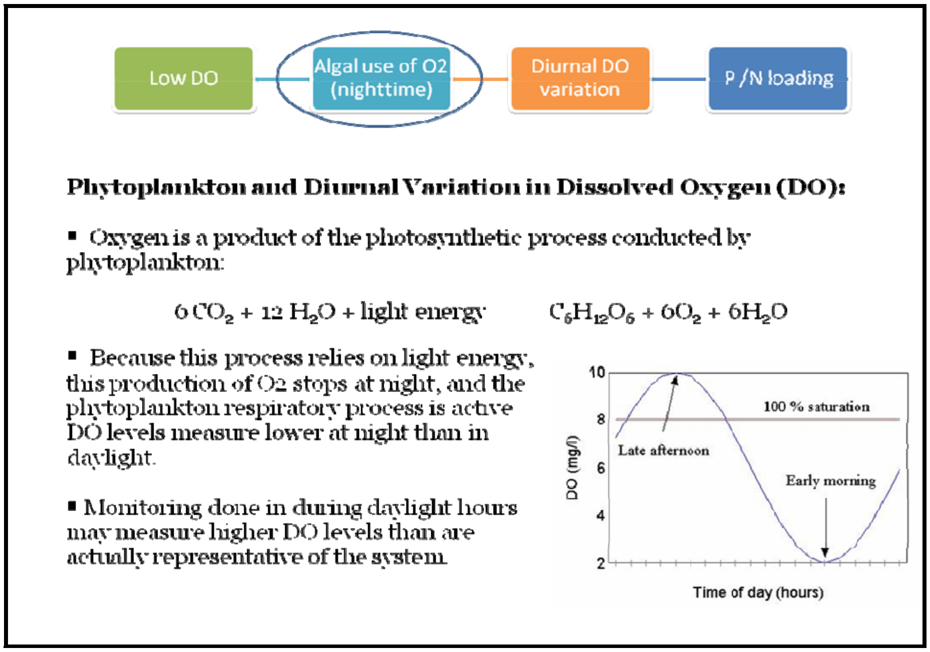

Figure 28. Nighttime algal effects on DO (from S. Rushforth presentation).

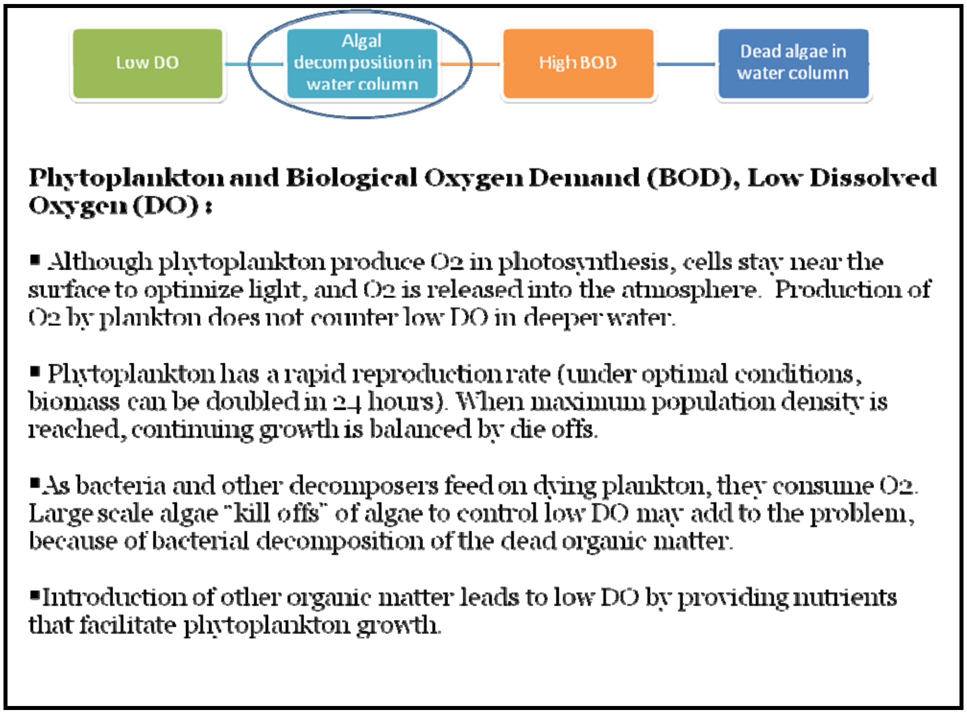

Figure 29. Phytoplankton effects on BOD (from S. Rushforth presentation).

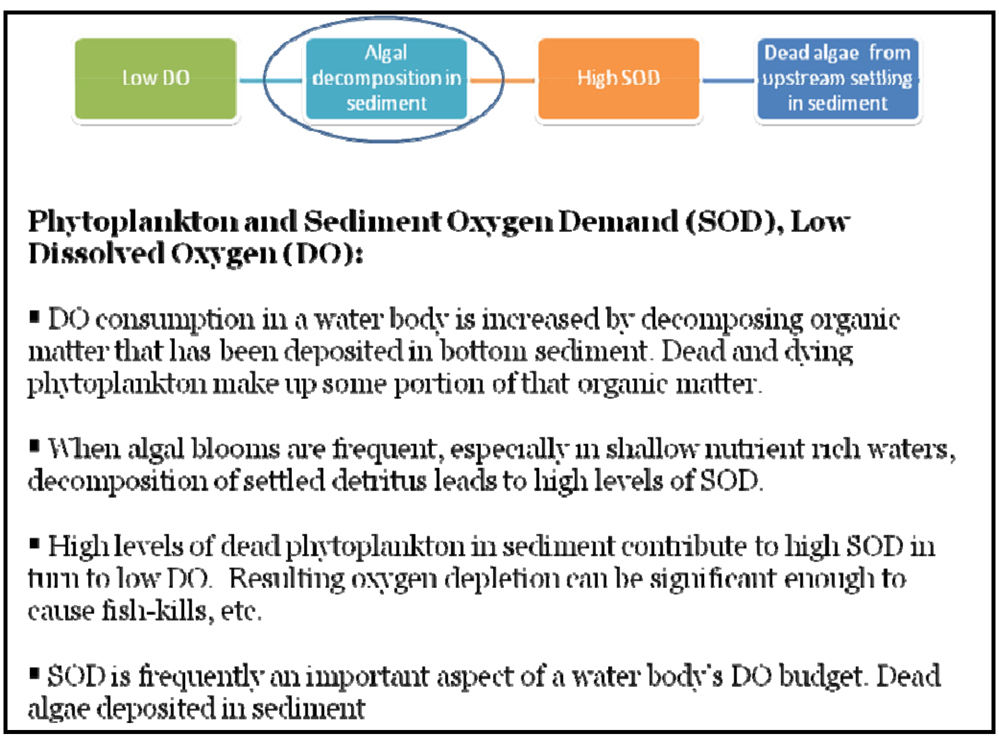

Figure 30. Algal effects on SOD (from S. Rushforth presentation).

Many algal species are facultative heterotrophs (i.e., they can derive their oxygen from other materials). One must look at the bottom sediments to know what species are present in the Jordan River. When water is warm, algae can double their biomass in 24 hours.

Knowledge of the taxonomic characteristics of algae can 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. Utah Lake undoubtedly contributes large quantities of algae to the Jordan River, and these 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 consequent change in algal species. It may then take some time for the "new" riverine species to grow.

Algae have been characterized by numerous conditions that augment or constrain their growth, such as pH, salinity, DO, and nutrients. Indices are available that help predict what algal species should exist. Knowing the species of algae can then lead to a better understanding of which conditions are occurring in which parts of the river.

Recommendations for additional algal data collection include the following:

- Examine phytoplankton samples at multiple sites along the Jordan River.
  - Seasonal samples.
- Examine bottom sediment samples at selected sites along the river.
- Examine phytoplankton samples at selected sites from the Surplus Canal.
  - Seasonal samples.
- Examine bottom sediment samples from the Surplus Canal.
- Examine phytoplankton samples in tributary streams.

6.3 PARTICIPANT DISCUSSION

One cause for poor Jordan River water quality documented in the Pollutant Loading Report is return flow from Utah Lake canals to the Jordan River, and it might be possible to measure the algal species to substantiate this.

Algal blooms do occur in Utah Lake, especially when water is warm and nutrients are plentiful. Algal growth can be so fast and heavy that their presence becomes light-limiting for growth in deeper water.

It is not known whether Geneva Steel influenced algal blooms. Core samples of bottom sediments as deep as 4 m look fairly homogeneous with respect to species of algae. Early records show large amounts of emergent vegetation in Utah Lake that have been destroyed by introduced carp. Geneva certainly didn't do as much damage to the lake as the carp. In Rushforth's opinion, removing the carp would improve the lake health to a large degree.

N:P ratios could be important. If the Jordan River is N-limited, it could become dominated by cyanobacteria which can fix their own N from the atmosphere. If not nutrient-limited, there will be a more diverse group.

There is a potential for algae to grow and die in the 24 hours of transit time below 2100 South. In the slow moving waters of the lower Jordan River, algae could settle out and increase SOD, which would help explain the lower DO concentrations below 2100 South.

Synoptic sampling of algae could help define the algal populations throughout the river; August would be the best time. Rushforth would expect 2-3 species of diatoms, likely a benthic community.

The QUAL2K modeling should make sure there is a buffer provided; allowable DO levels should be higher than just the minimum to provide for situations where sags occur due to short-term phenomena. Allowable levels need to protect for the "critical condition."

Salt Lake City is installing gages on City Creek, Dry Creek, and Midas Creek and all of the tributaries on the west side of the watershed, and the stations will include automatic water quality samplers. This should help to define the loads coming from these sources.

7. DISCUSSION AND PRIORITIES FOR ADDITIONAL UNDERSTANDING OF DO IN LOWER JORDAN RIVER

The participants were presented with a list of concerns and data needs that had arisen during the course of the symposium, organized into general categories. They edited this list and achieved a consensus on priorities for the near term. This list is reproduced below. **BOLD** text indicates a high priority.

1) Characterize organic matter
   - **a) Understand BOD decay rates – slow vs. fast degradability – in order to be able to estimate actual demand for DO while water travels through the lower Jordan River.**
     - **i) What forms of BOD are being measured by whom (total BOD_5 by DWQ, $cBOD_5$ by CVWRF?)**
     - **ii) Measure nBOD as well as cBOD in lower Jordan River.**
     - **iii) Characterize organic matter standing stock and flux.**
   - b) Better location on stormwater and canal return flow sources to evaluate where impacts occur in river – understand the seasonal variation in water source.
   - **c) Loads of sediment and organic matter from canals, pipes, lower tributaries emptying into Jordan River (not just into the lower Jordan River), especially storms and spring runoff (DWQ documented two fish kills in Jordan River in 2008 – where? when?).**
   - d) N:P ratios and availability (data from 2007-2008 not yet evaluated).
   - e) Experiments to measure local DO budgets – probes in water column short distance apart (~100 m) to measure DO and BOD dynamics without confusion of diverse inputs from long stretches upriver.
   - f) Chlorophyll-a (continuing) to measure the magnitude of algae populations.
   - **g) Species of algae and macrophytes to understand dynamics of growth and senescence as species composition changes from lacustrine (Utah Lake) to riverine. Evaluation of life cycles to estimate the impact of decomposition of suspended and settled organic material.**
   - h) Impacts of Utah Lake treatments, especially removal of carp, on water quality.
   - i) Historical impact of senescing algae from Utah Lake; look at stratigraphy of sediments.
   - j) Find a way to model DO following storm events on top of steady-state (chronic) conditions – to determine safety buffer needed for acute situations

2) Characterize inorganic processes
   a) **Chemical analysis of sediments (core samples).**
   b) Magnitude of oxidation of inorganic compounds, including NH4, CH4, sulfides, SO4, metals.
   c) Speciation of metals resulting from anaerobic conditions in sediments, e.g., species of ferrous ions.
   d) Chemical oxygen demand if sediments are disturbed or in steady state.
3) Temperature sensitivity of all reaction rates in QUAL2K
   a) Impact of temperature on nutrient availability.
   b) Impact of temperature on (net) reaeration (affects both rates of reaeration and saturated concentrations).
   c) **Opportunities for lowering temperature in lower Jordan River (characterize with continuous measurements, not grab samples); shading (East Canyon TMDL as an example), increased flows, etc.**
4) Benthic conditions
   a) **In-situ SOD measurements.**
      i) **Simple DO demand in lower Jordan River.**
      ii) **Look for places in upper Jordan River where diversions or other channel constrictions allow sedimentation – DO demand.**
      iii) **Sediment characteristics – organic and inorganic (above).**
   b) **Channel characteristics in lower Jordan River that may result in resuspension and reaeration.**
   c) Macroinvertebrate health as indicator.
   d) Turbidity and impacts on benthic processes.
   e) Changes in flow on turbidity and sedimentation (seasonal, storm events).
      i) **Measure sediment transport.**
5) Flows
   a) Opportunities for managing the river to provide higher flows to increase DO.
   b) **Measure detailed flows from canals and stormwater – quantity, timing – to evaluate short term but significant loading to Jordan River.**
   c) **Examine how source of water changes in lower Jordan River within and between years.**

Important interactions noted that may not have been studied but could be significant for understanding DO in lower Jordan River:

1) Temperature effects on reaeration.
2) Temperature effects on BOD rates.
3) Temperature effects on oxidizing inorganic materials.
4) Nutrients and SOD.
5) Nutrients and BOD.
6) Nitrification as a significant demand on DO.
7) Local diversions that trap and allow for resuspension of sediments; SOD in sediments behind diversions.
8) Impact of flows and changes in flows on settlement, resuspension, reaeration, and potential for flushing (“flushing” as in cleaning out sediments, but to where?).
9) Local and short term effects of algal growth and senescence.

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APPENDIX A. SYMPOSIUM ATTENDEES

Name	Organization	Title
Carl Adams	Division of Water Quality	DWQ TMDL Section Manager
Renette Anderson	Department of Environmental Quality	Director, Planning and Public Affairs
Hilary Arens	Division of Water Quality	DWQ Project manager
Neal Artz	Cirrus Ecological Solutions	Principal
Michelle Baker*	USU Dept of Biological Sciences	Associate Professor
Adrian Boogaard	SLC Department of Public Utilities	Water Maintenance Specialist
Royal Delegge	SLCo Department of Health	Director
Bryan Dixon*	Cirrus Ecological Solutions	Consultant
Dan Drumiller	SLCo Flood Control	Engineer
Eric Duffin*	Cirrus Ecological Solutions	Consultant
Ryan Dupont	Water Research Laboratory	Professor and Research Associate
Reed Fisher	Central Valley Wastewater Reclamation Facility	Engineer
Ramesh Goel*	University of Utah	Assistant Professor, Environmental Engineering U of U
Jim Harris	Division of Water Quality	DWQ Monitoring Section Manager
Marion Hubbard	SLCo Division of Engineering	Water Resources Specialist
John Kennington	Division of Water Quality	DWQ UPDES Section Manager
Briant Kimball	U.S. Geological Survey	Research Hydrologist
John Larsen	Jordan River Commission	Jordan River Commissioner
Theron Miller	Wastewater Consortium	Scientist
Bethany Neilson*	USU Dept of Civil and Environmental Engineering	Assistant Professor, CEE Dept - UWRL, USU
Karen Nichols	Stantec	Consultant
Jeff Niermeyer	SLC Department of Public Utilities	Director, Dept of Public Utilities
Jeff Ostermiller	Division of Water Quality	Water Quality Management
Florence Reynolds	SLC Department of Public Utilities	Administrator Water Quality and Treatment
Sam Rushforth*	Valley University	Dean - College of Science/Health
Sandie Spence	U.S. Environmental Protection Agency	TMDL Specialist
Neil Stack	SLCo Division of Engineering	Director
Nick von Stackleberg*	Stantec	Consultant
Dave Wham	Division of Water Quality	DWQ Environmental Scientist III
John Whitehead	Division of Water Quality	DWQ Branch Manager
* Presenter		

APPENDIX B. SYMPOSIUM SCHEDULE

JORDAN RIVER DO SYMPOSIUM APRIL 20, 2009 SCHEDULE	
9:00	Welcome and introductions
9:15	Cirrus and Stantec Presentation: Overview of Chapter 4 contained in *Jordan River TMDL Work Element 2 Pollutant Identification and Loading* report (January 2009)
9:30	Discussion Session 1 – Physical processes
10:30	Break and refreshments
10:45	Discussion Session 2 – Organic decomposition in water column
11:45	Short break
12:00	Discussion Session 3 – Organic decomposition in sediments
1:00	Lunch (provided)
2:00	Discussion Session 4 – Algae and other organisms
3:00	Wrap-up, including discussion on intervention and implementation opportunities and barriers
4:00	Close