Dissolved Oxygen Assessment Method for Streams and Rivers

Public Comment Draft
July 2024

WQDWQPBWQA-02, Version 1.0

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REVISION HISTORY

Revision No.	Date	Modified By	Sections Modified	Description of Changes

SUGGESTED CITATION

Montana Department of Environmental Quality (DEQ). 2024. Dissolved Oxygen Assessment Method for Streams and Rivers. Helena, MT: Montana Department of Environmental Quality. Document WQDWQPBWQA-02.

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ACRONYMS

ARM	Administrative Rules of Montana
AU	assessment unit
BOD	biochemical oxygen demand
CFR	Code of Federal Regulations
CWAIC	Clean Water Act Information Center
DEQ	Department of Environmental Quality
DO	dissolved oxygen
DQA	data quality assessment
EPA	U.S. Environmental Protection Agency
FWP	Montana Fish, Wildlife and Park
EQuIS	DEQ’s MT-eWQX Enterprise database
MCA	Montana Code Annotated
mg/L	milligrams per liter
MPDES	Montana Pollutant Discharge Elimination System
O_2	oxygen gas
QA	quality assurance
QAPP	quality assurance project plan
QC	quality control
SAP	sampling and analysis plan
SOP	standard operating procedure
TMDL	total maximum daily load
WARD	Water Quality Assessment and Reporting Documentation

1.0 Introduction

This document details the Montana Department of Environmental Quality's (DEQ) dissolved oxygen (DO) assessment method for Montana's streams and rivers. Results from this method will be used to assess the aquatic life beneficial use for all water classifications applicable to streams and rivers. The document *Beneficial Use Assessment for Montana's Surface Waters* (Makarowski 2020) describes the overall process to make a beneficial use assessment for a waterbody. This DO assessment method is not a state rule or regulation.

1.1 Applicability

This assessment method is guidance that only applies to streams and rivers and does not apply to lakes and reservoirs.

1.2 Background Information

State waters are classified in accordance with their present and future beneficial uses per the Montana Water Quality Act (75-5-301(1), Montana Code Annotated [MCA]). DO directly affects the fish and associated aquatic life beneficial use. Waters classified as A-Closed, A-1, B-1, B-2, B-3, C-1, C-2, C-3, and I are required to attain this beneficial use (Administrative Rules of Montana [ARM] 17.30.621 through 17.30.629).

DO is the concentration of oxygen gas (O_2) dissolved in water. Oxygen can enter the water via direct diffusion from the atmosphere, aeration by turbulence, and through photosynthetic release of O_2 by aquatic plants and algae (EPA 2023). Depletion of DO to low concentrations in a waterbody can negatively affect the growth and propagation of aquatic life and fish. Montana DO standards are based on the minimum acceptable DO concentrations needed to support aquatic life and fish, with the exception of class A-Closed waters, which does not allow for any change from the natural condition.

1.3 Common Sources and Factors Influencing Dissolved Oxygen

It is typical for rivers and streams to show regular diel cycles in DO, with lower concentrations in the night and early morning, when respiration dominates, and higher DO concentrations during the day, when photosynthesis prevails (Odum 1956). Humans can amplify this diel DO cycle by increasing nutrient (nitrogen and phosphorus) concentrations, which, in turn, stimulate aquatic plant and algae growth. Increased aquatic plant or algae growth produces more oxygen during the day than normal and consumes more oxygen (especially at night) through cellular respiration; this occurs through daily as well as seasonal photosynthetic cycles. Humans can also affect this diel cycle by adding organic matter to a stream or river that increases microbial respiration, leading to lower DO concentrations throughout the day. The most common nutrient sources that impact DO in Montana include, but are not limited to, fertilizers for crop production, wastewater, stormwater, stream bank erosion, confined feeding operations, intensive grazing near streams, septic systems, and nitrogen-based blasting materials at mines. All these sources act by stimulating aquatic plant and algae growth and, in turn, the ensuing effects on DO.

Water temperature also influences DO concentrations because it affects gas solubility. Cooler temperature water can hold more DO than warmer temperature water. In addition, if shade is reduced because of fewer streamside trees and shrubs, then available sunlight increases. This can increase water temperature by itself, and stimulate aquatic plant and algae growth, collectively altering daily DO patterns.

2.0 Montana Dissolved Oxygen Water Quality Standards

Montana's DO water quality standards are derived from the U.S. Environmental Protection Agency's (EPA) Quality Criteria for Water (Gold Book; EPA 1986) and are contained in Montana's regulations at ARM 17.30.621 through 17.30.629 and Circular DEQ-7 (DEQ 2019). DO concentration must not be reduced below the applicable standards given in department Circular DEQ-7. DO water quality standards vary by waterbody class as shown in **Table 2-1**, from DEQ-7, footnote 15).

Table 2-1. Montana's Dissolved Oxygen (mg/L) Standards (DEQ 2019)

	Standards for Salmonid Waters Classified		Standards for Non-Salmonid Waters Classified	
	A-1, B-1, B-2, C-1, and C-2		B-3, C-3, and I	
	Early Life Stages[1, 2]	Other Life Stages	Early Life Stages[2]	Other Life Stages
30-Day Mean	N/A[3]	6.5	N/A[3]	5.5
7-Day Mean	9.5 (6.5)	N/A[3]	6.0	N/A[3]
7-Day Mean Minimum[4]	N/A[3]	5.0	N/A[3]	4.0
1-Day Minimum[4]	8.0 (5.0)	4.0	5.0	3.0

[1]These are water column concentrations recommended to achieve the required inter-gravel DO concentrations shown in parentheses. For species that have early life stages exposed directly to the water column, the figures in parentheses apply.
[2]Includes all embryonic and larval stages, and all juvenile forms of fish to 30-days following hatching. See Appendix A for applicable timeframes.
[3]N/A (Not Applicable)
[4]All minima should be considered as instantaneous concentrations to be achieved at all times.

A detailed discussion of the time frames applicable to different life stages for each waterbody class is provided in **Section 3.3.1** below. DEQ should coordinate with Montana Fish, Wildlife, and Parks (FWP) in determining the applicability of timeframes for early life stages applicable to large rivers.

Assessors need to be aware of two instances in the ARMs where there are deviations from Circular DEQ-7. The first, at ARM 17.30.627(b), is Ashley Creek below the bridge crossing on Airport Road to its confluence with the Flathead River, near Kalispell. There, DO may not be reduced below 5.0 mg/L from October 1st through June 1st, nor below 3.0 mg/L from June 2 through September 30 (ARM 17.30.627(2)(b)).

The second instance applies to all class A-Closed waters where the standards require that "No change from the naturally occurring dissolved oxygen levels is allowed." (ARM 17.30.621(3)(b)). DEQ will use a reference approach for assessing all A-Closed classified waters; that is, DEQ will identify comparable streams and rivers with minimal human impacts and use their DO patterns as points of comparison. The reference approach for assessing A-Closed classified waters will be proposed in each sampling and analysis plan (SAP) and/or quality assurance project plan (QAPP). The section manager and quality assurance (QA) officer will need to approve the reference approach via QA system signatures. A complete list of A-Closed classified waters is included in **Appendix C**.

3.0 Sampling and Data Quality Considerations for Dissolved Oxygen Assessment

Waterbody condition must be evaluated based on all existing and readily available data and information (§75-5-702, MCA; 40 Code of Federal Regulations [CFR] 130.7(5)(b)). This section describes several considerations for developing monitoring designs and assessing data quality when performing DO assessments. Additional guidance is provided in the following documents for sample collection, handling, and use of continuous data loggers: Instantaneous Field Meter SOP (McWilliams 2020), Small Water Quality Dataloggers SOP (McWilliams and Nixon 2020), and Multiparameter Water Quality Sondes SOP (Milke 2023).

3.1 Data Currency

Data collected within the past ten years can be considered current and may be used in making assessment decisions (Makarowski 2020). If during this period, significant changes in sources, like those discussed in **Section 6.1** below, have been documented, the assessor may use best professional judgment when determining which data are appropriate to include in the assessment. The assessor should document the specific changes, identify data currency alternatives, and determine which years of data are appropriate to include in the assessment process.

3.2 Dissolved Oxygen Sample Collection, Analysis, and Units

DO can be measured by different methods. The Winkler titration method was the most commonly used method before the arrival of polarographic probes, which have themselves been replaced by optical sensors. Currently, handheld (instantaneous) meters and submersible instream datalogging meters (continuous dataloggers or sondes) are widely used (USGS 2020). Continuous DO dataloggers are preferred for assessment data collection. Many of Montana's DO standards are based on an average condition. Therefore, it is more accurate to calculate daily, weekly, or monthly averages if a continuous data logger is used as opposed to discrete data collection.

Amperometric (polarographic and galvanic) DO sensors use membranes, electrolyte solutions, and electrodes to measure DO in the water column. These sensors are flow and temperature dependent. They are not typically as stable as optical sensors. Optical sensors use a replaceable membrane or foil to measure DO in the water column and are not dependent on water flow. Optical sensors are highly recommended, but polarographic/galvanic sensors are acceptable so long as they are properly deployed to assure water movement across the sensor surface and membranes and electrolyte solutions are maintained.

DO results can be reported in percent oxygen saturation or concentration expressed as milligrams per liter (mg/L). Because water quality standards are provided in mg/L, only these results are to be used for this DO assessment method. Percent oxygen saturation data will not be applied to this method; however, it may be useful for other scientific purposes.

3.3 Temporal Requirements

3.3.1 Time of Year

Most low DO conditions in Montana's waters are driven by oxygen demand when plant, algal, or bacterial respiration occurs in excess of photosynthesis. This typically occurs during the night and during the warmest times of the year, when respiration rates are highest and the oxygen saturation concentration in a given waterbody is lowest. Other human caused activities, such as those outlined in **Section 6.1** below, may affect DO at any time of the year. Therefore, when designing a study, data should target a portion of the growing seasons as provided in **Table 3-1** (per Suplee and Sada 2016), however, peak senescence and non-growing season timeframes may also be targeted if decomposition, biochemical oxygen demand (BOD), or dam operation is suspected as a driver of low oxygen.

Table 3-1. Start and End Dates for Three Seasons (Winter, Runoff and Growing) by Level III Ecoregion (Suplee and Sada 2016)

Ecoregion Name	Start of Winter	End of Winter	Start of Runoff	End of Runoff	Start of Growing Season	End of Growing Season
Canadian Rockies	Oct. 1	April 14	April 15	June 30	July 1	Sept. 30
Northern Rockies	Oct. 1	March 31	April 1	June 30	July 1	Sept. 30
Idaho Batholith	Oct. 1	April 14	April 15	June 30	July 1	Sept. 30
Middle Rockies	Oct. 1	April 14	April 15	June 30	July 1	Sept. 30
Northwestern Glaciated Plains	Oct. 1	March 14	March 15	June 15	June 16	Sept. 30
Northwestern Great Plains	Oct. 1	Feb. 29	March 1	June 30	July 1	Sept. 30
Wyoming Basin	Oct. 1	April 14	April 15	June 30	July 1	Sept. 30

DO data can be collected at any time of the year, but different water quality standards apply to the different fish life stages. Adult life stages are assumed to be present in all waters at all times. Per Circular DEQ-7 and EPA (1986), early life stages are defined as the spawning, incubation period for eggs of salmonids, and the period in which salmonid sac-fry are in gravel. Due to the variety of fish in streams classified as A-1, B-1, B-2, C-1, and C-2 (stream classes where salmonid fishes are to be supported), there is always a chance some fish are in the early life stages (**Appendix A**). Therefore, DO standards for early stages in waters classified as supporting salmonid fish are applied year-round. For streams classified as C-3, B-3 (non-salmonid fishes), and Class I, the early life stage DO standards are to be applied from March 15th through August 31st. **Appendix A** contains detailed information about spawning timeframes for Montana's fish species.

Additionally, if Burbot (*Lota lota*) is known to be living in C-3 and B-3 streams or rivers, the early life stage DO standard will apply from February 1st through August 31st. The Montana Field Guide should be consulted to determine where Burbot are located (MTNHP and MTFWP 2021). **Appendix B** includes the current assessment units (AUs) where Burbot have been found in either C-3 or B-3 streams and rivers.

3.3.2 Time of Day and Frequency

To ensure that the daily minimum and maximum are captured, DEQ highly recommends continuous DO measurements over discrete data. Rivers and streams normally display a sinusoidal DO pattern during the growing season in Montana. Low DO concentrations typically occur after midnight and are lowest usually just before sunrise. It is highly recommended to sample before sunrise or use a continuous datalogger to capture this timeframe for any assessment purposes. Due to these sampling constraints, discrete samples collected between 4:00 am and 8:00 am are representative of the lowest daily DO conditions. The highest DO concentration will generally occur from 2:30 pm to 5:00 pm (Suplee and Sada 2016). Therefore, if using discrete data, the daily mean must be based on a minimum of two sample points: one from the daily minimum timeframe and one from the daily maximum timeframe. If this is not followed, only the 1-day minimum standard can be evaluated. **Section 5.2** provides information on how to perform statistical analyses for assessment efforts.

3.4 Sampling Locations and Spatial Independence

Guidance for selecting sampling locations is intended to help ensure spatial independence and appropriate representation of an assessment unit (AU).

3.4.1 Assessment Unit Selection

DO assessment decisions are made by AU. An AU may be an entire waterbody or a segment of a waterbody (e.g., headwaters to a tributary). DEQ or others may prioritize monitoring of waters that have been previously identified as impaired, waters at higher risk of DO impairment due to human activities, waters exposed to nutrient enrichment, areas where sources have been cleaned up, or other factors. DEQ may receive requests for assessing locally or regionally generated data and all readily available DO data that passes QA requirements must be included for assessment for any unit that is part of a 303(d) beneficial use assessment.

3.4.2 Assessment Reaches

Some of Montana's other pollutant assessment methods use assessment reach breaks because of statistical needs and specific data requirements that differ from the DO assessment method. Reaches are not required for DO assessment because minimum data requirements are reviewed and analyzed site by site.

3.4.3 Total Number of Sites and Site Locations

Data will be analyzed on a site-by-site basis because DO in streams changes quickly across space and time. DO assessment determinations will be made by looking at data available along the entire AU. The minimum number of sites is one site per AU if that site is located in the most at-risk area, that is, downstream of the most intensive sources (see **Section 6.1** for examples). It is preferable to collect data at multiple sites representing the entire AU to better capture variability in DO concentrations throughout the AU. The recommended number of sites is two or more within an AU, with one representing the most at-risk area. Best professional judgment should be applied to determine how many sites are needed to adequately represent the range of potential human sources influencing the AU. If sufficient data are only available in the least impacted areas, the assessor may proceed with analysis but ultimately may determine the AU lacks sufficient data for DO assessment if no DO standards exceedances are detected. Although total maximum daily load (TMDL) development may not always be necessary, sites may also bracket known or suspected sources to aid in TMDL and Montana Pollutant Discharge Elimination System (MPDES) development if sufficient monitoring resources are available (e.g., agricultural runoff, channel alteration, wastewater treatment outfalls, and dams; EPA, 2023). If eutrophication is a suspected problem, nutrient monitoring should occur along with DO since it is most likely a causal variable.

3.4.4 Spatial Independence

Sites are assessed independently; data are not aggregated by reach or AU, therefore spatial independence should not be a factor in assessment. Generally, sites should be placed at least a mile apart on streams or be separated by sources such as effluents or tributaries.

3.5 Parameters Required for Dissolved Oxygen Assessment

DO concentration (mg/L) is the only data type that is to be applied directly to the Montana DO water quality standards for rivers and streams.

3.5.1 Continuous Data - Minimum Data and Frequency

Sonde deployment is the preferred method to collect DO measurements for assessment. All continuous measurements that pass QA reviews will be compared to the 1-day minimum standard. The 7-day and 30-day mean standards require that daily means be calculated. Continuous data collection ensures that the maximum and minimum daily DO readings are recorded. Full 24-hour days of continuous data (12:00 am to 11:59 pm) will be used for assessment purposes. Data used for the assessment should be collected at equal intervals of 15 - 30 minutes, however, intervals of 1-hour or less may be considered as continuous for assessment. Mean daily DO can be calculated from full equal interval 24-hour dataset by averaging all DO concentration data taken within that day. All data will be considered for evaluating the daily minimum criteria analysis. Data for partial days should not be used for evaluating daily means unless an assessor has data from both the low and high DO timeframes identified in **Section 3.3.2.** Mean daily DO for partial days can be calculated by first averaging all low DO timeframe data, then averaging all high DO timeframe data, and then determining the mean of the two resulting values. If one of these times is not represented, then the daily mean cannot be calculated. To calculate a 7-day mean or a 7-day minimum mean, at least 5 days of data are required to be collected in a 7-day period. This is to create monitoring efficiencies while also limiting false positive[1] listing rates to approximately 10% or less (Tetra Tech and EPA 2023; **Attachment A**).

To calculate a 30-day mean, at least 16 full days are required to be collected during a 30-day period. This is to create monitoring efficiencies while also limiting false positive[2] listing rates to approximately 10% or less (Tetra Tech and EPA 2023). It is preferred that more than 7 or 30 days of data are collected so multiple means can be calculated for these timeframes but environmental conditions or monitoring resources do not always allow for such robust data collection. Any data are assessable, but it is preferred to have data collected during the growing season (as specified in **Table 3-1**, above)because DO problems most commonly occur during this period. However, if decomposition, BOD, or dam operation is suspected as a driver of low oxygen, then data should be collected during peak senescence (i.e., in early fall of the post-growing season) and non-growing season timeframes. If data are not available

[1] Here, false positives are situations where the stream meets DO criteria according to a full 7-day dataset but, using a shorter number of days for the dataset, there is indication of exceedance of the DO criteria.

[2] Here, false positives are situations where the stream meets DO criteria according to a full 30-day dataset but, using a shorter number of days for the dataset, there is indication of exceedance of the DO criteria.

during the growing season, the assessor should continue with the assessment but may determine there is insufficient data to determine full support of the use by DO conditions, and thus may determine the pollutant is not fully assessed (Makarowski 2020).

3.5.2 Discrete Data - Minimum Data and Frequency

The same 7-day and 30-day minimum day duration requirements apply for discrete data as well; to calculate a 30-day mean, at least 16 days of data are required to be collected during a 30-day period and to calculate a 7-day mean or a 7-day minimum mean, at least 5 days of data are required to be collected during a 7-day period. Since daily maximum and minimum measurements are required to calculate the daily means for the 30-day mean and 7-day mean standard, at least two discrete measurements, with one measurement collected between 4:00 am and 8:00 am, and another between 2:30 pm and 5:00 pm as described in **Section 3.3.2,** are required per 24-hour day to calculate these longer-term statistics. Only the daily minimum DO readings (4:00 am - 8:00 am) are required for the 7-day minimum mean.

All available discrete data should be used for the 1-day minimum analysis. If discrete data are collected alongside a sonde or datalogger at the same site and time the continuous data should be used instead of the discrete data (although the discrete data may be used for quality control (QC) purposes). Alternatively, daylong equal interval discrete sampling along the daily sinusoidal oscillation may be used to determine daily means if at least 4 measures are available. If assessors use discrete data outside these timeframes for other analyses, manager and QA approval is needed.

4.0 DATA QUALITY

This assessment method is subject to DEQ Water Quality Division's established policies and procedures for QA and QC, beneficial use assessment, and data management. Data quality requirements apply to all data used for making assessment decisions, whether collected internally or externally.

4.1 DATA QUALITY ASSESSMENT OVERVIEW

Data quality assessment (DQA) is the scientific and statistical evaluation of data to determine whether data obtained from monitoring operations are of the right type, quality, and quantity to support water quality assessments (EPA 2000). Assessors use DEQ's Water Quality Assessment and Reporting Documentation (WARD) System to document the DQA outcome (pass or fail) for each parameter group being assessed per beneficial use. All data quality indicators must be met to pass the DQA; if a single indicator is not met, the DQA fails for that parameter group. An assessor may override pass or override fail a DQA, but they must accompany this override with adequate justification.

Additional data quality screening may be necessary before the dataset is ready to support attainment decisions (EPA 2002), for example:

- Reviewing and rectifying changes in measurement values after a sensor cleaning event
- Evaluating database flags
- Evaluating QC samples (i.e., field checks)
- Reviewing QA/QC reports
- Investigating errors in collection or analysis
- Addressing missing data
- Reviewing deviations from SOPs and SAPs

- Reviewing percent change from previous and subsequent measures from dataloggers
- Documenting when calibration occurred and reviewing instrument calibration logs

Once DEQ determines the data meet basic documentation requirements, the data are ready to be analyzed to support water quality standards attainment decisions (EPA 2002).

4.2 Quality Control

A common way to measure DO is with a field meter using either an amperometric or optical sensor (as described in **Section 3.2**). The meter must be calibrated and properly maintained to be used for assessment purposes. Calibration logs must accompany data to be used in DO beneficial use assessments. Standard Operating Procedures (SOPs) related to DO data collection are available on the MT DEQ website. The appropriate SOP should be followed for continuous or discrete data collection. All data are subject to data QC checks before it is used for assessment (**Section 4.0**). A QA review of field meter calibration, post-deployment data review, and a post-deployment audit is mandatory for DEQ to consider DO data. Many interferences can occur when meters are deployed in streams and left to log data.

All dataloggers are to follow the manufacturer's calibration and maintenance schedule. Calibrations must be documented and summarized in a post-collection QA analysis. See the SOP for Small Water Quality Dataloggers (McWilliams and Nixon 2020) or the SOP for Multiparameter Water Quality Sonde (Milke 2023) for calibrations, post-deployment data review, and post-deployment audit information.

Any instantaneous field meters that are used to collect data for assessment are to follow the manufacturer's calibrations and maintenance schedule. See the Instantaneous Field Meter SOP (McWilliams 2020) for more information on how field meters are to be managed and maintained.

5.0 Data Analysis to Support Water Quality Standards Attainment Decisions

DO concentration (mg/L) is the only data type that is needed to complete a DO water quality assessment.

5.1 Preparing the Data for Assessment

The water quality standards are provided in **Section 2.0** and **Section 3.3.1**. Due to the variability of the early life stages for the fish found in cold water or marginal cold water streams, the early life stage standards should be applied year-round. Montana's warm water stream early life stages are applied from the 15th of March through the 31st of August. Exceptions for warm water streams are made for waterbodies where Burbot are found (see **Section 3.3.1**). **Tables 5.1 and 5.2** provide an example of how to calculate the 7-day mean (30-day mean values are calculated in a similar way, using ≥16 days of continuous or discrete data) and 7-day mean minimum, respectively.

5.1.1 Continuous Data

Continuous data collection via datalogger deployment is the preferred method for DO data collection. Any of the DO standard durations (e.g. 1-day, 7-day, 30-day) may be assessed for a new listing depending on the availability of data. If minimum data are available, the assessor should complete an analysis for each duration and statistical analysis provided in this section. All durations are needed for a delisting.

1. Determine the waterbody use class to identify which standards apply at specific timeframes.
2. Determine if Burbot are present if working on a warm water fishery and further adjust early life stage standard timeframe as appropriate.
3. Determine if there are sufficient continuous data. Days are defined as 12:00 am to 11:59 pm.
4. Organize available data by site in chronological order.
5. Evaluate as many applicable duration standards as possible, site by site.
    a. Early Life Stages – Present during applicable timeframes
        i. 1-Day Minimum:
            1. Minimum Data: All data will be compared to minimum DO criteria. At least two daily minimums are needed to assess the 1-day minimum standard for a waterbody.
            2. Statistical Comparison: Calculate daily minimum. No more than one daily minimum shall fall below the applicable standards more than once in any three-year timeframe.
        ii. 7-Day Mean:
            1. Minimum Data: At least 5 days within a 7-day period for representative data set.
            2. Statistical Comparison: First calculate the daily mean, then average the daily means to a 7-day mean (**Table 5-1**). Rolling mean timesteps should be daily (12:00 am – 11:59 pm), not hourly. Compare each rolling 7-day mean result to the applicable standard. If the dataset is equal to or less than 7 days, only one mean result is compared to standard. No mean result shall fall below the applicable standard.
    b. Other Life Stages – Present all the time
        i. 30-Day Mean:
            1. Minimum Data: At least 16 days within a 30-day period for representative data set.
            2. Statistical Comparison: Compare each rolling 30-day mean result to the applicable standard. First calculate the daily mean, then average the daily means to a 30-day mean. Rolling mean timesteps should be daily, not hourly. If the dataset is equal to or less than 30 days, only one mean result is compared to standard. No mean result shall fall below the applicable standard.
        ii. 7-Day Minimum Mean:
            1. Minimum Data: At least 5 days within a 7-day period.
            2. Statistical Comparison: Determine each day's minimum DO result then average the daily minimums (**Table 5-2**). Compare each rolling 7-day minimum mean of the minimum daily results to the applicable standard. If the dataset is equal to or less than 7 days, only one mean result is compared to standard. No mean result shall fall below the applicable standard.

5.1.2 Discrete Data

Discrete data from hand-held meters can be used but are not preferred for assessment as it is difficult to determine if sufficient data have been collected which represent conditions that would fully support aquatic life. Daily maximum and minimum measurements are required to calculate the 30-day and 7-day mean calculations (EPA, 1986). Daily minimum measurements (which must be collected from 4:00 am – 8:00 am) are needed to assess conditions to the 7-day minimum mean and the 1-day daily minimum standards. Daily maximum measurements should be collected between 2:30 pm and 5:00 pm. All the same steps in the continuous data assessment (**Section 5.1.1**) are followed for discrete data. If more than one sample is collected during the daily maximum or minimum periods, the assessor should average the conditions during each of these timeframes and then use the results to determine a mean for each day.

Mixed datasets of discrete and continuous data may occur over differing periods of time. As stated previously in **Section 3.5.2**, if discrete data is collected alongside a sonde or datalogger at the same site and time the continuous data should be used instead of the discrete data. Alternatively, daylong equal interval discrete sampling along the daily sinusoidal oscillation may be used to determine daily means if at least 4 measures are available. If assessors use discrete data outside these timeframes for other analyses, manager and QA approval is needed. Continuous data is preferred for assessment, however, if either dataset indicate impairment, then the AU is impaired.

Table 5-1. Example dataset explaining how to calculate a 7-day mean. Note that the entire dataset is used to compute rolling 7-day means (three were possible in this example).

Day (12:00am-11:59pm)	DO Daily Mean (mg/L)	7-Day Mean (mg/L)
1	8.5	…
2	8	…
3	9	…
4	9.5	…
5	9	…
6	8	…
7	8.5	8.6
8	9	8.7
9	9	8.9

Equation for calculating the 7-day mean is:

$$\text{7-Day Mean} = \frac{(A_1 + A_2 + ... + A_n)}{n}$$

A = each daily DO mean
n = total number of days that DO data was collected

For example, the equation for the first 7-day mean (Days 1-7) in **Table 5-1,** is:

$$\text{7-Day Mean} = \frac{(8.5 + 8 + 9 + 9.5 + 9 + 8 + 8.5)}{7}$$

7-Day Mean = 8.6

Table 5-2. Example dataset explaining how to calculate the 7-day minimum mean. Note that the entire dataset is used to compute rolling 7-day means (three were possible in this example).

Day	DO Daily Minimum (mg/L)	7-Day Minimum Mean (mg/L)
1	5	…
2	6	…
3	5	…
4	5.5	…
5	6	…
6	6.5	…
7	5	5.6
8	5	5.6
9	5.5	5.5

Equation for calculating the 7-day minimum mean:

$$\text{7-Day Minimum Mean} = \frac{(A_1 + A_2 + ... + A_n)}{n}$$

A = each daily DO minimum sampled between 4:00 am and 8:00 am
n = total number of days that DO data was collected

For example, the equation for the first 7-day minimum mean (Days 1-7) in **Table 5-2,** is:

$$\text{7-Day Minimum Mean} = \frac{(5 + 6 + 5 + 5.5 + 6 + 6.5 + 5)}{7}$$

7-Day Minimum Mean = 5.6

5.2 Assessment Decision Framework

The same process and decision framework will be applied to data that are collected any time of the year. For each AU the data will be compiled, evaluated for quality, then prepared for assessment (**Section 5.1**). Data will be analyzed, and the results will be compared to DO water quality standards (**Section 2.0**). Based on the data analysis, the assessor will determine if sites are or are not meeting the aquatic life standards or have insufficient information for assessment. If any site does not meet DO water quality standards, the AU will be identified as impaired for DO.

The DO beneficial use decision making framework process (**Figure 5-1**) defines which reporting category is assigned based on whether data meet criteria specifications. Montana uses a system of reporting categories to summarize the impairment status for each AU. Categories range from Pollutant Category 1 (fully supporting all uses) to Pollutant Category 5 (one or more uses is impaired by a pollutant and requires a TMDL). Categories describe impairment status for AUs but are also used to describe individual AU-cause combinations. More information on reporting categories is described in Makarowski (2020).

5.2.1 Category 1 - Use Supported

All data (both continuous and discrete) are subject to the 1-day minimum since all minima should be considered as instantaneous concentrations to be achieved at all times, to be evaluated consistent with **Figure 5-1**. For an assessor to categorize DO/AU combination as Pollutant Category 1 during an initial DO assessment, a 7-day mean and 7-day minimum mean statistics must be available. Data must meet all DO standards as outlined in **Table 2-1** and guidance provided in **Section 5.2.5** for the applicable waterbody class as well as meet minimum data and frequency requirements as outlined in **Sections 3.5.1** and **3.5.2**.

5.2.2 Category 5 - Use Not Supported

Analysis of data will occur site by site. If any site on an assessment unit (AU) fails to meet standards based on the guidance and analysis in this document, the whole AU will be listed and determined to be a Pollutant Category 5. If more than one sample in three years falls below the 1-day minimum DO standard, this would result in the AU being listed for DO. Any DO value that falls below the DO standard for the 30-day and 7-day mean calculations as well as the 7-day minimum mean for a site would result in the AU being listed for DO and determined to be a Pollutant Category 5. **Table 5-3** provides detailed guidance on how to interpret any DO value that falls below the DO standards.

For example, based on information provided in **Table 2-1**, if DO concentration is below 9.5 mg/L (for 7-day mean) or more than one DO observation is below 8 mg/L (for 1-day minimum) for salmonid waters during early life stages, then the waterbody must be listed for DO impairment. Inter-gravel studies should be considered according to guidance in **Section 5.2.5**.

5.2.3 Category 3 - Insufficient Information

An AU will be classified as Category 3 if data do not meet data quality requirements as outlined in **Section 4.0**. The assessor will also deem an AU's data as insufficient if no result falls below the 1-day minimum DO standard and there are insufficient data to calculate a 7-day minimum mean and 7-day mean as outlined in **Sections 3.5.1** and **3.5.2**.

Any data are assessable, but it is preferred to have data collected during the growing season (as specified in **Table 3-1**). If data are not available during the growing season, the assessor should continue with the assessment but may determine there is insufficient data to determine a Pollutant Category 1 -

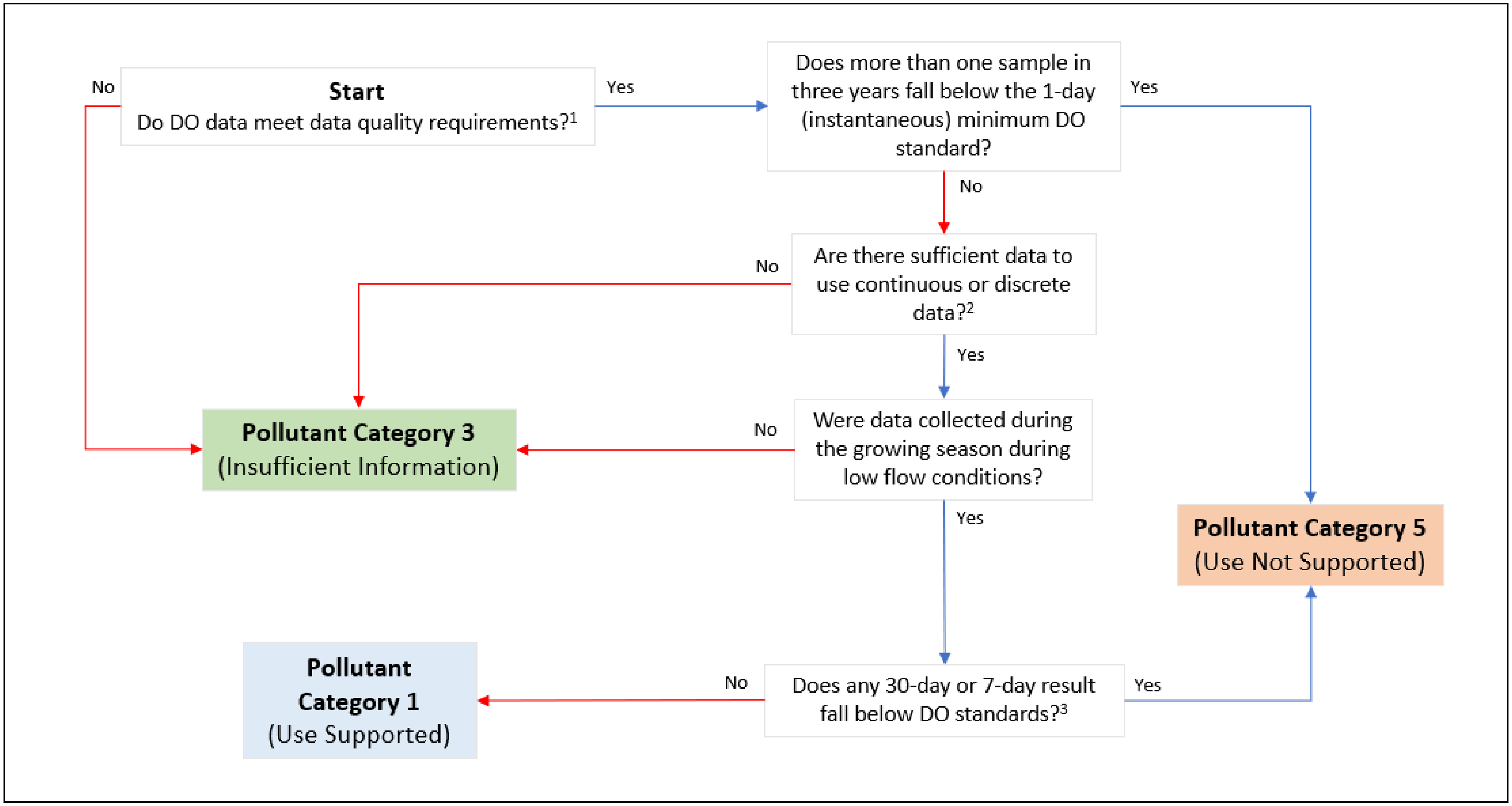
Use Supported, and thus move to a Pollutant Category 3 - Insufficient Information evaluation if data from other seasons pass applicable tests.

5.2.4 Delisting Decision

For a waterbody to be delisted, a 30-day mean must be evaluated, which equates to at least 16 days of data within a 30-day timeframe and these must be collected at multiple sites which include the most sensitive locations. Data for delisting must be collected during the growing season (**Table 3-1**) or if decomposition, biochemical oxygen demand (BOD), or dam operation is suspected as a driver of low oxygen, then data must be collected during peak senescence and non-growing season timeframes. Each applicable standard based on use class is evaluated independently and must be met for the AU to be delisted (i.e., no decisions to list from **Table 5-3**). All sites need to meet DO standards for the assessor to pursue a delisting.

5.2.5 Inter-gravel Dissolved Oxygen Data

If salmonid waters do not meet the 7-day mean or the 1-day minimum during early life stages, then it might be beneficial to conduct an inter-gravel DO study to determine DO impairment. Spawning, or inter-gravel, DO studies may be coordinated with FWP fisheries biologists for selection of critical spawning locations. If inter-gravel data meet the standard in parentheses of **Table 2-1**, then the early life stage DO standard will be met for salmonids if the water column also meets the thresholds in parenthesis and all other DO standard durations within the waterbody when early life stages are present (**Appendix A**). DO conditions in spawning gravel are highly variable and the standard was set for average conditions (EPA Gold Book 1986). Results from an inter-gravel study should average spatial and temporal results within the spawning areas and be compared to the thresholds within the parenthesis in **Table 2-1**. Sampling and analysis plans must be completed for any gravel studies and approved by the QA officer and program manager.



[1]Data follow QA and minimum requirements as explained in **Section 4.0**
[2]Sufficient data to assess 30-day or 7-day timeframe criteria as explained in **Sections 3.5.1 and 3.5.2.**
[3]Must have a 7-day minimum mean and 7-day mean. It is preferred to have a 30-day, but you can fulfill this box with a 7-day minimum mean and 7-day mean if during the growing season. DO standards as explained in **Table 2-1**.

Figure 5-1. Dissolved Oxygen Beneficial Use Decision Framework Process

Table 5-3. Assessment Method Decision Framework

Cold Water Sampling: Salmonid Fishes (A-1, B-1, B-2, C-1, and C-2)[1]				**Warm Water Sampling: Non – Salmonid Fishes (C-3, B-3, and I)**			
	Sampling Requirements	*Calculations*	*List*		*Sampling Requirements*	*Calculations*	*List*
30-day mean (year round)	16 days or more	Calculate the 30-day mean of the available dataset. Use rolling mean only if the available dataset has 31 days or more. Compare to 6.5mg/L DO.	1 exceedance of any 30-day mean.	30-day mean (year round)	16 days or more	Calculate the 30-day mean of the available dataset. Use rolling means only if the available dataset has 31 days or more. Compare to 5.5mg/L DO.	1 exceedance of any 30-day mean.
7-day mean (year round)	5 days or more	Calculate the mean of the available dataset. Use rolling mean averages if the available dataset has 8 days or more. Compare to 9.5 mg/L DO.	1 exceedance of any 7-day mean will list or must trigger spawning gravel DO study comparing to 6.5 mg/L DO.	7-day mean (applicable Mar 15-Aug 31)	5 days or more	Calculate the mean of the available dataset. Use rolling mean if the available dataset has 8 days or more. Compare to 6.0 mg/L DO.	1 exceedance of any 7-day mean.
7-day mean minimum[2] (year round)	5 days or more	Calculate the mean of the daily minimum[2] DO for the available dataset. Use rolling mean if the available dataset has 8 days or more. Compare to 5.0 mg/L DO.	1 exceedance of any 7-day mean minimum[2].	7-day mean minimum[2] (year round)	5 days or more	Calculate the mean of the daily minimum[2] DO for the available dataset. Use rolling mean if the available dataset has 8 days or more. Compare to 4.0 mg/L DO.	1 exceedance of any 7-day mean minimum[2].
1-day minimum[2] (year round)	2 days, more is recommended[3]	Calculate each daily DO minimum[2] of the available dataset. Compare to 8.0 mg/L DO.	>1 exceedance in 3 years will list or must trigger spawning gravel DO study comparing to 5 mg/L DO.	1-day minimum[2] (year round)	2 days, more is recommended[3]	Calculate each daily DO minimum[2] of the available dataset. Compare to 5 mg/L DO March 16-Aug 31. Compare 3.0 mg/L DO Sept 1-March 15.	>1 exceedance in 3 years.

[1]See **Section 2.0** for A-closed waters' assessment process

[2]Minimum measurements should be collected between 4am-8am.

[32]See **Section 5.2** for minimum requirements for beneficial use decision making

5.3 Document Assessment Decisions and Review with Management

The assessor must document all data and decisions made pertaining to DO impairment and beneficial use support determinations for AUs. Assessment outcomes for individual AUs, including data summaries, impairment determinations, and beneficial use support determinations are documented via Montana DEQ's Clean Water Act Information Center (CWAIC) available at www.cwaic.mt.gov. Waterbodies identified as impaired due to DO are included in Montana's biennial Water Quality Integrated Report and list of impaired waters. Assessment decisions are reviewed by the Monitoring and Assessment Section Supervisor and may be reviewed by the QA Officer and managers or staff from other DEQ programs.

6.0 Source Assessment and Supplemental Information

6.1 Probable Sources

Probable sources of impairment are the activities, facilities, or conditions that generate the pollutants that prevent waters from meeting water quality standards. The following sources are most commonly associated with conditions that lead to DO impairment listings in Montana; additional selections are available in the Water Quality Assessment and Reporting Documentation (WARD) system if needed:

- Dam or Impoundment
- Industrial Point Source Discharges
- Loss of Riparian Habitat
- Agriculture
- Municipal Point Source Discharges
- On-site Treatment Systems (Septic Systems and Similar Decentralized Systems)
- Urban Runoff/Storm Sewers
- Mining
- Natural Sources
- Golf Courses
- Erosion and Sedimentation
- Accidental Release/Spill

If water quality data are available that proves that a probable source is likely contributing to eutrophication and/or decreasing DO concentrations, the assessor should check the Source Confirmed box in WARD, whereas if probable sources are present in the watershed but are not confirmed, the assessor should check the Source Not Confirmed box. If source data exist, it should be incorporated into the data analysis and data matrix within WARD. The assessor may also include a brief description of sources in the overall condition of the waterbody summary in WARD.

For many of the streams in Montana, DO concentrations are related to and addressed by nutrients (nitrogen and phosphorus) and nutrient assessments. Human influences on low DO may be controlled through best management practices that reduce nutrients. Nutrient and/or temperature TMDLs will likely be completed to address DO problems.

7.0 PUBLIC INFORMATION

DO data collected by DEQ is stored in DEQ's MT-eWQX Enterprise (EQuIS) database and is uploaded weekly to the Water Quality Portal (EPA, USGS, and NWQMC 2018). The integrated report call for data requires that data be submitted in a format compatible for uploading to DEQ's EQuIS database. Assessment outcomes for individual AUs, including data summaries, impairment determinations, and beneficial use support determinations, are documented via Montana DEQ's Clean Water Act Information Center (CWAIC; available at www.cwaic.mt.gov).

8.0 References

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APPENDIX A: TABLE OF SPAWNING TIMES OF MONTANA FISHES

SPAWNING TIMES OF MONTANA FISHES, Prepared by Don Skaar, Montana Fish, Wildlife and Parks, 3/6/2001. This table is a combination of known spawning times for fish in Montana and estimates based on spawning times reported in other areas in North America of similar latitude. Sources used for this table include: G.C. Becker, Fishes of Wisconsin; C.J.D. Brown, Fishes of Montana; K.D. Carlander, Handbook of freshwater fishery biology, volumes 1 and 2; R.S. Wydoski, and R.R. Whitney. Inland fishes of Washington; Scott and Crossman. Freshwater fishes of Canada; Montana Fish, Wildlife and Parks fisheries biologists.

The code for the table is as follows: J1, J2, F1, F2 refer to the half month increments of January 1-15, January 16-31, February 1-14, February 15-29, and so on. In the table S = spawning period, I = incubation period for eggs of salmonids, E = time period in which salmonid sac-fry are in the gravels

Species	**J1**	**J2**	**F1**	**F2**	**M1**	**M2**	**A1**	**A2**	**M1**	**M2**	**J1**	**J2**	**J1**	**J2**	**A1**	**A2**	**S1**	**S2**	**O1**	**O2**	**N1**	**N2**	**D1**	**D2**
White sturgeon									S	S	S	S												
Pallid sturgeon										S	S	S	S	S										
Shovel. sturgeon										S	S	S	S	S										
Paddlefish									S	S	S	S	S	S										
Goldeye						S	S	S	S	S	S													
Cisco	I	I	I	I	I	I															S	S	S	S
Lake whitefish	I	I	I	I	I	I													S	S	S	S	S	S
Mount. whitefish	I	I	I	I	I	I												S	S	S	S	S	I	I
Pygmy whitefish																					S	S	S	S
Kokanee	I	I	I	I	I													S	S	S	S	S	I	I
Chinook salmon																			S	S				
Golden trout											S	S	S	S	I	I,E								
Cutthroat trout							S	S	S	S	S	S	S	I	I	E								
Rainbow trout					S	S	S	S	S	S	S	S	I	I	E									
Brook trout	I	I	I	I	E	E	E	E	E								S	S	S	S	I	I	I	I
Bull trout	E	E	E	E	E	E	E	E	E							S	S	S	S	S	I	I	I	I
Lake trout	I	I	I	I	I	I	I	I											S	S	S	S	S	I
Brown trout	S	I	I	I	I	I	I	I,E										S	S	S	S	S	S	S
A. grayling								S	S	S	S	S	S,I											

Species	**J1**	**J2**	**F1**	**F2**	**M1**	**M2**	**A1**	**A2**	**M1**	**M2**	**J1**	**J2**	**J1**	**J2**	**A1**	**A2**	**S1**	**S2**	**O1**	**O2**	**N1**	**N2**	**D1**	**D2**
Redband trout												S	S	I										
Northern pike					S	S	S	S	S															
Carp									S	S	S	S	S	S	S	S								
Golden shiner									S	S	S	S	S	S										
Pearl dace																								
Creek chub						S	S	S	S	S	S	S												
N. redbelly dace									S	S	S	S	S	S										
Finescale dace							S	S	S	S														
Utah chub									S	S	S	S	S	S										
Flathead chub									S	S	S	S	S	S	S									
Sturgeon chub										S	S	S	S	S	S									
Lake chub										S	S													
Sicklefin chub											S	S	S	S	S	S								
Peamouth									S	S	S	S												
Emerald shiner													S	S	S	S								
Spottail shiner											S	S	S	S	S	S								
Sand shiner									S	S	S	S	S	S	S	S								
Brassy minnow									S	S	S	S												
Plains minnow							S	S	S	S	S	S	S	S	S									
WSilveryminnow									S	S	S	S	S	S										
Fathead minnow									S	S	S	S	S	S	S	S								
N. Pike minnow									S	S	S	S	S											
Longnose dace									S	S	S	S	S	S	S									
Redside shiner										S	S	S	S	S	S									
River carpsucker									S	S	S	S												
Blue sucker							S	S	S	S	S													
Small. Buffalo									S	S	S													
Big. Buffalo									S	S	S	S	S											
Short. Redhorse							S	S	S	S	S	S												

Species	J1	J2	F1	F2	M1	M2	A1	A2	M1	M2	J1	J2	J1	J2	A1	A2	S1	S2	O1	O2	N1	N2	D1	D2
Longnose sucker						S	S	S	S	S	S	S	S											
White sucker							S	S	S	S	S	S												
Largesc. Sucker							S	S	S	S														
Mountain sucker											S	S	S	S										
Black bullhead									S	S	S	S	S											
Yellow bullhead									S	S	S	S	S											
Channel catfish									S	S	S	S	S											
Stonecat											S	S	S	S	S	S								
Burbot			S	S	S	S																		
Brook stickleback									S	S	S	S												
Rock bass									S	S	S	S												
Green sunfish									S	S	S	S	S											
Pumpkinseed										S	S													
Bluegill									S	S	S	S	S											
Smallmouth bass									S	S	S	S												
Largemouth bass									S	S	S	S	S											
White crappie										S	S	S	S											
Black crappie									S	S	S	S												
Yellow perch						S	S	S	S	S	S	S												
Sauger						S	S	S	S	S														
Walleye							S	S	S	S														
Iowa darter									S	S	S	S	S											
Mottled sculpin									S	S	S	S												
Slimy sculpin																								
Torrent sculpin																								
Shorthead sculpin																								
Spoonhead sculpin																								

APPENDIX B: B-3 AND C-3 STREAMS AND RIVERS WITH BURBOT (*LOTA LOTA*)

AUID	Waterbody Name, Description	Use Class
MT42M002_190	DEER CREEK, Confluence of Middle Fork Deer Creek and South Fork Deer Creek to mouth (Yellowstone River)	C-3
MT40E001_010	MISSOURI RIVER, Bullwhacker Creek to Fort Peck Reservoir	B-3
MT40S001_012	MISSOURI RIVER, Milk River to Poplar River	B-3
MT41Q001_014	MISSOURI RIVER, Morony Dam to Marias River	B-3
MT40S003_010	MISSOURI RIVER, Poplar River to North Dakota border	B-3
MT41Q001_013	MISSOURI RIVER, Rainbow Dam to Morony Dam	B-3
MT41T001_010	MISSOURI RIVER, the Marias River to Bullwhacker Creek	B-3
MT42J003_011	POWDER RIVER, Little Powder River to Mizpah Creek	C-3
MT42J003_012	POWDER RIVER, Mizpah Creek to mouth (Yellowstone River)	C-3
MT42J001_010	POWDER RIVER, Wyoming border to Little Powder River	C-3
MT40P001_013	REDWATER RIVER, Buffalo Springs Creek to Pasture Creek	C-3
MT40P001_011	REDWATER RIVER, headwaters to Hell Creek	C-3
MT40P001_012	REDWATER RIVER, Hell Creek to Buffalo Springs Creek	C-3
MT40P001_014	REDWATER RIVER, Pasture Creek to mouth (Missouri River)	C-3
MT42A001_011	ROSEBUD CREEK, boundary at S28/29 T6N R42E to mouth (Yellowstone River)	C-3
MT42A001_013	ROSEBUD CREEK, headwaters to Northern Cheyenne Reservation	C-3
MT42A001_012	ROSEBUD CREEK, Northern Cheyenne Reservation boundary to boundary at S28/29 T6N R42E	C-3
MT41K001_020	SUN RIVER, Muddy Creek to mouth (Missouri River)	B-3
MT41O001_010	TETON RIVER, Muddy Creek to mouth (Marias River)	B-3
MT42C001_014	TONGUE RIVER, Beaver Creek to Twelve Mile Dam, T6N R48E S29	B-3
MT42C001_013	TONGUE RIVER, Hanging Woman Creek to Beaver Creek	B-3
MT42C001_011	TONGUE RIVER, Twelve Mile Dam to mouth (Yellowstone River)	B-3
MT43F001_010	YELLOWSTONE RIVER, City of Billings PWS to Huntley Diversion Dam	B-3
MT43Q001_011	YELLOWSTONE RIVER, Huntley Diversion Dam to the mouth of Big Horn River	B-3
MT42M001_011	YELLOWSTONE RIVER, Lower Yellowstone Diversion Dam to North Dakota border	B-3
MT42M001_012	YELLOWSTONE RIVER, Powder River to Lower Yellowstone Diversion Dam	B-3
MT42K001_020	YELLOWSTONE RIVER, the Big Horn to Cartersville Diversion Dam	B-3
MT42K001_010	YELLOWSTONE RIVER, the Cartersville Diversion Dam to Powder River	B-3

(MTNHP and MTFWP, 2021)

APPENDIX C: TABLE OF A-CLOSED CLASSIFIED WATERS OF MONTANA

GNIS Name	Stream Type	Drainage Area
Ashley Creek	Mainstem	Clark Fork
Fifer Creek	Mainstem	Clark Fork
UnNamed Trib to Basin Creek	UnNamed Trib to Basin Creek	Clark Fork
Hearst Lake Drainage	Mainstem	Clark Fork
Trib to Basin Creek	Trib to Basin Creek	Clark Fork
Basin Creek	Mainstem	Clark Fork
Tin Cup Joe Creek	Mainstem	Clark Fork
Yankee Doodle Creek	Mainstem	Clark Fork
Rattlesnake Creek	Mainstem	Clark Fork
East Fork Rattlesnake Creek	Trib to Rattlesnake Creek	Clark Fork
Essex Creek	Mainstem	Flathead
Pilcher Creek	Trib to Rattlesnake Creek	Clark Fork
Fraser Creek	Trib to Rattlesnake Creek	Clark Fork
Beeskove Creek	Trib to Rattlesnake Creek	Clark Fork
Hyalite Creek	Mainstem	Missouri
Bozeman Creek	Mainstem	Missouri
East Fork Hyalite Creek	Trib to Hyalite Creek	Missouri
South Fork Bozeman Creek	Trib to Sourdough AKA Bozeman Creek	Missouri
Blackmore Creek	Trib to Hyalite Creek	Missouri
Lick Creek	Trib to Hyalite Creek	Missouri
Wild Horse Creek	Trib to Hyalite Creek	Missouri
Flanders Creek	Trib to Hyalite Creek	Missouri
Moser Creek	Trib to Hyalite Creek	Missouri
History Rock Creek	Trib to Hyalite Creek	Missouri
Shower Creek	Trib to Hyalite Creek	Missouri
Lyman Creek	Mainstem	Missouri
Buckskin Creek	Trib to Hyalite Creek	Missouri
Hood Creek	Trib to Hyalite Creek	Missouri
Maid of the Mist Creek	Trib to Hyalite Creek	Missouri
Summit Creek	Two Medicine River Drainage	Missouri
High Falls Creek	Trib to Rattlesnake Creek	Clark Fork
Lake Creek	Trib to Rattlesnake Creek	Clark Fork
Porcupine Creek	Trib to Rattlesnake Creek	Clark Fork

Attachment A: Analysis of Different Durations of Continuous Dissolved Oxygen Data Using Equivalence Testing