Montana Department of
ENVIRONMENTAL QUALITY

A Review of the Rationale for EC and SAR Standards

FINAL

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Prepared by:
Water Quality Planning Bureau, Water Quality Standards Section
Montana Department of Environmental Quality
1520 E. Sixth Avenue
P.O. Box 200901
Helena, MT 59620-0901

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

Acronym	Definition
7Q10	Lowest flow occurring for a 7 day period every 10 years
ARM	Administrative Rules of Montana
CBM	Coalbed Methane
CBNG	Coalbed Natural Gas
CWA	Clean Water Act
DEQ	Department of Environmental Quality (Montana)
EC	Electrical Conductance or Electrical Conductivity
EC_E	Soil Water Salinity Threshold
EC_W	Irrigation Water Salinity Threshold
EPA	Environmental Protection Agency (US)
ESP	Exchangeable Sodium Percentage
ET	Evapotranspiration
MCA	Montana Codes Annotated
MPDES	Montana Pollutant Discharge Elimination System
NRCS	National Resources Conservation Service
S_{AC}	Final soil electrical conductivity
SAR	Sodium Absorption Ratio
S_{SW}	Initial salt present in soil water
TMDL	Total Maximum Daily Load
TY	Tongue-Yellowstone
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WET	Whole Effluent Toxicity
W_{SP}	Depth of total water in soil profile, inches

1.0 BACKGROUND

On April 15, 2010, the Board of Environmental Review (Board) gave notice of its intent to review Montana's water quality standards through the triennial review process, as required by the federal Clean Water Act, 33 U.S.C. § 1313 (c). Included in this review was a solicitation for public input on the standards for Electrical Conductivity (EC) and Sodium Adsorption Ratio (SAR) in the Tongue and Powder River basins of Montana. This document provides an analysis of new information obtained during the Department of Environmental Quality's (Department) triennial review process relating to the standards for EC and SAR.

In 2003, the Board of Environmental Review adopted new rules to establish numeric water quality standards for EC and SAR for the Tongue River, Rosebud Creek, Powder River, and Little Powder River watersheds. The Board determined that rules were necessary to ensure that the designated uses of these waters for agricultural purposes would be protected during the development of coalbed methane (CBM). Environmental Protection Agency (EPA) approved the new rules later in 2003.

In 2006, the Board adopted numeric nondegradation criteria by designating EC and SAR as harmful parameters. This designation resulted in treatment of EC and SAR for purposes of nondegradation review in the same manner as all other constituents for which there are numeric standards.

The Board also made several other administrative and implementation changes to the rules. After several Wyoming gas producers sued the Department and the Board in state district court, claiming that there was insufficient scientific basis for the standards. EPA approved the changes in February of 2008. The State prevailed in that litigation, a decision which was later upheld by the Montana Supreme Court.

The Wyoming producers also sued EPA for approving Montana's standards in federal district court in Wyoming. That court found for the plaintiffs, and the standards were remanded to EPA for reconsideration. During EPA's reconsideration of the standards on remand, the Board initiated a triennial review of Montana's water quality standards. In the public notice initiating the review, the Board specifically requested comment on the standards and nondegradation requirements for EC and SAR. The Board also requested that, if any suggestions for revisions to those standards and nondegradation requirements were made, the technical basis for the request should be provided. To facilitate public input on this issue, the Department compiled about 40 new studies and research efforts that had been conducted since the Board's original rulemaking in 2003. These studies were made available to the public online, and a 60 day public comment period was held to solicit input from interested persons.

2.0 NEED FOR STANDARDS

- Water produced during CBM development has an average EC value of 2,200 μS/cm and a SAR value often greater than 40. These values, especially the SAR values, are well above almost all of the ambient water quality values of the rivers and streams in CBM country. In addition, the SAR value of CBM water is well above the value that will adversely impact irrigated agriculture (Ayers and Westcot, 1985; Oster, 1994).

- The numeric standards chosen by the Board in 2003 were based on the analysis and recommendations of the Department, the available scientific data, and public comments received during rulemaking. The Department also hired Dr. James Oster, Extension Soil and Water Specialist (Emeritus) at the University of California at Riverside, to assist its technical staff during rulemaking.

- Studies conducted since the Board's adoption of numeric standards have confirmed the need for and value of Montana's regulatory approach.

- Paige and Munn (2010), found that salinity and sodicity issues with CBM produced water, in addition to issues of volume and flow, remain unresolved on the Wyoming side of the Powder River basin as development enters a second decade.

- There are identified needs to develop effective standards and management strategies to put the CBM product water to beneficial use and minimize impacts to soil, vegetation and water resources.

- Different approaches to regulate and dispose of the produced water have been developed by the four states along the Front Range; Wyoming, Montana, Colorado and New Mexico.

- Attempts by the Wyoming Department of Environmental Quality to develop an Agricultural Protection Policy based on end of pipe water quality standards remain controversial, and have been unsuccessful to date.

- Milligan, Reddy, and Legg (2010), found that in the Powder and Tongue River watersheds, produced water SAR exceeded the limit for irrigation water.

- Several public comments stressed the need for protective numeric standards. The EC & SAR standards are intended to protect riparian plants and crops that are irrigated with water from the rivers and streams and their tributaries. EC directly affects a plant's ability to uptake water while the SAR affects the soils in which the plants grow.

2.1 ELECTRICAL CONDUCTIVITY

Electrical Conductivity (EC) is a measure of the amount of dissolved solids (salts) in water and is generally expressed as microsiemens per centimeter (µS/cm), or decisiemens per meter (dS/m). For example, 2000 µS/cm equals 2.0 dS/m. As the EC in the soil water increases, a threshold is reached where further increases in EC cause decreases in plant growth. The EC in the soil water is directly affected by the EC of the irrigation water, and it is important to distinguish between the two.

The EC of the soil water may be higher than the EC of the irrigation water because plants and evaporation remove water from the soil but do not remove salts. Unless salts are removed or leached from the soil by excess water, the concentration of salts in the soil will build up as irrigation water is added over time.

The water in excess of the plant and evaporative needs applied to a given area of soil is termed the leaching fraction. This excess water may be supplied by irrigation and by precipitation. However, that portion of the water that is used by plants or which evaporates does not directly add to the leaching fraction. Precipitation or irrigation that occurs when the soils are saturated with water or that is stored in the soil when excess water is applied, does directly add to the leaching fraction.

2.2 SODIUM ADSORPTION RATIO

The sodium adsorption ratio (SAR) is a measure of the abundance of sodium relative to the abundance of calcium and magnesium in water. It is directly related to the amount of sodium that is absorbed by soils. A high SAR in irrigation water has the potential to impair soil structure and thus, the permeability of the soil leading to a lack of soil moisture. This is particularly so when the EC of the soil water or applied water is insufficient to counteract the negative effects of adsorbed sodium on soil structure. The SAR of irrigated soils equilibrates with the SAR and the EC of the applied irrigation water over time. That is, if the average SAR of the irrigation water is 5 and the EC is 1500 μS/cm, the SAR and EC of the soils at and near the soil surface will also be about 5 and 1500 μS/cm within a few years.

3.0 DERIVATION OF EC STANDARDS

The Board adopted numeric standards for EC that are applicable during the irrigation season when the protection of water quality for agricultural use is a concern, and during the late fall and winter months when irrigation is not a concern. The time period between March 1 and October 31 was chosen for the irrigation season standards, because that is the time that irrigation in the affected area normally occurs.

Several comments suggested a detailed explanation of the scientific basis for the numeric standards. In order to derive standards for EC during the irrigation season, the Board considered the type of plants being irrigated in the affected area, the sensitivity of those plants to EC, the leaching fractions that are occurring, the correction factors that should be applied due to precipitation, and an adjustment for the rainfall effect.

The plants being irrigated in the affected area are summarized in **Table 1**. The list of crop types in the table was compiled by the Department in 2001 after receiving more than 200 responses to several surveys asking the agricultural community what type of plants they cultivate each year[1]. Column 2 of the table lists the soil water salinity thresholds (as EC_E) for each of these plants from Maas and Grattan (1999), for example, 1000 μS/cm for common beans. Another source, Ayers & Westcot (1985), contains these same values. When these thresholds are exceeded plant or crop yields begin to decrease. The standards for irrigation water EC_w are intended to protect the most salinity sensitive plants listed in **Table 1** that are produced in the affected area.

The most salinity sensitive crops irrigated with water from the Tongue River are strawberry, common beans, and carrots, with an EC_w threshold of 1000 μS/cm. The most salinity sensitive crops being irrigated with water from the Powder River are corn and alfalfa, with an EC_w threshold of 1700 and 2000 μS/cm, respectively. While alfalfa is the dominant crop on both the Tongue and Powder rivers, the naturally high quality of Tongue River water allows for the more sensitive crops to be grown, and the Board wanted to preserve that opportunity for farmers to continue growing sensitive crops even though alfalfa might tolerate higher concentrations of EC_w. There were about 325 acres of beans grown on the Tongue in 2009 (United States Department of Agriculture, National Agricultural Statistics Service, 2011),

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[1] Unpublished Results from 2001 Grower Surveys, DEQ Files, and Federal Litigation Administrative Record

and about 275 of these acres were irrigated (United States Department of Agriculture Farm Service Agency, National Agricultural Imagery Program, 2009).

The marginal quality of Powder River water limits the opportunity to irrigate these more sensitive crops, so alfalfa (the dominant crop) was chosen as the target crop. There were about 16,800 acres of alfalfa on the Powder in 2009 (United States Department of Agriculture, National Agricultural Statistics Service, 2011), and about 4,300 acres were irrigated (United States Department of Agriculture Farm Service Agency, National Agricultural Imagery Program, 2009). In comparison, there were less than 100 acres of beans grown on the Powder in 2009 (United States Department of Agriculture, National Agricultural Statistics Service, 2011), and only 13 acres of irrigated beans were identified (United States Department of Agriculture Farm Service Agency, National Agricultural Imagery Program, 2009).

Table 1. Threshold of salinity (as electrical conductivity, EC) impacts to the growth of plants commonly grown in the Powder and Tongue River Basins, from Maas & Grattan (1999).

Assumed leaching fractions associated with each cultivation practice are shown. For each plant and leaching fraction, an increase in irrigation water salinity beyond the table value will cause plant yield decreases.

		Irrigation water EC_w (µS/cm) : Threshold for no-impact to growth			
		Rosebud Creek[#]	Tongue River[#]	Powder & Little Powder Rivers[¢]	Tributaries
Name of Plant or crop	EC_E Threshold	(Conventional Flood Irrigation)	(Conv. Flood & Sprinkler)	(Flood Irrigation)	(Water Spreader)
		15% Leaching Fraction	15% L.F.	30% L.F.	0% L.F.
Strawberry	1000	(667) 1000	(667) 1000	1000	
Common Beans	1000	(667) 1000	(667) 1000	1000	
Carrots	1000	(667) 1000	(667) 1000	1000	
Radish	1200	(795) 1193	(795) 1193	1155	
Onions, Bulb	1200	(795) 1193	(795) 1193	1155	
Lettuce	1300	(860) 1290	(860) 1290	1250	
Clover (all types)	1500	(990) 1485	(990) 1485	1445	500
Orchard Grass	1500	(990) 1485	(990) 1485	1445	500
Corn & Sweet Corn	1700	(1126) 1689	(1126) 1689	1640	
Alfalfa	2000	(1330) 2000	(1330) 2000	2000	500

[#] On the Tongue River and Rosebud Creek, precipitation correction factor of 1.5 has been applied to values in the right hand, unbracketed column. Left hand column values in parentheses are uncorrected.

[¢] On the Powder and Little Powder Rivers, no precipitation correction factor has been applied.

See text for details of how these EC standards were developed.

3.1 LEACHING FRACTIONS

The standards for irrigation season also vary depending upon the type of irrigation used in the various watersheds and the differing leaching fractions that occur as a result of these irrigation practices. For the Tongue River, a leaching fraction of 15% is assumed as a basis for the EC standards. This is assumed because a leaching fraction of 15% is typical of conventional sprinkler and flood irrigation, which is used in the basin (Oster, J.D., personal communications 6/2/2002). There has been a progressive shift, in many areas, from flood irrigation practices to sprinkler irrigation (Wyoming Water Development Office, 2002). The Board assumed a 30% leaching fraction for the Powder River standards, because the work of deMooy and Franklin (1977) identifies the actual leach rate at the four to five foot root depth for alfalfa as 31% in the Powder River Valley. Finally, the Board also used a leaching fraction to derive EC standards for Rosebud Creek because there is some conventional flood irrigation in the lower reaches (McRae, Clint, personal communications 6/21/2002).

The leaching fractions discussed above are averages and it is assumed that leaching is uniform throughout a field. In practice the leaching fraction is not uniform throughout a field and local impacts due to salinity can occur.

AGRICULTURAL SALINITY AND DRAINAGE *Maintenance Leaching*

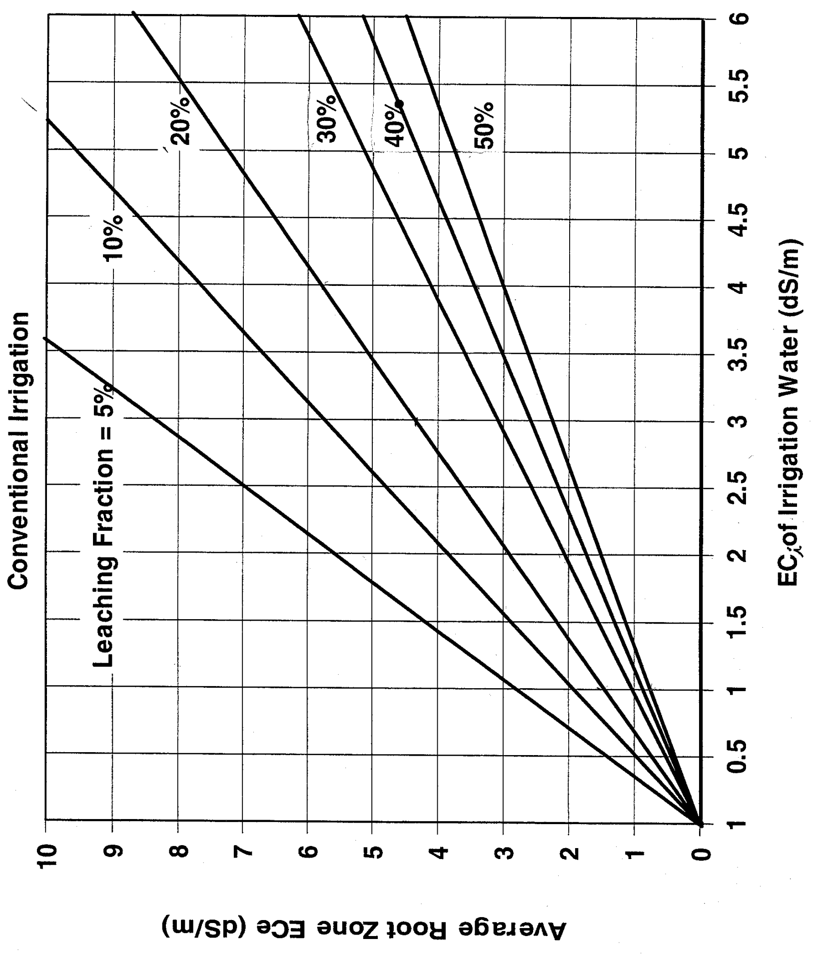

Figure 1. Assessing the maintenance leaching fraction under conventional irrigation methods.

Figure 1. Assessing the maintenance leaching fraction under conventional irrigation methods. (United States Department of the Interior, Bureau of Reclaimation, 2008). No net evaporation occurs outside the irrigation season (Western Regional Climate Center, 2010). At a leaching fraction of 15 Relationships between leaching fractions, irrigation water and soil water ECs (from Hanson, Grattan, and Fulton (1999))

Figure 1 illustrates the permissible value of EC in the irrigation water based upon a maximum permissible level of EC in the soil water and a leaching fraction. The figure is originally from Ayers &

Westcott (1985). At 15% leaching fraction, the relationship between soil water EC_E and irrigation water EC_W is defined by **equation 1** from that source:

$$EC_w = EC_E / 1.5 \qquad \textbf{(eq. 1)}$$

Thus, the 1000 μS/cm soil water requirement for full yield for common beans, one of the most sensitive crops grown on the Tongue, equates to an irrigation water EC_w of 667 μS/cm.

Hanson, Grattan and Fulton (1999), the more recent study from which **Figure 1** is drawn, is described by Dr. James Bauder, one of the leading Montana experts in the field, as the authoritative source for salinity and drainage calculations (Bauder, James W., personal communications 8/25/10).

3.2 PRECIPITATION CORRECTION FACTOR

Equation 1 was used to calculate the "uncorrected" EC values given in parentheses for each leaching fraction listed in **Table 1**. These values represent the values of EC in the irrigation water that will cause no decrease in yield for sensitive crops that are grown in the Tongue and Powder River basins if precipitation is ignored. These values differ for the various leaching fractions.

In the Tongue River basin, where there is sufficient available water to fully support the needs of a crop, the diluting effect of precipitation must also be considered in order to correctly calculate EC values for irrigation water that will protect irrigated plants.

The average annual total precipitation at Brandenburg, Montana, chosen for its central location in the Tongue River basin, for the period from 5/1/1956 to 12/31/2009 is 14.44 inches. This value is within the range of the numbers reported for other stations in the Tongue and Powder River valleys for which there is data for the same time period. Average annual precipitation at these stations range from 15.51 inches at Lame Deer and 15.06 inches at Colstrip, to 14.38 inches at Forsythe and 13.34 inches at the Miles City Airport. (Western Regional Climate Center, 2011)

The diluting effect of this precipitation is dependent on the amount of irrigation water that is applied. According to deMooy and Franklin, the effective infiltration of precipitation in the region is about 80% (DeMooy and Franklin, 1977). That is, some of the precipitation simply runs overland to the nearest drainage without soaking into the soil. This is especially true during thunderstorms, which are common in the region. An effective precipitation of about 11.5 inches (0.80 X 14.44 = 11.55) is a reasonable value for calculating the correction factor.

In the Tongue and Powder River basins, plant growth and evaporation require about 31 inches of water per growing season. No net evaporation occurs outside the irrigation season(Western Regional Climate Center, 2010). Sprinkler and conventional flood irrigation throughout the valley is generally applied in amounts that result in leaching fractions of about 15%. At a leaching fraction of 15% an additional 4.65 inches (15% of 31 inches) is needed during the growing season for a total of 35.6 inches. Of this, about 11.55 inches is normally supplied by effective precipitation, which has no salts. The remaining 24 inches of crop agronomic need is assumed to be met by the application of irrigation water. One operator on the Tongue confirms that he applies about two feet of water to his crop served by sprinklers (Fix, Mark, personal communication 9/29/2010).

Using the following formula, the salt content of about 24 inches of irrigation water is diluted by 11.5 inches of precipitation to calculate a correction factor of 1.5. For these reasons, the Board used a precipitation factor of 1.5 to derive the EC standards for the Tongue River basin.

$$\text{Correction Factor} = (\text{Depth}_{\text{(precipitation)}} + \text{Depth}_{\text{(Irrigation water)}}) / \text{Depth}_{\text{(Irrigation water)}}$$

The correction factors are applied to the “uncorrected” threshold values (in parenthesis) for EC in the irrigation water to calculate the corrected threshold values. For example **Table 1** lists the irrigation water EC thresholds as 1000 µS/cm (667 X 1.5 = 1000) for no impact on the yield of strawberry, common beans (a commercial crop in the area) and carrots at a leaching fraction of 15%.

The standards for irrigation water EC for the Tongue River are also applied to Rosebud Creek due to the conventional flood irrigation in the lower reaches of Rosebud Creek, and to the Tongue River Reservoir because it stores Tongue River flows.

On the Powder River, water quality is highly variable. Irrigators on the Powder exercise selective use of water when it is of adequate quality. The challenge on the Powder is to protect the use of better water quality when that use is exercised.

Flood irrigation with a leaching fraction of 30% was assumed based on deMooy & Franklin’s (1977) study of irrigation of Powder River soils. Alfalfa is the commonly grown most sensitive crop and requires that soil water EC_E be maintained below 2,000 µS/cm. Some silage corn is also grown and it requires an EC_E below 1700 µS/cm to avoid adverse effect on production. Because alfalfa dominates crop acreage on the Powder, and because more sensitive crops cannot be successfully grown due to variable water quality, it was used as the target crop.

The irrigation water EC_W for alfalfa on the Powder is 2000 µS/cm, based on a soil water EC_E of 2000 µS/cm, because at a leaching fraction of 30%, the relationship between soil water EC_E and irrigation water EC_w is one to one (**Figure 1**).

This value compares favorably to the reported threshold used by Powder River irrigators when applying water to their heavier soils. One farmer easily measures real-time EC with a salinity meter and uses this value as an indication of elevated SAR and generally will not divert water for irrigating these soils when EC exceeds about 2000 µS/cm (Griffin, Bill, personal communication 8/24/2010). The USGS uses this same approach to report real-time SAR, using a regression equation that correlates EC and SAR at a number of water quality monitoring stations (Clark and Mason, 2007; 2006). Another irrigator reports that he goes by the USGS real-time data at Morehead, and doesn’t apply water that exceeds about 1500 µS/cm on a new alfalfa crop (Gay, Glenn, personal communication 8/31/2010).

Calculation of a valid correction factor on the Tongue River and Rosebud Creek was possible because sufficient irrigation water is available to fully meet the agronomic need of the crop. The Powder and Little Powder Rivers are only marginally supportive of agricultural uses (Montana Department of Environmental Quality, 2008). There is not sufficient irrigation water of acceptable quality available to fully meet this need. The opportunistic use of Powder River water for irrigation generally doesn’t support full yields, and salts are more likely to accumulate in the soil. For these reasons, the 31 inch value for seasonal agronomic water uptake on the Tongue is not applicable to the Powder.

When water quality is adequate, the beneficial use of river water for irrigation is exercised. When water quality is not adequate, it is not exercised. The calculated EC_w of 2000 μS/cm is the appropriate standard, and a valid correction factor cannot be applied.

3.3 THE TRIBUTARIES

Two comments addressed the need for standards protective of irrigation use on the tributary streams of the basin. EC levels in runoff events on tributaries have a high level of variability and can be elevated for extended periods of time (Sanders, Frank, personal communication 2011).

The methodology for arriving at the EC standard on the tributaries is contained in the Department's July 2002 Technical Basis (Montana Department of Environmental Quality, 2002). The approach has not changed, but is restated here, along with the calculations, documentation, and cites to the authoritative literature.

Irrigation on the tributaries consists largely of gates and canals on lower mainstems, and spreader dike systems on ephemeral tributaries. A leaching fraction of 30% is not reasonable for these systems (Oster, J.D., personal communication 6/2/2002). Leaching will occur only under wet spring conditions when the total infiltrated water from rain, snowmelt, and operation of the system exceed evapotranspiration by about 14 inches. This occurs about once out of every 8 to 10 years. In the intervening years salts, in the water applied accumulate in the upper 3 feet of soil increasing the salinity of the soil water.

One irrigator on Hanging Woman Creek, a tributary to the Tongue, reports that he normally only gets a single seasonal opportunity of a few days duration to access good water; some years this happens twice (Punt, Terry, personal communication 4/28/2009). The most common month for this better quality water to be available is February, when he often turns the water out on frozen fields.

The tributary EC standard was calculated using a basic soil water-salt mass balance calculation to calculate water quality necessary to protect against crop loss. Expected increase in salinity associated with water quality was calculated based on the following assumptions:

1) Alfalfa is the major crop grown with these systems.
2) The rate of water addition to the soil water is 6 inches per year.
3) The average initial soil water salinity is 0.25 dS/m (250 μS/cm.)
4) The water holding capacity of the soil is 2 inches per foot (United States Department of Agriculture Farm Service Agency, National Agricultural Imagery Program, 2009).
5) The salinity is measured on water extracts obtained on saturated soil pastes that have a water content that is two times higher than that of the soil.
6) Leaching only occurs once every 8 to 10 years, with no leaching during intermediate years.
7) No significant removal of salt in the harvested alfalfa.

The full calculations and citations to the literature are included in **Appendix 1**. The EC of the applied water should not exceed 500 μS/cm in order to prevent salt accumulation in 8 years to 2.3 dS/m (2300 μS/cm) and in 10 years to 2.8 dS/m (2800 μS/cm). These levels can reduce the yield of alfalfa by 2.2 and 5.9% respectively. If the average EC of the applied water was 600 μS/cm, the average root-zone salinity could reach levels in 8 to 10 years that range from 2.6 – 3.2 dS/m (2600 – 3200 μS/cm). For alfalfa these salinities correspond to yield declines that range from 4.8 to 9.3%. Thus, 500 μS/cm was selected as a monthly average value protective of target crop production.

Discharges of CBM produced water into ephemeral tributaries may result in perennialization of the stream bed. This is a concern unique to the tributaries, particularly in view of recent findings. Hendrickx and Buchanan (2009), found that perrenialization of ephemeral tributaries causes elevated water tables, waterlogging, and elevated salinity in the root zones of vegetation and crops along the tributaries.

3.4 DERIVATION OF EC STANDARD FOR NON-IRRIGATION SEASON

The Tongue River Reservoir stores water all year round. Storage of non-irrigation season flows are released at the beginning of the irrigation season and are available for beneficial use. For this reason, the irrigation season limits apply year round in the Reservoir. The same rationale used to determine irrigation season standards for the Tongue River and Rosebud Creek apply to the standards set for the Tongue River Reservoir.

One comment questioned the need for a non-irrigation season standard. Non-irrigation season limits are adopted to protect riparian vegetation. Montana’s narrative water quality standards prohibit concentrations of substances that are harmful to plant life (ARM 17.30.637 (1) (d)).

Water moving through the alluvium provides water for plant growth in the riparian zone. The riparian zone is continually exposed to water. In addition, in some places the water in the alluvium will tend to "wick" to the surface and evaporate leaving the salts at or near the soil surface. An increase in the salinity of the water may result in an increase in the accumulation of salt. Such an increased accumulation could impact the riparian plant communities.

Warrence, Bauder, and Pearson (2004) found that common riparian species such as service berry, dogwood, gooseberry, chokecherry, and aspen are sensitive to salinity, and vulnerable to effects at ECs greater than 2000 μS/cm. One of the main effects of salinity is the delay of germination and seedling development. This means that roots of emerging seedlings are exposed to a greater degree of stress than indicated by usual salinity measurements which are usually averaged from soil samples taken throughout the soil profile. Plant loss during this seedling stage can reduce the plant population density to below optimal levels and significantly reduce yields. Montana DEQ (Tetra Tech, Inc., 2003c) identifies chokecherry and dogwood as common riparian species on the Tongue, so a monthly average EC value of 1500 μS/cm will provide non-irrigation season protection for Tongue River and Rosebud Creek. Other common riparian species such as snowberry, horsetail, watercress, willow, cattail, and cottonwood were found to be moderately sensitive, and susceptible to impacts at ECs greater than 4000 μS/cm (Warrence, et al., 2004). Montana DEQ (Tetra Tech, Inc., 2003a) identifies snowberry and willow as common riparian species on the Powder, so a monthly average EC value of 2500 μS/cm will provide non-irrigation season protection for the Powder and Little Powder Rivers.

The tributary EC value of 500 μS/cm reflects the fact that soil salinity and crop yield on the tributaries is a product of an eight to ten year water cycle. Much of the water input that drives the tributary standard calculations occurs during the non-irrigation season.

3.5 MAXIMUM EC STANDARDS

Instantaneous maximum standards are generally adopted for those criteria for which there are numeric standards. Maximum values for irrigation season EC criteria were set at 150% of the average monthly value, up to a maximum of 2500 μS/cm. Two EPA guidance documents for the establishment of acute to chronic ratios for aquatic life support suggest that 150% of the chronic, average value is an appropriate maximum (United States Environmental Protection Agency, 1991; 1994). While the EC and SAR standards address agricultural protection rather than aquatic life, the Department believes that a similar approach to the designation of maximum values is appropriate. It is not necessary for any maximum value to exceed 2500 μS/cm. CBM produced water generally does not exceed an EC of 2000-2300 μS/cm.

The tributary EC maximum value of 500 μS/cm reflects the fact that soil salinity and crop yield on the tributaries is a product of an eight to ten year water cycle. The tributary EC calculation is based on a consistent quality of water input during this cycle, and cannot accommodate a temporary influx of poorer quality water.

4.0 DERIVATION OF SAR STANDARDS

A high SAR in irrigation water has the potential to impair soil structure and thus the permeability of the soil. One comment pointed out that three-fourths of the Tongue-Yellowstone (TY) irrigation district is on the Yellowstone River drainage, which contains a higher proportion of clay soils.

Soils in the Tongue and Powder River drainages are generally loams and silty clay loams (Bauder, 2008). The higher the clay content, the greater the soil's vulnerability to dispersion. Soils in the Yellowstone River floodplain irrigated by the TY Irrigation District are some of the most sensitive soils in the region. These soils are dominated by Yamacall loam and Kobase silty clay loam, but contain widely distributed Harlake and Lallie silty clays, which are probably the soils most susceptible to the effects of elevated SAR.

Montana DEQ, TetraTech, and EPA 2003 (Tetra Tech, Inc., 2003a; 2003b; 2003c) found clay dominated soils widespread in the Tongue, Powder, and Rosebud drainages, containing clay fractions up to 70%. However, The Tongue River Information Program (Agricultural Monitoring and Protection Program) study conducted by Fidelity E & P and the MT Oil & Gas Conservation Division found that clay soils are rare in the Tongue River drainage (Schafer, et al., 2007).

Suarez, Wood, and Lesch (2006), found that for bare clay soil an increase from SAR 2 to SAR 4 resulted in a significant decrease in infiltration rate. For loam soil the increase in infiltration time was significant at the SAR 6 level, and that for cropped soil the increases in infiltration time were statistically significant at SAR 6. In 2008 the researchers found reductions in water infiltration in both clay & loam soils at SAR above 2, and found that the reductions become more severe with increasing SAR. (Suarez, et al.,)

Some studies suggested that laboratory soil study protocols may yield inconsistent results. Harvey (2009) suggested that crushing, drying and sieving soil samples destroyed natural soils structure, although the Tongue River AMPP Study, (Schafer, et al., 2007), in which he participated, prepared soil samples for laboratory study in a similar fashion.

Suarez, Wood & Lesch (2008) found that hydraulic conductivity measurements taken from undisturbed cores at the end of the experiment were highly variable, suggesting that in-situ infiltration measurements may be preferred when evaluating SAR effects. The researchers noted that existing irrigation water quality criteria related to sodium and salinity are based primarily on short-term laboratory column studies (Suarez, et al., 2008). These earlier studies measured infiltration or hydraulic conductivity of disturbed soil under continuously saturated conditions. They suggested that application of these standards to field conditions is uncertain, as it does not account for wetting and drying conditions, formation of crusts and impact of rain events, etc. Finally, the investigators concluded that the study results show a greater sensitivity to SAR than indicated by laboratory column studies and existing water quality criteria.

Schafer, Fehringer, Brown (2007) found no statistically significant changes in EC & SAR in study soils irrigated with Tongue River water, which they described as loam soils with a maximum clay content of about 40%. This study found that there has been no apparent damage from irrigation with Tongue River water on less sensitive soils. Suarez, Wood, and Lesch (2006) examined soils with a clay content of 54% in arriving at their conclusions that reductions in infiltration occurred at SAR's as low as 4.

Bauder (2008) examined soils that varied in clay content from a low of about 28% for loam soils, up to 62% for clay soils on a lower Tongue River Valley farm. He found that dispersion/soil structure loss was specific to areas where soil was more than 30% smectite-clay, had higher cation exchange capacity values, and higher exchangeable sodium percentage values (ESP). This study examined the apparent collapse of a newly planted alfalfa crop following irrigation and then significant rainfall on very sensitive soil.

Other studies have investigated the application of CBM produced water directly to soils through land application/disposal and managed irrigation projects. While different from the application of river water containing produced water, they shed light on the effects of elevated SAR on soil structure.

Ganjegunte, Vance, and King (2005), found that EC and SAR of soil saturated paste extracts were significantly higher than control sites for five areas experiencing land application of CBM water, and that there was a significant buildup of sodium in irrigated soils as well as sodium mobilization within the soil profiles. They concluded that irrigation with CBM produced water significantly impacts certain soil properties. They state that applications of CBM water significantly increased soil EC, SAR, and ESP values (up to 21, 74, and 24 times, respectively) compared with non-irrigated soils. They observed that differences in soil chemical properties between an irrigated and non-irrigated coarse-textured soil were less than that of fine-textured soils, emphasizing texture as an important factor for salinity buildup. They found that pretreatment of CBM water using a sulfur burner and application of gypsum and elemental soil amendments reduced soil pH but did not prevent the build-up of salts and sodium. Finally, the researchers suggested that current CBM water management strategies are not as effective as projected.

Johnston, Vance and Ganjegunte (2008), reported that CBM water with no amendments significantly increased sodium concentration within the soil profile. Finally, they observed that in all treatment combinations, both EC and SAR increased significantly in the top two sampling depths.

4.1 THE RAINFALL EFFECT

The effects of elevated sodium adsorption ratios increase as the salinity of the water decreases (Hanson, et al., 1999). This relationship is shown in **Figure 2**.

Leaching of salts with excess irrigation water or from precipitation will lower the EC of the soil solution while its SAR will remain about the same. SAR of the soil water is controlled by the composition of the exchangeable ions (calcium, magnesium, sodium and potassium) adsorbed on the soil. The number of adsorbed ions is from 10 to 30 times greater than the number of ions dissolved in the soil water. Further, the total number of adsorbed ions does not change as a result of leaching. Consequently the reduction in EC as a result of leaching can only have a small impact on the composition of the adsorbed ions and the SAR of the soil solution. It requires only a very small fraction of adsorbed sodium to be replaced by calcium, magnesium and potassium to maintain the SAR level in the soil water that was present before leaching occurred. In other words, the exchangeable ion composition buffers the composition of the soil water with the result that while leaching will reduce the EC of the soil water, the reduction in SAR will be far smaller. As a result, leaching as a result of a rainstorm can cause SAR problems in the surface soil because the stabilizing effects of salinity on aggregate stability is lost when the EC is reduced (Oster, J.D., personal communication 6/2/2002).

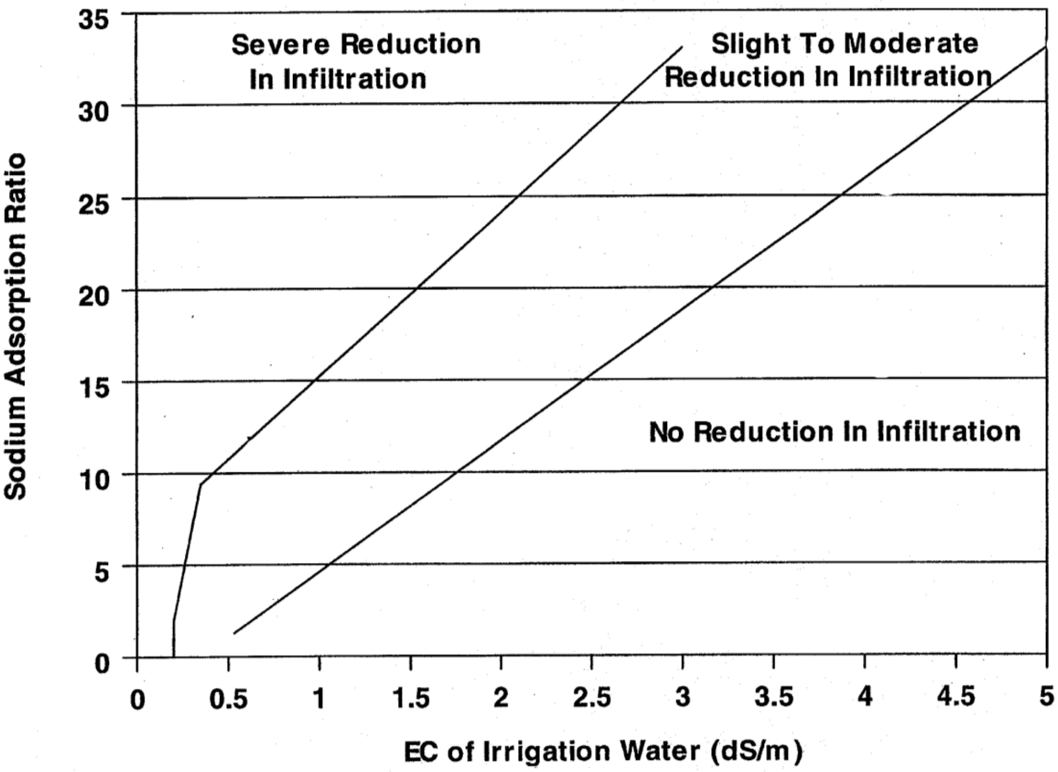

Figure 2. Relationship between EC and SAR and the effect on infiltration of water into the soil (Hanson, et al., 1999)

The lower line and the area below it reflect conditions of EC and SAR for which there will be no reduction in infiltration under normal field conditions. This line can be mathematically expressed as SAR= (EC x 0.0071) – 2.475 (Shaffer, et al., 2001). Several commenters suggested using this formula to establish the applicable SAR standard. However, at an EC of 350 μS/cm or less the formula would indicate that the allowable SAR would be less than zero. At ECs above 1000 μS/cm a SAR limit would be greater than 5. A maximum of 5 is justified to consider the effects of rainfall on the EC and the SAR. When rainfall reduces the salinity in a soil irrigated with water with a SAR greater than 5, there is a risk that infiltration rates will be reduced.

On the Tongue and Rosebud, from **Figure 2**, a soil irrigated with water at 1000 μS/cm, could experience a decrease in EC down to 700 μS/cm, a 30% reduction. At an SAR of 3, no resulting decrease in infiltration would occur. Above an SAR of 3, a rainfall-induced reduction in EC to 1000 μS/cm would result in a decrease in infiltration. Therefore, a rainfall effect-adjusted monthly average SAR of 3.0 was chosen for the Tongue and Rosebud, to correspond to the EC standard of 1000 μS/cm. The SAR standards for the Tongue River are also applied to the Tongue River Reservoir because it stores Tongue River flows.

For the Powder and Little Powder, a rainfall event could reduce EC in soil irrigated with water at the 2000 μS/cm standard to 1000 μS/cm, a 50% reduction. A rainfall effect-adjusted monthly average SAR of 5.0 was chosen to protect soils from this possible occurrence. The rainfall-effect adjustment for the Powder is greater than that for the Tongue, reflecting the higher EC's and SAR's, the lower availability of irrigation water, and the resulting greater ratio of precipitation to irrigation water applied.

Suarez, Wood, and Lesch (2008) reported that salinity and SAR criteria in earlier literature had been developed for conditions where irrigation was the only water source. The investigators found that these criteria may not be applicable where there is a combination of rain AND irrigation during the growing season.

Bauder, Hershberger and Browning (2008) found that decreases in EC upon leaching with distilled water were of greater magnitude than corresponding decreases in SAR, reinforcing supposition of sodium induced dispersion of fine textured soils as a consequence of rainfall following irrigation with water having salinity and sodicity levels equal to previously published irrigation guidelines.

For irrigation systems on tributary streams, infiltration of rainfall and snowmelt is crucial to maintaining soil salinity levels that have little or no impact on crops, particularly alfalfa. The EC of rainfall is near zero. Thus during a wet spring, the salinity of the soil surface can be low due to leaching by rain during times when there is no water of acceptable quality available for irrigation. The SAR of the captured runoff water should not result in adsorbed levels of sodium in the soil that will impede the infiltration of rain.

Schaefer, et al cites Ayers and Westcott (1985), and Hanson et al. (1999) in stating that for irrigation water with low salinity (EC between 200 and 700 μS/cm) the lowest SAR required to protect soil permeability is 3.0. For these reasons, a monthly average SAR of 3.0 during the irrigation season was adopted for tributary streams, to correspond with the EC standard of 500 μS/cm.

4.2 SAR DURING THE NON-IRRIGATION SEASON

Warrance, Bauder, and Pearson (2004) report that the two main risks of high sodium levels in soil water are toxic effects and impacts on plant growth from changes in soil structure. Excess sodium present in soil water can cause soil dispersal, especially in soils with high clay contents. Soil dispersal causes loss of soil structure and surface crusting. Surface crusting leads to reduced hydraulic conductivity, reduced water infiltration, and increased water runoff. These conditions can make seedling establishment very difficult, if not impossible. Decreased drainage from sodium-induced soil dispersal can also increase the sodicity in the root zone. If water containing salts is not allowed to drain below the root zone, the salt concentration of soil water will increase as plants take up water by transpiration and as evaporation occurs.

The authors found that sensitive and moderately sensitive riparian species require an SAR between 1.6 and 8 to protect against adverse impact from waterlogging and anaerobic conditions in riparian soils. Monthly average SAR limits of 5.0 on the Tongue and Rosebud Creek, where sensitive riparian species were inventoried were chosen to protect these riparian species during the non-irrigation season. Monthly average SAR limits of 6.5 on the Powder and Little Powder, where moderately sensitive species were recorded were chosen. On the tributaries, a non-irrigation season SAR standard of 5 was retained, for consistency with other lower EC waters like the Tongue River.

4.3 MAXIMUM SAR STANDARDS

Short-time period, maximum (acute) standards are generally adopted in addition to longer duration (chronic) standards for those pollutants for which there are numeric standards. Maximum values for SAR criteria were set at 150% of the average monthly value. Two EPA guidance documents for the establishment of acute to chronic ratios for aquatic life support suggest that 150% of the chronic, average value is an appropriate maximum (United States Environmental Protection Agency, 1991; 1994). While the EC and SAR standards address agricultural protection rather than aquatic life, the Department believes that a similar approach to the designation of maximum values is appropriate.

5.0 DECLINE IN PRODUCED WATER QUALITY BETWEEN DISCHARGE AND ULTIMATE USE

CBM produced water may decline in quality between the point and time it is discharged, and where it ultimately winds up and may affect beneficial use. A number of studies since 2003 investigate this decline in quality. The decline makes protective standards even more important.

Jackson and Reddy (2007) reported that outfalls are chemically different from corresponding discharge ponds. They found that sodium, alkalinity, and pH all tend to increase, possibly due to environmental factors such as evaporation, while calcium decreased due to calcite precipitation. Most discharge ponds within individual watersheds tended to increase in sodium and SAR from 2003 to 2005.

Brink, Drever and Frost (2008) report that the interaction of CBM produced waters with semiarid Powder River basin soils can mobilize accumulated salts, which, through infiltration, can then reach the water table, potentially affecting the quality of the groundwater. They found that the mobilization of the soil based salts may render the composition of the water recharging the near surface groundwater very different from the initial chemical composition of the CBM produced water. The researchers went on to say that prolonged exposure to CBM produced water can cause the salinization and sodification of soils surrounding CBM produced water ponds and streams. They concluded that the high SAR of CBM produced water requires careful management to prevent sodification of irrigated soils when it is used as an irrigation source.

Patz, Reddy, and Skinner (2004) found that the dissolved calcium concentration of produced water decreased significantly in the downstream channel water, and SAR increased from 32.9 to 45.5 in downstream channels after the confluence of Sue Draw with Burger Draw in Wyoming.

They concluded that significant increase in SAR values of CBM discharge water in tributaries suggest a careful monitoring of salinity and sodicity is needed if CBM discharge water is used for irrigation in semiarid environments.

McBeth, Reddy, and Skinner (2003) found that mean EC of CBM produced water increased from 1.93 to 2.09 dS/m (1930 to 2090 μS/cm), between discharge point and pond waters in the Little Powder watershed. They concluded that release of CBM product water onto the rangelands of the Little Powder may precipitate calcium carbonate ($CaCO_3$) in soils, which in turn may decrease infiltration and increase runoff and erosion.

6.0 STANDARDS EXCEEDED BY EXISTING WATER QUALITY

One public comment received by the Department noted that some recorded values in streams have values that exceed the proposed standards due to natural fluctuations of EC in the water throughout the year. When the natural EC values exceed the proposed EC standards, the provisions of 75-5-306, MCA would apply. This section of the Montana Water Quality Act allows for natural exceedances of standards by providing that: "It is not necessary that wastes be treated to a purer condition than the natural condition of the receiving stream as long as the minimum treatment requirements established under this chapter are met". Thus, if the standard is 1000 μS/cm and the natural condition of the receiving water is 1500 μS/cm, a discharge could occur as long as the discharge did not raise the instream concentration above 1500 μS/cm. The Department will determine the natural condition of the stream at any given point in time through monitoring, interpretation of historic data, and modeling to ensure that water quality is not diminished under the guise of ambient conditions

7.0 NONDEGRADATION

Two commenters questioned why EC & SAR were found to be harmful parameters. The previous nondegradation criterion was based upon a narrative standard that provided that changes in existing surface and groundwater quality were non-significant if the changes would not have measureable effect on any existing or anticipated use, or cause changes in aquatic life or ecological integrity. All other DEQ-7 parameters for which there are numeric standards have numeric antidegradation criteria. Applying this policy to the numeric EC & SAR standards is necessary to protect the existing water quality of the Tongue River from degradation from CBM discharges. Designation of EC & SAR as harmful parameters merely applies numeric nondegradation thresholds, and makes the handling of the parameters consistent with all other constituents in DEQ-7.

The Montana Supreme Court has deferred to the Department's decision to treat harmful parameters with numeric standards in a consistent fashion, and rejected industry's proposal that the 2006 treatment of EC and SAR was novel. (Pennaco Energy Inc. v. Bd. of Environmental Review, 2008)

Since salinity and sodium as measured by EC & SAR are harmful to plants and soils, the appropriate nondegradation category for them is harmful. For harmful parameters changes in existing water quality are considered nonsignificant if the change is less than ten percent of the numeric standards and the ambient water quality of the receiving stream is less than 40% of the standard.

The Department does not consider the Powder and Little Powder Rivers to be High Quality Waters for salinity and subject to anti-degradation policy. These rivers exceed some of the numeric standards as much as 40% of the time. The Department also found that these waterbodies are impaired for salinity in the 2008 Water Quality Integrated Report (Montana Department of Environmental Quality, 2008).

8.0 FLOW BASED PERMITTING

One commenter suggested using flow-based permitting in implementing the numeric standards. In 2006, the Board adopted the section of the proposed rule that deleted the requirement to use flow based dilution when calculating MPDES permit discharge limits. The Board also rejected the proposal to require the DEQ to use the 7Q10 low flow value to calculate permits. These decisions give the DEQ the discretion to use either method or combination of the two and will make the analysis of CBM produced water permit applications consistent with other types of discharge permits.

9.0 SEVERABILITY

The nonseverability requirement was originally recommended by DEQ and adopted by the Board at the CBM industry's request. The intent was to prevent a situation in which narrative nondegradation criteria were struck down in court, leaving only the numeric standards in effect. Since the Board approved the replacement of the narrative nondegradation criteria with a conventional numeric approach, the nonseverability provision was no longer necessary.

10.0 RECOMMENDATION

The Department finds that the great majority of the literature published since 2003 supports the need for protective numeric standards, the manner in which they were developed, and the ultimate values that the Board adopted. The Department has considered all of the studies identified in its public notice dated April 10, 2010, as well as all public comments received, and determines that the rules adopted in 2003 and 2006 are adequate to protect beneficial uses and do not require any amendment. The Department has not identified any basis through these recent studies, nor through the public comments received, that argue re-visitation of the general approach, the numbers themselves, or the manner in which they are implemented.

In Montana water quality standards are adopted as rules by the Board of Environmental Review (Board). The Department summarized and presented the preceding information to the Board at their regularly scheduled May 13, 2011 meeting. Based on this information the Board determined that the existing standards are necessary to protect water quality and soils, and the Board declined to initiate rulemaking to modify the standards.

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APPENDIX 1 - CALCULATION OF ELECTRICAL CONDUCTIVITY STANDARDS FOR LONG-TERM IRRIGATION ON THE TONGUE/POWDER/ROSEBUD TRIBUTARIES

In southeastern Montana, the consumptive use of water on the tributaries is very different than the mainstem rivers. Irrigation consists largely of gates and canals on the mainstems, and spreader dike systems on the tributaries (Punt, Terry, personal communication 4/28/2009). Water is in short supply on the tributaries, application is very opportunistic, and limited to snow melt and rain driven events. The Department of Environmental Quality (DEQ) calculated water quality standards for tributaries to protect the long term irrigation use in these systems.

DEQ took a three step approach to calculate a protective electrical conductivity (EC) limit on the tributaries:

- Estimate the frequency of conditions resulting in leaching of the soil-profile
- Calculate the amount of salt accumulated between leaching events
- Determine the amount of salt accumulation possible without any significant crop loss.

Leaching of the majority of salts will occur only under wet conditions when the total infiltrated water from rain, snowmelt, and operation of the spreader dike system exceeds evapotranspiration (ET) by about 14 inches (American Society of Agronomy, 1999).

To determine the target crop to determine ET, information from the 2001 grower surveys was used. DEQ received more than 200 responses to several surveys asking the agricultural community what type of plants they cultivate each year. One of the surveys was targeted at tributary water use, and 15 of 16 respondents grew alfalfa [2]. Actual evapotranspiration for alfalfa was calculated at 5.17 inches (DeMooy and Franklin, 1977) from the start of the growing season (April 1) through May 15th.

Total precipitation was estimated from data from National Oceanic and Atmospheric Administration National Climatological Data Center (National Oceanic and Atmospheric Administration, National Climatological Data Center, 2011). Data from the Broadus, MT station was used from 1920-2010. A conservative assumption was made that when mean monthly temperatures were at or below freezing, snow buildup occurred (November through March). The water content from this snow was added to rain through May to estimate the total available water for infiltration in the spring.

Water contribution from the spreader dike systems was estimated to be 6 inches per year. This assumption was based on an infiltration rate study in the Powder River drainage presented in deMooy and Franklin (DeMooy and Franklin, 1977). The average infiltration rate across 6 sites was 1.6 inches per hour. Assuming the duration of 4 hours of flooding for one event per year, approximately 6 inches of water would infiltrate into the soil profile.

Leaching events are promoted when 14 inches of water is available in excess of the 5 inches to meet ET (that is 19 inches of total water). This is achieved with the combined water contributions from the following sources: 6 inches from spreader dike irrigation systems, 6 inches held in the 3 foot soil profile (2 inches/foot) (Montana Testing Labs and Yellowstone-Tongue APO, 1978), and 7 inches precipitation in

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[2] Responses to Grower Surveys Distributed by Montana Department of Environmental Quality, 2001

the form of snow melt and rain. A recurrence frequency was calculated for the total available water from precipitation at Broadus (**Figure A-1**).

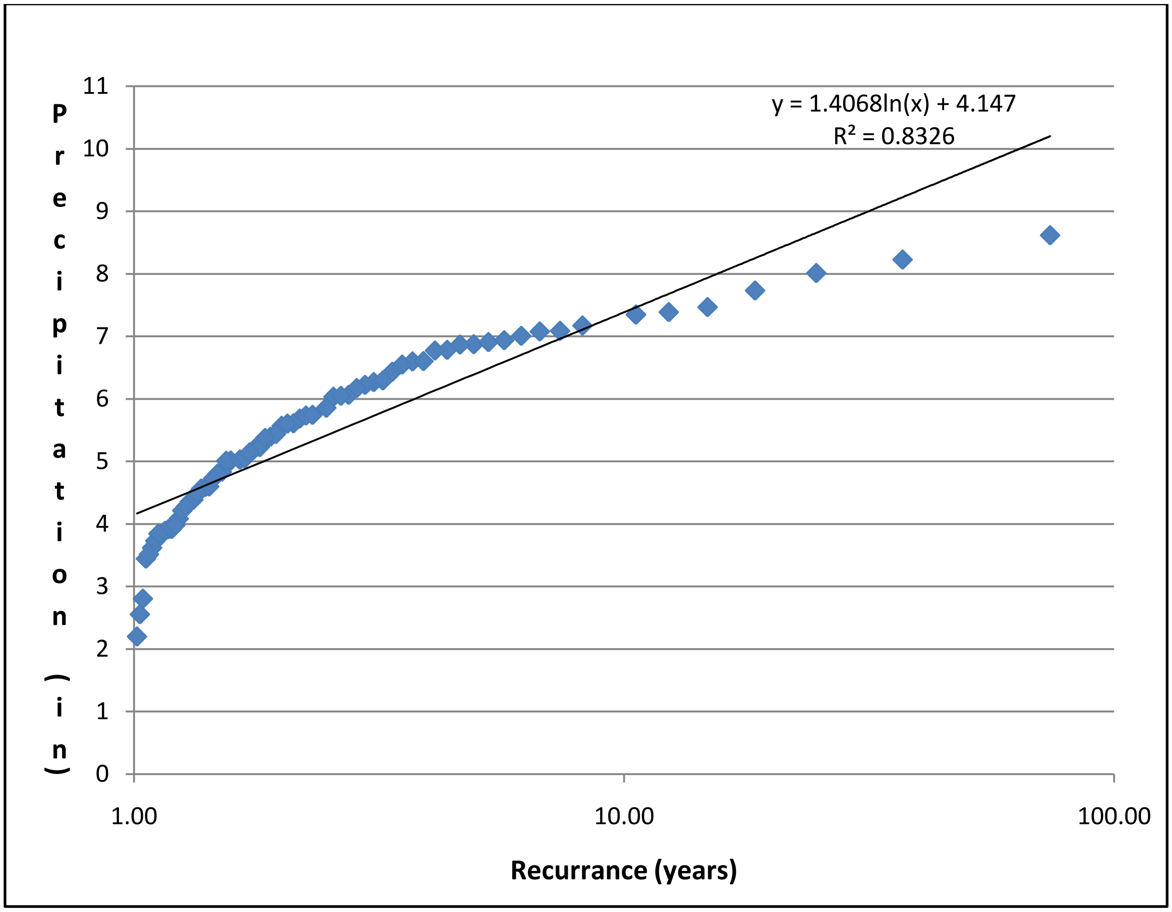

Figure A-1. Precipitation Recurrence Frequency at Broadus, MT

Sufficient water to drive the leaching events occurs once every 8 to 10 years. In the intervening years, when leaching does not occur, salts in the water applied with the spreader dike system accumulate in the upper 3 feet of soil.

A water-salt mass balance calculation (***eq. 1***) was used to determine the total salt accumulating from applied irrigation water between leaching events. This approach accounts for the initial salt present in the soil, plus salt added with irrigation water.

$$\left[\frac{S_{SW} + (I_S * D)}{W_{SP}}\right] = S_{AC} \qquad (\textit{\textbf{eq. 1}})$$

where:

S_{SW} = Initial salt present in soil water, [dS*inches]/m
I_S = Salt water added annually through irrigation, [dS*inches]/m
D = Duration between leaching events
W_{SP} = Depth of total water in soil profile, inches

S_{AC} = Final soil electrical conductivity, dS/m

The mathematical steps to apply the equation are as follows:

- Salt accumulates in the upper 3 feet of soil
- Water holding capacity is 2" water/foot soil
- Therefore, total water in the soil is:
- 3' soil * 2"/foot = 6" total water

The average initial soil salinity was assumed to be 0.25 dS/m (250 µS/cm) as measured on extracts from saturated soil pastes that have a water content two times higher than that of the soil. To correct the dilution factor, the initial soil quality was multiplied by 2.

Therefore:
0.25 dS/m * 2 = 0.5 dS/m

The initial soil salinity was multiplied by the total depth of soil water to quantify the total initial salt present in the 3 foot soil profile:
S_{SW} = 0.5 dS/m * 6" total soil water = 3 [dS*inches]/m

500 µS/cm (or 0.5 dS/m) was used as a surrogate water quality. The following calculation derives the amount of water and salt added annually through the application of irrigation water:
I_S = 0.5 dS/m * 6" = 3 [dS*inches]/m added annually

Leaching occurs at a frequency of once every 8 to 10 years (D).
Therefore (I_S * D):
3 [dS*inches]/m * 8 years = 24 [dS*inches]/m increase over 8 years
3 [dS*inches]/m * 10 years = 30 [dS*inches]/m increase over 10 years

The EC increase over 8 and 10 years of irrigation plus the initial soil EC ([($I_{S\,*}$ D)+ S_{SW}]):
8 years: 24 [dS*inches]/m + 3 [dS*inches]/m = 27 [dS*inches]/m
10 years: 30 [dS*inches]/m + 3 [dS*inches]/m = 33 [dS*inches]/m

The calculated EC increase is contained in the 6 inches of water that is distributed throughout the 3 foot soil profile so we divided by 6 to determine the average condition of the soil profile.
S_{AC} = 8 years: 27 [[dS*inches]/m]/ 6" water = 4.5 dS/m
S_{AC} = 10 years: 33 [[dS*inches]/m]/ 6" water = 5.5 dS/m

The EC of the soil was converted back to EC of soil water extract by dividing by a dilution factor of 2:
8 years: (4.5 dS/m) / 2 = 2.3 dS/m
10 years: (5.5 dS/m) / 2 = 2.8 dS/m

After 8 to 10 years of irrigation with 500 µS/cm (0.5 dS/cm) water, EC of soil water extract would range from 2.3 -2.8 dS/m.

The approach (***eq. 2***) used by Ayers (1975) and Ayers and Westcot (1976) was used to relate soil water extract quality to potential crop yield loss.

$$Y = 100 - b(\mathrm{ECe} - a) \qquad (\textbf{\textit{eq. 2}})$$

where:

Y = relative crop yield in %

EC_e = salinity of the soil saturation extract (mmhos/cm)

a = threshold value for the crop representing the maximum EC_e at which 100% yield can be obtained (mmhos/cm)

b = yield decrement per unit of salinity, or percent yield loss per unit of salinity (EC_e) between the threshold value (a) and the EC_e value representing the 100% yield decrement

The following yield threshold values for alfalfa taken from Ayers and Westcot (1976) were used (1 mmhos/cm is equivalent to 1 dS/m):

100% yield for alfalfa: 2.0 dS/m EC_e
0% yield for alfalfa: 15.5 dS/m EC_e

The following method to calculate b ws used:

0% yield – 100% yield = range of EC_es
Range of EC_es / 100 = EC_e per 1% loss
b * EC_e per 1% loss = 1dS/m

15.5 dS/m – 2.0 dS/m = 13.5 dS/m
13.5 / 100 = 0.135 dS/m per 1% loss
b * 0.135 dS/m = 1dS/m (solve for unknown)
7.4% loss per dS/m = b

The calculated relative crop loss (Y) range from 2.2% to 5.9% when applying 500 µS/cm water for 8 to 10 years. If 600 uS/cm was used as a surrogate quality of the irrigation, the range of crop loss would increase to 4.8% to 9.3%.

To protect the agricultural water supply designated use, a tributary electrical conductivity standard of 500 µS/cm is warranted.

REFERENCES CITED IN APPENDIX 1

American Society of Agronomy. 1999. Agricultural Drainage. R. W. Skaggs and Jan Van Schilfgaarde (Eds.), Vol. 38: American Society of Agronomy - Crop Science Society of America - Soil Science Society of America.

Ayers, R. S. 1975. Interpretation of Quality of Water Quality for Irrigation, Paper 16. *Soils Bulletin.*(131)

Ayers, R. S. and D. W. Westcot. 1976. Water Quality for Argriculture, Paper No. 29. *Irrigation and Drainage.*

DeMooy, C. J. and W. T. Franklin. 1977. Determination of Maximum Tolerable Salinity Levels for Continuous Irrigation on Various Soils Along the Powder River. Fort Collins, CO: Yellowstone-Tongue APO.

Montana Testing Labs and Yellowstone-Tongue APO. 1978. Agricultural Report. Fort Collins, CO.

National Oceanic and Atmospheric Administration, National Climatological Data Center. 2011. Precipitation Records for the Years 1920-2010 for Broadus, MT. http://www.ncdc.noaa.gov/oa/ncdc.html.

APPENDIX 2 - PUBLIC COMMENT CATEGORIES RECEIVED, AND DEPARTMENT RESPONSES

COMMENTS ON SCIENTIFIC & TECHNICAL BASIS

1. The standards cannot be met, because historic water quality sometimes exceeds them.

   When the natural EC values exceed the proposed EC standards, the provisions of 75-5-306, MCA would apply. This section of the Montana Water Quality Act allows for natural exceedances of standards by providing that: "It is not necessary that wastes be treated to a purer condition than the natural condition of the receiving stream as long as the minimum treatment requirements established under this chapter are met". Thus, if the standard is 1000 μS/cm and the natural condition of the receiving water is 1500 μS/cm, a discharge could occur as long as the discharge did not raise the instream concentration above 1500 μS/cm.

2. Montana has only established standards for the waters of CBM country. It seems they would be needed for all waterbodies in the state that support irrigation.

   Narrative standards are in effect for salinity and sodium in all state waters. Numeric standards were adopted for the Powder River basin because there is a risk to beneficial uses from a significant volume of discharge of water with elevated salinity and sodium.

   The use of the standards by the Department may result in their application on other waterbodies that have narrative standards. The Department would likely use the same approach used here in permit specific narrative standard translation.

3. What crop, soil, and irrigation methods were used to justify the standards? We do not believe MT has provided adequate scientific justification for the selected standards.

   The original 2003 Technical Basis included an in depth analysis of crop tolerances, irrigation methods, leaching fractions, and rainfall effects. The updated rationale revisits this analysis with additional findings from recent literature and scientific studies, and response to public comment. The analysis provides a sound basis for the identification of appropriate numeric standards, and the manner in which they are implemented.

4. We see no scientific justification for the determination that EC & SAR are harmful parameters and thus subject to non-degradation criteria.

   The existing literature and recent studies affirm that elevated salinity adversely affects plant's ability to draw water from the soil. Elevated SAR causes dispersal and reduction in infiltration in sensitive soils. All water quality parameters that have numeric standards are also subject to numeric nondegradation criteria, and EC & SAR should be no exception.

5. We question the need for non-irrigation season limits on the Powder and Little Powder. With no impoundments, this water will not be used for irrigation.

Non-irrigation season limits are adopted to protect riparian vegetation. Montana's narrative water quality standards prohibit concentrations of materials that are harmful to plant life (ARM 17.30.637 (1) (d)).

The updated Rationale includes recent studies that identify typical riparian species in each of the Tongue and Powder River basins, and the salinity levels that adversely affect their propagation and growth.

7. Montana should return to the narrative standards that serve almost all other states for beneficial use protection.

   All states use a combination of narrative and numeric standards to protect beneficial uses and Montana is no exception. With respect to the EC & SAR standards, numeric standards provide more consistency and greater predictability in agency permitting.

8. If MT persists in using numeric values, it should adopt "sliding" or flow based values, which recognize that lower flows naturally result in higher EC and SAR.

   The Department can and does use flow based permit limits in some situations. For instances when the natural water quality exceeds the standards, see the response to Comment No. 1.

9. If MT persists in using numeric values, it should adopt the Hanson formula to determine the SAR limit based on the existing EC.

   The Board used a range of alternative methods, and relied on established literature, to identify the appropriate SAR for given ranges of ECs, including the Hanson formula for mid-range ECs. As identified in both the original 2003 technical basis and the updated Rationale, the Hanson formula is not effective in identifying meaningful SAR levels at very low ECs, when the existing authoritative literature identifies an SAR of 3 as the appropriate level. The formula is also ineffective at high ECs, when the indicated SAR level would leave soils vulnerable to the rainfall effect. In these cases, a maximum SAR level of 5 insures that a rainfall induced reduction in EC won't result in dispersal of sensitive soils.

10. Dawson Powder study concludes no change in Water Quality between '69 & '04; no studies on Tongue or Little Powder yet.

    The Dawson Powder study found small changes in the quality of river flow when pre-1990 data were not included. 1990 is about the time that the Salt Creek oil fields in Wyoming ceased discharging poor quality produced water. Montana maintains that it is not appropriate to include this data, which was affected by human caused discharges which have ceased and will not occur again. Dr. Dawson also conducted a Tongue River analysis; see Comment No. 12.

11. Department has failed to explain why it changed its 2003 decision on numeric nondeg.

    The comment responses in the 2006 Montana Administrative Rules rule adoption notice include an explanation of the decision to adopt numeric nondegradation criteria by designation EC & SAR as harmful parameters. The reasons for this decision include the Board's 2003 direction to the Department to come up with an alternative to the narrative nondegradation approach approved at *that time. The narrative nondegradation approach also left EC and SAR as the only two parameters, out of hundreds of parameters in DEQ-7, that had numeric standards and narrative nondegradation criteria. Finally, the Department concluded that the high quality water of the Tongue River required protection through the numeric nondegradation approach. This protection was lacking under the narrative nondegradation approach*

12. The Dawson Tongue report concludes that there is no statistically significant difference in pre- and post-CBM EC at Stateline. The report notes a post-CBM increase in SAR, but states that there is insufficient monitoring information to determine whether the post-CBM development increase in SAR in the Tongue River at Stateline station is due to:
    - direct discharges to the river from CBM development in Montana,
    - discharge from Prairie Dog Creek (which has had CBM development in Wyoming and is characterized by higher SAR than the main stem)
    - or a characteristic of the lower flows observed during the post-CBM development time period

    The Department agrees with this interpretation of the Dawson Tongue report.

13. Irrigation water from the Tongue has damaged clay soils in the TY irrigation district.

    The Department agrees with the conclusions of the study, Rainfall induced dispersion and hydraulic conductivity reduction under low SAR x EC combinations in smectite-dominated soils of eastern Montana by Dr. James W. Bauder. Among his conclusions are that the observed adverse effects were not necessarily linked to CBM discharges. He found, however, that application of even low SAR water can cause dispersion on very sensitive soils in combination with other events, such as significant precipitation.

14. Numeric standards that protect the broad range of soils in the Tongue and Yellowstone valleys are critical.

    The Department agrees. The updated Rationale includes information on specific soil types found in the Powder River basin.

15. The science to date supports Montana's numeric standards and the designation of EC & SAR as harmful parameters.

    The Department agrees.

16. Produced water accumulates in the Tongue River Reservoir; if there is insufficient spring runoff, it contributes to standards exceedances at gauging stations downstream.

    The Board adopted year round standards for the reservoir so that higher non-irrigation season standards could not contribute to downstream exceedances when the stored water is released.

17. Three-fourths of the TY irrigation district is on the Yellowstone River drainage, which contains a high proportion of clay soils. These soils do not have adequate ability to disperse the level of sodium in CBM produced water.

The Department agrees, although the study referenced in the response to Comment No. 13 concludes that soils effects can occur even with low EC's under certain circumstances.

18. USGS grab sample SAR levels have increased by 27% pre- and post development.

    The USGS has two trend analysis studies ongoing, one in each state. No results have been published yet. When they are, these study efforts will aid the identification of any water quality trends. State agencies, including the Department, also track water quality. If significant trends are identified, actions can be taken to mitigate them.

19. DEQ's hired expert during standards development concluded there is insufficient diluting flow in the tributaries; hence the EC standard of 500 dS/cm.

    DEQ assumes the Tongue River tributary standard for EC of 500 μS/cm is intended in this comment. It was necessary because in most years there is insufficient water to allow for leaching fraction on tributaries which renders the comparatively straight forward approach used for other waterbodies with leaching fractions inappropriate.

    The Department has restated the analysis in the updated Rationale, with greater detail, documentation, and cites to the authoritative literature.

20. More acreage is being converted from flood to sprinkler irrigation; this fact supports the use of the 30% leaching fraction in arriving at the standards. In some cases, the 30% leaching fraction may be insufficient to flush salts from soils.

    The Department agrees that the Tongue River drainage has experienced this conversion; it is described in the updated Rationale. However, a 15% leaching fraction was used for sprinkler irrigation, which is more efficient than flood irrigation. The numeric standards represent water quality levels for which sufficient leaching is available to flush salts from the root zone. That is, application of irrigation water meeting the numeric standards will result in sustainable agricultural practices.

21. The tribs are a source of high quality irrigation water. Maintaining the current standards will help prevent perennialization and preserve their value for supporting this beneficial use.

    The updated Rationale includes cites from Hendrickx and Buchanan, 2009, which describe the adverse effects of perrenialization of ephemeral drainages. The Department recognizes that changes in flow regimes can alter ecosystems and water quality.

COMMENTS ADDRESSING LEGAL ISSUES

Because these issues were raised in litigation, the Department does not feel it is appropriate to respond.

1. EPA conditioning of permits based on downstream state Water Quality Standards applies only to federal permits, not state-issued permits. Section 1342 (b) of the CWA does not require Wyoming to comply with Montana's water quality standards at the border.

2. Section 510 of the CWA explicitly preserves a state's jurisdiction over its own waters. This fact prevents Montana from directing Wyoming producers to meet limits more restrictive than those provided in the CWA.

3. As written, the rules impermissibly discriminate against Wyoming, contrary to the Commerce Clause.

4. Construing the CWA to allow Montana's water quality standards would intrude upon Wyoming's sovereignty.

5. The federal district court ruling does not void Montana's EC & SAR standards; they remain in effect.

6. The court did not rule on Wyoming & industry's argument that the standards violate Wyoming's sovereignty.

7. Wyoming & industry misconstrue the purpose of the Triennial Review when they reargue the points raised in their Pennaco briefs. EPA has not determined that Montana's standards are inconsistent with the CWA.

8. No changes should be made to the EC & SAR standards. EPA cannot approve the standards until it has reviewed the entire admin record, and even then approval is dependent upon Montana's review and upon the state's preparation of the requisite admin record.

COMMENTS ADDRESSING ADMINISTRATIVE AND IMPLEMENTATION ISSUES

1. EPA approval is also inappropriate at this time because the agency is conducting its own review of CBM produced water through its Effluent Guidelines Program.

   Federal promulgation of ELGs, if it occurs, is likely a number of years away. Water quality based standards are necessary and appropriate at the present time. Ultimately, when both technology-based and water quality based standards exist, the more stringent of the two will be used in permitting decisions.

2. Will MT use average historic data or instantaneous data to determine background water quality in compliance determinations?

   The Department would consider all data that is readily available to determine background.

3. The fact that CBM discharges in Montana actually control water quality at Stateline suggests that setting Montana standards for use in Wyoming's discharge permits is unwarranted.

   We disagree that Montana discharges control salinity at the stateline USGS gaging station. MT DEQ's 2010 mass balance analysis on the Tongue River indicates that MT authorized discharges comprised about two to three percent of the salinity load at Stateline station under spring base flow conditions, and less at higher flows. Since this analysis, untreated discharges to the Tongue have ceased in Montana. Prairie Dog Creek in Wyoming, where there is extensive CBM development, contributes between 10 and 15% of the load in its surface flow, and probably more than that in subsurface flows through alluvial soils.

4. Discharges in Wyoming are degrading Montana waters. Montana needs to uphold their standards and promote federal compliance support.

   The Department intends to resubmit the water quality standards for EPA review and re-approval.

5. The recent Montana Supreme Court decision appears to impose treatment requirements on produced water. Standards changes should not occur until agencies can determine the best method to comply with the Court's decision.

   Montana's standards are still in effect in-state, and permits are being rewritten to accommodate the Supreme Court's decision on treatment.

6. The numeric standards in place for EC & SAR are protective of existing uses and in many cases overly protective given that the ambient water quality in tributaries exceeds these standards.

   Please see the response to ***Scientific Basis comment No. 1****.*

7. The SAR standards should apply in the receiving waters, not at the end of the pipe. Addition of calcium salts to meet end of pipe criteria unnecessarily raises the EC of the receiving water.

   Water quality standards and nondegradation criteria always apply to the receiving water. Water quality based effluent limitations always apply to the quality of the effluent prior to dilution in the receiving water (end of pipe) and are based on meeting the applicable water quality standard in the receiving water after giving consideration for any allowable dilution. If no dilution or mixing zone is granted, the water quality standards and effluent limits are equivalent.

8. In the absence of a proposed revision to an existing rule, it is not possible to offer specific comments.

   Any changes proposed to the standards will include a separate rulemaking process including public comment on the proposed revision.

9. DEQ should provide an explanation of the relevance of each of the CBM studies listed on the agency's site, and how it supports the standards so that the public can comment on the Department's rationale.

   In the updated Rationale, the Department has included references to and interpretations of the studies that relate directly to the technical issues addressed. The Department has also summarized the findings of each study which was reviewed for relevance to this effort, and posted online to support the public involvement process.

10. Existing discharge permits must apply nondegradation provisions when renewed.

    The Department conducts a non-significance determination in accordance with ARM 17.30.705(2) and 706(2) based on the criteria adopted by the Board at the time the application is received. Water quality based effluent limitations based on nondegradation criteria may be imposed in the permit or approval, to insure that changes in water quality do not exceed the applicable non-significance *criteria. These limitations are maintained in subsequent permit renewals. New or revised nondegradation criteria adopted by the Board may be considered in subsequent permit renewals if the facility proposes to modify or increase the volume or nature of the discharge such that another non-significance determination is necessary.*

11. The recent Supreme Court decision requires all produced water to be treated before discharge. If nondegradation and treatment are required, the produced water will no longer fail WET testing.

    The Department agrees that treatment will likely reduce toxicity to levels that will routinely pass whole effluent toxicity tests. Once treatment is in place for CBM discharges, the WET testing protocols will serve the function of assuring that no acute or chronic toxicity remains after treatment.

12. Access points are necessary for the monitoring of water quality in the Tongue. Enforcement of the standards is impossible otherwise.

    75-5-603, MCA authorizes the Department to enter upon any public or private property to investigate conditions relating to pollution of state waters, inspect any monitoring equipment, and sample any effluents.

13. Nondegradation requires that discharges that add more than 15% of the flow be deemed significant.

    The Department agrees. However, ARM 17.30.715 (3) allows the Department to find these increases are nonsignificant based on the criteria of 75-5-301 (5) (c). These include the discharge's potential for harm, its quality and strength, its duration, and the character of the pollutant.

14. The standards should not be flow-based. At low flows, discharges are not curtailed, resulting in the majority of the flow in the river being produced water.

    ARM 17.30.623 (2) (j) and 635 (1) (e) require that permit be issued based on the design flow or 7-day, 10-year low flow. Water quality based effluent limits must be based on this design condition to ensure compliance with water quality standards. When in-stream flow is below this level, the discharge is to be governed by the permit conditions developed and implemented in the permit.

15. When TMDL's are completed, it may be necessary to revisit the standards.

    TMDL's represent the highest level of pollutants that a waterbody can experience and still meet standards and support its beneficial uses. The TMDL does not generally affect the standards, rather it is driven by them.

16. Montana permits have not taken into consideration the standards proposed by the Northern Cheyenne tribe; these standards need to be considered in drafting permits.

    The Northern Cheyenne Tribe is presently revising its proposed standards and they have not yet been approved. When they are, the Department will insure that state issued permits comply with them.

17. The existing standards cannot be protective until MT DEQ and EPA enforce them.

Water quality standards serve as a basis for permit limits and are enforceable as permit limitations. Other provisions of state and federal statutes prohibit the discharge of pollutants without a permit. Water discharges and instream water quality are monitored for compliance by a number of methods, including field sampling, real time reporting, and industry self monitoring and reporting of discharge quality and volume.

18. MT should formally reopen the numeric standards.

    The Department advertised the current review as open to any and all technical and public input. If changes to the standards are proposed, a separate rulemaking will be undertaken, which will include another call for public comment.

19. The inquiry of the Triennial Review is whether there is additional scientific or technical data that requires revision of the existing rules.

    The Department agrees. Studies conducted between 2003 and 2010 were reviewed and analyzed in the Rationale.

20. The EC & SAR standards should not be part of the Triennial Review constituents proposed for EPA approval. A comprehensive rulemaking should be conducted, taking into account public comment and all scientifically sound data.

    As elements of the State's water quality standards, the EC & SAR criteria are part of the Triennial Review. A rulemaking will be conducted if the Board determines that new information and data requires it. The Department's recommendation is that no rulemaking is necessary at this time.

APPENDIX 3 - STUDIES NOT CITED IN THE RATIONALE

The following studies posted to support public review were not cited in the Rationale, for the reasons provided:

- Bauder, James. 2007. Comments regarding *Potential Impacts of Coal Bed Methane Development to the Buffalo Rapids Project: Draft Agreement Between Montana and Wyoming*

  Dr Bauder provides observations on other studies cited in the Rationale. These studies themselves are cited.

- Clearwater, Susan, Brady Morris & Joseph Meyer. 2002*. A Comparison of Coalbed Methane Product Water Quality Versus Surface Water Quality in the Powder River Basin of Wyoming, and An Assessment of the Use of Standard Aquatic Toxicity Testing Organisms for Evaluating the Potential Effects of Coalbed Methane Product Waters*

  Dr. Clearwater's conclusions on the variability in quality of CBM produced water and the manner in which discharge might impact surface waters are valid and informative, but are not necessary to expand the Rationale's discussion of the numeric standards required to protect beneficial uses.

- Bauder, T.A., R.M. Waskom, and J.G. Davis. 2004. *Irrigation Water Quality Criteria*, Crop Series: Irrigation No. 0.506. Colorado State University Cooperative Extension.

  Dr. Bauder's observations are cited in the Rationale from his other works.

- Suarezk, Donald L., James D. Wood, and Scott M. Lesch. 2006. *Effect of SAR on Water Infiltration Under a Sequential Rain-Irrigation Management System.* Agricultural Water Management Vol. 86.

  Dr. Suarez's observations are cited in the Rationale from his original study.

- Steg, Ron, with technical support provided by TetraTech, Inc. April 6, 2007. *Tongue River Modeling Approach and Results.* U.S. Environmental Protection Agency, Region 8 Montana Operations Office.

  At the time this report was published, the initial modeling results and analysis did not bear on the development of numeric standards to protect beneficial uses.

- Cannon, M.R., David A. Nimick, Thomas E. Cleasby, Stacy M. Kinsey, and John H. Lambing. 2007. *Measured and Estimated Sodium-Adsorption Ratios for Tongue River and its Tributaries, Montana and Wyoming 2004 – 2006*. USGS Scientific Investigations Report 2007-5072

  This USGS study describes the regression method used to estimate SAR levels from the real-time EC readings. It is an important tool in the reporting of real-time data, but does not reflect on the development of numeric standards required to protect beneficial uses.

- Dawson, Helen E. 2007. *Pre- and Post-Coal Bed Natural Gas Development Surface Water Quality Characteristics of Agricultural Concern in the Upper Tongue River Watershed*. U.S. EPA, Region 8, Denver, CO

- Dawson, Helen. March 2007. *Powder River Watershed Stream Water Quality Pre- and Post-CBM Development*. US EPA Region 8.

  Dr Dawson's conclusions about whether or not CBM development to date has had any measurable effect on the quality of surface waters in the Powder River basin do not bear on the development of numeric standards required to protect beneficial uses.

- Wang, Xixi, Assefa M. Melesse, Michael E. McClain and Wanhong Yang. December 2007. *Water Quality Changes as a Result of Coalbed Methane Development in a Rocky Mountain Watershed*. Journal of the American Water Resources Association Vol. 43, No. 6.

  Although Dr. Wang's work provides valuable information on the measured effects of upstream CBM produced water management, the results do not bear on the development of numeric standards to protect beneficial uses.

- Healy, Richard W., Cynthia A. Rice, Timothy T. Bartos, and Michael P. McKinley. 2008. *Infiltration from an impoundment for coal-bed natural gas, Powder River Basin, Wyoming: Evolution of water and sediment chemistry*. Water Resources Research, Vol. 44.

  Dr Healy's conclusions on the impacts of water infiltrating from CBM ponds are certainly cause for concern, but do not directly bear on the development of numeric standards required to protect beneficial uses in surface waters.

- Frost, Carol, Elizabeth Brink, Jason Mailloux, Shaun Carter, and Shikka Sharma. 2009. *Environmental Tracers Applied to Quantifying Causes in Water Quality Along the Powder River, Wyoming*.

  Sharma, S. and C.D. Frost. March-April 2008. *Tracing Coalbed Natural Gas-Coproduced Water Using Stable Isotopes of Carbon*. Ground Water, Vol. 46, No. 2,

  Campbell, Catherine E., Benjamin N. Pearon and Carol D. Frost. 2008. *Strontium isotopes as indicators of aquifer communication in an area of coal-bed natural gas production, Powder River basin, Wyoming and Montana*. Rocky Mountain Geology, Vol. 43, No. 2.

  Dr Frost's isotope tracer studies are innovative and informative, but the amount of CBM produced water in the Powder River does not directly bear on the development of numeric standards required to protect beneficial uses in the Powder. Dr Frost's study on the geochemical evolution of produced water in the environment was cited in the Rationale.

- Gajegunte, Girisha K., Lyle A. King, and George F. Vance. 2008. *Cumulative Soil Chemistry Changes from Land Application of Saline-Sodic Waters*. Journal of Environmental Quality Vol. 37.

  Dr. Ganjegunte's and Dr. King's observations from their 2005 study are cited in the Rationale.

- Patz, M.J., K.J. Reddy, and Q.D. Skinner. 2006. *Trace Elements in Coalbed Methane Produced Water Interacting with Semi-arid Epemeral Stream Channels*. Water, Air and Soil Pollution, Vol. 170.

Jackson, Richard E. and K.J. Reddy. 2007. *Trace Element Chemistry of Coal Bed Natural Gas Produced Water in the Powder River Basin, Wyoming*. Environmental Science and Technology, Vol. 41, No. 17.

Dr.s Patz, Reddy, and Jackson's observations are cited in other studies and journal articles referenced in the Rationale.

- Wang, Xixi and Wanhong Yang. 2008. *Modeling potential Impacts of Coalbed Methane Development on Stream Water Quality in an American Watershed*. Hydrological Processes, Vol. 22, No. 1.

  Dr Wang's predictive modeling work does not directly bear on the development of numeric standards required to protect beneficial uses in surface waters. Dr. Wang's JAWRA study was cited in the Rationale.

- Milligan, C., K.J. Reddy, K.J. and D. Legg. 2010. *Monitoring Geochemistry of CBNG Produced Water Outfalls, Disposal Ponds, and Sediments in the Powder river Basin, Wyoming*. Chapter 8. Coalbed Methane: Energy and Environment. Nova Science Publishers, New York.

  Recommendations for the monitoring of produced water do not directly bear on the development of numeric standards required to protect beneficial uses. Two other studies conducted by Dr. Reddy were cited in the Rationale.