Electrical Conductivity (EC) and Sodium Adsorption Ratio (SAR) Assessment Method for Rosebud Creek, the Tongue, Powder, and Little Powder Rivers, and the Tongue River Reservoir

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ACRONYMS

ARM	Administrative Rules of Montana
CBM	Coalbed Methane
CFR	Code of Federal Regulations
DEQ	Department of Environmental Quality
EC	Electrical Conductivity
MAR	Montana Administrative Record
MCA	Montana Code Annotated
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
RPD	Relative Percent Difference
SAP	Sampling and Analysis Plan
SAR	Sodium Adsorption Ratio
SC	Specific Conductance
TDS	Total Dissolved Solids
TMDL	Total Maximum Daily Load
WARD	Water Quality Assessment and Reporting Documentation

1.0 Introduction

This document details the Montana Department of Environmental Quality (DEQ) assessment method for determining attainment of electrical conductivity (EC) and sodium adsorption ratio (SAR) numeric water quality standards. Results from this method are used in the overarching process of Beneficial Use Assessment for Montana's Surface Waters (Makarowski, 2020). This assessment method pertains only to the mainstems of Rosebud Creek, the Tongue, Powder, and Little Powder rivers, and the Tongue River Reservoir, and specifically to the agriculture beneficial use.

EC and SAR numeric water quality standards for the waterbodies named in this assessment method were developed and adopted by the Board of Environmental Review (BER) in the early 2000s to protect the agriculture beneficial use. The most significant anthropogenic sources of salt loading in this area of Montana include coalbed methane production, dryland crop-fallow farming, coal production, and irrigated crop production. Natural salinity in this region is present in geological strata influenced by a prehistoric inland sea (Bhattacharya and Willis, 2001).

1.1 Applicability

This assessment method is only applicable to Rosebud Creek, the Tongue River, the Powder River, the Little Powder River, and the Tongue River Reservoir for EC and SAR under the state of Montana jurisdiction. State waters are defined in the Montana Water Quality Act (75-5-103(34), MCA).

2.0 Montana Water Quality Standards

Montana water quality standards are developed to protect water resources, to identify polluted waters or healthy waters in need of protection, as well as to establish limits for discharges from regulated facilities. The state of Montana designates beneficial uses for all state waters and establishes numeric or narrative water quality standards. Beneficial uses, and water quality standards provide the framework for achieving Federal Clean Water Act and Montana Water Quality Act goals and protections for Montana's water resources.

2.1 Montana Numeric EC and SAR Water Quality Standards

In 2003, the BER adopted EC and SAR numeric water quality standards for Rosebud Creek, the Tongue, Powder, and Little Powder rivers, and the Tongue River Reservoir. The numeric standards established for EC and SAR which apply to these waters are contained in the Administrative Rules of Montana (ARM 17.30.670). Administrative rules are agency regulations, standards or statements of applicability that implement, interpret or set law or policy. The BER determined that rules were necessary to ensure that the designated beneficial uses of these waters for agricultural purposes would be protected during the development of CBM and future land use changes.

For Rosebud Creek and the Tongue, Powder and Little Powder rivers, numeric water quality standards for EC and SAR are categorized into two distinct seasons: the irrigation season (March 2nd – October 31st) and the non-irrigation season (November 1st – March 1st) (ARM 17.30.670(1)). For the Tongue River Reservior, a single standard applies year-round (ARM 17.30.670(5)). These standards are set to protect the agriculture beneficial use during irrigation season, and to protect riparian vegetation during the non-irrigation season. Numeric water quality standards for EC and SAR for these waters are shown in **Table 1-1.**

Table 1-1. Numeric EC and SAR Water Quality Standards

Waterbody	**Irrigation Season (3/2 – 10/31)**				**Non-Irrigation Season (11/1 – 3/1)**			
	EC (µS/cm) (monthly average)	EC (µS/cm) (no sample may exceed)	SAR (monthly average)	SAR (no sample may exceed)	EC (µS/cm) (monthly average)	EC (µS/cm) (no sample may exceed)	SAR (monthly average)	SAR (no sample may exceed)
Tongue River	1000	1500	3.0	4.5	1500	2500	5.0	7.5
Powder River	2000	2500	5.0	7.5	2500	2500	6.5	9.75
Little Powder River	2000	2500	5.0	7.5	2500	2500	6.5	9.75
Rosebud Creek	1000	1500	3.0	4.5	1500	2500	5.0	7.5
Tongue River Reservoir	1000	1500	3.0	4.5	1000	1500	3.0	4.5

2.2 Electrical Conductivity and Specific Conductance

Specific conductance or conductivity (SC) is a measurement of the ability of water to conduct an electrical current at or corrected to 25 °C (Miller, Bradford, and Peters, 1986). State law defines another term, electrical conductivity: "Electrical conductivity (EC) means the ability of water to conduct an electrical current at 25°C" (ARM 17.30.602(7)).

From these definitions, it is assumed EC and SC can be used interchangeably for this assessment method. Throughout this document, EC and SC are used interchangeably, but each term is used within the appropriate context: EC is used when referencing Montana's standard whereas SC is used when referencing monitoring and data analysis. EC and SC are related to the total amount of dissolved solids in water. The more ions in the water, the more easily it conducts electricity. Excessive amounts of salts in water can reduce overall crop production.

2.3 Sodium Adsorption Ratio

Sodium adsorption ratio (SAR) is a unitless ratio representing a measure of the amount of sodium (Na) relative to calcium (Ca) and magnesium (Mg), where all concentrations are expressed as milliequivalents/L (ARM 17.30.602(25)). Specifically, it is the ratio of the Na concentration divided by the square root of one half of the Ca + Mg concentration (Soil Survey Staff, 2017). SAR is important in supporting agricultural crop production as high SAR values in clay and loam soils will reduce soil permeability, thereby concentrating salts near the surface and inhibiting plant growth (Warrence, Bauder, and Pearson, 2002).

3.0 DATA CONSIDERATIONS FOR BENEFICIAL USE ASSESSMENT

Waterbody condition must be evaluated based on all existing and readily available data and information (75-5-702, MCA; 40 CFR 130.7(b)(5)). This section describes important considerations for determining SC and SAR data quality and currency when performing beneficial use assessments. Data considerations apply to discrete data (ambient water grab samples), *in-situ* data (instantaneous measurements from a field meter), or continuous data (instrument deployed to collect data systematically over time).

3.1 DATA CURRENCY

Data collected within the past ten years are considered current and may be used in making assessment decisions (Makarowski, 2020). If during this period, significant changes in sources during the past decade have been documented, the assessor may use best professional judgement when determining which data are appropriate (no less than three years) to include or not in the assessment. The assessor should document the specific changes, identify data currency alternatives, and determine which years' data are appropriate to include in the assessment process. To proceed with assessment, the resulting dataset must represent at least three years that occurred after the documented changes in the source(s).

3.2 TIME OF YEAR

The EC and SAR numeric water quality standards are applicable year-round (**Table 1-1**). Therefore, samples may be collected during all times of the year. For any type of data collection, the assessor must evaluate the time of year samples were collected and reference **Table 1-1** to determine which standards are appropriate for the assessment.

For all types of data collection (discrete SC and SAR and continuous SC), it is highly recommended that the crop production timeframe (March 2 – October 31) is targeted, especially during early season crop production when historical data have shown the most variability in SC.

3.3 TIME OF DAY

SC and SAR samples may be collected at any time of the day. Significant intra-daily fluctuations are uncommon unless there is significant precipitation or snowmelt.

3.4 SPATIAL AND TEMPORAL REQUIREMENTS

This assessment method does not require a minimum distance between sites to attain spatial independence because DEQ assumes that there is usually no spatial independence within an assessment unit. For determining standards attainment, all individual result values from an assessment unit (**Section 3.4.1**) are considered dependent and are pooled together to calculate monthly averages. However, discrete samples are considered temporally independent if sampled greater than three days [72 hours] apart at a single site location[1]. Continuous datasets are not subject to temporal

[1] DEQ carried out an analysis on continuous EC data from the Tongue River by examining months when EC is fairly stable and months when it changes rapidly. DEQ used the Durbin-Watson test (Savin and White, 1977) to evaluate

independence evaluation unless there is a situation where a partial dataset is being used along with discrete data (**Section 6.0**). Temporal independence is especially important when evaluating discrete data during months with highly variable SC (e.g., from ice-off to June).

3.4.1 Assessment Units and Assessment Reaches

EC and SAR assessment decisions are made for assessment units (i.e., waterbody segments). Monitoring and Assessment Program prioritization criteria may include waters that have been previously identified as impaired for EC, SAR or both, or waters considered at higher risk of EC or SAR impairment due to human sources in the watershed.

If an assessment unit exhibits one or more significant shifts in type and intensity of potential SC or SAR sources such that clear breaks could be made to designate new homogenous reaches, sub-segmenting may be justified (Makarowski, 2020). For example, if a relatively un-impacted upstream reach can be isolated and its condition is likely substantially different from other downstream parts of the assessment unit, the assessment unit may be split into two reaches for assessment purposes. When contemplating assessment reaches, consider:

- Each reach should have the same general data requirements (e.g., dataset minimums) as the parent assessment unit would have had if it hadn't been divided. If resources are a consideration, a reach that has the most source contributions should be targeted.
- If one reach indicates impairment, the entire assessment unit receives the impairment determination.
- It is better to limit the number of reaches to avoid excessive reaches and the consequential administrative and sampling requirements that result.
- With some exceptions (**Section 3.4.2**), an assessor must decide whether to split an assessment unit into multiple assessment reaches before data collection and identify the proposed reaches in a sampling and analysis plan; this will help ensure that reach breaks are based on considerations of land use and sources rather than on differences in concentrations among sites discovered after monitoring.

3.4.2 Sample Location Requirements and Number of Sites within an Assessment Unit

Assessment decisions are made using data pooled for an entire assessment unit (or reach), not for individual sites. This applies to both continuous and discrete SC and SAR data sets. Best professional judgment may be applied to determine how many sites are needed to adequately represent the range of potential human sources influencing each assessment unit.

During assessment, it is preferable to incorporate data collected at multiple sites to better capture variability of SC and SAR throughout the assessment unit. Assessment decisions can be based on data collected at a single sampling location only if that single location can reasonably be considered representative of the assessment unit. Data collection at multiple sites enables a multifaceted approach to data analysis. For example, in addition to pooling data from the entire assessment unit to make impairment determinations, an assessor may compare data from site to site after the monitoring to determine if the segment is homogenous or if sources affect EC and SAR and thus different reaches are assessed. The dispersed data can also be used by the Total Maximum Daily Load (TMDL) program.

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temporal serial correlation for these months, and to identify the minimum number of days necessary to establish temporal serial independence using methods in Suplee et al. (2019).

During the assessment process, if data analysis shows that one site's data are not like the other sites in the assessment unit, a further reach break may be called for after data have already been collected. This could be due to previously unknown sources, especially those that are associated with groundwater.

3.5 Parameter Requirements and Minimum Data Requirements

This section describes the parameters required for this assessment method, and the minimum data requirements for each parameter.

3.5.1 Required Parameters

SC and SAR are the only parameters needed for this assessment method. Assessors must search for, document, and use all readily available EC and SAR data at the onset of data analysis; if there is enough data for one parameter but not the other, the assessor continues with data analysis for the parameter that meets data requirements. Both parameters are evaluated independently during data analysis to determine if there is an impairment based on the EC and/or SAR numeric water quality standards (**Table 1-1)**. SC can be measured in three acceptable ways: 1) *in-situ* (instantaneous) with a hand-held field meter, 2) using a continuous data logger, or 3) via ambient water collected and sent to a laboratory for SC measurement. For SAR, ambient water sample collection and laboratory determination of sodium (Na), magnesium (Mg), and calcium (Ca) is necessary. SAR is a calculated value based on these three elements.

Ambient water samples collected for any EC or SAR assessment project must also be analyzed for total dissolved solids (TDS). Although not used for assessment, TDS is used for calculating salt loads during TMDL modeling and development. Additionally, tight correlations between TDS and SC might be developed so that, if needed, future SC data can be extrapolated from TDS estimates (and vis-versa).

All parameters collected for this assessment method must adhere to all applicable DEQ standard operating procedures (e.g. sample collection, handling and analysis, and field instruments use and maintenance).

In addition, for the Tongue River Reservoir, water temperature data should be collected at the same location as water quality data. Water temperature data collected systematically throughout the water column, also called a depth profile, will help the assessor determine whether there is lake stratification and assist in data preparation when calculating monthly averages (**Section 6.2**).

3.5.2 Minimum Data Requirements

This section outlines the general minimum data requirements for performing attainment assessments for the numeric EC and SAR water quality standards. **Section 5.3** gives further guidance on how to calculate monthly averages when (1) only discrete SC data are available, (2) when only continuous data are available, and (3) when both continuous and discrete data are available. For both EC and SAR, when comparing against the "no sample may exceed" standards, a single sample can indicate impairment, so a single sample can constitute sufficient data if that sample meets data quality requirements (**Section 5.0)**. **Table 4-1** summarizes the requirements that are detailed further below.

3.5.3 Minimum Years Required for Assessments

ARM 17.30.670 does not indicate the minimum number of years of data required to assess for EC or SAR; this has been left to DEQ's professional discretion. For the purposes of assessing these waterbodies' EC and SAR results against the numeric standards (**Table 1-1**), at least three years (consecutive or non-consecutive) from the most recent ten years must have been sampled to meet DEQ's minimum data requirements. If there have been significant and documented changes in sources, use the procedure indicated in **Section 3.1.**

3.5.4 Minimum Months Required for Assessments

ARM 17.30.670 does not indicate the minimum number of months per year required to assess EC or SAR per season. For the purposes of assessing these waterbodies using EC and SAR numeric standards for either season (**Table 1-1**), at least three calendar months must have been sampled in during the irrigation season, and at least two calendar months must have been samples during the non-irrigation season to meet minimum monthly data requirements. Irrigation season minimum data requirements must be met to assess a waterbody. If minimum data requirements are met for the non-irrigation season it must be accompanied by qualifying data during the irrigation season. The years in which minimum data requirements are met for both seasons do not need to be the same.

3.5.5 Minimum Number of Discrete SC and SAR Samples

ARM 17.30.670 does not indicate the minimum number of samples needed to calculate monthly average values for discrete data. To assess monthly conditions using discrete samples, sample frequency must include a minimum of four individual samples within each calendar month with approximately one week between samples at any single site location.

In the Tongue River Reservoir, if temperature samples have been collected throughout the water column (systematically from near the surface to the bottom) the assessor must evaluate the dataset for indicators of lake stratification such as a temperature gradient in the middle layer of the lake indicating a thermocline. If the dataset indicates stratification, each strata should meet minimum data requirements. If the reservoir samples are a mix of stratified and unstratified conditions, further analysis, professional judgement, and management consultation will determine how reservoir data is analyzed (**Section 3.5.8**).

3.5.6 Minimum Continuous SC Data Requirements

ARM 17.30.670 does not indicate the minimum number of samples needed to calculate monthly average values for continuous data. To assess monthly conditions using continuous SC measurements, a preferred sample frequency should include every 24-hour period of an entire calendar month sampled on a frequency no greater than 30-minute intervals; it is acceptable to collect data at a higher frequency (i.e. 15-minute intervals). Other sample frequencies may be acceptable. If a continuous dataset has been obtained where the sample frequency is greater than 30-minute intervals, consult the section supervisor or technical lead to determine how monthly averages will be calculated **(Section 5.3)**.

3.5.7 Alternate Minimum Data Requirements

SC and SAR monitoring on Rosebud Creek, and the Tongue, Powder, and Little Powder rivers can be logistically challenging because of travel distances to reach these waterbodies. Additionally, continuous data loggers can become fouled or malfunction. Because of these challenges, alternate sample frequencies may be considered acceptable so long as they still account for intra-monthly variability in SC.

Continuous SC datasets that do not contain data on equal time interval for every 24-hour period of a calendar month may still be acceptable. An acceptable partial continuous dataset would still need to meet the minimum data requirements in **Section 3.5.5,** where at least one sample was obtained during each calendar week that has more than three days, temporal independence does not apply. There may be instances where a partial continuous dataset does not meet the minimum data requirements in **Section 3.5.5** but a discrete sample(s) was obtained during a calendar week where continuous data is absent, in this case the continuous dataset and discrete dataset may be combined to meet the minimum monthly data requirements. The assessor must follow the appropriate process in **Section 5.4.2**.

The alternate minimum SC data requirements must also meet minimum requirements in **Section 3.5.3** and **Section 3.5.4.** It is important for the assessor to indicate when a partial continuous dataset is used in order to use the appropriate method of monthly average calculation (**Section 5.3.2**). There is no acceptable alternate approach for calendar months with only discrete data available.

3.5.8 Alternate Minimum Data Requirements for Tongue River Reservoir

SC and SAR monitoring for the Tongue River Reservoir can also be logistically challenging because of travel distances. Sampling during the non-irrigation season can be difficult and sometimes unsafe due to Montana's winters. Reservoir conditions are variable for duration and timing of stratification so it may be challenging to meet minimum data requirements to assess different layers of the reservoir. Because of these challenges, alternate sample frequencies may be considered acceptable so long as they are representative of reservoir conditions.

4.0 Data Quality

Established policies and procedures used by DEQ's Water Quality Planning Bureau for quality assurance and quality control, beneficial use assessment, and data management apply to this assessment method. Data quality requirements apply to all data incorporated while making assessment decisions, whether collected internally (by DEQ) or externally. All data will go through established procedures for quality assurance to ensure data are acceptable for making decisions. For inclusion in assessment decision making, data must represent ambient conditions of the waterbody being assessed and therefore cannot be collected within the mixing zone of permitted point source discharges and must be collected directly from the assessment unit itself. Assessors should thoroughly review continuous SC data to ensure all data are accurate, especially if result values exceed the may not exceed standards. For further details on general data quality requirements see Section 5.0 of Makarowski (2020).

4.1 Data Quality Requirements for EC and SAR Field Instruments

In addition to the general data quality requirements outlined or referenced above, SC data collection has additional data quality requirements. Continuous data loggers must adhere to the manufacturer's calibration and maintenance requirements if the data are to be considered useable for assessment. Continuous data must also be corrected for drift if necessary. It is preferred that handheld field meters are used to compare against continuous data logger values to ensure data quality.

4.2 Field Blanks

Field blanks are samples collected and handled following the same methods as routine samples except that laboratory-grade deionized or distilled water is used rather than ambient water. Field blanks represent total ambient conditions during sampling, transport, and laboratory sources of contamination (EPA, 2009). Typically, field blanks are prepared at the end of the sampling event and at least one field blank is analyzed along with each batch of routine discrete samples. Field blanks are not necessary to incorporate into a sample design when only continuous data or *in-situ* samples are being used, although appropriate equipment calibration and maintenance should be completed per each instrument's user manual and recorded to ensure data quality.

Assessors may decide to reject discrete samples collected during a sampling event in which a field blank returns detectable levels of SC or SAR. If field blank detections are found, assessors should attempt to identify the probable source of contamination, report it to the Project Manager and QA officer. Corrective measures include but are not limited to laboratory re-analyzing the samples, evaluating processes for collecting, handling, storing, and delivering or collecting field blanks.

4.3 Field Duplicates

Field duplicates are discrete samples collected as close as possible to the same point in space and time; duplicates should be collected by the same person and using the same collection method, though they are stored in separate bottles and analyzed independently. For discrete water samples to be analyzed by a lab, duplicate samples should be collected for at least 10% of the total number of samples collected per parameter. Duplicate sampling should be documented in a QAPP or SAP.

Relative percent difference (RPD) is used to evaluate results between two duplicate discrete samples:

$$RPD = \frac{|(result\ 1 - result\ 2)|}{(result\ 1 + result\ 2)/2} \text{ X } 100$$

Field duplicates should generally be within 25% RPD of one another. If RPD greater than 25% is found among field duplicates, the assessor should verify data quality to confirm that the routine result values are valid for inclusion in assessment.

For continuous SC data, a field duplicate should be obtained by placing a handheld field meter probe as near to the deployed instrument as possible and recording the SC value and time. These data can later be compared to the deployed instrument's data using the RPD method. Data accuracy checks, calibration and equipment maintenance should be performed for continuous and hand-held SC meters throughout deployment to validate the quality of the data.

5.0 Data Analysis to Support Water Quality Standards Attainment

5.1 Preparing Data for Assessment

Preparing data for assessment should take into consideration the minimum data requirements that are described in **Section 4.2**. It is important for the assessor to evaluate data quality for every available result and document any that cannot be used. This is especially important when comparing results to the "no sample may exceed" standards.

5.1.1 Preparing Stream Data for Assessments

Steps should be followed when organizing and preparing data for assessment to determine attainment of the monthly average standards for Rosebud Creek, and the Tongue, Powder and Little Powder rivers. This process includes a step where the assessor determines if the data suggest there is a reason to further subdivide the assessment unit into reaches.

1. Compile all SC and SAR data for an assessment unit or assessment reach. Compare data from site to site to see if there should be a previously unfound need for a reach break.
2. Perform data quality assessment to identify the usable dataset (**Section 4.0**); document all data that is excluded from the assessment and justify the exclusion.
3. Organize data by year.
4. Organize data by season according to Montana's EC and SAR standards (**Table 1-1)**.
5. Group continuous SC and discrete SC and SAR values by calendar month, sorted by date.
6. Within a calendar month for all data, identify samples that are temporally independent. Within each calendar month for all data, identify samples that *may* be spatially independent (i.e., sites that are longitudinally separated along the assessment unit or reach). If spatial samples are clearly dependent, those values are grouped.
7. Review data site by site to see if any spatial patterns emerge (at a given point in time, DEQ would generally expect relatively consistent values throughout an assessment unit); if unexpected spatial patterns emerge (e.g. two adjacent sites within an assessment unit contain noticeably different values), consult the section manager or technical lead for guidance. This step may result in sub-segmenting of the assessment unit.
8. Group result values that are temporally dependent.
9. Group result values that are spatially dependent within an assessment unit (reach).
10. Once data has been reviewed site by site, an average can be computed. See **Section 6.4** for step by step instructions to calculate monthly averages.

5.1.2 Preparing Tongue River Reservoir Data for Assessments

Preparing Tongue River Reservoir data for assessment should take into consideration the minimum data requirements that are described in **Section 4.2.** Preparing reservoir data for assessments is largely the same as for the streams except for cases where the lake is stratified.

These steps should be followed when organizing and preparing data for assessment to determine attainment of the monthly average standards. This process includes a step where the assessor determines if the data suggest there is a reason to further subdivide the reservoir into smaller assessment areas, both longitudinally and vertically (the latter addressing stratification).

1. Compile all SC and SAR data for the Tongue River Reservoir.
2. Perform data quality assessment to identify the usable dataset (**Section 5.0**); document all data that is excluded from the assessment and justify the exclusion.
3. Organize data by year.
4. Organize data by season according to EC and SAR standards in **Table 1-1**
5. Group continuous SC and discrete SC and SAR values by calendar month.
6. Within calendar month group data by site from each strata if sites are stratified. Determine if strata are spatially dependent. If they are spatially dependent, complete step 7 for each strata independently.
7. Within calendar month for all data, identify sample sites that are temporally independent.
8. Group result values that are spatially and temporally dependent.
9. Compute average EC and SAR conditions for each dependent data set. See **Section 5.3** for step by step instructions to calculate monthly averages.

5.2 Handling Non-Detects and Greater-Than-Detect Values

All historical data is at detectable levels. If non-detects or greater-than-detect results are attained, be suspect of data and any associated meters.

5.3 Calculating Monthly Averages

There are two distinct scenarios for calculating monthly averages depending on the type of data available. Each is discussed below. However, in the decision framework (**Section 7.0**), averages are compared to the monthly average standard in the same manner.

5.3.1 Monthly Continuous SC datasets

This method for calculating monthly averages is the preferred approach when evaluating standards attainment using continuous SC data. When collecting continuous SC data that will or may be used for assessment purposes, reference **Section 9.0** for supplemental monitoring guidance in addition to **Section 3.0**.

Where only continuous SC data have been collected for every 24-hour period of a given calendar month on an equal time interval at one site (e.g., every 30 minutes), each data point collected over the entire month carries equal weight, therefore the entire dataset is averaged for each assessment unit to derive the monthly average. This monthly average can then be compared against the monthly average numeric EC standards (**Table 1-1**). The approach of averaging all data also applies to situations where data have been collected at multiple sites within an assessment unit and are spatially dependent, but only if all sites have an equal number of samples per day for the entire month (**Table 5-1**). In a case where multiple sites within an assessment unit do not have equal number of samples per day, the dataset would have to follow the three-step process in **Section 5.3.2.**

Table 5-1. Calculating a Monthly Average from Full and Similarly-timed Continuous Datasets from Multiple Sites in an Assessment Unit

Site Name (Upstream to Downstream)	Number of Samples per Day (30 min interval)	Number of Days Sampled	Number of Samples per Month
Upper Site	48	30	1440
Middle Site	48	30	1440
Lower Site	48	30	1440
Total number of samples to calculate grand monthly average from all three sites:			**4320**

If every 24-hour period of a dataset does not have an equal number of samples, data for that month will follow the three-step process described in **Section 5.3.2**. Or, if a continuous SC dataset obtained from another entity contains only daily means and not individual result values, refer to **Section 5.3.2** to calculate monthly averages for the dataset.

5.3.2 Discrete SC and SAR Data, Partial Continuous SC Data and Combined SC Discrete and Continuous Data—Data Reduction Process

In cases where there is only discrete SC and SAR data, combined discrete and continuous SC datasets, or partial continuous datasets from multiple sites, each monthly dataset that meets minimum data requirements (**Section 4.1.2**) should go through a three-step process to derive a monthly average. The three-step process to average data collected in a single month ensures that all data collection timeframes are represented in the monthly average equally, and no one data type or timeframe has stronger representation than another. Examples have been included for reference; **Table 5-3** describes discrete datasets, **Table 5-4** describes combined discrete and continuous datasets, **Table 5-5** describes partial continuous datasets and **Table 5-6** describes partial continuous datasets where data is collected at multiple sites within an assessment unit.

1. All data that have been collected within an assessment unit or reach are averaged into a single daily average for each corresponding day of the month. This would apply, for example, to samples which were obtained on the same day at two separate site locations within an assessment unit and the sites are not considered independent.
2. Daily averages are then averaged to a single value for each calendar week (i.e., a weekly average) in a given month. Averaging the daily values into a weekly average ensures the monthly average is not skewed by intensive sampling during non-equally spaced sampling events
3. To derive a final monthly average, all the weekly averages are averaged. This monthly average can then be compared against the monthly average numeric standard (**Table 1-1)**.

In cases where this approach is being applied, it is not acceptable to use samples outside of the constrained calendar week even if the sample being used is temporally dependent to the associated calendar week and that samples are spaced out over the month. An example of this is presented in **Table 5-2**, where two samples were collected in the first week of the month, no sample in the second week, one sample in the third week and one sample in the fourth week. Again, samples would need to be spaced out across the month adequately where every calendar week that has more than three days is sampled.

Table 5-2. Example of Temporal independence of a sample to be associated with weekly averages in an alternate approach.

Week	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Week 1	Sample 1						Sample 2
Week 2							
Week 3			Sample 3				
Week 4					Sample 4		

DEQ is not trying to create an amalgamation paradox[2] by using averages of averages. Rather, we are trying to assure equal representation of dissimilarly-timed sampling events. Thus, the preferred approach to monitoring SC is to collect a temporally equally distributed dataset over a full month such that one calculated average is produced (**Section 6.4.1**).

Table 5-3 Calculating monthly averages from a discrete SC or SAR dataset; five weeks in this scenario, fifth week is not greater than 3 days

Week	Day of month sample Collected	Samples per week	Daily Average	Weekly Average	Monthly Average
Week 1	2nd	1 Discrete	1 sample is Daily average	1 Sample is weekly average	Sum of 4 Weekly averages divided by 4 = Monthly average to be used in assessment
Week 2	8th	1 Discrete	1 sample is Daily average	Sum of 2 samples in week 2 divided by 2 = weekly average	
	12th	1 Discrete	1 sample is Daily average		
Week 3	19th	1 Discrete	1 sample is Daily average	1 Sample is weekly average	
Week 4	26th	1 Discrete	1 sample is Daily average	1 Sample is weekly average	
Week 5	N/A		Sample not collected	Sample not collected	

[2] Amalgamation paradox, also called Simpsons paradox or Yule-Simpson effect is an effect that occurs when the marginal association between two categorical variables is qualitatively different from the partial association between the same two variables after controlling for one or more other variables (Carlson, 2019).

Table 5-4. Calculating monthly averages from a combined discrete and continuous dataset

Week	Day of month	Samples per Day (30-minute interval)	Daily Average	Weekly Average	Monthly Average
Week 1	1 - 7	48	Sum of 48 samples divided by 48 = daily average	Sum of 7 daily averages in Week 1 divided by 7 = Week 1 average	Sum of 4 Weekly averages divided by 4 = Monthly average to be used in assessment
Week 2	8	48	Sum of 48 samples divided by 48 = daily average	Sum of 6 daily averages in week 2 divided by 6 = Week 2 average	
	9	48	Sum of 48 samples divided by 48 = daily average		
	10	48	Sum of 48 samples divided by 48 = daily average		
	11	48	Sum of 48 samples divided by 48 = daily average		
	12	48	Sum of 48 samples divided by 48 = daily average		
	13	30	Sum of 30 samples divided by 30 = daily average		
	14		No sampled collected		
Week 3	15 - 21	1 Discrete	1 sample is weekly average	1 Sample is weekly average	
Week 4	22 - 29	1 Discrete	1 sample is weekly average	1 Sample is weekly average	
Week 5	30 - 31		Sample not collected	No Sample Collected	

Table 5-5. Calculating monthly averages from a partial continuous dataset

<table>
<tr><th>Week</th><th>Day of month</th><th>Samples per Day (30-minute interval)</th><th>Daily Average</th><th>Weekly Average</th><th>Monthly Average</th></tr>
<tr><td>Week 1</td><td>1 - 7</td><td>48</td><td>Sum of 48 samples divided by 48 = daily average</td><td>Sum of 7 daily averages in Week 1 divided by 7 = Week 1 average</td><td rowspan="9">Sum of 5 Weekly averages divided by 5 = Monthly average</td></tr>
<tr><td rowspan="3">Week 2</td><td>8 - 12</td><td>48</td><td>Sum of 48 samples divided by 48 = daily average</td><td rowspan="3">Sum of 6 daily averages in week 2 divided by 6 = Week 2 average</td></tr>
<tr><td>13</td><td>30</td><td>Sum of 30 samples divided by 30 = daily average</td></tr>
<tr><td>14</td><td></td><td>No samples collected</td></tr>
<tr><td rowspan="3">Week 3</td><td>15 -17</td><td></td><td>No samples collected</td><td rowspan="3">Sum of 4 daily averages in week 3 divided by 4 = Week 3 average</td></tr>
<tr><td>18</td><td>18</td><td>Sum of 18 samples divided by 18 = daily average</td></tr>
<tr><td>19 - 21</td><td>48</td><td>Sum of 48 samples divided by 48 = daily average</td></tr>
<tr><td>Week 4</td><td>22 - 29</td><td>48</td><td>Sum of 48 samples divided by 48 = daily average</td><td>Sum of 7 daily averages in Week 4 divided by 7 = Week 4 average</td></tr>
<tr><td>Week 5</td><td>30 - 31</td><td>48</td><td>Sum of 48 samples divided by 48 = daily average</td><td>Sum of 2 daily averages in Week 5 divided by 2 = Week 5 Average</td></tr>
</table>

Table 5-6. Calculating Monthly Averages from Multiple Sites Within an Assessment Unit with Partial Continuous Datasets

<table>
<tr><th>Week</th><th>Day of Month</th><th>Samples per Day (30-minute interval)</th><th>Daily Average</th><th>Daily Average for data collected on same day at different sites</th><th>Weekly Average</th><th>Monthly Average</th></tr>
<tr><td>Week 1 (Upper Site)</td><td>1 - 7</td><td>48</td><td>Sum of 48 Samples divided by 48 = Daily Average</td><td>Daily average calculated in previous step, continue to weekly average</td><td>Sum of 7 daily averages in Week 1 divided by 7 = Week 1 Average</td><td rowspan="7">Sum of 5 weekly averages divided by 5 = Monthly Average</td></tr>
<tr><td>Week 2 (Upper Site)</td><td>8 - 9</td><td>48</td><td>Sum of 48 Samples divided by 48 = Daily Average</td><td>Daily average calculated in previous step, continue to weekly average</td><td rowspan="4">Sum of 7 daily averages in week 2 divided by 7 = Week 2 average</td></tr>
<tr><td>Week 2 (Upper Site)</td><td>10</td><td>24</td><td>Sum of 24 Samples divided by 24 = Upper Site Daily Average</td><td rowspan="2">Sum of Daily Average from upper site and Daily average from lower site divided by 2 = Daily Average</td></tr>
<tr><td>Week 2 (Lower Site)</td><td>10</td><td>30</td><td>Sum of 30 Samples divided by 30 = Lower Site Daily Average</td></tr>
<tr><td>Week 2 (Lower Site)</td><td>11 - 14</td><td>48</td><td>Sum of 48 Samples divided by 48 = Daily Average</td><td>Daily average calculated in previous step, continue to weekly average</td></tr>
<tr><td>Week 3 (Lower Site)</td><td>15 - 17</td><td>48</td><td>Sum of 48 Samples divided by 48 = Daily Average</td><td>Daily average calculated in previous step, continue to weekly average</td><td rowspan="2">Sum of 7 daily averages in Week 3 divided by 7 = Week 3 Average</td></tr>
<tr><td>Week 3 (Lower Site)</td><td>18</td><td>38</td><td>Sum of 18 Samples divided by 38 = Lower Site Daily Average</td><td>Sum of Lower site daily average and Middle Site Daily average divided by 2 = Daily Average</td></tr>
</table>

Week 3 (Middle Site)	18	20	Sum of 20 Samples divided by 20 = Middle Site Daily Average			
Week 3 (Middle Site)	19 - 21	48	Sum of 48 Samples divided by 48 = Daily Average	Daily average calculated in previous step, continue to weekly average		
Week 4 (Middle Site)	22 - 28	48	Sum of 48 Samples divided by 48 = Daily Average	Daily average calculated in previous step, continue to weekly average	Sum of 7 daily averages in week 4 divided by 7 = Week 4 average	
Week 5 Middle Site)	29 - 31	48	Sum of 48 Samples divided by 48 = Daily Average	Daily average calculated in previous step, continue to weekly average	Sum of 3 daily averages in week 5 divided by 3 = Week 5 Average	

6.0 Assessment Decisions and Documentation

The EC and SAR assessment decision framework is based on the EC and SAR numeric water quality standards indicated in **Table 1-1,** and is the same for both seasons (**Table 1-1**; irrigation season from March 2nd to October 31st and non-irrigation season from November 1st to March 1st) but the thresholds used when assessing standards attainment differ by season for all applicable waterbodies except the Tongue River Reservoir.

6.1 Impairment Listing and Delisting

The minimum data requirements described in **Section 3.5** must be met to make an assessment decision. Refer to **Section 4.0 and 5.0** for guidance on data quality assessment. Refer to **Section 5.0** for guidance on preparing data for assessment (e.g., calculating monthly averages).

Once the data has been evaluated against the numeric water quality standards for EC and SAR through this assessment method process, an assessment decision can be made. When assessment confirms that an assessment unit is not attaining water quality standards, the assessment decision is either to "list" the waterbody-cause combination if it is a newly discovered impairment, or to "keep listed" if the waterbody-cause combination is already listed. When assessment confirms that a waterbody is attaining water quality standards for a parameter, the assessment decision is either "do not list" if the waterbody-parameter combination is not already listed, or "delist" if the waterbody-cause combination was listed previously.

EC and SAR are assessed independently of each other. An assessment unit may be listed or delisted for only one or the other salinity parameter (SC or SAR) if data for only one parameter is available.

6.1.1 Specific Conductance (SC)

List/Keep Listed

- An assessment unit will be considered impaired for SC if any single monthly average SC concentration exceeds the monthly average EC standard and/or if one single SC concentration exceeds the no sample may exceed standard.
- An assessment unit will remain listed for SC if it is already listed for SC and minimum data requirements for SC assessment are not met, even if there are no exceedances of the monthly average standard or no sample may exceed standard. This is because there would not be a good cause for delisting (i.e., there was insufficient data to make a new decision).
- Include "Specific Conductance (SC)"as a pollutant impairing the agricultural use of the assessment unit.

Do Not List/Delist

- An assessment unit will be considered not impaired for EC if no month's monthly average SC concentration exceeds the monthly average EC standard and if no single SC concentration exceeds the no sample may exceed EC standard.

- An assessment unit will be delisted for EC if there are no exceedances of either the monthly average EC standard or the no sample may exceed standard over the ten-year period. If data have been excluded because they are no longer representative of current conditions due to significant documented changes in a watershed, an assessment unit can be delisted only if there are no exceedances of either the monthly average standard or no sample may exceed standards over three consecutive representative years of *recent* data. The assessor must document when data has been excluded due to significant source changes in the watershed.

6.1.2 Sodium Adsorption Ratio (SAR)

List/Keep Listed

- An assessment unit will be considered impaired for SAR if any single monthly average SAR exceeds the monthly average SAR standard and/or if one single SAR value exceeds the do not exceed standard.
- An assessment unit will remain listed for SAR if it is already listed for SAR and minimum data requirements for SAR assessment are not met, even if there are no exceedances of the monthly average standard or do not exceed standard. Without minimum data requirements there is not a good cause to delist.
- Include "Sodium Adsorption Ratio" as a pollutant impairing the agricultural use of the assessment unit.

Do Not List/Delist

- An assessment unit will be considered not impaired for SAR if no month's monthly average SAR exceeds the monthly average SAR standard and if no single SAR value exceeds the do not exceed SAR standard.
- An assessment unit will be delisted for SAR if there are no exceedances of either the monthly average SAR standard or the do not exceed standard over the ten-year period If data have been excluded because they are no longer representative of current conditions due to significant documented changes in a watershed, an assessment unit can be delisted only if there are no exceedances of either the monthly average standard or no sample may exceed standards over three consecutive representative years of *recent* data. The assessor must document when data has been excluded due to significant source changes in the watershed.

6.2 Documenting Assessment Decisions and Review

The assessor must document all data and decisions pertaining to SC and SAR impairment and agriculture beneficial use support determinations for the applicable assessment units. Assessment outcomes for individual assessment units, including data summaries, impairment determinations, and beneficial use support determinations are documented by assessors using the Water Quality Assessment and Reporting Documentation (WARD) system. Waterbodies identified as impaired due to SC and/or SAR 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 and staff from other programs (e.g., Watershed Management (TMDL) Program).

6.2.1 Decision Error

Following the guidelines in this document will produce consistent results to ensure decisions are accurate.

6.2.2 Source Assessment and Supplemental Information

Probable sources of impairment are required to be placed in the WARD database, and may include 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 SC and SAR impairment listings in the Rosebud Creek, Tongue, Powder, and Little Powder rivers, and the Tongue River Reservoir:

- Natural Sources
- Coal Mining, Coal Mining (Subsurface), or Coal Mining Discharges (Permitted)
- Crop Production (Irrigated)
- Crop Production (non-irrigated)
- Petroleum/natural Gas Production Activities (Permitted). This source includes coalbed methane (CBM) production, as CBM is not an available source in WARD.

Additional probable source options are available in the WARD system, if needed. If an assessor identifies any other probable sources, the assessor must verify their use with the section manager before entry into WARD. If water quality data are available that prove a probable source is contributing loads or increasing 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. The assessor should also include a brief description of sources in the overall condition of the waterbody summary in WARD.

7.0 PUBLIC INFORMATION

SC and SAR data collected by DEQ are stored in DEQ's MT-eWQX Enterprise (EQuIS) database and are uploaded weekly to the Water Quality Portal (EPA, USGS and NWQMC, 2018). Assessment outcomes for individual assessment units, including data summaries, impairment determinations, and beneficial use support determinations, are documented and accessible to the public in Montana DEQ's Clean Water Act Information Center (CWAIC) (available at http://deq.mt.gov/Water/Resources/cwaic). Waterbodies identified as impaired due to SC and SAR are included in Montana's biennial Water Quality Integrated Report and list of impaired waters submitted to EPA every two years.

8.0 MONITORING AND SAMPLE DESIGNS RECOMMENDATIONS

This section includes considerations for designing a project where new data is collected for assessment purposes. Water quality sample collection for evaluating EC and SAR standards attainment must adhere to DEQ's standard operating procedures for chemistry sample collection, handling, and analysis (Makarowski, 2019).

8.1 SITE SELECTION AND SPATIAL INDEPENDENCE

Sampling designs for SC and SAR assessment should apply a targeted sampling approach that is intended to spatially represent ambient water quality conditions throughout the assessment unit. The applicable assessment units are considered relatively homogenous with respect to geology and major tributary inflows which are two factors likely to influence salinity conditions. Also, SC and SAR are not influenced by cycling and uptake like some other pollutants are (e.g., nutrients), so longitudinal spatial variability is generally expected to be low between sites within a single assessment unit or reach. However, human activities and land uses that modify SC and SAR can increase variability among sites and must therefore be considered when selecting sites. The following guidance aims to help ensure spatial representativeness of datasets (including continuous datalogger deployment):

- Bracket potentially significant human sources (e.g., irrigation return flows, MPDES permit discharges).
- Always collect samples outside of mixing zones of permitted discharges, tributaries or irrigation returns.
- Select sites to represent each stratification layer of the reservoir (e.g. some sites may have no lake stratification whereas others may have it during different time periods). Select reservoir sites that represent distinct bays, especially those with inflows.

For river and stream assessment units, all data collected within an assessment unit or reach, regardless of site, are pooled together when performing assessment for SC and SAR (**Section 5.1.1**), whereas for the reservoir, data from each strata may be analyzed independently for SC and SAR, if feasible.

Any SC or SAR sampling design intended for assessing water quality standards attainment should incorporate field blanks and the frequency should be documented in a Quality Assurance Project Plan (QAPP) or Sampling and Analysis Plan (SAP)

8.2 Sample Size

Data quality requirements including minimum sample size should be reviewed prior to designing a monitoring strategy for SC and SAR assessment. Minimum sample sizes are specified in **Section 3.5** it may be desirable to surpass these minimum requirements as resources allow to obtain better spatial and temporal representation and a more robust data set. Although a minimum sample size can be met by sampling at a single representative site location, it is generally preferable to strategically collect samples at multiple sites that represent a range of conditions along a waterbody/assessment unit.

It is preferable to use continuous data loggers for SC data collection. Winter conditions usually preclude the use of continuous data loggers, and at times, data loggers may not be available. If continuous data loggers are not a feasible approach to data collection, then the goal would be to meet minimum discrete sample size requirements for each month including data from the most critical months (March – May). Sampling plans should clarify that sampling efforts start as soon as ice-off occurs for continuous data collection, and potentially earlier with discrete sampling, and sampling should continue throughout the irrigation season and include the non-irrigation season if possible.

9.0 References

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