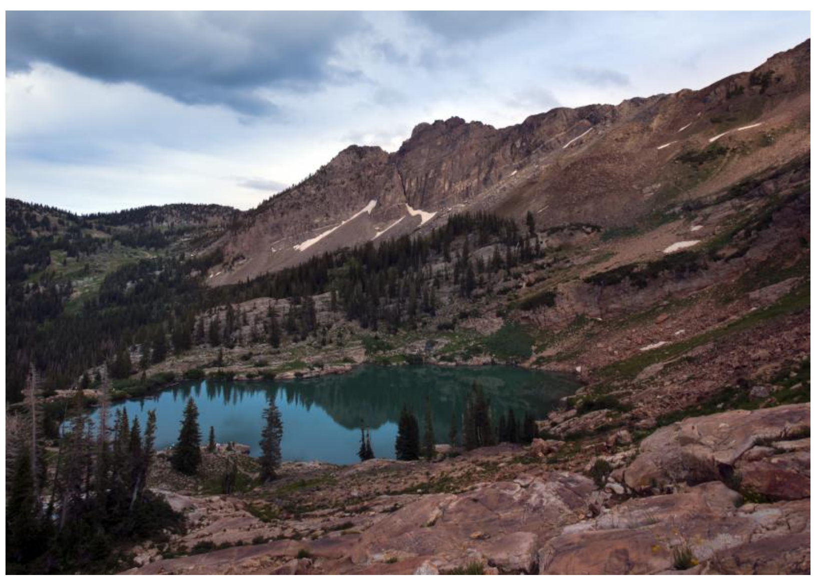
CHAPTER 7: UTAH'S DRAFT ASSESSMENT METHODS FOR HIGH FREQUENCY DATA AND PILOT APPLICATION FOR THE JORDAN RIVER



UTAH DEPARTMENT of ENVIRONMENTAL QUALITY
WATER QUALITY

2016 Final Integrated Report

[This page is intentionally left blank].

ACRONYMS

AU	Assessment Unit
CWA	Clean Water Act
DO	Dissolved Oxygen
DWQ	Utah Division of Water Quality
EPA	U.S. Environmental Protection Agency
IR	Integrated Report
MLID	Monitoring Location ID
QA/QC	Quality Assurance/Quality Control
POR	Period-of-record
POTW	Publicly Owned Treatment Works
WQS	Water Quality Standard

Contents

INTRODUCTION

Utah's Draft Assessment Methods and for High Frequency Data provide a framework for determining whether a waterbody or segment within a waterbody supports or does not support the Dissolved Oxygen (DO) criteria that were establish to protect the applicable aquatic life designated uses found in **UAC R317-2**. These water quality criteria include several different averaging periods that prescribe the magnitude and the duration of low levels of DO that should not be exceeded to maintain support groups of biota that vary in their relative susceptibility to low DO conditions. The assessment methods include several summary statisitics to facilitate the use of high frequency data to assess ambient conditions against both acute and chronic criteria.

The draft assessments methods are intended to be as closely aligned with Utah's existing water quality criteria, and the underlyng rationale used to support these criteria (EPA 1986), as possible. The methods also attempt to encapsulate the underlying rationale behind these criteria and the current scientific evidence with respect to the various ways that low DO conditions can degrade the health of stream biota. DWQ welcomes input on the draft assessment methods and recommendations for other approaches that could be used to interpret high frequency DO data in a way that improves the accuracy and interpretation of DO assessments. DWQ will evaluate and incorporate suggestions that are received, as appropriate, into revised assessment methods that will be used to make impairment decisions in subsequent *Integrated Reports*.

Background

DWQ's current assessment methods for field parameters (e.g., DO, temperature, pH) are based on data obtained from discrete water quality measurements (e.g., grab samples) during routine water quality sampling activities. While ongoing assessments based on discrete water chemistry collections enable DWQ to identify and address many water quality concerns, DWQ also acknowledges that there are important water quality parameters where instantaneous measurements are often insufficient. For instance, discrete samples are difficult to interpret for parameters that exhibit strong diel variation, such as dissolved oxygen, which can result in either over- or under-protection of water quality, depending on the time of day when the samples were collected.

Recent technological advances make obtaining high-frequency data (i.e., data collected on intervals of 1 minute to 1 hour to several hours) for field parameters more affordable and therefore more readily available. In many cases, these data provide more ecologically meaningful water quality information, particularly for temporally variable water quality parameters (i.e., dissolved oxygen concentration and saturation, specific conductance, pH, temperature, and turbidity) (EPA 1986). For example, high frequency data are more likely to reveal patterns of daily, weekly, monthly, or seasonal variation. Similarly, high frequency data can be used to more accurately quantify important water quality summary statisitics such as maxima (or minima) that are equally important determinants of threats to biological assemblages. In an assessment context, high frequency characterizations of water quality more closely mirror the duration and frequency components of water quality standards, which should lead to a reduction of both false positive and false negative impairment decisions.

While high frequency data offer numerous advantages, there are several unique challenges with their analysis and interpretation. For instance, the large data sets generated by such monitoring can be a challenge to manage, apply Quality Assurance/Quality Control (QA/QC) procedures to, and ultimately to interpret. For example, drift (systematic bias) sometimes occurs during long-term deployment of high frequency data collection instruments and methods are required for identifying and addressing suspect data.

Care must also be taken to ensure that summary statistics generated from these data sets quantify conditions that are consistent with the studies or investigations that were originally used to support water quality criteria. Together, the unique characteristics of these data mean that alternative assessment procedures are required.

Dissolved Oxygen

Of all the field-measured parameters, Dissolved Oxygen (DO) offers an opportunity to improve existing assessment methods based on high frequency data readings. DO often exhibits pronounced diel variation, particularly in highly productive environments where problems with low DO are most likely to occur. Utah's acute water quality criteria for DO are expressed as absolute minima, which are unlikely to be captured by grab sample data because these conditions are least likely to occur in the daytime when most water quality samples are collected.

Longer periods of low DO conditions can also lead to chronic effects on stream biota such as reductions in abundance or growth rates. Like many states, Utah's water quality standards protect against chronically low DO conditions with longer, 7-day or 30-day, averaging periods (Table 1). Periodic grab samples of DO make the direct calculation these averaging periods impossible. Even among streams where chronic conditions have been previously identified, the lack of long-term, high frequency data precludes identification of longer term (e.g., seasonal or year-to-year) temporal trends in DO conditions which could help identify appropriate mitigation efforts.

Table 1: Dissolved Oxygen (DO) standards for the State of Utah and site specific DO standards for the Jordan River, Utah.

Site specific criteria for DO for the *Jordan River*				
Time of year	**May-July**	**August-April**		
30 Day Average (mg/L)	5.5	5.5		
7 Day Average (mg/L)	5.5	NA		
Minimum daily (mg/L)	4.5	4		
DO criteria for the *State of Utah*				
Designated waterbody type	**3A**	**3B**	**3C**	**3D**
30 Day Average (mg/L)	6.5	5.5	5.0	5.0
7 Day Average (mg/L)	9.5/5.0*	6.0/4.0*	NA	NA
Minimum daily (mg/L)	8.0/4.0*	5.0/3.0*	3.0	3.0

Note: As per R317.2.1.1(b), up to 10% of representative samples may exceed the minimum criterion for dissolved oxygen.
* Early life stages present / all other life stages present. Early life stages assumed present unless demonstrated otherwise.

ANALYSIS AND INTERPRETATION OF HIGH FREQUENCY DISSOLVED OXYGEN DATA

If high frequency data are to be used to make water quality assessment decisions, it is necessary to summarize the data in a way that allows direct interpretation of the magnitude, duration and frequency components of water quality standards. The selection of appropriate summary statistics should also align with the scientific basis behind DO criteria, as described in the EPA guidance that provided their underlying rationale. This section describes how DWQ proposes summarizing and assessing high frequency DO data, and the underlying rationale behind the draft assessment methods.

Quality Assurance: Screening Raw DO Data

DWQ has developed a detailed QA/QC process for high frequency monitoring data. First, data sets are graded into several discrete categories based on the relative rigour of collection methods (see Chapter 7 Appendix 1). High frequency data sets that receive data quality grades of an A or B will be considered suitable for formal assessment purposes. Next, qualifying data sets are screened for data anomalies such as data drift or other instrument errors following the procedures and recommendations of the US Geologic Survey (Wagner et al. 2006). All questionable data points are removed prior to analysis and interpretation. These data quality screens are particularly important for DO sensors because they are subject to bio-fouling, especially in nutrient-rich waters where they have a higher potential to become covered with algae growth. When bio-fouling occurs, it results in erroneous logger measurements, or sensor drift.

Assessing DO with High Frequency Data: Draft Methods

Utah's DO criteria are largely based on USEPA's guidance "Ambient Water Quality Criteria for Dissolved Oxygen" (USEPA, 1986). When drafted, this guidance document compiled existing scientific literature and made several recommendations for appropriate DO criteria based on the following assumptions:

- Chronic criteria (7-day and 30-day moving averages) are needed to minimize the extent to which low DO threatens the condition of fish populations (e.g., density, growth rates)
- Acute (1-day minimum) criteria are intended to protect against the lethal effects of low DO
- More strigent criteria are required for protection of early life stages
- Together chronic and acute criteria are intrinsically protective of biota other than fish
- Warm water fish assemblages are more tolerant to low DO than cold water fish assemblages

With these assumptions in mind, DWQ identified several summary statistics that can be calculated from high frequency data and used to evaluate the acute and chronic effects of low DO to biological designated uses. These statistics were then divided into two classes: Primary Statistics and Secondary Statistics. Primary statistics are measure with direct linkages to Utah's water quality standards, which are used to evaluate both acute and chronic DO impairments. Supplemental statistics are measures that are intended to provide insight into the nature and extent of any DO impairments that are identified.

Primary Statistics: Assessing Acute and Chronic DO Impairments

These draft assessmenrt methods use summary statistics that can be most directly linked to Utah's DO criteria (UAR R317-2) to make impairment decisions (Table 1). These primary statistics include considerations for whether or not sensitive life stages are present, as well as alternative measures for acute and chronic DO conditions. Table 2. Summary of primary statistics

Primary statistics
7-day moving mean
30-day moving mean
Single day (24 hour) minimum
Frequency of minimum exceedance

CONSIDERATION FOR SENSITIVE LIFE STAGES

As discussed earlier, water quality standards include dual criteria for both acute and chronic 7-day average criteria depending on whether early life stages are present. This difference can complicate interpretation of chronic DO criteria, because data that documents the presence or absence of sensitive life stages is often unavailable. In such circumstances, the more conservative criterion will be applied for assessment purposes (i.e., assume that sensitive life stages are present unless data exist to demonstrate that they are not). This is consistent with the application of early life stage assumptions in other DWQ programs, such as wasteload analyses. If an impairment decision hinges on this conservative assumption (i.e., the site would not be considered impaired if sensitive life stages are not present), then DWQ will conduct further investigations on the fish assemblage in the assessment unit and modify the assessment decision if appropriate.

DO MINIMA STATISTICS AS INDICATORS OF ACUTE IMPAIRMENTS

DO minima criteria are intended to protect resident biota against lethal (acute) effects of low levels of DO (USEPA 1985, 1986). Consistent with this guidance, Utah's water quality criteria includes daily minima DO criteria to protect aquatic life against acutely low DO. This is expressed in Utah's water quality criteria using the averaging period "*not less than at any time*". Again consistent with EPA guidance, DWQ interprets any single reading lower than the applicable DO minima as a WQS violation; however, biota do not generally respond to very short intervals of low DO, so interpreting a criterion violation of short duration as an impairment may be be overly conservative. As a result, and per 317.2, up to 10% of all acute criteria were allowed to be exceeded without DWQ inferring an impairment .

Two acute DO minima summary statistics were calculated:

1) The percentage of total measurements that exceed the criterion versus the total number of measurements in the Index Period and the Period-of-Record respectively and the,
2) the percentage of days in which the minimum was exceeded

DO AVERAGE STATISTICS (7-DAY AND 30-DAY) AS INDICATORS OF CHRONIC IMPAIRMENTS

Chronic DO water quality concerns are evaluated with long-term (7-day and 30-day) averages. When calculating longer-term averages from high frequency data, one important consideration is the recording frequency of individual observations. Currently, there is no standard recording frequency for the collection of high frequency DO concentrations. The instruments that collect these data can generally be set at any user-defined interval. These differences among data sets create problems with the consistent analysis and interpretation of high frequency data. This is especially true if data from different sources are combined—as required for 303(d) assessment programs by CWA regulations. The interval between DO readings can alter the ecological interpretation of low DO conditions, which could potentially lead to differing impairment conclusions. For instance, longer intervals may be more consistent with DWQ's ongoing use of instantaneous DO measurements, whereas higher frequency data (i.e., 1, 5, 15 minutes rather than 2 hour) more accurately quantifies the temporally dynamic variation in DO concentrations. Ideally, datasets should be generated in hourly (or less) intervals.

Utah's DO water quality criteria also include protection against chronic problems resulting from extended periods of low DO conditions. The criteria specify an averaging period of 7- and 30-days (Table 1). DWQ proposes that these calculations should mirror those originally used to derive Utah's DO criteria (EPA 1985, 1986). Specifically, DWQ first calculated the daily mean DO from all of a single days measurements. Next, DWQ used these daily averages to calculate a moving average over both 7-day and 30-day intervals to facilitate interpretation of the data against the chronic DO criterion.

ACUTE ASSESSMENT PROCEDURES

The draft assessment methods (Figure 1) uses high frequency DO measurements to assess the frequency of excursions below the DO minima criteria based on the duration of these violations within a day and also the total number of days where DO minima criteria violations were observed. For this assessment draft, the total number of days where the minima criterion was exceeded at least once was tabulated. Also, the sum total of all observed excursions below the minima criterion is compared against the total number of observations within the Period-of-Record and Index Periods. Any site, and associated assessment unit, where acute criteria are exceeded for >10% of *days* over the Period-of-Record and/or the Index Period will be considered impaired (Figure 1). Additionally any site where acute criteria exceed >10% of *observations* over the Period-of-Record and/or the Index Period will result in the site being considered impaired. Chronic and acute criteria will be evaluated independently.

CHRONIC ASSESSMENT PROCEDURES

Chronic DO criteria are intended to protect against conditions that may alter the health, condition or productivity of aquatic biota (EPA 1985, 1986). Consistent with EPA guidance, the duration of exposure to low DO conditions is dependent upon whether sensitive life stages—most commonly fish fry—are present. If sensitive life stages are present, then the more stringent 7-day criterion is required, otherwise the less stringent 7-day criterion is applied for other life stages (see Table 1).

Where data of sufficient duration are available, DWQ will assess the chronic DO criteria with both the 7-day and 30-day averaging periods using moving average summary statistics. These calulations are made by first calculating the daily arithmetic mean of DO observations. Next, these daily means are averaged over both 7- and 30-days, moving from one day to the next over the POR. Consistent with the rationale that EPA used to support the DO recommendations (EPA 1986), these calculations allow DWQ to evaluate not just the total number of violations of the DO chronic criteria, but also the persistence of any observed excursions. Also, comparisons between these averaging periods will allow DWQ to evaluate whether or not chronic DO impairments hinge on the presence or absence of sensitive life stages. If neither the acute nor chronic assessments result in an impairment decision, then the site would be considered to be fully-supporting its aquatic life uses with respect to dissolved oxygen.

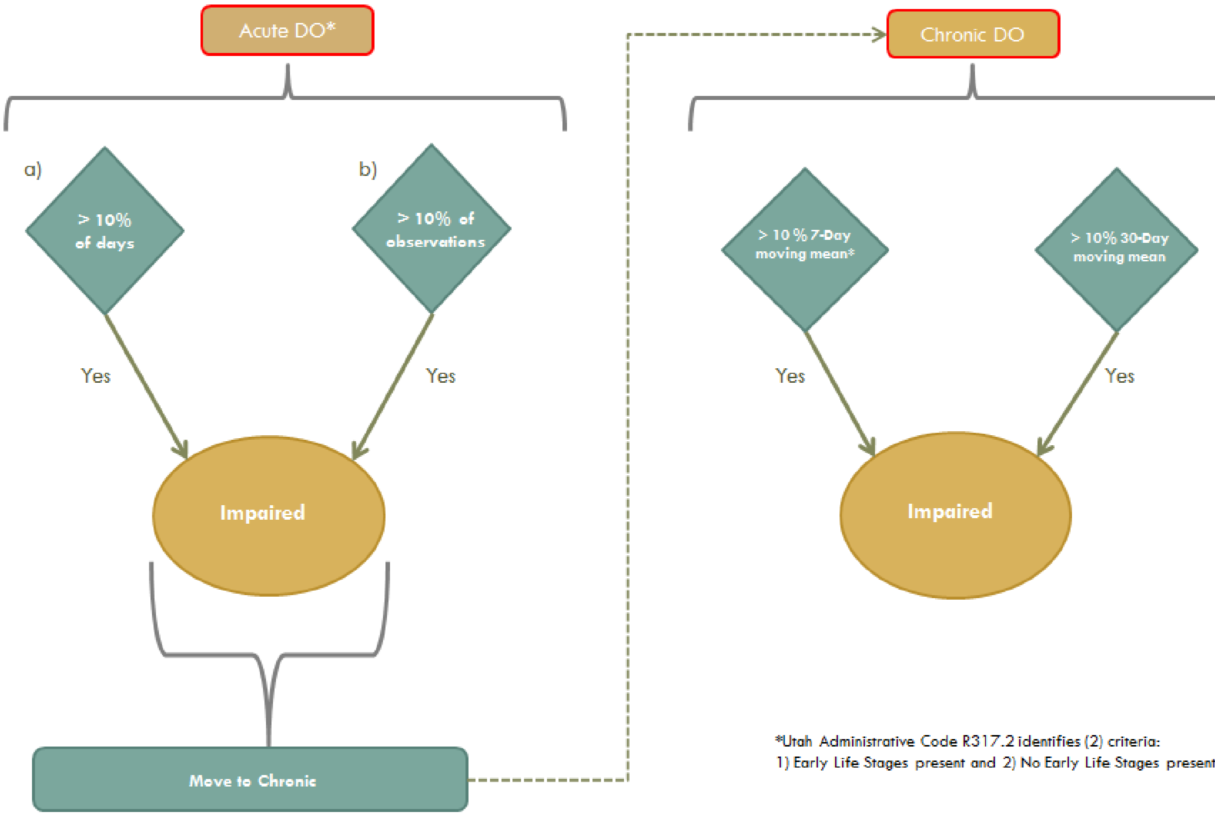


Figure 1: Assessment methods for high-frequency dissolved oxygen (DO) measurements.

Secondary Statistics: Better Interpretations of DO Water Quality Concerns

DWQ's draft assessment methods also incorporate several secondary statistics as supplemental water quality indicators (Table 3). These supplemental statistics are not intended to identify water quality impairments, but to provide supporting information to better understand the nature and extent of any DO imparments that are ultimately identified. For instance, supplemental summary statistics can be used to better link DO observations to independent scientific investigations on the effects of low DO conditions on aquatic biota.

Since USEPA's guidance was initially drafted, scientists have continued to explore the specific mechanisms that can cause low levels of DO and have deleterious effects on fish and other aquatic biota (see WSDE, 2002 for an extensive review). These investigations highlight several secondary statistics that may be used to help summarize and interpret low DO events (Table 3). DWQ calculated several of these measures as secondary statistics to help better understand any DO impairment that are ultimately identified (Table 3). For instance, long durations of low DO concentrations, particularly acutely low concentrations, can be particularly stressful to biota, which makes the duration of low DO event ecologically meaningful). Another example is the diel flux of DO. Large differences between the daily maximum and minimum DO concentrations are stressful to stream biota. Temporal patterns of these fluxes can also be used to understand changes in relative rates of Gross Primary Production and Ecossytem Respiration, which has the potential to provide insights into the underlying causes—and potential solutions to—low DO concentrations.

Table 3. Summary of secondary statistics

Secondary Statistics
Duration of DO conditions below criterion
Frequency of recurrent low DO events
Spatial extent of low DO
Diel flux of DO

JORDAN RIVER PILOT STUDY: AN APPLICATION OF DRAFT ASSESSMENT METHODS

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

Designated beneficial uses for the various segments of the Jordan River include domestic uses (with prior treatment), secondary contact recreation (boating, wading, fishing, etc.), cold and warm water fisheries, other wildlife that depend on an aquatic environment (waterfowl, shorebirds, and the aquatic organisms in their food chains), and agricultural irrigation. These uses are protected by a variety of water quality standards, but every segment of the Jordan River has been found to be non-supporting of one or more beneficial uses (i.e., impaired) due to exceeding one or more of these water quality standards. With respect to DO, only the lower Jordan River downstream of the Surplus Canal (north of 2100 South in Salt Lake City) is listed as impaired.

The decision to pilot the draft methods with a water body that is already listed for DO was intentional. DWQ does not intend to use the draft high frequency DO methods to make new impairment decisions until they are fully vetted with stakeholders. Instead these assessment results are intended to highlight areas where the draft assessment methods can potentially be improved and to provide conformational support for the existing DO listings.

Methods

DO data for this pilot application of the draft high frequency assessment methods were obtained from data sondes (YSI EX01) that were deployed and are maintained by the Jordan River, Farmington Bay Water Quality Monitoring Council (JRFBWMC) at (5) sites along the lower Jordan River, from upstream to downstream: 3300 South (MLID # 4992880), 2100 South and 1100 West (MLID #4992320), 800 South above drain outfall (MLID #4992050), 300 North (MLID #4991900) and Cudahy Lane above the South

Davis POTW (MLID # 4991820) (Figure 2). At each of these locations sondes recorded DO concentrations in 15-minute intervals. While these data collection efforts are ongoing, data from 2014 were used for this pilot investigation because this was the most complete data set available at the beginning of this investigation.

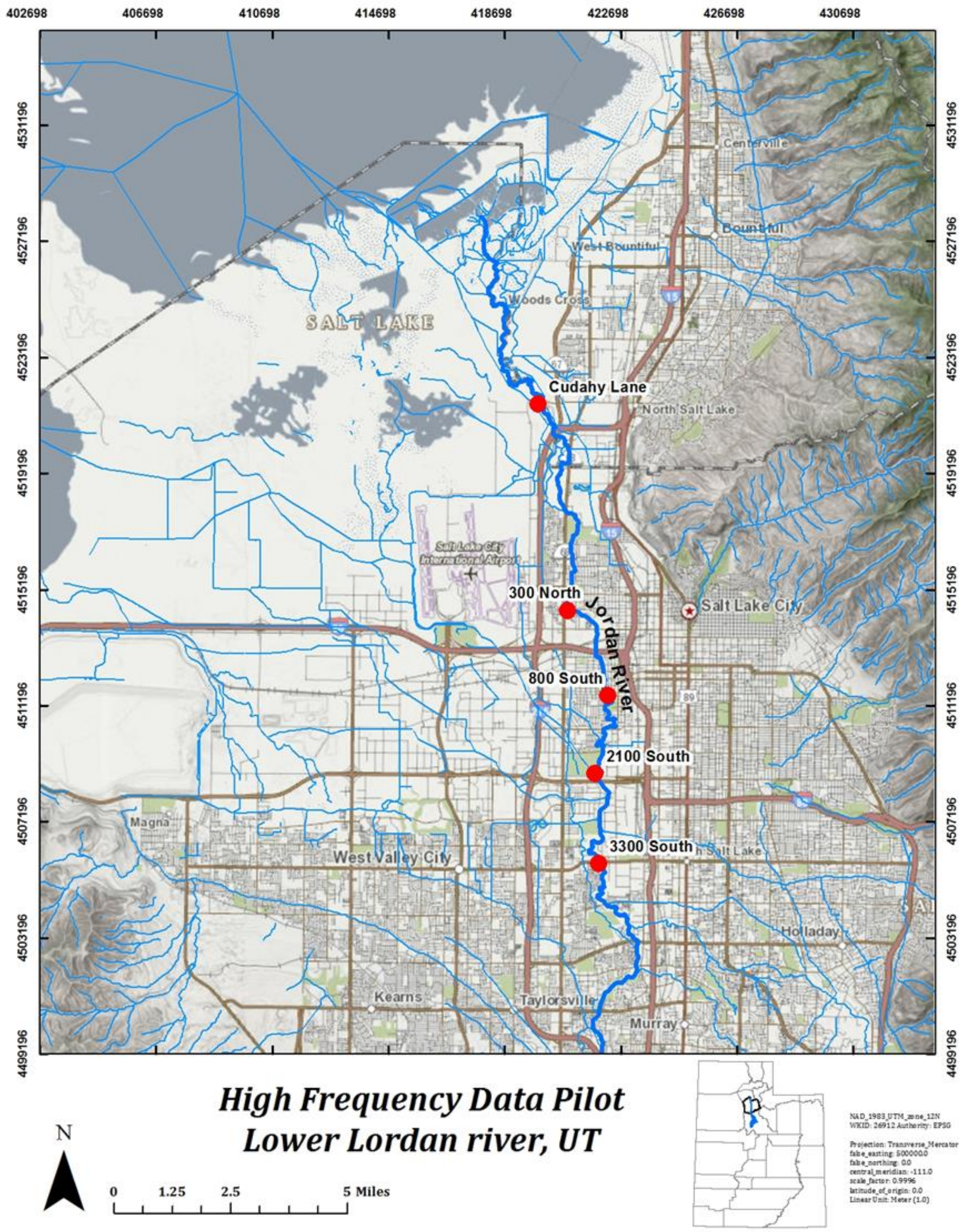


Figure 2: Locations of high-frequency sites along the lower Jordan River, Utah.

DO data from each location were screened with existing credible quality control procedures. Specifically, a database was used to plot the raw data to facilitate identification of anomalous data. Data that was deemed erroneous either via known issues with the logging device, sensor issues, or where no data was recorded by the logger were removed from data analysis. Using a simple database, the raw data (dissolved oxygen and battery voltage) was plotted and examined. In many instances where the DO measurements seemed erroneous (e.g., 0 or 25mg/L) there was an associated issue with battery voltage (i.e., 0 or 236) which resulted in sensor malfunction. Similarly, at several different sites the DO would remain at the same concentration from days to months. Any questionable DO observations that were identified were not used in the analysis. In all cases careful best professional judgement (BPJ) was used to aggregate and retain the clean data for subsequent analysis.

All summary statistics were calculated from all credible data that were not eliminated in the QA/QC process. Data were analyzed independently for the two periods (i.e., May through July and August through April) defined in the site-specific standards for the Jordan River (Table 1). All summary statistics were then plotted for each monitoring location. In total, three figures were generated for each monitoring location to summarize different DO characteristics: 1) a daily minimum DO and duration of exceedances of acute criteria, 2) 7- and 30-day moving mean, and 3) DO daily maximum and minimum and diel variation. Once generated, these plots were used to conduct pilot assessments for each monitoring location to illustrate the draft assessment process.

Results

QA/QC of the Jordan River DO Records

The QA/QC process was successful in the identification and removal of suspect/erroneous data. For instance, there were several instances where one or two consecutive observations differed greatly from the overall trend immediately prior to or following the observations. There were also several circumstances where observations were not recorded creating gaps in an otherwise continuous data record. Using DWQ's Data Quality Matrix for High Frequency Data (see Chapter 7, Appendix 1.) The data for this pilot project would be a "C" on an A through D scale. The data had no definable verification or calibration reports which would indicate periods of sensor drift or the like. As a result, DWQ was unable to address instrument drift associated with bio-fouling or calibration drift. There are QAQC methods to account for drift but the data used in this pilot project does not include any data verification or calibration records that could be used to correct drift in the dataset. Consequently, the data used as part of this pilot project is considered *provisional*. Typically, the lack of independent measures that could be used to QC sensor data would be sufficient to disqualify a high frequency dataset from use in making 303(d) impairment decisions. However, given that this is a pilot investigation and conducted on a stream segment that is already listed for DO, DWQ opted to proceed with the analysis.

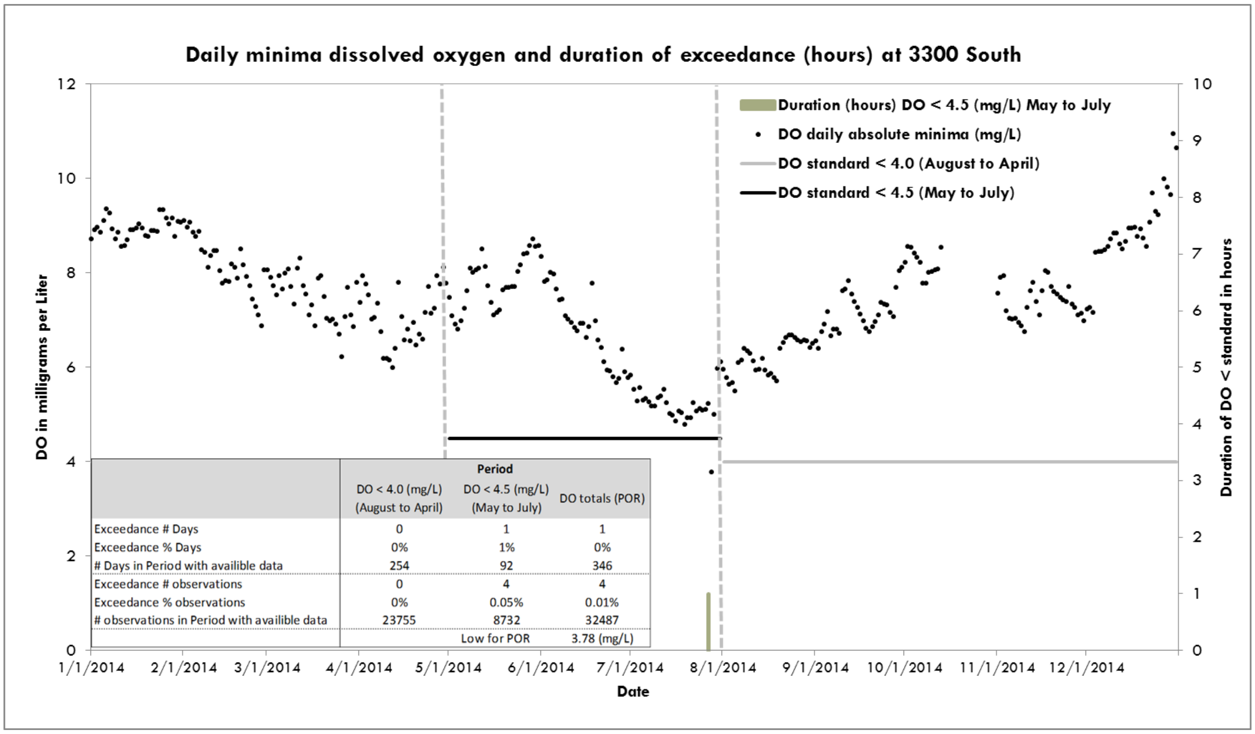
Site-Specific Characterization of DO on the Lower Jordan River

This section summarizes the pilot high frequency data analysis using draft assessment methods for sites along the lower Jordan River, from upstream to downstream.

3300 SOUTH MONITORING LOCATION

Following the draft assessment methods, there was no evidence of of a DO impairment at the most upstream location on the lower Jordan River. With respect to potential acute DO concerns, the absolute minimum DO observed at this location was 3.78 mg-DO/L, which does exceed the minimum criterion of 4.5 mg-DO/L (Figure 3). However, this only occurred once for one hour in duration, which means that the site would not be considered impaired according to the acute criteria assessment rules. In addition, no violation of either the 7-day or 30-day moving averages occurred (Figure 4), which means that chronic DO violations were not observed, irrespective of whether or not early life stages are present at this site.

With respect to supplemental statistics, the average diel variation at this site was the greatest of all sites (4.09 mg-DO/L/day) (Figure 5). The large diel variation may be stressful to biota, though this is not overly concerning, given that acute and chronic criteria were met. Of note was an extended period of relatively high variation in late winter. Given that low DO observations were not made over the same period, this suggests that there may be a peak in primary production immediately prior to spring runoff. The daily minima indicator also reveal a pattern of relatively low DO conditions in late July (Figure 3).



	Period		
	DO < 4.0 (mg/L) (August to April)	DO < 4.5 (mg/L) (May to July)	DO totals (POR)
Exceedance # Days	0	1	1
Exceedance % Days	0%	1%	0%
# Days in Period with availible data	254	92	346
Exceedance # observations	0	4	4
Exceedance % observations	0%	0.05%	0.01%
# observations in Period with availible data	23755	8732	32487
		Low for POR	3.78 (mg/L)

Figure 3: The daily minima represents the lowest measured value of each day and is used as a primary statistic for 3300 South.

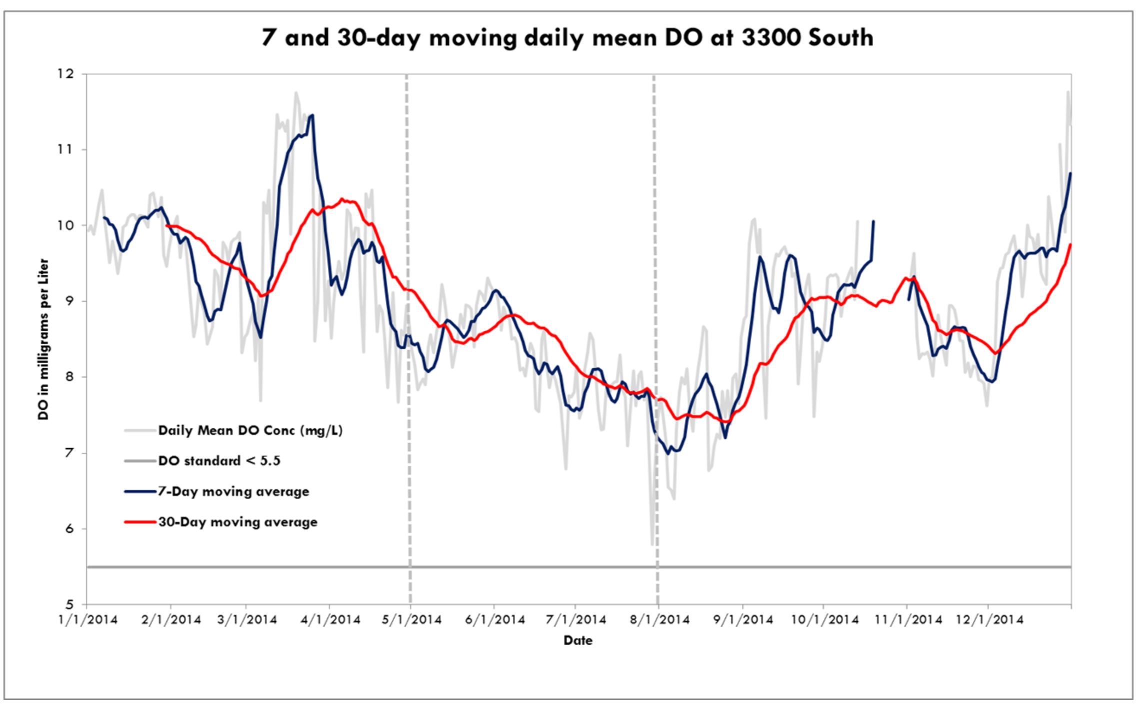


Figure 4: The 7- and 30-day moving daily mean dissolved oxygen from 3300 South. The gray horizontal line denotes the water quality standard of 5.5 (mg/L) for the entire year for the 7- and 30-day moving daily mean.

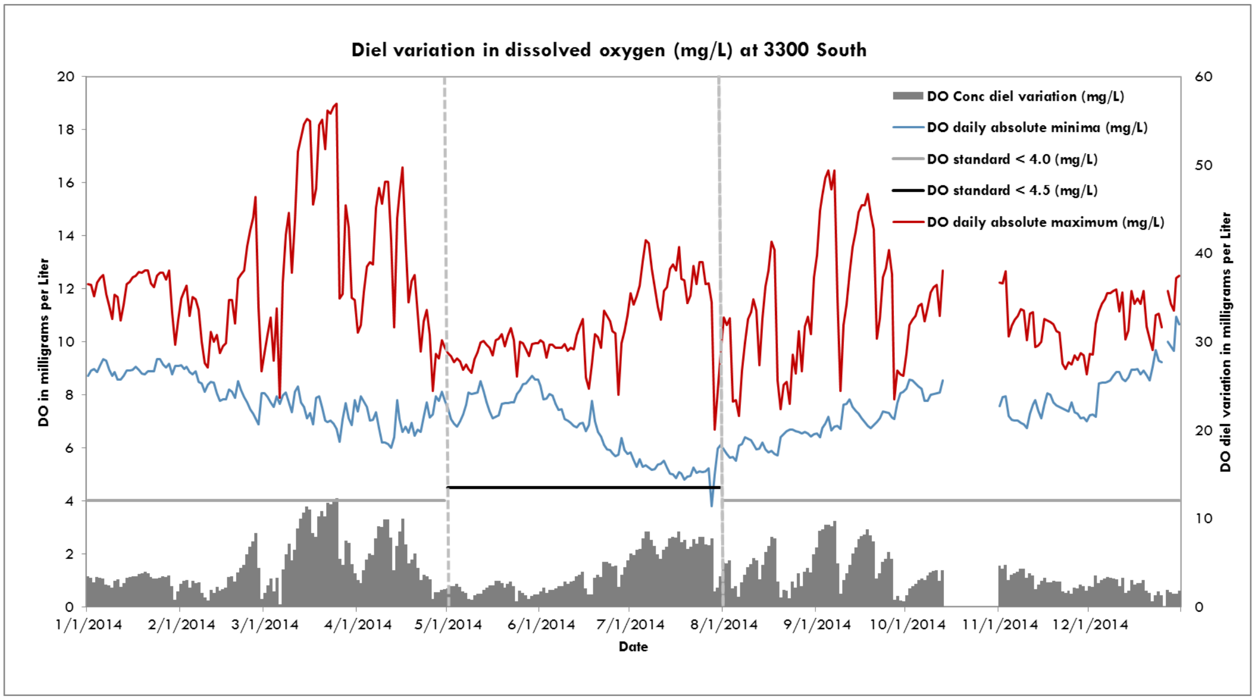
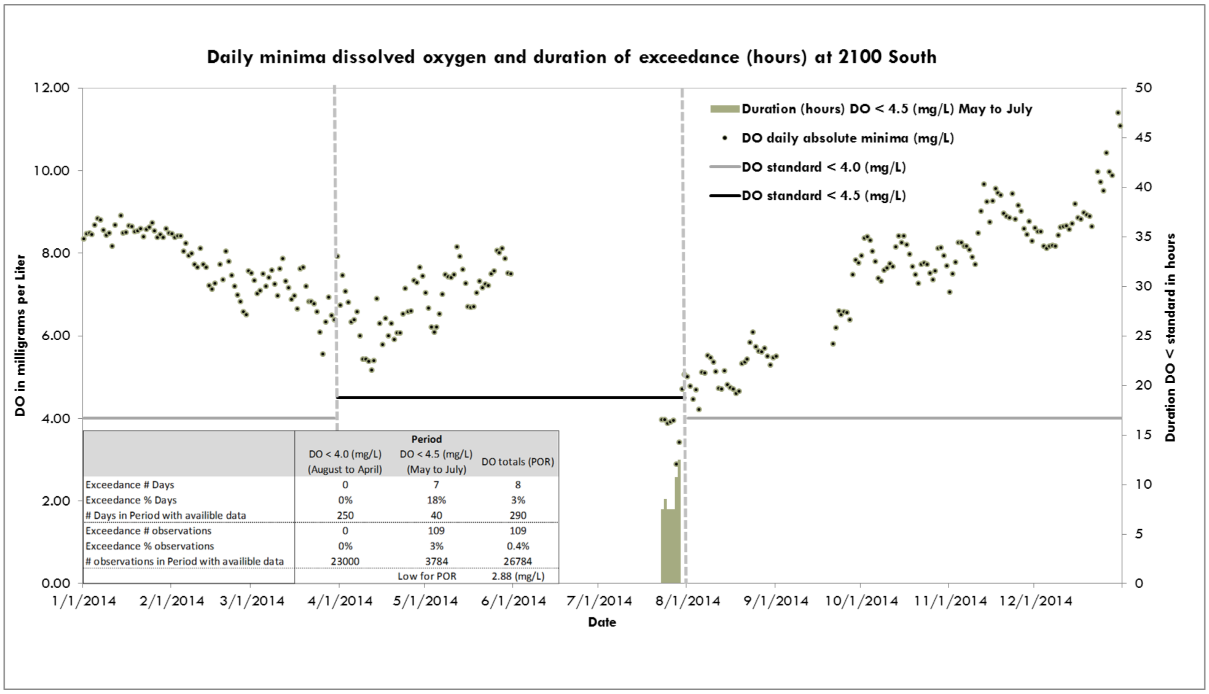


Figure 5: Temporal trends in dissloved oxygen and the diel variation (mg/L) at 3300 South. The water quality standards for the Jordan River for dissloved oxygen (mg/L) are dennoted by the gray and black lines and are 4.0 (mg/L) and 4.5(mg/L) with respect to the times of the year.

2100 SOUTH MONITORING LOCATION

The 2100 South monitoring location exhibited mixed results with respect to the draft acute DO impairment decision rules. The daily DO minima criterion was only exceeded 3% or 8 days in the Period of Record which fails to meet the draft impairment threshold of 10% (Figure 6). The available data suggest that these instantaneous minima violations may have been confined to a single incident in late July. However, this interpretation is complicated by the fact that DO data at this location were not recorded for several weeks immediately preceding this incident due to suspected equipment failure. Interpretation of the chronic DO criteria is similarly complicated by missing data during the peak growing season. Nevertheless, among data that were recorded, violations of the chronic DO criteria were not observed for the 7-day and 30-day moving averages (Figure 7).

Daily DO diel variation was generally much lower at this location than it was at the next location upstream (3300 South) (Figure8). Similar to the 3300 S location upstream, high variation values were observed in late winter, although the magnitude of diel variation in DO was not as pronounced. The daily minima is also difficult to interpret due to missing data, but those observations that were recorded suggest that late summer may also be a period of particular interest at this monitoring location (Figure 6).



	Period		
	DO < 4.0 (mg/L) (August to April)	DO < 4.5 (mg/L) (May to July)	DO totals (POR)
Exceedance # Days	0	7	8
Exceedance % Days	0%	18%	3%
# Days in Period with availible data	250	40	290
Exceedance # observations	0	109	109
Exceedance % observations	0%	3%	0.4%
# observations in Period with availible data	23000	3784	26784
		Low for POR	2.88 (mg/L)

Figure 6: The daily minima represents the lowest measured value of each day of the period-of-record and for the time being will be used as supplemental data for 2100 South. Additionally the inserted table reflects seasonal exceedences in days, the percentage of exceedances in relation to the total days in the period-of-record as well as the number of observations that are exceeding the standard and the percentage as compared to the total observations.

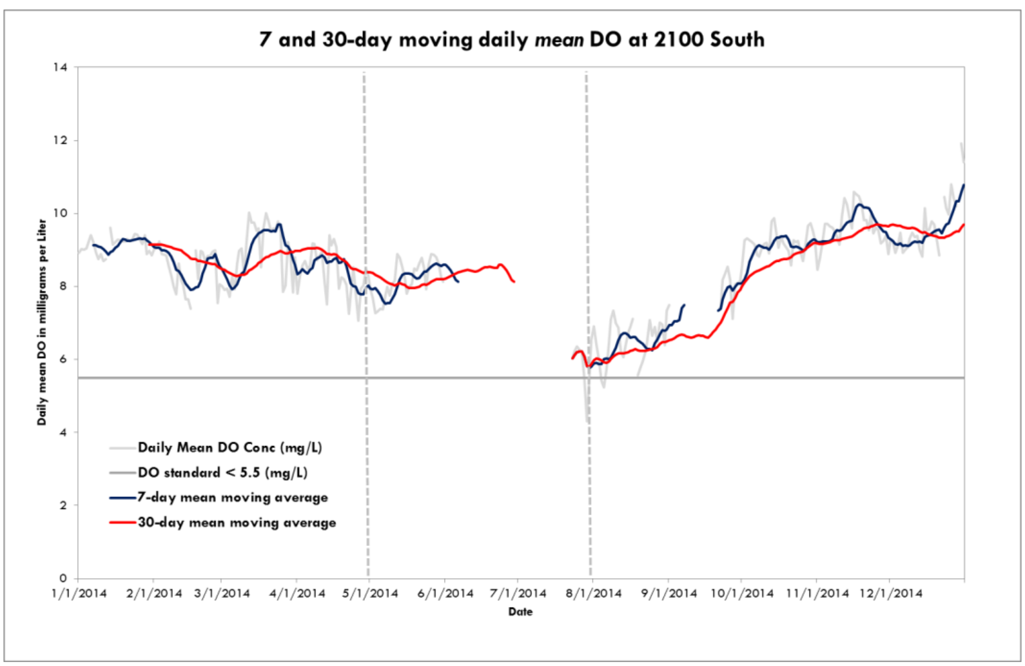


Figure 7: The 7- and 30-day moving daily mean dissolved oxygen from 2100 South. The gray horizontal line denotes the water quality standard of 5.5(mg/L) for the entire year for the 7- and 30-day moving daily mean.

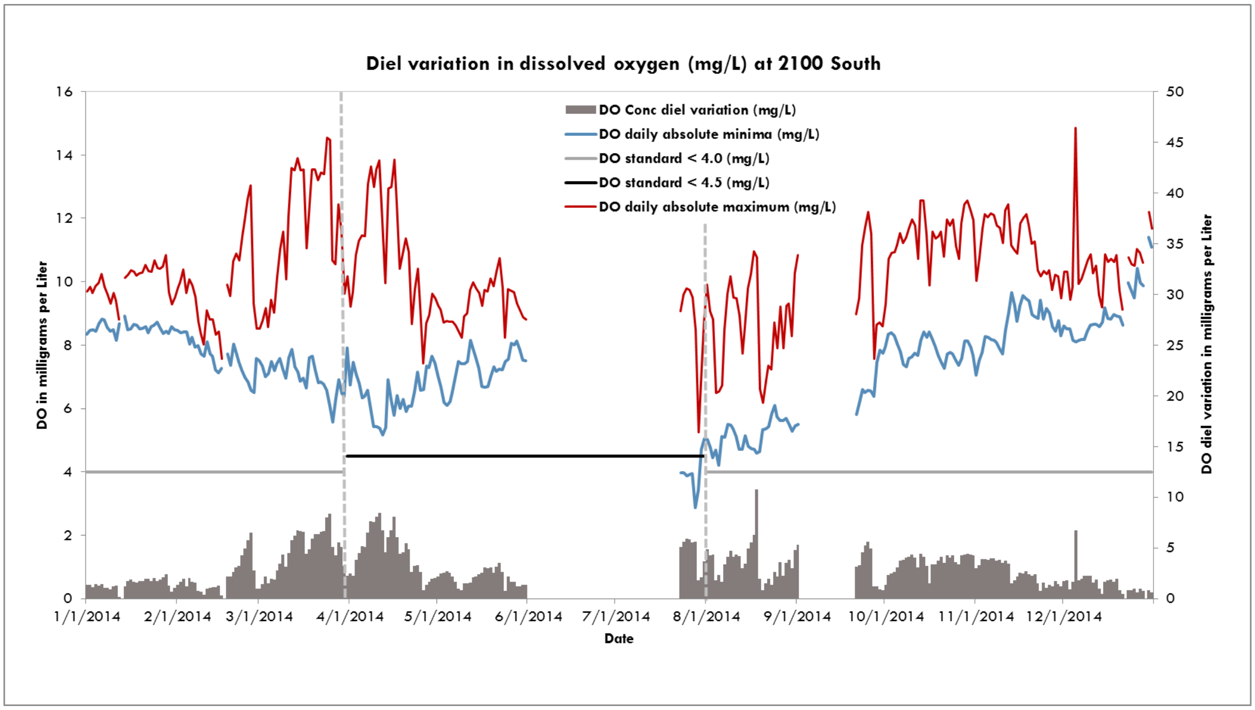


Figure 8: The dissloved oxygen(DO) daily minima and the diel variation in hours that the measured DO is below the water quality standard in hours per day at 2100 South. The water quality standards for the Jordan River for dissloved oxygen (mg/L) are dennoted by the gray and black lines and are 4.0(mg/L) and 4.5(mg/L) with respect to the times of the year.

800 SOUTH MONITORING LOCATION

Data from the 800 South monitoring location are also complicated by missing summertime data, however those data that were recorded indicate an impairment based on the draft assessment methods. The absolute minimum DO observed at this location was 1.64 mg-DO/L, which is less than ½ of the instantaneous minima criterion (Figure 9). The acute criteria were violated on 8 days in the Index Period and 22 days in the period from August to April. In total there were 30 days or 42% of the POR where DO was lower than the site specific standards. More concerning with repect to potentially deleterious affects on aquatic biota, the longest single continuous recorded period of acutely low DO conditions was 39 hours. Daily moving average calculations among the recorded data reveal violations of both 7-day and 30-day chronic criteria with 45% and 46% of observations exceeding the criteria respectively (Figure 10).

As intended, the draft supplemental statistics highlight several interesting patterns in the temporal DO conditions at this location. Unlike the locations upstream, the daily variation in DO was relatively small and did not exhibit any obvious patterns among seasons (Figure 11). The daily minima violations suggest a much longer period of potential concern than either of the upstream locations with a cumulative duration for the Period of Record when the DO was less than the standard for 233.5 hours (Figure 9).

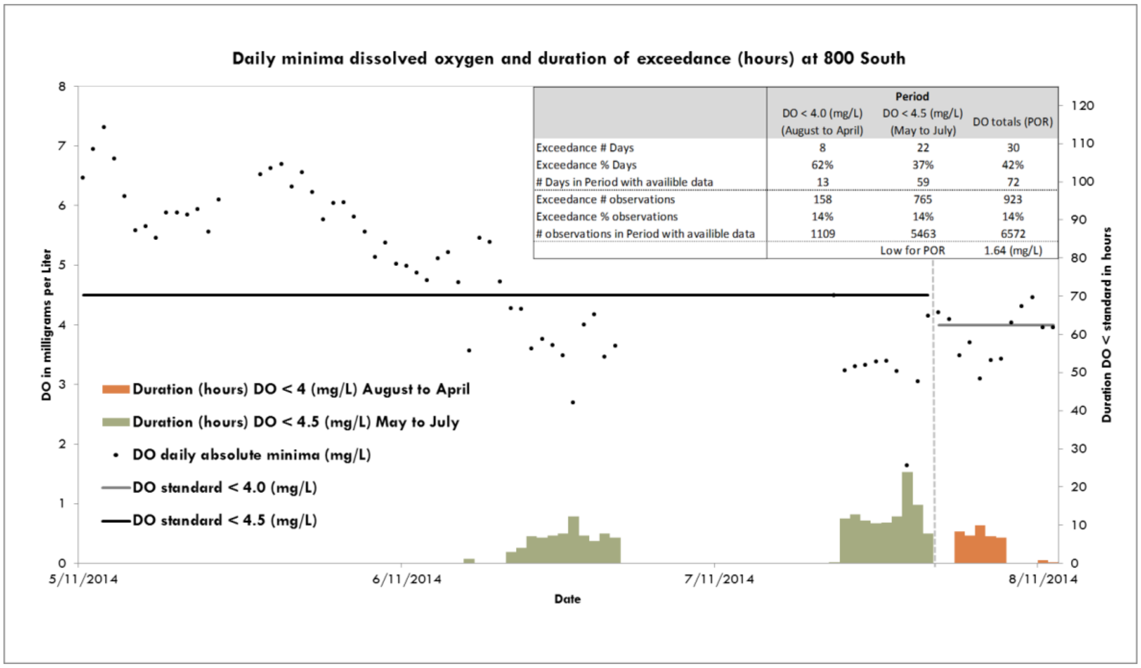


Figure 9: The daily minima represents the lowest measured value of each day of the period-of-record and for the time being will be used as supplemental data for 800 South. Additionally the inserted table reflects seasonal exceedences in days, the percentage of exceedances in relation to the total days in the period-of-record as well as the number of observations that are exceeding the standard and the percentage as compared to the total observations.

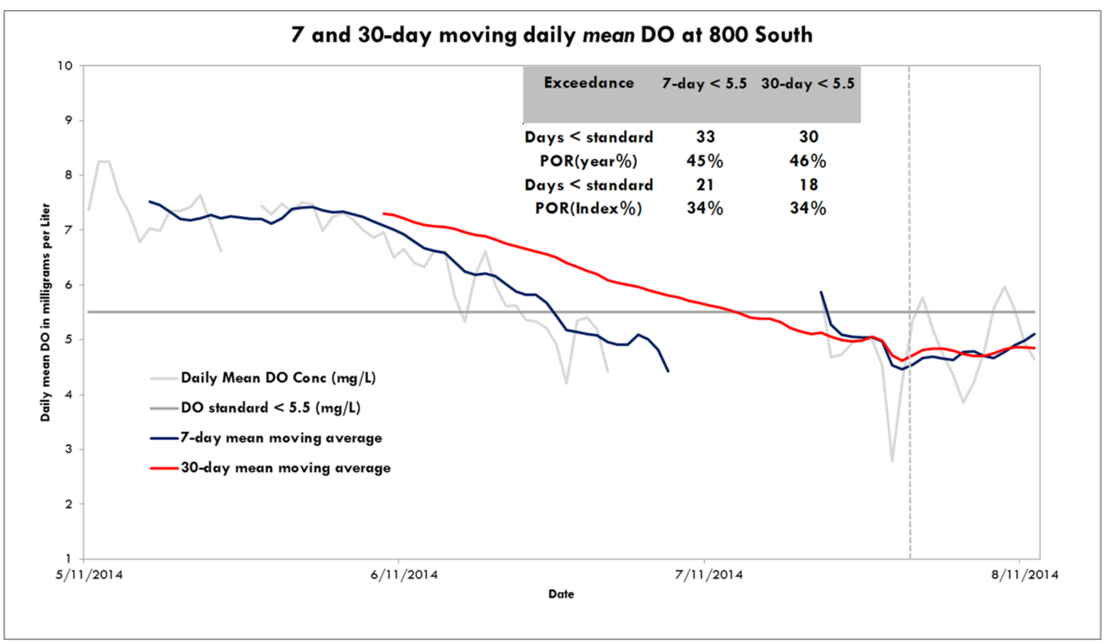


Figure 10: The 7- and 30-day moving daily mean dissolved oxygen from 800 South. The gray horizontal line denotes the water quality standard of 5.5(mg/L) for the entire year for the 7- and 30-day moving daily mean.

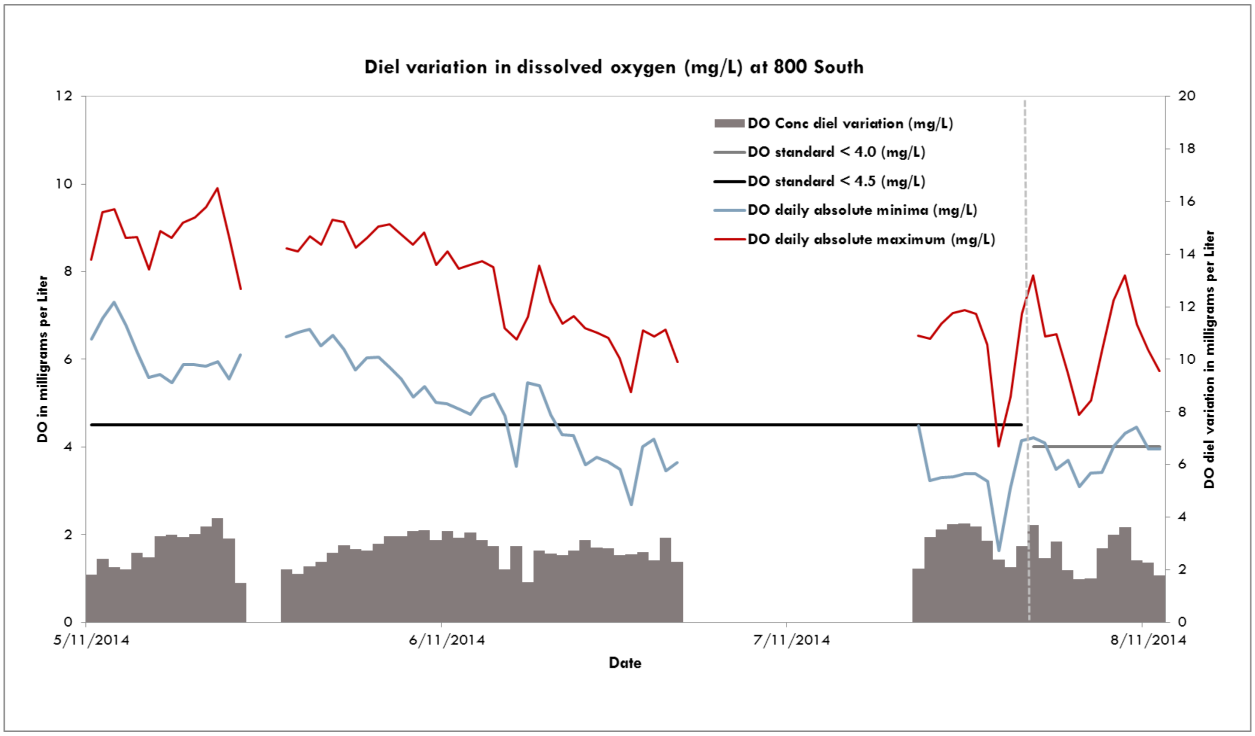


Figure 11: The dissloved oxygen(DO) daily minima and the diel variation in hours that the measured DO is below the water quality standard in hours per day at 800 South. The water quality standards for the Jordan River for dissloved oxygen (mg/L) are dennoted by the gray and black lines and are 4.0(mg/L) and 4.5(mg/L) with respect to the times of the year.

300 NORTH MONITORING LOCATION

The next monitoring location downstream, at 300 North, has a record that encompasses much of the August through April period and nearly all of the Index or May through July period. The acute criterion was violated 14% or 38 days over the Period-of-Record which included extended periods of prolonged daily periods of acutely low DO (Figure 12). On one occasion, DO remained below the minima criterion for 21 hours.

The draft chronic criteria assessment rules suggest concerns with persistently low DO at this location. The 7-day and 30-day chronic criteria were exceeded on ~20% of days over the POR (Figure 13). Given that chronic criteria are ultimately intended to be protective against deleterious consequences resulting from long periods of exposure to low DO, long periods of exposure are particularly concerning with respect to threats to aquatic life designated uses.

The supplemental statistics illustrate several interesting trends in DO concentration at this location. Similar to the 800 South location, the daily diel variation measurements continue to be less pronounced than the two most upstream locations, without any distinct seasonal patterns (Figure 14). The daily minima data indicate a fairly long period where low DO is of concern (July-late August) (Figure 12), which is consistent with the general trends observed in the chronic criteria analysis discussed above. DO peaks, absolute minimum, and average concentrations were all higher than observations at the 800 South location.

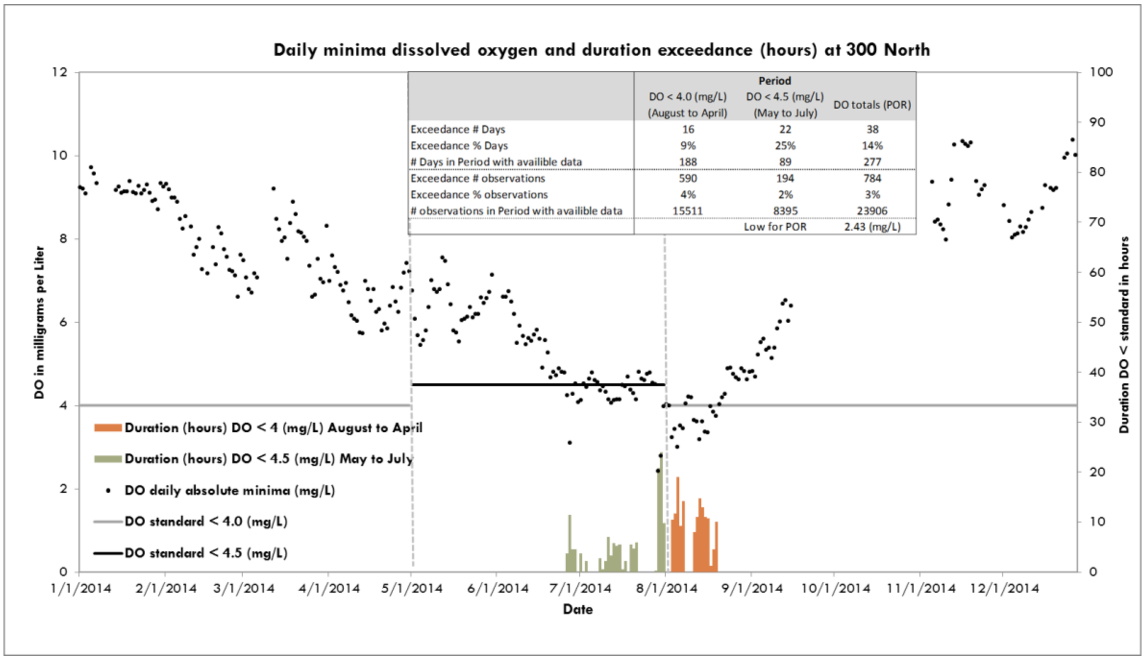


Figure 12: The daily minima represents the lowest measured value of each day of the period-of-record and for the time being will be used as supplemental data for 300 North. Additionally the inserted table reflects seasonal exceedences in days, the percentage of exceedances in relation to the total days in the period-of-record as well as the number of observations that are exceeding the standard and the percentage as compared to the total observations.

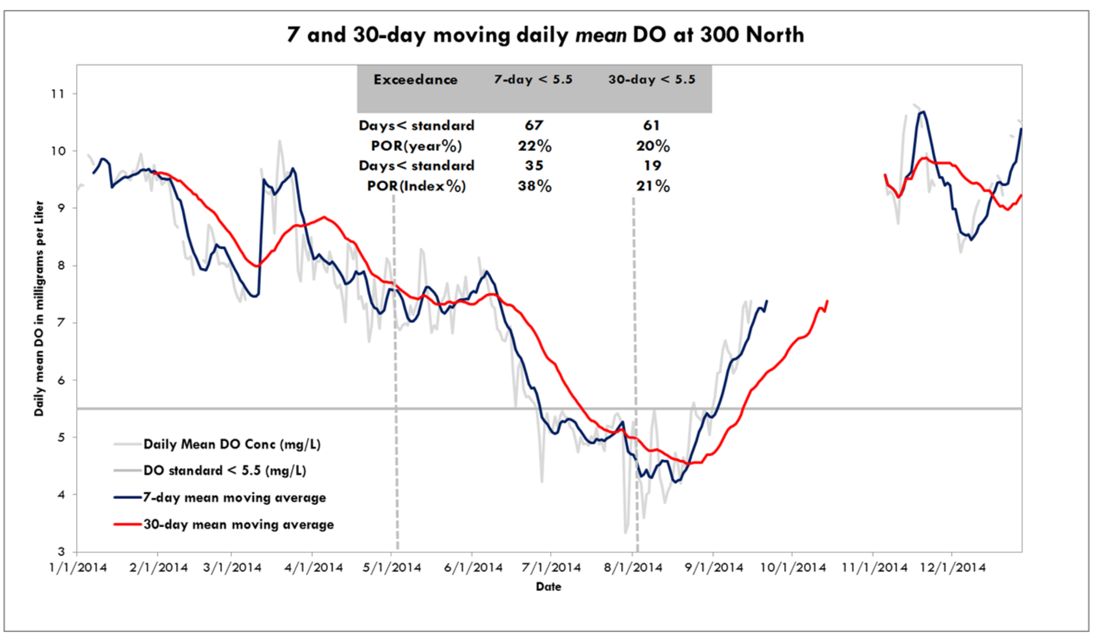


Figure 13: The 7- and 30-day moving daily mean dissolved oxygen from 300 North. The gray horizontal line denotes the water quality standard of 5.5(mg/L) for the entire year for the 7- and 30-day moving daily mean.

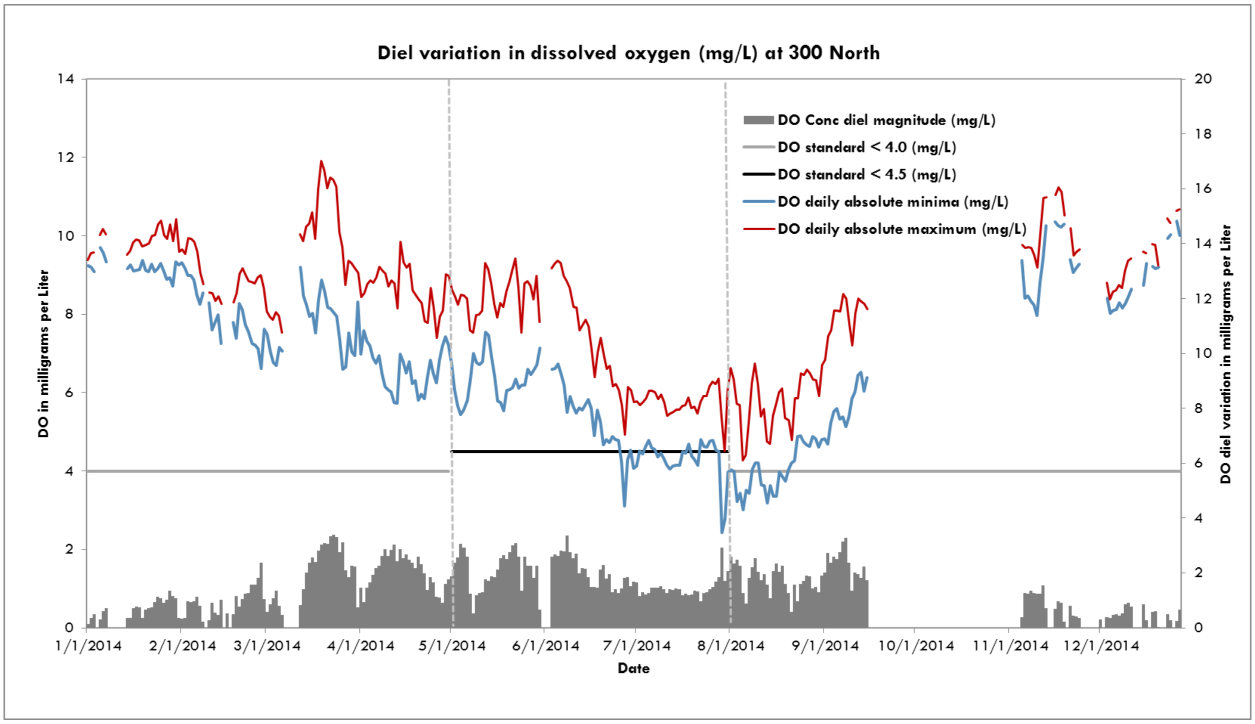


Figure 14: The dissloved oxygen(DO) daily minima and the diel variation in hours that the measured DO is below the water quality standard in hours per day at 300 North. The water quality standards for the Jordan River for dissloved oxygen (mg/L) are dennoted by the gray and black lines and are 4.0(mg/L) and 4.5(mg/L) with respect to the times of the year.

CUDAHY LANE MONITORING LOCATION

Cudahy Lane is the site furthest downstream and had the most pronounced issues with low DO of all of the sites evaluated in this pilot investigation. Both of the draft decision rules with respect to the acute criteria were violated. With respect to within day water quality standard violations, there were several extended periods where DO fell below the minimum criterion for over 20 hours per day (Figure 15). Among day violations were also frequent: DO fell below the acute criterion on 38 days, 32% of all days over the POR. As might be expected given the acute violations, this site also revealed fairly extensive chronic violations. Over the POR the 7-day moving day average was exceeded 46% of the time and the 30-day moving average was exceeded 49% of the time (Figure 16).

Both DO diel variation and the daily minima exhibited similar trends to those observed at the sites immediately upstream. Daily DO variation remained relatively small, without any obvious seasonal pattern (Figure 17). Similarly, the moving 7-day absolute minima plot suggests that the potential for low DO exists throughout the growing season (Figure 15).

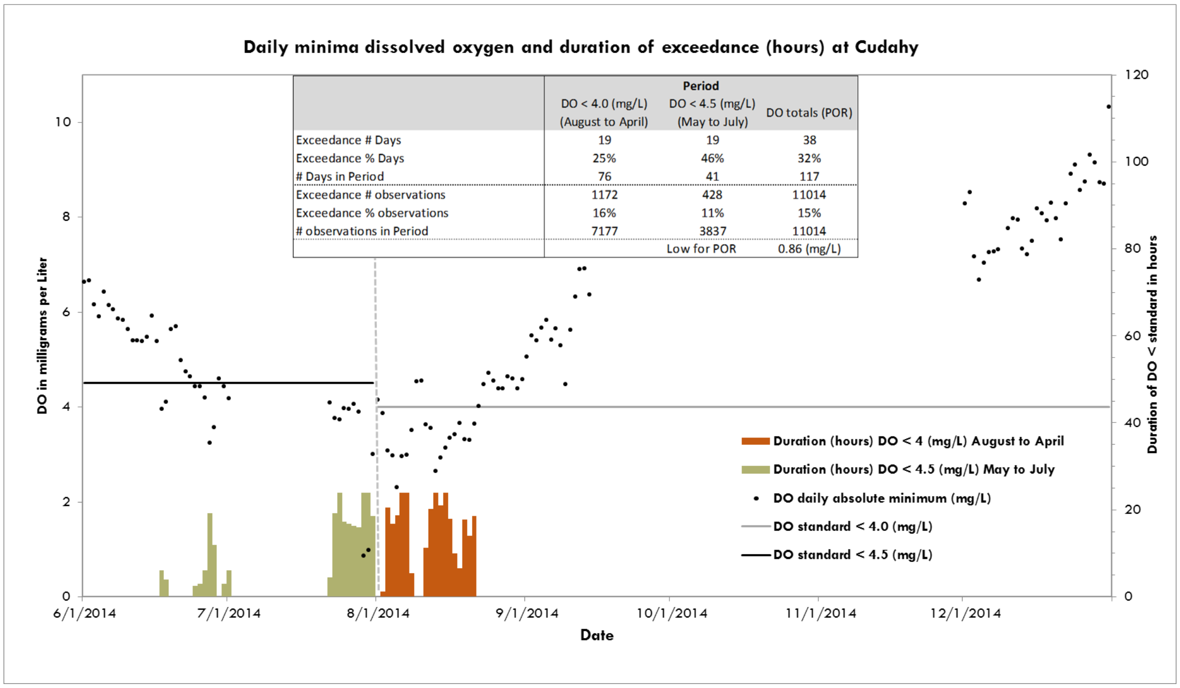


Figure 15: The daily minima represents the lowest measured value of each day of the period-of-record and for the time being will be used as supplemental data for Cudahy. Additionally the inserted table reflects seasonal exceedences in days, the percentage of exceedances in relation to the total days in the period-of-record as well as the number of observations that are exceeding the standard and the percentage as compared to the total observations.

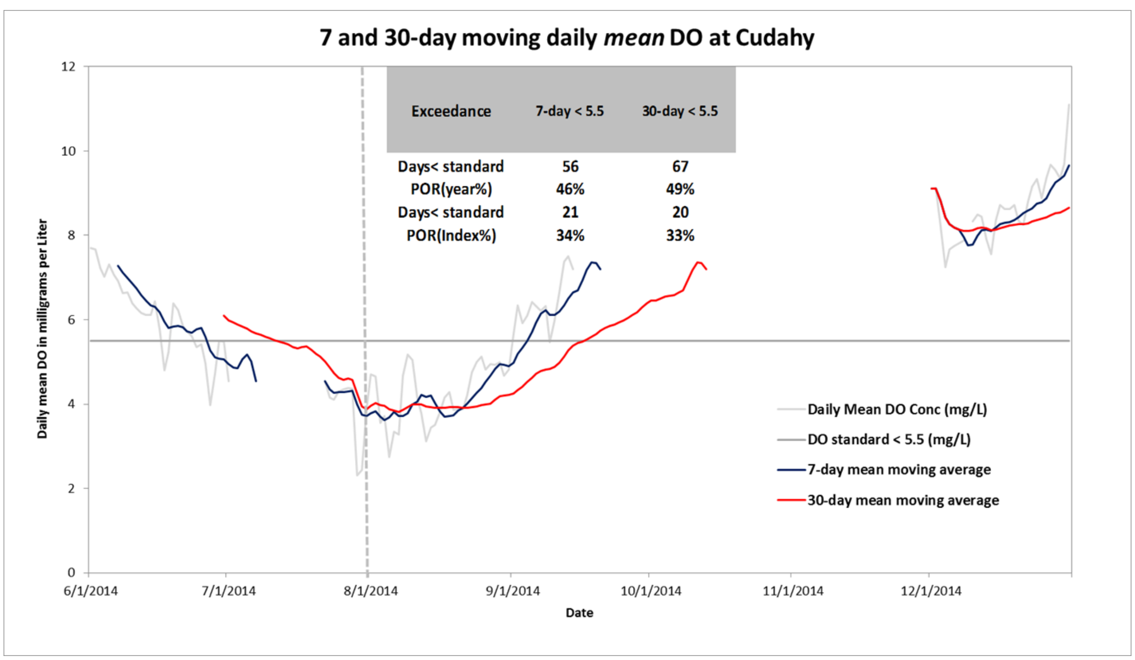


Figure 16: The 7- and 30-day moving daily mean dissolved oxygen from Cudahy Lane. The gray horizontal line denotes the water quality standard of 5.5(mg/L) for the entire year for the 7- and 30-day moving daily mean.

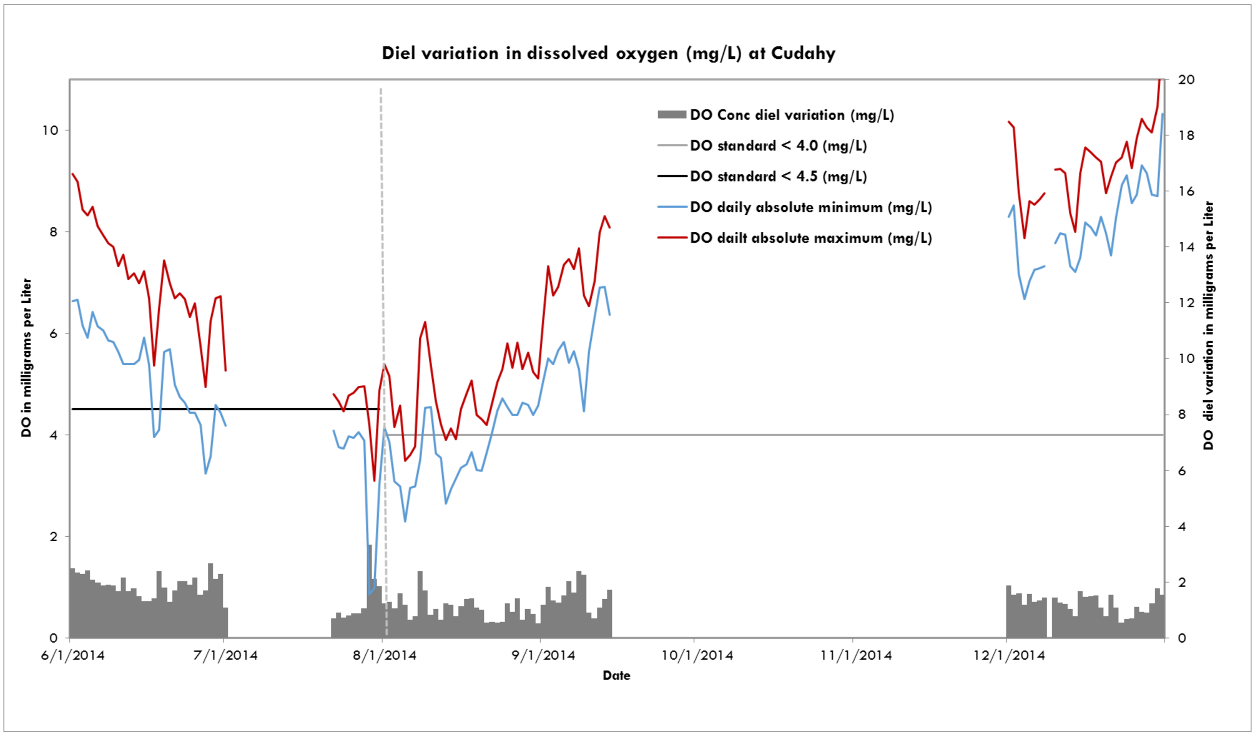


Figure 17: The dissloved oxygen(DO) daily minima and the diel variation in hours that the measured DO is below the water quality standard in hours per day at Cudahy Lane. The water quality standards for the Jordan River for dissloved oxygen (mg/L) are dennoted by the gray and black lines and are 4.0 mg/L and 4.5 mg/L with respect to the times of the year.

Site DO Trends

A comparison of all summary statistics reveals a fairly distinct trend of increasing problems with low DO from upstream to downstream monitoring locations (Table 4). For example, DO only fell below the minima criterion at the site furthest upstream (3300 South) for 1 hour or 4 observations, whereas violations of this criterion occurred on over 38 days (32% of POR) at the site furthest downstream. The frequency of DO violations shows a similar trend (Figure 18). Acute criterion violations were first observed at the 2100 South location, but these excursions only lasted ~62 hours or 14% of observations. In contrast, the minima criterion was exceeded for ~538 hours or13.5% of all observations at Cudahy Lane.

Table 4. Site-specific statistics for 2014 dissolved oxygen data for the Jordan River.

Site specific statistics viewed longitudinally for Jordan River High-Frequency Pilot for 2014					
Statistic	***Site***				
Acute Criteria	***3300 South***	***2100 South***	***800 South***	***300 North***	***Cudahy***
DO daily minima exceedance versus POR(days)	1/346	8/290	30/72	38/277	38/117
% daily minima exceedance in POR	<1	3%	42%	14%	32%
Daily absolute ***minimum*** *exceedence for* DO < 4 (mg/L) (August to April) (Days)	0	1	8	16	19
Daily absolute ***minimum*** *exceedence for* DO < 4.5 (mg/L) (May to July) (Days)	1	7	22	22	19
Maximum consecutive ***duration*** in hours < standard for both 4 or 4.5 mg/L	1	13	39	21	78
Number of DO observations exceeding standard of < 4 (mg/L) versus ***total*** obs. (August to April)	0/23755	0/23000	158/1109	590/15511	1172/7177
Number of DO observations exceeding standard of < 4.5 (mg/L) versus ***total*** obs. (May to July)	1/8732	109/3784	765/5463	194/8395	428/3837
Percentage of DO observations exceeding standard of < 4 (mg/L) (August to April)	0	0	14%	4%	16%
Percentage of DO observations exceeding standard of < 4.5 (mg/L) (May to July)	<1%	3%	14%	2%	11%
Chronic Criteria					
7-day moving *mean* exceedance in POR(days)	0	0	33	67	56
% 7-day moving *mean* exceedance in POR			45%	22%	46%
30-day moving *mean* exceedance in POR(days)	0	0	30	61	67
% 30-day moving *mean* exceedance in POR			46%	19%	49%
Supplemental Data					
Mean DO (mg/L) for POR	8.91	8.56	6.05	7.39	6.11
Instantaneous absolute minimum DO (mg/L) for POR	3.78	2.88	1.64	2.43	0.86
Duration daily minima (hours) < standard for POR	1	62	233.5	285.25	538.25
Mean DO diel variation (mg/L/day) for POR	4.09	2.99	2.77	1.58	1.41

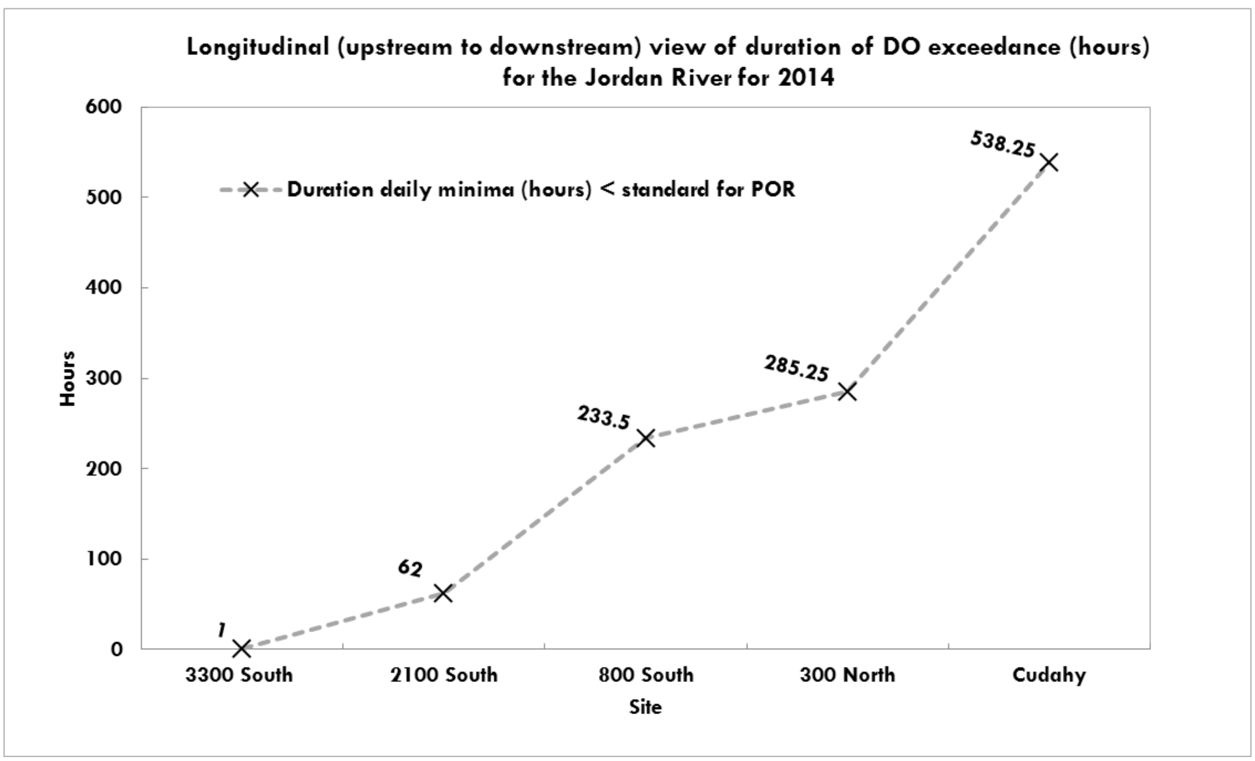


Figure 18: Longitudinal view of exceedances in hours and days of measured dissolved oxygen data from 3300 South to downstream at Cudhy Lane.

DISCUSSION

The draft assessment methods described in this chapter provide a framework for future DO high frequency data assessments. The summary statistics used for the analysis are straightforward and provide measures of averaging periods and duration that closely align with the language in Utah's water quality standards. Similarly, these analyses demonstrate that high frequency data provide an ecologically accurate description of temporally dynamic water quality parameters like DO. High frequency DO datasets provide a sufficient frequency of observations to draft assessment methods that are consistent with the averging periods defined in Utah's DO criteria. Moreover, the summary statistics derived from these data were consistent with the interpretation of temporal DO dynamics which provide the basis of EPA's DO criteria recommendations. While the assessment procedures were drafted to be broadly applicable statewide, they also proved compatible to the site-specific DO criteria on the Jordan River.

Evidence from the Jordan River pilot largely corroborates other data supporting the existing DO impairment for this stream segment. The Jordan River pilot also demonstrates advantages of using high frequency data to characterize DO conditions. For instance, several important seasonal patterns were revealed that would have been unlikely to manifest with instantaneous DO measurements.

Ongoing Considerations

In proposing and evaluating these draft assessment methods several issues were raised that will ultimately need to be resolved before the methods are finalized and implemented state-wide.

INDEX PERIOD

The Jordan River pilot investigation used index periods that were previously established for the Jordan River. However, it is not currently clear whether this is an appropriate index period to apply elsewhere. Whatever form the final assessment methods take, DWQ does not consider it appropriate to incorporate data collected in winter months when calculating the percent of water quality excursions as this "stacks the deck" against identification of conditions that can potentially degrade aquatic life. However, the Jordan River pilot also demonstrates the value in understanding year-round DO dynamics.

LONGER-TERM TEMPORAL VARIATION

This pilot investigation highlights the importance of understanding the temporal variation of DO. However, year-to-year differences may be equally important. It may not always be possible to obtain multiple years of high frequency data when making impairment decisions. Nevertheless, it is important to acknowledge the value of long-term monitoring stations such as those maintained by the JRFBWQMC. These permanent stations will ultimately allow DWQ to conduct similar analyses to better understand the long-term dynamic of DO on the Jordan River.

DRAFT SUPPLEMENTAL SUMMARY STATISTICS

Given that high frequency data sets are rich with information, DWQ proposes that several additional summary statistics be calculated to help better interpret DO conditions. Daily DO variation (absolute difference between the daily maximum(i.e., peak) and minimum(i.e., trough) DO concentration) is a potentially meaningful metric because high variation in daily DO is a demonstrated sources of stress to stream biota. Consistent with the recommendations of Washington's Department of Ecology (2002), DWQ proposes that a diel variation of > 3 mg-DO/L/day be used as a screening level to identify sites where daily variation is of potential concern. Screening levels will only be used in identifying potential sites for future monitoring and will not be used for assessment purposes in the IR. DWQ also proposes calculating a moving 7-day average of daily minima since this metric may help identify long-term trends in low DO conditions and index periods where DO issues may be of particular concern. Finally, DWQ proposes that the duration of DO water quality criteria violations be tabulated, both within a day (number of hours below the criterion) and among days to describe the duration and recurrence of low DO events.

Conclusions

This pilot investigation provides a useful "real world" example of how the draft assessment methods would be used to make impairment decisions with high frequency DO data. The summary of data from 2014 confirmst the existing dissolved oxygen impairments in the lower Jordan Rive (Assessment Units Jordan River-1, Jordan River-2, and Jordan River-3). These analyses were successful in highlighting several details that will need to be considered as DWQ adopts the draft assessment methods. These analyses will also provide an empirical basis for ongoing discussions with stakeholders on how to make these final assessment procedures both scientifically defensible and consistent with state and federal regulations.

LITERATURE CITED

AWCA/EPA. 2014. Options for Addressing Continuous Monitoring Data, ACWA/EPA Water Quality Standards Forum Discussion Paper, Mike Tate (KS), Randy Pahl (NV) and Don Essig (ID), April 18, 2014

DWQ. 2005. Standards of quality for waters of Utah, R317-2, Utah Administrative Code, Utah Department of Environmental Quality, Utah Division of Water Quality.

DWQ. 2014b. Nutrients in Utah's Waters. Available at: http://www.nutrients.utah.gov/. Accessed September 19, 2014.

EPA. 1985. Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and their Uses. EPA-PB85-227049.

EPA, 1986. Quality Criteria for Water 1986, EPA. 440/5-86-001., U.S. Environmental Protection Agency, Washington, D.C.

EPA. 1986. Ambient Water Quality Criteria for Dissolved Oxygen (Freshwater). EPA 440/5/86- 003. U.S. Environmental Protection Agency, Washington, D. C.

EPA. 2005. *Guidance for 2006 assessment, listing and reporting requirements pursuant to Sections 303(d) and 305(b) of the Clean Water Act*. Available at: https://www.epa.gov/sites/production/files/2015-10/documents/2006irg-report.pdf. Accessed September 19, 2014.

WSDE. 2002. *Evaluating Criteria for the Protection of Freshwater Aquatic Life in Washington's Surface Water Quality Standards*. Watershed Management Unit. Washington State Department of Ecology Water Quality Program. Olympia, Washington.

APPENDIX 1.

Utah Division of Water Quality
Water Quality Assessment
Version 1.0 December 16, 2014

Data Quality Matrix for Continuous Data

Data Quality Grade Level	Assessment Program Data Uses	Quality Assurance Project Plan (QAPP)	Sampling Analysis Plan (SAP)	Calibration and Field Documentation*	Metadata**	$Discharge_a$***	SpC_a	Water $Temperature_a$	pH_a	$Dissolved\ Oxygen_a$**** %Saturation for Calibrated Meter	$Dissolved\ Oxygen_a$**** Concentration Methods for Calibrated Meter	Turbidity
A	**Regulatory, permitting, compliance (e.g., 303(d) and 305(b) assessments)**	Approved QAPP	Approved SAP	Mandatory- calibration record(s) (e.g., 1-point, 2-point, and/or multi-point field records of calibration and/or fouling) and field survey information	Approved information of pertinent data associated with deployment (i.e., all of the associated metadata necessary for interpreting the data)	±0.05% Full Scale (at 15° C), ±0.1% Full Scale (maximum)	±5 µS/cm or ±3% of the measured value, whichever is greater	Thermometer Accuracy checked with NIST standards A ≤ ± 0.5°C R ≤ ± 0.5°C	Calibrated pH electrode A ≤ ± 0.2 S.U. R ≤ ± 0.3 S.U.	0-200% mg/L: A ≤ ± 1% R≤0.1%	0-8 mg/L: A ≤ ± 0.01mg/L > 8mg/L: A ≤ ± 0.02 mg/L R≤0.01	± 0.5 NTU or ± 5%, whichever is greater
B	**Regulatory, permitting, compliance (e.g., 303(d) and 305(b) assessments) with professional judgment**	Approved QAPP	Approved SAP	Mandatory- calibration record(s) (e.g., 1-point, 2-point, and/or multi-point field records of calibration and/or fouling) and field survey information	Approved information of pertinent data associated with deployment (i.e., all of the associated metadata necessary for interpreting the data)	±0.05% Full Scale (at 15° C), ±0.1% Full Scale (maximum)	±10 µS/cm or ±6% of the measured value, whichever is greater	Thermometer Accuracy checked with NIST standards A ≤ ± 1.0°C R ≤ ± 2.0°C	Any Method A ≤ ± 0.5 S.U. R ≤ ± 0.5 S.U.	0-200% mg/L: A ≤ ± 2% R≤0.2%	0-20 mg/L: A ≤ ± 0.1 mg/L R≤0.1	± 0.5 NTU or ± 5%, whichever is greater

C	**Not to used for 303(d) and 305(b) assessments Based on project manager judgment, the data may be Voided with a DQL of D.**	Approval of project manager that Minimum Data Acceptance Criteria Met	Approval of project manager that Minimum Data Acceptance Criteria Met	Mandatory-calibration records (e.g., 1-point, 2-point, and/or multi-point field records of drift from bio-fouling, etc.) and field survey information**	Approved information of pertinent data associated with deployment-all of the associated metadata necessary for interpreting the data	±0.05% Full Scale (at 15° C), ±0.1% Full Scale (maximum)	±10 µS/cm or ±6% of the measured value, whichever is greater	A ≥ ± 0.5 ºC R ≥ 0.05 ºC	Any Method A ≤ ± 0.5 S.U. R ≤ ± 0.5 S.U.	0-200% mg/L: A ≤ ± 2% R≤0.2%	0-20 mg/L: A ≤ ± 0.1 mg/L R≤0.1	± 0.5 NTU or ± 5%, whichever is greater
D	**Not used by the Assessment Program**	Not Submitted	Not Submitted	Missing or Unavailable for DWQ review if needed	Missing or Unavailable for DWQ review if needed	Not Submitted	Not a calibrated meter, missing, or rejected data	Not a calibrated meter, missing, or rejected data	Not a calibrated meter, missing, or rejected data	Not a calibrated meter, missing, or rejected data	Not a calibrated meter, missing, or rejected data	Not a calibrated meter, missing, or rejected data

a- Resolution and accuracy as reported by Hydrolab, In-Situ, and YSI

Notes

QA definitions of Data Quality Levels:

A – Data of known quality; meets QC limits established in a DEQ approved QAPP.

B – Data of known but lesser quality; Data may not meet established QC but is within marginal acceptance criteria; or data value may be accurate, however controls used to measure Data Quality Objective (DQO) elements failed (e.g., batch failed to meet blank QC limit); the data is generally usable for most situations or in supporting other, higher quality data. (Equivalent to the "J" (estimated) qualifier used by EPA).

Note: Statistics for turbidity and conductivity are concentration-dependent; thus low-concentration B level data may be considered acceptable for all uses.

C – Data of unacceptable quality; generally due to QC failures but may be related to other known information about the sample. Data should not be used for quantitative purposes but may have qualitative use. (Equivalent to the "R" (rejected) validation qualifier used by EPA)

D –Data of unknown quality; Insufficient QA/QC or other information available to make determination. Data could be acceptable; however, no evidence is available to prove either way. Data is provided for Educational Use Only.

Data Quality Level Grading Criteria:

A = Accuracy as determined by comparison with standards, e.g., during equipment calibration or pre- and post-deployment checks
R = Resolution as determined by replicate measurements, e.g., during field duplicates, field audits, or split samples

*** Calibration and Field Documentation**

- Submitted ancillary data **must** include "raw" data. This includes the data that was initially downloaded from the deployed device (e.g., power settings, barometric pressure, battery status, memory status to name a few). The raw data has not been aggregated, disaggregated, and/or manipulated in any manner.

**** Metadata minimum requirements:**

- Station name including- Location description and picture of monitor in waterbody
- Geo-location(i.e., Lat./Lon., elevation)
- Date and time of measurements (i.e., deployment start/end, calibration, etc…)
- Frequency of measurements(i.e., 1, 10, 15, 30 60 minutes)
- Manufacturer and name field meter(s) and monitor

- Name(s) of data collector(s)
- Lot numbers and expiration dates of standard solutions-if applicable
- Monitor values, field meter values, and corresponding time for pre-cleaned, cleaned, calibration checks, calibrations/recalibrations, and final readings
- If system has a large-cross-section then survey data(locations of points, measured values, and corresponding times), and monitor values before and after the cross-section survey
- Measured flow or gage-height data
- Comments on site conditions, sensor condition, and any other pertinent observations
- Battery voltage of monitor at departure and if the batteries were replaced
- Notes on sensor/monitor changes or replacements, and other comments that facilitate processing/analysis of the record

***** Discharge**

- Flow measurement(s) including; date, time and Q
- Stage/Discharge relation(s) if completed at time of submittal
- Any notes that will facilitate analysis
- A linear relation on the least squares analysis in the stage/discharge relation (i.e., R^2) equal to or above 0.70

****** Dissolved Oxygen**

- Calibration data pre- and post-deployment
- Calibration data pre- and post-maintenance during deployment for bio-fouling and other mechanisms of drift in associated data