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DEC - 8 2015

Ref: 8EPR-EP

Joan Miles, Chair
Montana Board of Environmental Review
1520 E. Sixth Avenue
P.O. Box 200901
Helena, MT 59620-0901

Re: EPA Approval of Montana's Water Quality Standards for EC and SAR

Dear Chairperson Miles:

The U.S. Environmental Protection Agency (EPA) has completed its review of Montana's water quality standards (WQS) for electrical conductivity (EC) and sodium adsorption ratio (SAR) applicable to the Tongue River, Powder River, Little Powder River, and Rosebud Creek mainstems, tributaries, and other surface waters in these watersheds (TPR watersheds[1]). This includes Surface Water Quality Standards and Procedures, Chapter 30, Sub-Chapter 6, ARM 17.30.670(2) – (5), and the EC and SAR definitions in ARM 17.30.602. The EPA concludes these WQS are consistent with the Clean Water Act (CWA) and the implementing federal WQS regulation at 40 C.F.R. Part 131 and therefore approves these WQS pursuant to CWA Section 303(c).

Background

The Board of Environmental Review (Board) initially adopted definitions, numeric criteria, and a nondegradation provision for EC and SAR on March 28, 2003 and April 11, 2003 and submitted them to the EPA for review with a June 12, 2003 letter from Jan P. Sensibaugh, Director of the Montana Department of Environmental Quality (MDEQ). The submittal package included: (1) the WQS and rationale; (2) Attorney General's certification that the revisions were duly adopted pursuant to state law; and (3) responses to public comments. The EPA approved Montana's WQS for EC and SAR on August 28, 2003.

On March 23, 2006, the Board adopted a revision to the nondegradation provision that applies to EC and SAR (ARM 17.30.670(6)). On April 25, 2006, several coal bed methane (CBM) companies filed a Petition for Review of the EPA's approval of Montana's 2003 numeric standards for EC and SAR in U.S. District Court in Wyoming. Subsequently, Wyoming, additional CBM companies, and several landowners intervened as Petitioners. Montana, Powder River Basin Resource Council, and Tongue River Water Users Association intervened as Defendants with the EPA.

[1] "TPR watersheds" refers to all of the Tongue and Powder River, and Rosebud Creek waters in Montana to which the WQS for EC and SAR apply.

Montana submitted the 2006 revised nondegradation provision for EC and SAR to the EPA for review with a letter dated June 5, 2006, from Richard H. Opper, Director of MDEQ. The submittal package included: (1) the WQS and rationale; (2) Attorney General's certification that the revisions were duly adopted pursuant to state law; and (3) responses to public comments.

On September 11, 2006, CBM companies and Wyoming filed a Petition for Review of the EPA's failure to disapprove Montana's 2006 nondegradation provision within the 90-day CWA requirement. The U.S. District Court in Wyoming consolidated the 2003 and 2006 WQS cases and stayed the litigation in order to provide time for possible settlement of the issues. Ultimately, no resolution was reached and on February 29, 2008, the EPA approved Montana's nondegradation provision for EC and SAR.

The litigation proceeded, and on October 13, 2009, the U.S. District Court in Wyoming vacated the EPA's approvals of Montana's 2003 and 2006 WQS and remanded the matter to the EPA to:

1. Consider the entire 2003 administrative record;
2. Determine whether the 2003 numeric standards are based on appropriate technical and scientific data;
3. Make plain its course of inquiry, analysis and reasoning for its action as to the 2003 and 2006 standards, including whether appropriate scientific data supports the actual numeric values adopted by the state of Montana; and
4. Clarify that the EPA is not approving classification of the Powder River and Little Powder River as Tier 2 waters. (Tier 2 refers to the antidegradation review for high quality waters required by 40 CFR § 131.12(a)(2).)

At the time of the court's Order, Montana was in the process of preparing for the triennial review of its WQS required by 40 CFR § 131.20(a). The state decided to specifically solicit public comment on the EC and SAR WQS as part of that process to determine if the state wanted to revise the criteria based on new science. The Board initiated the triennial review on March 19, 2010. In a letter dated March 31, 2010, MDEQ requested the EPA refrain from acting on the remand of its WQS for EC and SAR until the completion of the triennial review. On April 15, 2010, the state published MAR Notice No. 17-303, which solicited comment "on any aspect of Montana's water quality standards that a person believes the board should consider for potential revision." The notice also included the following:

> In addition, the board is specifically soliciting comment on the numeric standards for electrical conductivity (EC) and sodium adsorption ratio (SAR) adopted in 2003 and subsequent revision to the nondegradation requirements for EC and SAR adopted in 2006. Comments on EC and SAR should identify the specific standard at issue, any suggested revision to the standard and the basis for the revision, including technical information or reports supporting the revision. Interested persons are encouraged to submit any new data, information, or scientific literature that became available after the board's adoption of water quality standards for EC and SAR in 2003.

The notice also stated that if the Board decided to pursue revisions to the EC and SAR criteria based on the comments received, the Board would initiate a new rulemaking. The notice was sent to the state's list of interested parties and published in local newspapers for three consecutive weeks. Copies of some of the post-2003 reports and scientific literature pertaining to EC and SAR were posted on MDEQ's website to facilitate public comment. The public comment period was initially 45 days, but the Board granted a two-week extension until June 16, 2010.

In a letter dated July 8, 2010, MDEQ notified the EPA of its intention to draft a report to the Board outlining the rationale for MDEQ's recommendation on how to proceed. After reviewing the public comments and post-2003 scientific literature, MDEQ presented the results of its review to the Board on May 13, 2011. MDEQ concluded that the WQS adopted in 2003 and 2006 were still scientifically defensible and recommended the Board not initiate new rulemaking to revise the WQS for EC and SAR. The Board agreed with MDEQ's recommendation, and MDEQ requested the EPA act on the remanded WQS for EC and SAR and provided the results of the triennial review in a letter dated July 21, 2011 (received July 26, 2011).

Clean Water Act Review Requirements

CWA Section 303(c)(2) requires states and authorized Indian tribes[2] to submit new or revised WQS to the EPA for review. The EPA is required to review and approve, or disapprove, the submitted standards. Pursuant to CWA Section 303(c)(3), if the EPA determines that any standard is not consistent with the applicable requirements of the Act, the Agency shall, not later than the ninetieth day after the date of submission, notify the state or authorized tribe and specify the changes to meet the requirements. If such changes are not adopted by the state or authorized tribe within ninety days after the date of notification, the EPA is to promptly propose and promulgate such standards changes pursuant to CWA Section 303(c)(4). The EPA's goal has been, and will continue to be, to work closely with states and authorized tribes throughout the standards revision process so that submitted revisions can be approved by the EPA. Pursuant to the EPA's Alaska Rule (40 CFR Section 131.21(c)), new or revised state standards submitted to the EPA after May 30, 2000, are not effective for CWA purposes until approved by the EPA.

Today's Action

In order to comply with the court's Order, the EPA considered the entire U.S. administrative record for both the 2003 and 2006 WQS. In addition, the EPA considered documents from the Montana administrative record that were not in the previous U.S. administrative record, as well as the material from Montana's 2010/2011 triennial review.[3]

Montana's numeric criteria for EC and SAR were adopted in 2003 to protect the agricultural water supply use. In preparation for taking today's action, the EPA reviewed over 12 years of additional scientific literature relevant to the evaluation of numeric criteria for EC and SAR. Appendix 1 provides a summary of certain scientific literature that is relevant to the EPA's review of Montana's numeric water quality criteria for EC and SAR. In addition to the scientific literature referenced in Appendix 1, the EPA considered other scientific literature, data, reports, and supplemental materials.

The EPA also initiated an Interagency Agreement with the U.S. Department of Agriculture, Agricultural Research Service, U.S. Salinity Laboratory to assist in the EPA's review of the current science. The

[2] CWA Section 518(e) specifically authorizes EPA to treat eligible Indian tribes in the same manner as states for purposes of CWA Section 303. See also 40 CFR Section 131.8.

[3] For example, the review included all public comments, hearing transcripts, and the state's response to comments.

Laboratory Director, Dr. Donald Suarez, is recognized internationally as an expert in the effects of irrigation water on crops and soils. Dr. Suarez completed a technical analysis of Montana's rationale for their numeric criteria for EC and SAR (Appendix 2), and reviewed and provided comments on the irrigated agriculture section of the literature review (Appendix 1) in order to ensure the EPA's action today is based on current science.

The definitions of EC and SAR (ARM 17.30.602(7) and (25), respectively) are consistent with the definitions of these terms in the scientific literature and the requirements of the CWA and EPA's implementing regulation at 40 CFR Section 131.11. The 2003 numeric criteria for EC and SAR (ARM 17.30.670(2) – (5)) protect Montana's agricultural water supply use and are scientifically defensible consistent with 40 C.F.R. § 131.11. The 2006 nondegradation provision (ARM 17.30.670(6)) protects and maintains high quality waters where a proposed activity will result in significant changes in water quality for the parameters of EC and SAR, consistent with Montana's nondegradation policy and 40 C.F.R. § 131.12. As ordered to do so by the U.S. District Court in Wyoming, the EPA clarifies that approval of the nondegradation provision does not approve classification of the Powder River and Little Powder River as Tier 2 for nondegradation purposes. The EPA concludes the definitions, 2003 numeric criteria, and 2006 nondegradation provision for EC and SAR are consistent with Clean Water Act (CWA) Section 303(c) and the implementing federal WQS regulation at 40 C.F.R. Part 131 and approves ARM 17.30.602(7) and (25) and ARM 17.30.670(2) – (6). The detailed rationale[4] for today's action is enclosed.

Endangered Species Act Requirements

The EPA's approval of Montana's WQS is considered a federal action that may be subject to the Section 7(a)(2) consultation requirements of the Endangered Species Act (ESA). Section 7(a)(2) of the ESA states that "each federal agency ... shall ...insure that any action authorized, funded or carried out by such agency is not likely to jeopardize the continued existence of any endangered species or threatened species or result in the destruction or adverse modification of habitat of such species which is determined to be critical..." The EPA concludes that its approval of Montana's EC and SAR antidegradation provision and numeric criteria for the protection of agricultural water supply uses is not subject to ESA consultation. Consistent with the EPA's Memorandum *Antidegration Policy Approvals and Endangered Species Act Consultations,*[5] ESA consultation with the U.S. Fish and Wildlife Service is not required where the EPA determines that a state's antidegradation policy and/or procedures meet the requirements of, i.e., is consistent with, 40 CFR § 131.12. The EPA lacks discretion to alter its action or require further measures to benefit listed species. Similarly, where the EPA determines a state's numeric criteria adopted for the protection of agricultural water supply uses protect that designated use and are scientifically defensible consistent with 40 C.F.R. § 131.11, the EPA lacks discretion to alter its action or require further measures to benefit listed species.

[4] The EPA's Rationale for Approval of Montana's Water Quality Standards for Electrical Conductivity and Sodium Adsorption Ratio.

[5] Memorandum from Geoffrey H. Grubbs, Director, Office of Science and Technology to Water Management Division Directors, Regions 1- 10 (January 27, 2005). Available at http://www2.epa.gov/wqs-tech/reference-library-water-quality-standards-policy-and-guidance-documents.

Indian Country

The WQS approvals in today's letter apply only to waterbodies in the state of Montana, and do not apply to waters that are within Indian country, as defined in 18 U.S.C. Section 1151. Today's letter is not intended as an action to approve or disapprove WQS applying to waters within Indian country. The EPA, or authorized Indian tribes, as appropriate, will retain responsibilities for WQS for waters within Indian country.

Implementation

The EPA is committed to protection of Montana's surface waters and will continue coordination with the Board and the MDEQ regarding implementation of the EC and SAR WQS. The EPA is aware that MDEQ is developing revised EC and SAR site-specific criteria for Otter Creek, a tributary to the Tongue River. The EPA's WQS regulations at 40 CFR section 131.11(b) allow states to establish numeric criteria to reflect site-specific conditions by modifying the EPA's 304(a) guidance or by using other scientifically defensible methods. Consistent with the EPA's regulations, criteria must protect the designated use and be based on sound scientific rationale, and be submitted to the EPA for review/action under CWA 303(c). Only after EPA approval are those criteria effective for CWA purposes and implementable in the other CWA programs. The EPA staff will continue to work with MDEQ on development of site-specific criteria for Otter Creek. If adopted, the EPA would take a separate action on the Otter Creek criteria pursuant to CWA Section 303(c).

Conclusion

The EPA commends Montana for developing WQS for EC and SAR to protect Montana's agricultural water supply use. Based on the EPA's extensive review of the 2003 and 2006 administrative records, the results of Montana's 2010/2011 triennial review, and current scientific literature, the EPA concludes the 2003 numeric criteria and 2006 nondegradation provision for EC and SAR are consistent with Clean Water Act (CWA) Section 303(c) and the implementing federal WQS regulation at 40 C.F.R. Part 131 and approves ARM 17.30.602(7) and (25) and ARM 17.30.670(2) – (6). If you have questions concerning this letter, please contact Tonya Fish on my staff at (303) 312–6832 or fish.tonya@epa.gov.

Sincerely,

Martin Hestmark,
Assistant Regional Administrator
Office of Ecosystems Protection
and Remediation

Enclosures

cc: Tom Livers, Director, Montana Department of Environmental Quality

The EPA's Rationale for Approval of Montana's Water Quality Standards for Electrical Conductivity and Sodium Adsorption Ratio

PURPOSE

The purpose of this enclosure is to explain in detail the U.S. Environmental Protection Agency's (EPA's) rationale for approval of Montana's water quality standards (WQS) for electrical conductivity (EC) and sodium adsorption ratio (SAR), which include definitions, numeric water quality criteria, and an antidegradation provision. This action applies to the Tongue River, Powder River, Little Powder River, and Rosebud Creek mainstems, tributaries, and other surface waters in these watersheds (TPR watersheds[1]) within the state of Montana.

EC AND SAR

EC is a measure of salinity or the amount of dissolved salts in water. SAR is a measure of sodicity and is a mathematical expression of the concentration of sodium relative to calcium and magnesium in water. High EC levels in the soil make plants exert more energy to extract water from the soil, decreasing crop production. EC also has an interactive effect with SAR that can affect soil physical properties. High SAR levels may cause soil swelling and dispersion in soils, plugging of soil pores, and surface crusting resulting in reduced soil permeability and crop yields. Appendix 1 to today's action letter describes EC and SAR and their relationship in more detail.

LEGAL CONTEXT

Under Clean Water Act (CWA) Section 303, the EPA must review and approve or disapprove state-adopted WQS. For water quality criteria, the EPA's review includes a determination of whether the state has adopted criteria that: (1) protect the designated use; and (2) are based on sound scientific rationale (i.e., appropriate technical and scientific data and analysis).[2] Economic and technological factors cannot be considered in the EPA's evaluation of whether criteria protect the designated use. For antidegradation provisions, the EPA's review is limited to ensuring that such methods are consistent with the EPA's regulation[3] and do not undermine the intent of the state's antidegradation policy.

DEFINITIONS

Montana revised ARM 17.30.602 to include the following definitions:

"Electrical conductivity (EC)" means the ability of water to conduct an electrical current at 25°C. The electrical conductivity of water represents the amount of total dissolved solids in the water and is expressed as microSiemens/centimeter (µS/cm) or micromhos/centimeter (µmhos/cm) or equivalent units and is corrected to 25°C.

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[1] "TPR watersheds" refers to all of the Tongue and Powder River, and Rosebud Creek waters in Montana to which the WQS for EC and SAR apply.
[2] 40 C.F.R. § 131.5(a)(7) and § 131.11(a)(1)
[3] 40 C.F.R. § 131.12

"Sodium adsorption ratio (SAR)" means a value representing the relative amount of sodium ions to the combined amount of calcium and magnesium ions in water using the following formula: SAR = [Na]/(([Ca]+[Mg])/2)½, where all concentrations are expressed as milliequivalents of charge per liter.

These definitions mandate how the criteria will be expressed and are consistent with the definitions of these terms in the scientific literature (see Appendix 1, Background section). Therefore, the EPA approves these definitions[4] consistent with the requirements of the CWA and EPA's implementing regulation at 40 CFR Section 131.11.

APPLICABILITY AND SUMMARY OF MONTANA'S NUMERIC CRITERIA FOR EC AND SAR

Montana's EC and SAR criteria are not statewide criteria – they are site-specific criteria that apply to the TPR watersheds within the state of Montana. The TPR watersheds are located in the southeast corner of Montana (see Figure 1) and flow northeast and confluence with the Yellowstone River in Montana. Montana's EC and SAR monthly average and instantaneous maxima criteria (ARM 17.30.670(2) through (5)) vary by waterbody and irrigation season, and are summarized in Table 1.

> 17.30.670 NUMERIC STANDARDS FOR ELECTRICAL CONDUCTIVITY (EC) AND SODIUM ADSORPTION RATIO (SAR)
> (2) The numeric standards for electrical conductivity (EC) and sodium adsorption ratio (SAR) for the mainstems of Rosebud Creek, the Tongue, Powder, and Little Powder rivers from November 1 through March 1 are as follows:
> (a) for Rosebud Creek and the Tongue River, the monthly average numeric water quality standard for EC is 1500 µS/cm and no sample may exceed an EC value of 2500 µS/cm. The monthly average numeric water quality standard for SAR is 5.0 and no sample may exceed an SAR value of 7.5; and
> (b) for the Powder River and the Little Powder River, the monthly average numeric water quality standard for EC is 2500 µS/cm and no sample may exceed an EC value of 2500 µS/cm. The monthly average numeric water quality standard for SAR is 6.5 and no sample may exceed an SAR value of 9.75.
> (3) The numeric standards for EC and SAR for the mainstems of Rosebud Creek, the Tongue, Powder, and Little Powder rivers from March 2 through October 31 are as follows:
> (a) for Rosebud Creek and the Tongue River, the monthly average numeric water quality standard for EC is 1000 µS/cm and no sample may exceed an EC value of 1500 µS/cm. The monthly average numeric water quality standard for SAR is 3.0 and no sample may exceed an SAR value of 4.5; and
> (b) for the Powder River and Little Powder River, the monthly average numeric water quality standard for EC is 2000 µS/cm and no sample may exceed an EC value of 2500 µS/cm. The monthly average numeric water quality standard for SAR is 5.0 and no sample may exceed an SAR value of 7.5.
> (4) For all tributaries and other surface waters in the Rosebud Creek, Tongue, Powder, and Little Powder river watersheds, the monthly average numeric water quality standard for EC is 500 µS/cm and no sample may exceed an EC value of 500 µS/cm. The monthly average numeric water quality standard for SAR from March 2 through October 31 is 3.0 and no sample may exceed an SAR value of 4.5. The monthly average numeric water

[4] Currently numbered ARM 17.30.602(7) and (25), respectively.

quality standard for SAR from November 1 through March 1 is 5.0 and no sample may exceed an SAR value of 7.5.
(5) For the Tongue River Reservoir, the monthly average numeric water quality standard for EC is 1000 μS/cm and no sample may exceed an EC value of 1500 μS/cm. The monthly average numeric water quality standard for SAR is 3.0 and no sample may exceed an SAR value of 4.5.

Waterbody	Irrigation Season (3/2 - 10/31)				Non-Irrigation Season (11/1 - 3/1)			
	EC (ave)	EC (max)	SAR (ave)	SAR (max)	EC (ave)	EC (max)	SAR (ave)	SAR (max)
Rosebud Creek	1000	1500	3.0	4.5	1500	2500	5.0	7.5
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
Tongue River Reservoir	1000	1500	3.0	4.5	1000	1500	3.0	4.5
Tributaries	500	500	3.0	4.5	500	500	5.0	7.5

Table 1. Summary of Montana's adopted numeric criteria for EC (μS/cm) and SAR

EPA ANALYSIS OF THE NUMERIC CRITERIA[5]

Montana adopted numeric criteria for EC and SAR to protect the agricultural water supply use of the TPR watersheds. The EPA must determine whether the state has adopted criteria that: (1) protect the designated use; and (2) are based on sound scientific rationale.[6] Montana's WQS do not define "agricultural water supply," therefore, the EPA evaluated Montana's numeric criteria against this broad designated use, including use of surface waters (lakes and streams) for irrigating a range of crops and soils that vary in their sensitivity to EC and SAR and livestock water supply. Based on the EPA's review of the scientific literature (Appendix 1), irrigated agriculture is more sensitive than livestock to the effects of EC. SAR is not a parameter that is used in research on water quality effects on livestock, therefore the EPA cannot make comparisons between the sensitivity of irrigated agriculture to SAR and the sensitivity of livestock to SAR based on the current scientific literature. Therefore, the EPA's analysis below focuses on the scientific literature related to irrigated agriculture.

Montana's *A Review of the Rationale for EC and SAR Standards*[7] (Montana's Rationale) summarizes the state's consideration of site-specific variables such as crop salt tolerance, irrigation methods, leaching fraction, soil solution salinity, and soil types. In addition to Montana's Rationale, the EPA considered, among other information, the entire 2003 administrative record, the results of Montana's 2010/2011 triennial review (which includes Montana's Rationale), over 12 years of additional scientific literature relevant to the evaluation of numeric criteria for EC and SAR (Appendix 1), and Dr. Suarez's technical

[5] Complete citations for the references discussed in this section can be found in the References of Appendix 1.
[6] 40 C.F.R. § 131.5(a)(2) and 40 C.F.R. § 131.11(a)(1)
[7] See http://deq.mt.gov/CoalBedMethane/finaleis.mcpx.

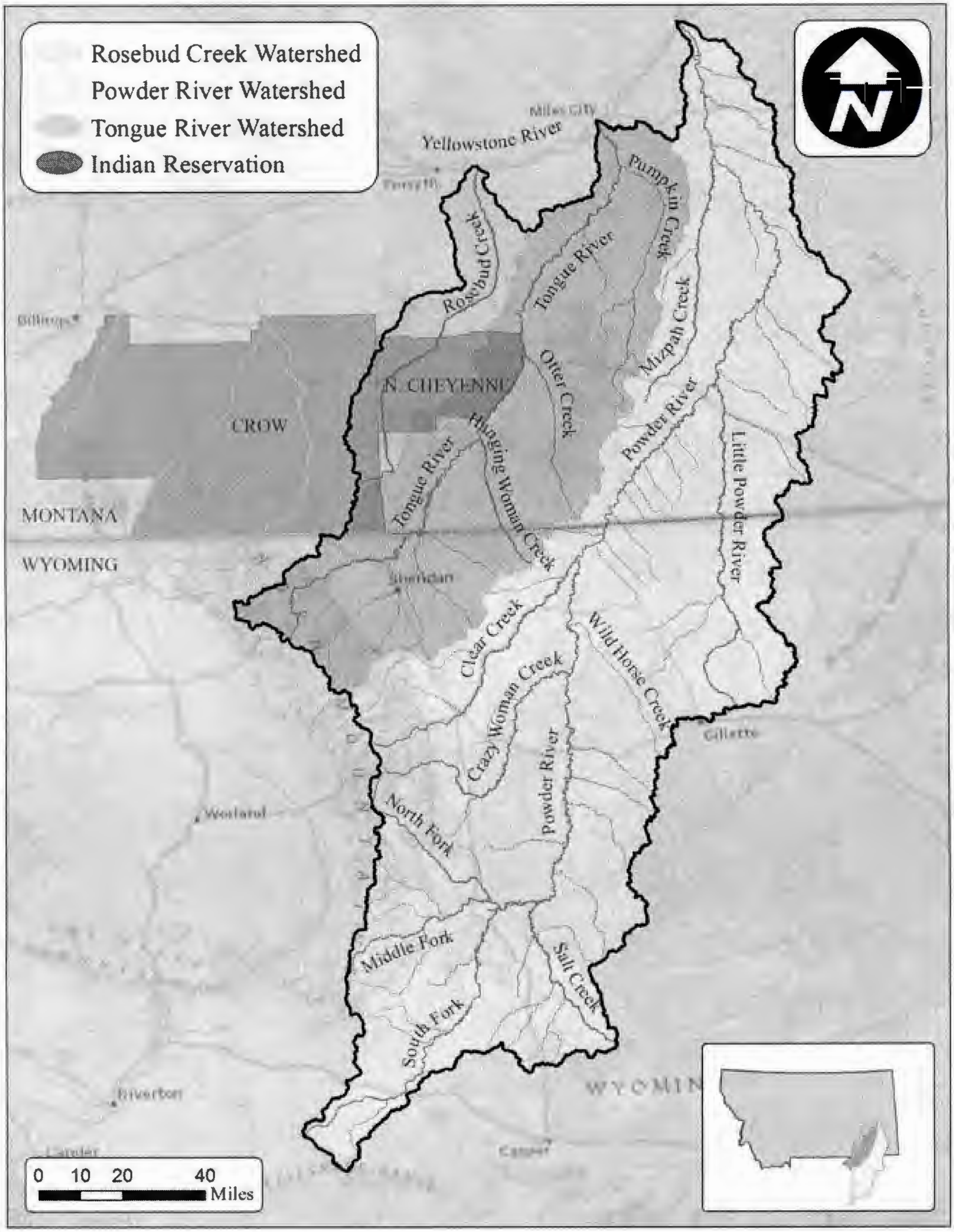

Figure 1. Map of the TPR Watersheds in Montana

analysis of Montana's Rationale (Appendix 2). Following is a summary of the EPA's inquiry, analysis and reasoning for today's action.

EC Monthly Average Criteria

Montana's monthly average EC criteria range from 500 – 2000 μS/cm during the irrigation season, and up to 2500 μS/cm during the non-irrigation season (see Table 1). The EPA evaluated these criteria against the available national/international guidelines and scientific literature (see Appendix 1 and discussion below).

The national/international guidelines discussed below represent a wide range of agricultural crops, soils, and experimental methods. The assumptions of these guidelines can make them over- or under-protective when applied site-specifically. Therefore, the guidelines are a good first step in evaluating water quality for irrigation, but should be considered in combination with local research and field experience whenever possible.

The Food and Agricultural Organization of the United Nations (Ayers and Westcot 1985) guidelines for water quality for agriculture are recommended by USDA's Natural Resources Conservation Service, state university Extension Services, the Western Fertilizer Handbook, standard textbooks, and widely used internationally (see Appendix 1). Table 2 summarizes the salinity guidelines for water quality for irrigation.

	Use Restriction		
	None	**Slight to Moderate**	**Severe**
EC (μS/cm)	< 700	700 – 3000	> 3000

Table 2. Salinity guidelines for water quality for irrigation (adapted from Ayers and Westcot 1985)

Based on Table 2, EC less than 700 μS/cm has no use restriction (i.e., protects full production capability of all crops without use of special practices). In the range of 700 – 3000 μS/cm, there is slight to moderate use restriction, meaning that increasing care in selection of crop and management practices is required to achieve full yield potential. For EC greater than 3000 μS/cm, there is severe use restriction. These guidelines indicate that Montana's monthly average EC criteria of 500 μS/cm have no use restriction (Montana's tributary criteria), and Montana's monthly average criteria of 1000, 1500, 2000, and 2500 μS/cm have slight to moderate use restriction.

The EPA also considered whether Montana's criteria protect the crops the state intended to protect based on the 2003 administrative record. Plant salt tolerance varies by crop type, variety, and growth stage (see Appendix 1). Mass and Hoffman (1977) conducted an extensive literature review and compiled salt tolerance data for over 70 crops. They created a crop salt tolerance table that included a threshold above which there is yield loss, as compared to yields under nonsaline conditions, and a slope describing the percentage of expected yield reduction per unit increase in salinity above the threshold. These salt tolerance tables have been adapted over the years, and are still widely used today. Montana conducted irrigator surveys[8] to identify crops grown in the TPR watersheds and considered the salt tolerance thresholds for those crops in selecting the EC monthly average criteria. For the crops Montana identified

[8] E.g., AR01010 – 01452.

in its 2002 Technical Basis,[9] below is a summary of the crop tolerance and yield potential as influenced by irrigation water salinity (EC_{iw}).

Crop	100% Yield EC_{iw}	90% Yield EC_{iw}	75% Yield EC_{iw}	50% Yield EC_{iw}
Strawberry	700	900	1200	1700
Field beans	700	1000	1500	2400
Carrots	700	1100	1900	3000
Radish	800	1300	2100	3400
Onions	800	1200	1800	2900
Lettuce	900	1400	2100	3400
Clover	1000	1600	2400	3800
Orchard grass	1000	2100	3700	6400
Corn	1100	1700	2500	3900
Alfalfa	1300	2200	3600	5900

Table 3. Estimated crop tolerance and yield potential of Montana's selected crops as influenced by irrigation water salinity (EC_{iw} in µS/cm) (adapted from Ayers and Westcot 1985, adapted from Maas and Hoffman 1977 and Maas 1984)

Table 3 estimates that Montana's monthly average EC criteria of:

- 500 µS/cm protect all target crops at 100% yield (tributary criteria, irrigation and non-irrigation season);
- 1000 µS/cm protect clover, orchard grass, corn, and alfalfa at 100% yield, and all other crops except strawberry at 90% yield (Rosebud Creek, Tongue River, and Tongue River Reservoir irrigation season criteria);
- 1500 µS/cm protect clover, orchard grass, corn, and alfalfa at 90% yield, and all other crops except strawberry at 75% yield (Rosebud Creek and Tongue River non-irrigation season criteria);
- 2000 µS/cm protect orchard grass and alfalfa at 90% yield, and radish, lettuce, clover, and corn at 75% yield, and all other crops except strawberry at 50% yield (Powder and Little Powder River irrigation season criteria); and
- 2500 µS/cm protect orchard grass, corn, and alfalfa at 75% yield, and all other crops except strawberry and field beans at 50% yield (Powder and Little Powder River non-irrigation season criteria).

The 2003 administrative record demonstrates that Montana's intent was to protect the more sensitive crops on Rosebud Creek, the Tongue River, and Tongue River Reservoir, whereas the target crop on the Powder River and Little Powder River was alfalfa. Even at 2500 µS/cm during the non-irrigation season, the estimated yield for alfalfa is closer to 90% (2200 µS/cm) than 75% (3600 µS/cm). Table 3 estimates 90 – 100% yield for the target crops except strawberry, which is slightly less than 90%, during the irrigation season, and 75 – 90% yield for the target crops except strawberry, which is between 50% and 75% yield, during the non-irrigation season. Therefore, Table 3 indicates the EC monthly average criteria protect Montana's target crops, although at varied yield potentials, and Montana's agricultural water supply use.

[9] See AR00234, also summarized in Montana's Rationale (page 4).

Similar to Montana's consideration of the crops grown in the TPR watersheds described above, Montana also considered the species of riparian plants in the TPR watersheds and their sensitivities to EC (see Montana's Rationale, page 9). Montana concluded, and the EPA agrees, that the non-irrigation season monthly average EC criteria are protective of riparian plants in the TPR watersheds.

In addition to the information above, the EPA considered the interactive effects of EC with SAR on soil physical properties. As discussed in Appendix 1, the salinity of the irrigation or rain affects how a soil responds to sodicity. Elevated salinity has a flocculating effect on soil, meaning the soil clumps together in aggregates, which facilitates water movement through soil pores. Elevated sodicity has a dispersive effect on soil, meaning soil particles detach and aggregates break apart, which can result in plugging of soil pores and surface crusting, thereby reducing soil permeability and crop yields. Therefore, the adverse impacts of sodicity may be reduced with increasing salinity.

The following studies are particularly relevant to the evaluation of Montana's EC monthly average criteria. Mace and Amrhein (2001) treated California clay loam soil with water of SAR 1, 3, 5, and 8, and EC 0, 250, 500, 1000, 2500, and 10,000 µS/cm. They found no significant reductions in hydraulic conductivity[10] below EC 2500 µS/cm and no significant differences in clay dispersion between EC 500 and 2500 µS/cm. This indicates that in the range of Montana's SAR criteria, that EC monthly average criteria of 500 – 2500 µS/cm are protective of an agricultural water supply use. In addition, Suarez et al. 2006 and 2008 tested Montana soils from the Tongue River and Powder River watersheds and found no difference in infiltration rate[11] between EC 1000 and 2000 µS/cm (see Appendix 1 and the discussion in SAR section below for more details).

In summary, the EPA reviewed the available national/international guidelines and scientific literature on salinity effects on plants and the interactive effects of EC with SAR on soil physical properties, and local research and information relevant to the TPR watersheds in Montana. The EPA agrees with Dr. Suarez's conclusion that Montana's EC monthly average criteria "are in line with the bulk of the scientific literature on the subject and with the current consensus of experts in this area of research" (Appendix 2). The EPA approves the EC monthly average criteria in ARM 17.30.670(2) – (5) because they protect Montana's agricultural water supply use and are based on a sound scientific rationale consistent with the requirements of the CWA and EPA's implementing regulation at 40 CFR Section 131.11.

EC Instantaneous Maxima Criteria

Montana's instantaneous maxima EC criteria range from 500 – 2500 µS/cm during the irrigation and non-irrigation season (see Table 1). The EPA evaluated these criteria against the available national/international guidelines and scientific literature (see Appendix 1 and discussion below).

Salt tolerance experiments generally focus on growing-season average exposures to established crops at different salinity levels, as opposed to impacts from single event exposures to high salinities. Most studies examine growing-season length salinity effects (or lethality, whichever comes first), and present results occurring across the entire growing season. Therefore, single event salinity exposures are not generally reported in the literature. For example, the scientific literature currently does not quantify the

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[10] The ability of soil to conduct water through the soil profile.
[11] Infiltration is the movement of rain or irrigation water on the soil surface into the upper layer of soil (Gardiner and Miller 2008). Infiltration rate is the volume of water entering a specified cross-sectional area of soil per unit time (Soil Science Society of America 2008).

effects of a single event exposure of 2500 μS/cm water on crops. Therefore, the EPA used the available guidelines and scientific literature on growing-season average exposures to evaluate Montana's instantaneous maxima criteria.

The Ayers and Westcot guidelines (Table 2) indicate that Montana's instantaneous maxima EC criteria of 500 μS/cm have no use restriction (Montana's tributary criteria), and Montana's instantaneous maxima EC criteria of 1500 and 2500 μS/cm have slight to moderate use restriction.
Table 3 estimates that Montana's instantaneous maxima EC criteria of:

- 500 μS/cm protect all target crops at 100% yield (tributary criteria for the irrigation and non-irrigation season);
- 1500 μS/cm protect clover, orchard grass, corn, and alfalfa at 90% yield, and all other crops except strawberry at 75% yield (Rosebud Creek and Tongue River criteria for the irrigation season, and Tongue River Reservoir criteria for the irrigation and non-irrigation season); and
- 2500 μS/cm protect orchard grass, corn, and alfalfa at 75% yield, and all other crops except strawberry and field beans at 50% yield (Powder and Little Powder criteria for the irrigation season, Rosebud Creek, Tongue River, Powder River, and Little Powder River criteria for the non-irrigation season).

The EPA also considered local research and information relevant to the TPR watersheds in Montana. The Mace and Amrhein (2001) study discussed above indicates that instantaneous maxima EC criteria of 500 – 2500 μS/cm are protective of an agricultural water supply use in the range of Montana's SAR criteria. Likewise, the results of Suarez et al. 2006 and 2008 found no difference in infiltration rate between EC 1000 and 2000 μS/cm (see Appendix 1 and the discussion in SAR section below for more details).

In summary, the EPA reviewed the available national/international guidelines, scientific literature on salinity effects on plants, and local research and information relevant to the TPR watersheds in Montana. The scientific literature indicates that EC 500 – 2500 μS/cm is protective of growing-season average exposures, therefore this EC range is also protective of a single-event exposure. Montana's EC maxima criteria protect crops from these short-term exposures and provide a margin of safety appropriate for an area of scientific uncertainty. In addition, the maxima criteria function as an upper limit on short-term high EC levels that could otherwise be averaged out over multiple samples during a month. The EPA approves the EC instantaneous maxima criteria in ARM 17.30.670(2) – (5) because they protect Montana's agricultural water supply use and are based on a sound scientific rationale consistent with the requirements of the CWA and EPA's implementing regulation at 40 CFR Section 131.11.

SAR Monthly Average Criteria

Montana's monthly average SAR criteria range from 3 – 5.0 during the irrigation season, and up to 6.5 during the non-irrigation season (see Table 1). The EPA evaluated these criteria against the available national/international guidelines and scientific literature (see Appendix 1 and discussion below).

The national/international guidelines discussed below represent a wide range of soils and experimental methods. The assumptions of these guidelines can make them over- or under-protective when applied site-specifically. Therefore, the guidelines are a good first step in evaluating water quality for irrigation, but should be considered in combination with local research and field experience whenever possible.

The Ayers and Westcot guidelines for evaluating irrigation water quality for soil infiltration problems are summarized below (Table 4). No restriction on use is defined as full production capability for all soils without use of special practices. Restriction on use indicates special soil management practices are necessary to maintain full production.

SAR	Use Restriction (EC in µS/cm)		
	None	Slight to Moderate	Severe
0-3	> 700	200 – 700	< 200
3-6	> 1200	300 – 1200	< 300
6-12	> 1900	500 – 1900	< 500
12-20	> 2900	1300 – 2900	< 1300
20-40	> 5000	2900 – 5000	< 2900

Table 4. Soil infiltration guidelines for water quality for irrigation (adapted from Ayers and Westcot 1985)

These guidelines indicate that Montana's monthly average SAR criteria of:

- 3.0 have no use restriction if EC > 700 µS/cm (Rosebud Creek and the Tongue River during the irrigation season, and for the Tongue River Reservoir during the irrigation and non-irrigation season with an EC monthly average of up to 1000 µS/cm);
- 3.0 have slight to moderate use restriction if EC 200 – 700 µS/cm (tributaries with an EC monthly average of up to 500 µS/cm during the irrigation season);
- 5.0 have no use restriction if EC > 1200 µS/cm (Powder River and Little Powder River during the irrigation season with an EC monthly average of up to 2000 µS/cm, and Rosebud Creek and the Tongue River during the non-irrigation season with EC monthly average of up to 1500 µS/cm);
- 5.0 have slight to moderate use restriction if EC 300 – 1200 µS/cm (tributaries with an EC monthly average of up to 500 µS/cm during the non-irrigation season);
- 6.5 have no use restriction if EC > 1900 µS/cm (Powder and Little Powder during the non-irrigation season with an EC monthly average of up to 2500 µS/cm).

Based on Table 4, the monthly average SAR criteria protect Montana's agricultural water supply use, including the soils in the TPR watersheds (see Montana's Rationale, page 10 – 11), however the level of protection will vary based on the combination of SAR and EC in each soil.

Similar to Montana's consideration of the soils in the TPR watersheds, Montana also considered the levels of SAR necessary to protect against adverse impacts to riparian soils (see Montana's Rationale, page 13 – 14). Montana concluded, and the EPA agrees, that the non-irrigation season monthly average SAR criteria are protective of riparian soils in the TPR watersheds.

The Ayers and Westcot guidelines (Table 4) only considered the effects of irrigation water (i.e., did not consider the effects of rain). As discussed in the EC section above, in addition to the national/ international guidelines, the EPA considered the scientific literature on the interactive effects of EC with SAR on soil physical properties. Montana crops are exposed to irrigation and rain during the cropping season. The only experiment on soil response to EC and SAR in a combined rain and irrigation system with surface wetting and drying used Montana soils from the Tongue River and Powder River watersheds and was conducted by Dr. Suarez of the USDA Salinity Laboratory and funded by the EPA. The results were published by Suarez et al. in 2006 and 2008. Uncropped clay and loam soils were flood irrigated with SAR 2, 4, 6, 8, 10 and EC 1000 and 2000 µS/cm, with alternating rain and irrigation and drying between irrigations. For the loam soil, during the last rain event the infiltration rate decreased above SAR 2 for both EC 1000 and 2000 µS/cm, with the largest decrease between SAR 4 and 6. For the clay soil, the infiltration rate generally decreased above SAR 2 for both EC 1000 and 2000 µS/cm, with the largest decrease (about 30%) between SAR 2 and 4 (Suarez et al. 2006). The results of this experiment suggest that certain Montana soils exposed to irrigation and rain during the cropping season may experience reduced infiltration above SAR 2, and that the Ayers and Westcot guidelines may underestimate sodicity hazards experienced under Montana field conditions.

The most recent scientific guidelines on infiltration effects of EC and SAR were published in 2012 by Dr. Suarez based on the results of the experiments described above and others at the USDA Salinity Lab (Figure 2). These guidelines indicate a > 25% reduction in infiltration above about SAR 2 at EC 1000 µS/cm and above SAR 5 regardless of EC. However, a 25% loss in infiltration in a well-drained sandy-loam soil may have little effect on crop production, whereas the same infiltration reduction in a poorly-drained clay soil could significantly affect crop yield. SAR > 10 is not protective of most soils when irrigating in the presence of rain.

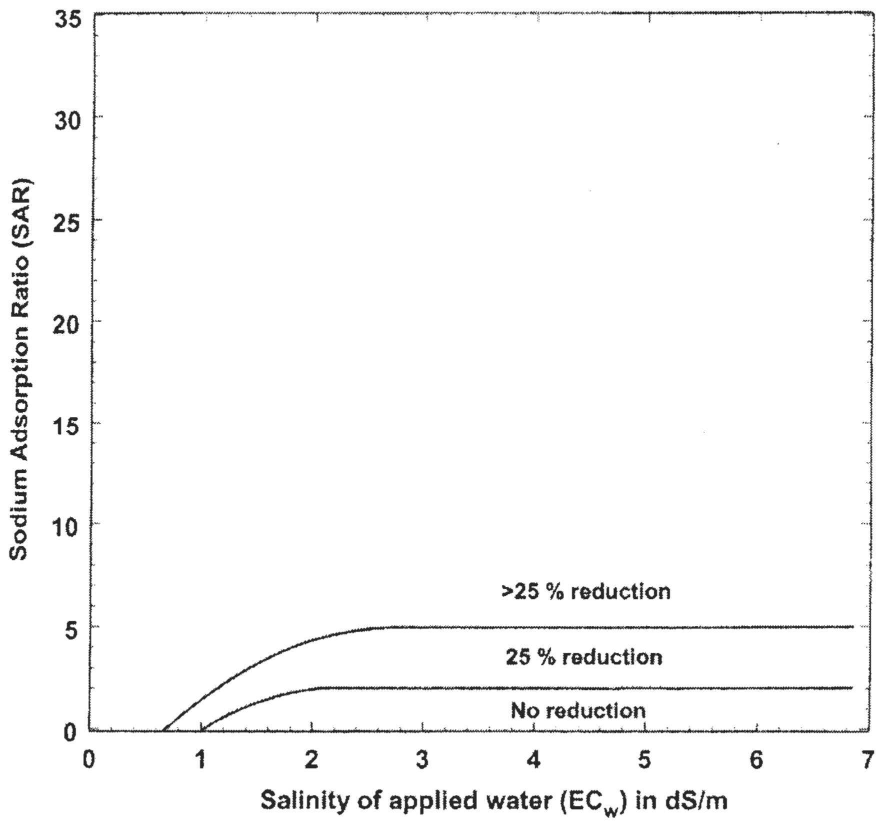

Figure 2. Relationship between SAR and EC at which 25% reduction in infiltration is expected when irrigating in the presence of rain (Suarez 2012, p. 357)

In summary, the EPA reviewed the available national/international guidelines and scientific literature on sodicity effects on soil and the interactive effects of EC with SAR on soil physical properties, and local research and information relevant to the TPR watersheds in Montana. Montana's monthly average SAR criteria ranging from 3 – 5.0 during the irrigation season, and up to 6.5 during the non-irrigation season are protective of Montana's agricultural water supply use. Within this range, some of Montana's soils may experience > 25% reduction in infiltration based on Figure 2, however, as discussed above, a 25% loss in infiltration may or may not effect crop production depending on the soil. The EPA agrees with

Dr. Suarez's conclusion that Montana's SAR monthly average criteria "are in line with the bulk of the scientific literature on the subject and with the current consensus of experts in this area of research" (Appendix 2).The EPA approves the SAR monthly average criteria in ARM 17.30.670(2) – (5) because they protect Montana's agricultural water supply use and are based on a sound scientific rationale consistent with the requirements of the CWA and EPA's implementing regulation at 40 CFR Section 131.11.

SAR Instantaneous Maxima Criteria

Montana's instantaneous maxima SAR criteria range from 4.5 – 7.5 during the irrigation season, and up to 9.75 during the non-irrigation season (see Table 1). The EPA evaluated these criteria against the available national/international guidelines and scientific literature (see Appendix 1 and discussion below).

Studies on the impacts of SAR or different combinations of EC and SAR focus on short-term exposures, typically from days to weeks. While the duration of experimental SAR exposures varies,[12] many SAR exposure studies are carried out until a soil reaches some initial stabilization with the SAR level of the irrigation water, or stepwise through a series of higher SAR levels. Therefore, neither single event exposures nor growing-season exposures are typically reported in the literature. In other words, the scientific literature currently does not quantify the effects of a single event exposure of high SAR water on soils, or the effects of high SAR on soils over a growing-season. Therefore, the EPA used the available guidelines and scientific literature on short-term exposures to evaluate the SAR instantaneous maxima criteria.

The Ayers and Westcot guidelines (Table 4) indicate that Montana's SAR criteria of:

- 4.5 have slight to moderate use restriction if EC 300 – 1200 μS/cm (Rosebud Creek and the Tongue River criteria during the irrigation season, Tongue River Reservoir during the irrigation and non-irrigation season with an EC monthly average of up to 1000 μS/cm, and tributaries during the irrigation season with EC of 500 μS/cm);
- 7.5 have no use restriction if EC > 1900 μS/cm (Powder River and Little Powder River during the irrigation season with an EC monthly average of up to 2000 μS/cm);
- 7.5 have slight to moderate use restriction if EC 500 – 1900 μS/cm (Rosebud Creek and the Tongue River criteria during the non-irrigation season with EC of 1500 μS/cm, and the tributaries during the non-irrigation season with EC of 500 μS/cm); and
- 9.75 have no use restriction if EC > 1900 μS/cm (Powder River and Little Powder River during the non-irrigation season with EC of 2500 μS/cm).

Based on Table 4, the SAR maxima criteria protect Montana's agricultural water supply use, however the risk will vary based on the combination of SAR and EC in a waterbody. In general, the greatest risk of detrimental effects occurs when SAR is in combination with EC < 500 μS/cm. Laboratory studies have found impacts on soil physical properties even in the SAR 1– 6 range when EC is 500 μS/cm or less (see Appendix 1). The EPA did not find any Montana studies that addressed the combination of SAR 1– 6 when EC is 500 μS/cm or less, however Montana's 2003 response to comments includes anecdotal evidence that "long-term irrigation of comparable soils in the Yellowstone Valley using water with an EC less than 500 μS/cm and a SAR of 2 has not caused noticeable damage to soils" (AR00954).

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[12] For example, Oster and Schroer (1979) exposed soils for 19 months, while Quirk and Schofield (1955) measured results after 12-hour exposures.

The guidelines in Figure 2 predict a > 25% reduction in infiltration when irrigating in the presence of rain for Montana's SAR instantaneous maxima criteria of 4.5 at EC 500 – 1000 μS/cm, SAR 7.5 at EC 500 – 2000 μS/cm, and SAR 9.75 at EC 2500 μS/cm. However, infiltration effects will vary based on the combination of SAR and EC in a waterbody. In addition, a 25% loss in infiltration in a well-drained sandy-loam soil may have little effect on crop production, whereas the same infiltration reduction in a poorly-drained clay soil could significantly affect crop yield.

In summary, the EPA reviewed the available national/international guidelines and scientific literature on sodicity effects on soil and the interactive effects of EC with SAR on soil physical properties, and local research and information relevant to the TPR watersheds in Montana. Montana's SAR instantaneous maxima criteria are protective of Montana's agricultural water supply use, but are in the range of SAR for which risk of reduced infiltration is > 25% and may not protect all soils. As discussed above and in Appendix 1, the effect of a 25% reduction in infiltration will vary among soils. Statistically, the maxima criteria function as an upper limit on short-term high SAR levels that could otherwise be averaged out over multiple samples during a month. The EPA approves the SAR instantaneous maxima criteria in ARM 17.30.670(2) – (5) because they protect Montana's agricultural water supply use and are based on a sound scientific rationale consistent with the requirements of the CWA and EPA's implementing regulation at 40 CFR Section 131.11.

AQUATIC LIFE

Since Montana adopted its EC and SAR criteria for protection of the agricultural water supply use in the TPR watersheds, the scientific literature related to salinity effects on aquatic life has grown significantly. The EPA is currently working to develop a draft recommended field-based method for states to develop ambient aquatic life water quality criteria for specific conductivity. The field-based method will allow states to develop science-based conductivity criteria that appropriately reflect ecoregional- or state-specific factors such as background conductivity and ionic and aquatic community composition. The draft method recently underwent independent external peer review. The EPA plans to release the draft method for public comment in early 2016. The EPA encourages Montana to consider the new methodology as the science related to conductivity and aquatic life protection evolves.

ANTIDEGRADATION (NONDEGRADATION)

The federal antidegradation policy establishes three levels (tiers) of water quality protection: Tier 1 protects existing uses and the level of water quality necessary to protect those uses; Tier 2 protects high quality waters unless a lowering of water quality is deemed necessary through a public process in order to allow important economic or social development; and Tier 3 protects outstanding national resource waters (ONRW) of exceptional recreational or ecological significance. Today's action addresses Montana's approach to Tier 2 waters. In August 2015, the EPA finalized revisions to its WQS regulations at Part 131, including revisions to the antidegradation requirements at 40 CFR 131.12.[13] The current regulation, effective on October 20, 2015, requires states and authorized tribes to develop and adopt an antidegradation policy and to develop implementation methods for the policy that are consistent with §131.12(a). The revisions did not alter the three levels of water quality protection but added more specific requirements pertaining to the identification of high quality waters, and an analysis of alternatives when determining if a lowering of water quality is necessary when protecting Tier 2 waters. The EPA notes that Montana's WQS were submitted to the EPA before the effective date of the

[13] See 80 Fed. Reg. 51,020, 51,029 (August 21, 2015), available at http://water.epa.gov/lawsregs/lawsguidance/wqs_index.cfm.

EPA's final rule, and, therefore, fall within the transition period during which the EPA reviewed them for consistency with the regulations in effect prior to the final rule.[14]

Montana's antidegradation (nondegradation is the term used by Montana) policy is in state statute (MCA 75-5-303) and was approved by the EPA in January 1999. Montana's antidegradation implementation methods are in regulation at ARM 17.30.701-718 and were also approved by the EPA in January 1999. Montana's nondegradation policy applies to all state waters and, consistent with 40 CFR § 131.12, protects existing uses (Tier 1), *at a minimum*. Whether specific waterbodies are afforded additional protections under Tier 2 is determined by the state's implementation methods, specifically ARM 17.30.715.

The WQS regulation does not specify how to identify Tier 2 waters, so states and tribes have developed different approaches. Montana implements a parameter-by-parameter approach,[15] so the state does not identify specific water bodies for Tier 2 protection until a regulated activity, such as a Montana Pollutant Discharge Elimination System permit, proposes to degrade water quality. Therefore, Montana waters are not pre-designated for Tier 2 protection, and a water body with a proposed activity could be, for example, Tier 2 for EC and Tier 1 for SAR. Montana's WQS establish the process by which the state will determine whether a proposed activity that would lower water quality is subject to Tier 2 review and for which water quality parameters.

In addition, some states use significance thresholds to focus Tier 2 reviews on those activities that will result in significant degradation.[16] In its August 10, 2005 Memorandum from Office of Science and Technology Director, Ephraim S. King,[17] the EPA recognizes states' and tribes' flexibility to identify significance thresholds below which lowering of water quality would be considered 'insignificant' and for which a state will not conduct further Tier 2 antidegradation findings of necessity and social and economic importance.[18] Most states structure significance tests to identify specific activities that would cause significant water quality changes, and therefore trigger Tier 2 review. However, Montana's regulation is structured to identify activities that will result in *nonsignificant* changes in water quality (ARM 17.30.715). Therefore, if an activity meets all of the criteria listed, it is nonsignificant and would not require Tier 2 review.

In 2006,[19] Montana revised ARM 17.30.670(6) to designate EC and SAR as "harmful parameters" for nondegradation purposes: "EC and SAR are harmful parameters for the purposes of the Montana Water Quality Act, Title 75, chapter 5, MCA." This means the nonsignificance test for harmful parameters in ARM 17.30.715(f) applies to EC and SAR:

> 17.30.715 CRITERIA FOR DETERMINING NONSIGNIFICANT CHANGES IN WATER QUALITY (1) The following criteria will be used to determine whether certain activities or classes of activities will result in nonsignificant changes in existing water quality due to their low potential to affect human health or the environment. These criteria consider the quantity and strength of the pollutant, the length of time the changes

[14] See 80 Fed. Reg. 51,020, 51022 (August 21, 2015).

[15] For a detailed description of different state approaches, including the parameter-by-parameter approach, see 80 Fed. Reg. 51,020, 51,030 (August 21, 2015).

[16] See 63 Fed. Reg. 36,742, 36,783 (July 7, 1998).

[17] See http://www2.epa.gov/wqs-tech/reference-library-water-quality-standards-policy-and-guidance-documents.

[18] See, e.g., *Ky. Waterways Alliance v. Johnson*, 540 F. 3d 466, 483 (6th Cir. 2008) and *Ohio Valley Envtl. Coal. v. Horinko*, 279 F. Supp. 2d 732 (S.D. W.Va. 2003).

[19] The EPA is not acting on the 2003 antidegradation provision because that was superseded by the 2006 provision.

> will occur, and the character of the pollutant. Except as provided in (2), changes in existing surface or ground water quality resulting from the activities that meet all the criteria listed below are nonsignificant, and are not required to undergo review under 75-5-303, MCA:
> (a)...
> (f) changes in the quality of water for any harmful parameter, and parameters listed in Department Circular DEQ-12A, except as specified in (1)(g), for which water quality standards have been adopted other than carcinogenic, bioconcentrating, or toxic parameters, in either surface or ground water, if the changes outside of a mixing zone designated by the department are less than ten percent of the applicable standard and the existing water quality level is less than 40 percent of the standard;[20]

In order to understand what activities *would* trigger Tier 2 review, this test can be translated to: a proposed activity is <u>significant</u> if changes in ambient water quality for any harmful parameter outside of a mixing zone designated by MDEQ are <u>10 percent or more</u> of the numeric criterion <u>or</u> the ambient water quality is <u>40 percent or more</u> of the numeric criterion. Thus, a water body that meets one or both parts of this regulatory test would trigger Tier 2 review. For example, a proposed discharge to the Tongue River during the irrigation season would trigger Tier 2 review for EC if the proposed discharge would increase ambient EC 100 μS/cm or more (10% of 1,000 μS/cm), or if ambient EC is 400 μS/cm or more (40% of 1,000 μS/cm). If ambient quality for EC or SAR is at or above the numeric criterion, then the water body is not a high quality water for that parameter and the level of water quality necessary to protect the existing uses, which is generally the applicable criterion, would be protected under Tier 1 for that parameter.

As described in the EPA *Water Quality Standards Handbook*, "EPA's review of the implementation procedures is limited to ensuring that procedures are included that describe how the State will implement the required elements of the antidegradation review. EPA may disapprove and federally promulgate all or part of an implementation process for antidegradation if, in the judgment of the Administrator, the State's process (or certain provisions thereof) can be implemented in such a way as to circumvent the intent and purpose of the antidegradation policy."[21] The 2006 revision did not change the nonsignificance thresholds themselves, it simply changed which significance threshold applies to EC and SAR (i.e., the threshold for harmful parameters described above). This change does not circumvent the intent and purpose of Montana's previously-approved nondegradation policy. This change protects and maintains high quality waters where a proposed activity will result in significant changes in water quality for the parameters of EC and SAR, which is clearly consistent with the intent and purpose of Montana's nondegradation policy and 40 C.F.R. § 131.12. Accordingly, the EPA approves ARM 17.30.670(6).

As ordered to do so by the U.S. District Court in Wyoming, the EPA clarifies that the approval of ARM 17.30.670(6) does not approve classification of the Powder River and Little Powder River as Tier 2 for nondegradation purposes. As described above, Montana implements the parameter-by-parameter approach, therefore, specific water bodies are not pre-designated Tier 2. The EPA is approving the *process* (i.e., significance threshold) by which Montana will determine whether a proposed activity will result in significant changes in water quality for the parameters of EC and SAR. If the change in water quality is determined to be significant, then Tier 2 review is required for that parameter.

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[20] Note that Montana revised ARM 17.30.715(f) on July 25, 2014 to include the parameters listed in DEQ-12A. The EPA approved this revision on February 26, 2015.

[21] See http://www2.epa.gov/wqs-tech/water-quality-standards-handbook (Section 4.3).

PROVISIONS THE EPA IS NOT TAKING ACTION ON TODAY

The EPA is not acting on ARM 17.30.670(1) which states:

No person[22] may violate the numeric water quality standards or the criteria for determining nonsignificant changes in water quality identified in (2) through (6).

This provision is not a WQS requiring review and approval under CWA Section 303(c).[23]

[22] The EPA notes the term "person" is defined in MCA 75-5-103: "Person" means the state, a political subdivision of the state, institution, firm, corporation, partnership, individual, or other entity and includes persons resident in Canada.
[23] See the EPA's October 2012 *What is a New or Revised Water Quality Standard Under CWA 303(c)(3)? – Frequently Asked Questions* available at http://www2.epa.gov/wqs-tech/what-new-or-revised-water-quality-standard-under-cwa-303c3-frequently-asked-questions.

APPENDIX 1
TO THE EPA'S APPROVAL OF MONTANA'S WQS FOR EC AND SAR

LITERATURE REVIEW

PURPOSE AND SCOPE

The purpose of this document is to summarize the current scientific literature on electrical conductivity (EC) and sodium adsorption ratio (SAR) that is relevant to the U.S. Environmental Protection Agency's (EPA) review of numeric water quality criteria adopted by states and authorized tribes. Pursuant to the Clean Water Act (CWA) Section 303(c) and the EPA's Water Quality Standards Regulation,[1] the EPA must determine whether such numeric criteria protect the state or tribe's designated use and are based on sound scientific rationale. Specifically, this review focuses on EC and SAR numeric criteria adopted for the protection of an agricultural water supply designated use. States and tribes define agricultural designated uses in different ways. Some have a very broad agricultural water supply designated use, whereas others may further subcategorize an agricultural use into uses such as irrigated agriculture and livestock watering. This document will summarize the scientific literature relevant to protection of a broad agricultural water supply designated use, which includes use of surface waters (lakes and streams) for irrigated agriculture and livestock water supply. Such a broad use necessarily includes a spectrum of sensitivities for individual crops, soils, and livestock species. The EPA's review of numeric criteria considers how a state or tribe defines its agricultural designated use (e.g., whether target crops, soils, or livestock species are identified), and whether the criteria protect the used defined by the state or tribe.

Economic and technological factors cannot be considered in the EPA's evaluation of whether criteria protect the designated use. Therefore, the following topics are outside the scope of this literature review: treatment technologies and associated costs, effluent limitations, technologies and costs of remediation of saline and/or sodic soils, industrial water management options, and evaluations of whether industrial discharges negatively impact stream chemistry, designated uses, or water tables. In addition, because EC and SAR are the focus of this review, the toxicity of specific ions and trace elements is also outside the scope.

SUMMARY

For agricultural water supply uses, the most recent guidelines for salinity effects on plants indicate that EC less than 700 μS/cm is protective of most crops. However, laboratory studies indicate EC less than 500 μS/cm may not be protective of some soils. The range of EC 700 – 3000 μS/cm is protective of a general agricultural water supply use, but there is increased risk of detrimental effects as EC increases (e.g., reduced yields for field crops start above 700 μS/cm). Whether this range is protective of a state or tribe's designated use will depend on the target crops and desired yield. Greater than 3000 μS/cm is not protective of many crops. Part of the challenge for states and tribes in determining what level of EC is protective of their irrigated agriculture use is balancing the negative effect of increasing EC on plants and the positive effect of increasing EC on soil physical properties. For SAR, less than 2 is protective of most soils. The range of SAR 2 – 5 is protective of a general agricultural water supply use, but may not protect all soils. Within the range of SAR 5 – 10 there is increased risk of detrimental effects as SAR increases. Greater than SAR 10 is not protective of most soils, particularly when irrigating in the presence of rain.

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[1] 40 C.F.R. § 131.5(a)(2) and § 131.11(a)(1)

The guidelines and scientific literature indicate that irrigated crops are generally more sensitive to EC than livestock. EC is not recommended as the sole metric for evaluating water quality for livestock, but if other metrics are not available, the scientific literature indicates EC less than 3000 µS/cm protects a livestock water supply use. SAR is not a parameter that is used in research on water quality effects on livestock, therefore the EPA cannot make comparisons between the sensitivity of irrigated agriculture to SAR and the sensitivity of livestock to SAR based on the current scientific literature.

Many variables influence the EC and SAR level necessary to protect agricultural water supply uses. The EPA's action under CWA Section 303(c) on EC or SAR numeric criteria adopted by states or tribes will depend on site-specific considerations.

BACKGROUND

Electrical Conductivity

Salinity is the concentration of dissolved mineral salts, in water or soil (Gardiner and Miller 2008). Salt is any mineral composed of a cation (positively charged ion) and anion (negatively charged ion), not just table salt (NaCl). The major soluble salts are combinations of the cations sodium (Na^+), calcium (Ca^{2+}), or magnesium (Mg^{2+}), with the anions chloride (Cl^-), sulfate (SO_4^{2-}), and bicarbonate (HCO_3^-) (Gardiner and Miller 2008). Electrical conductivity (EC) is the ability of water to conduct electricity, and is used as a measure of salinity (Soil Science Society of America 2008, p. 18). The more dissolved salts there are in water, the better it will conduct electricity, and the higher the EC will be. In this literature review, "salinity" refers to the environmental property that is measured, and "EC" refers to the measurement and resulting data.

The primary source of salts in waters and soils is natural chemical weathering of rocks and soils. Anthropogenic sources include irrigation and drainage waters, soil and water amendments, waters from oil and gas production or mining, sewage sludge and effluent, runoff from treating icy pavements, and water diversions (U.S. EPA 2011,[2] Suarez and Jurinak 2012,Tanji and Wallender 2012). The U.S. Geological Survey reported that the total amount of dissolved solids delivered to the Nation's streams is 272 million metric tons annually, of which 71.4% come from geologic sources, 13.9% come from road deicers, 6.7% come from pasture lands, 5.1% come from urban lands, and 2.9% come from cultivated lands (Anning and Flynn 2014).[3]

The typical EC range varies by water type:

Water Type	EC (µS/cm)
Rain	2 - 100
Freshwater lakes/streams	2 - 100
Ground water	50 - 50,000
Ocean water	~ 50,000
Wetlands/bogs	50 - 50,000

Table 1. Typical EC range for some water field measurements (Sanders 1998, p. 294)

[2] Available at http://cfpub.epa.gov/ncea/CFM/recordisplay.cfm?deid=233809.
[3] Available at http://pubs.usgs.gov/sir/2014/5012/.

Under the International System of Units, "siemens" (symbol S) per meter is the unit of EC (American Public Health Association 1998).[4] The current agricultural literature usually reports data in decisiemens per meter (dS/m), but other units used in the scientific literature include siemens per meter (S/m), microsiemens per centimeter (µS/cm), millimhos per centimeter (mmhos/cm), and micromhos per centimeter (µmhos/cm). This review will use microsiemens per centimeter (µS/cm) because that is the units used by states and tribes that have adopted EC criteria currently under review by the EPA. Below are the conversions for the various units:

0.1 S/m = 1 dS/m = 1 mmhos/cm = 1000 µS/cm = 1000 µmhos/cm

EC can be measured in the field using relatively inexpensive conductivity meters, and the data are usually corrected to 25°C. The terms "specific conductance" and "conductivity" are often used synonymously[5] in the literature.

Total dissolved solids (TDS) is the portion of solids in a water sample that can pass through a 2.0 µm (or smaller) filter under specified conditions (American Public Health Association 1998). For example, under the American Public Health Association method 2540C, the filtrate is evaporated in a dish at 180°C and the increase in weight of the dish represents the TDS and is reported in mg/L. In contrast to using conductivity meters in the field, this procedure must be done in a laboratory and is comparatively expensive. Some sources also report TDS in parts per million (ppm), which is roughly equivalent to mg/L when TDS is less than 2000 mg/L.

For purposes of this literature review, where the original data are reported as TDS it is necessary to convert the data to EC in order to evaluate the relative sensitivities of irrigated agriculture and livestock water supply to EC. Agricultural literature generally estimates conductivity in dS/m by dividing TDS in mg/L by 640 (Tanji and Wallender 2012). Site specific data can also be used to establish a conversion factor. For simplicity, in this document TDS in mg/L is converted to µS/cm by dividing by 0.64, but the reader should recognize that this is an approximation and the relationship between EC and TDS will vary based on site-specific circumstances.

Sodium Adsorption Ratio

Whereas EC is a measure of the total cations and anions in a water, sodium adsorption[6] ratio (SAR) is a measure of only the cations sodium (Na^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}). SAR is a mathematical expression of the concentration of sodium relative to the amount of calcium and magnesium, and is used to measure sodicity -- a high ratio of exchangeable sodium in relation to other exchangeable cations (Rhoades 2012). SAR is defined as $Na / ((Ca + Mg)/2)^{1/2}$ where concentrations are expressed as milliequivalents per liter (meq/L) or millimoles of charge per liter ($mmoles_c$/L). Alternatively, if the cation measurements are expressed in millimoles per liter (mmol/L), SAR is defined as $Na / (Ca + Mg)^{1/2}$ (Lesch and Suarez 2009). The units of SAR are $(mmol/L)^{1/2}$ and are ignored in typical usage (Gardiner and Miller 2008). Determining SAR typically requires laboratory analysis of water samples to measure concentrations of calcium, magnesium, and sodium to calculate SAR. In this

[4] See also http://www.bipm.org/utils/common/pdf/si_brochure_8_en.pdf (page 118).
[5] Technically not equivalent, as conductivity (1/resistance) does not contain a length unit, and specific conductance (1/resistivity) does.
[6] Adsorption is "The process by which atoms, molecules, or ions are taken up from the soil solution or soil atmosphere and retained on the surface of solids by chemical or physical binding" (Soil Science Society of America 2008, p. 2).

literature review, "sodicity" refers to the environmental property that is measured, and "SAR" refers to the measurement and resulting data.

Some sources also report "adjusted SAR" concentrations, which account for the precipitation or dissolution of calcium that is expected to occur where a water reacts with alkaline earth carbonates in the soil (Soil Science Society of America 2008). For example, if irrigation water containing bicarbonate is applied to soil containing calcium, the result is precipitation of calcium carbonate, which decreases EC and increases SAR in the soil water. Use of adjusted SAR is most important when using groundwaters or waste waters for irrigation because the waters will often degas carbon dioxide when exposed to the air, resulting in calcite precipitation and an increase in SAR (Suarez and Jurinak 2012). Usually, surface waters used for irrigation are already at steady state and SAR does not need adjustment (Suarez 1977, Suarez and Jurinak 2012).

The paragraph regarding sources of salts in the EC section above is also applicable to SAR. The distinction is that EC represents the concentration of all ions, whereas SAR represents a subset of cations (Na, Ca, and Mg).

LITERATURE SEARCH

The EPA staff conducted a structured literature search using search terms relevant to irrigated agriculture and livestock. The databases searched included Web of Science and ScienceDirect, which the EPA staff had access to through the EPA National Library Network. Search results were refined by research area, language (English), document type (e.g., article, review, book), and journal/book titles. Staff reviewed abstracts and, where relevant, the full article/book chapter. If the EPA did not have access to the full article due to subscription limitations, the article was requested through interlibrary loan. Weekly keyword searches were also established to notify staff via email if new articles were published to ensure the literature review is current. The results are summarized below.

Based on the literature search, SAR is not a parameter that is used in research on water quality effects on livestock, therefore the EPA cannot make comparisons between the sensitivity of irrigated agriculture to SAR and the sensitivity of livestock to SAR based on the current scientific literature. As a result, the effects of EC on livestock are discussed in the livestock water supply section, but the effects of SAR are not discussed.

LITERATURE REVIEW

Irrigated Agriculture

Salinity Effects on Plants

When evaluating the protection of irrigated agriculture, for salinity (the concentration of dissolved mineral salts in water, measured by EC) there are two effect endpoints that must be considered: (1) effects on plant growth, and (2) effects on soil physical properties due it its interactive effects with SAR. The latter will be discussed in the *Sodicity Effects on Soil* section below.

Salinity adversely impacts plants by osmotic effects, which occur within minutes after exposure to salinity, and specific ion effects, which may take days to months and can lead to salt toxicity, primarily in the older leaves (Munns and Tester 2008, Läuchli and Grattan 2012). Shavrukov (2013) separates osmotic stress from osmotic shock with the latter occurring with sudden, high increases in salt concentration.[7] Salinity reduces the external osmotic potential below that of the cell water potential, reducing water availability to the plant (See Figure 1) (Bauder and Brock 2001, Hanson et al. 2006, Läuchli and Grattan 2012). To maintain a salt concentration gradient sufficient to extract water, the plant must either absorb ions from the soil, or synthesize organic compounds such as sugars or acids to increase the salt concentration in the root cell (Läuchli and Grattan 2012). Either process uses energy the plant would otherwise use for growth. In addition to growth reductions, salinity can adversely affect the quality of some plants by decreasing the size and/or quality of fruits or other edible parts (Grieve et al. 2012). As noted by Läuchli and Grattan (2012), there is "no clear distinction between salt tolerance and salt sensitivity. Salt sensitivity of a given plant is indicated by the point or range in the continuum of stress where the plant shows visual or quantitative signs of being adversely affected" (p. 169).

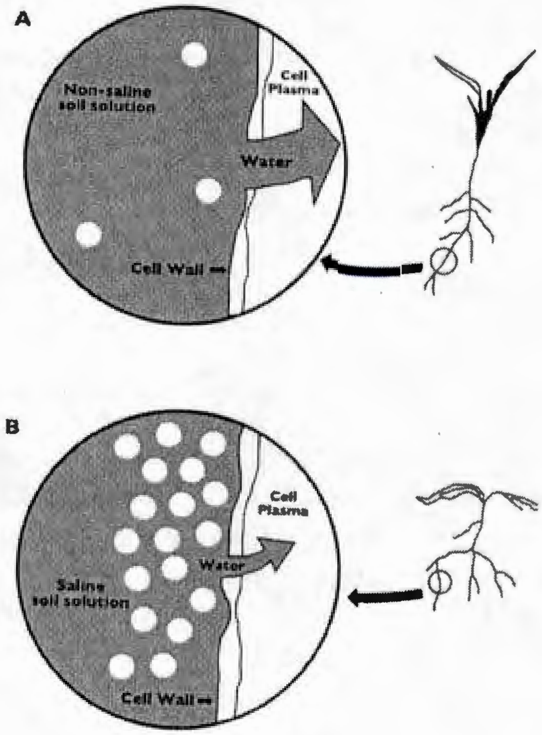

Figure 1. Effect of salts on plant water uptake (McCauley and Jones 2005, adapted from Seelig 2000)

All irrigation waters contain salts, and plants generally take up only 5-10% of those salts (Suarez 2012). Over time, due to soil evaporation and plant transpiration (or evapotranspiration (ET)), salts will concentrate in the root zone. To prevent reductions in plant growth, salts must be leached below the root zone. Leaching is the process of removing soluble components, such as salts, in percolating water. Percolation is the movement of water through the wetted soil profile (Gardiner and Miller 2008).

Guidelines

Some of the guidelines for EC and irrigated crops are summarized below. These guidelines represent a wide range of agricultural crops, soils, and experimental methods. The assumptions of these guidelines can make them over- or under-protective when applied site-specifically. Therefore, the guidelines are a

[7] Osmotic shock occurs when the salinity is increased by above 50-100 mM of salt - roughly equivalent to an increase in EC of 5000-10000 µS/cm.

good first step in evaluating water quality for irrigation, but should be considered in combination with local research and field experience whenever possible.

Individual scientists with the United States Department of Agriculture (USDA) have provided maximum recommendations for salinity levels in irrigation water since at least the late 1800's.[8] In 1937, the United States Regional Salinity Laboratory was established in Riverside, California. It is currently named the George E. Brown, Jr. Salinity Laboratory and administered by the Agricultural Research Service. The ARS is the USDA's chief scientific in-house research agency, and conducts basic research on the chemistry, physics, and biology of salt-affected soil-plant-water systems. In 1954, the U.S. Salinity Laboratory Staff published *Diagnosis and Improvement of Saline and Alkali Soils.*[9] Table 2 summarizes the 1954 guidelines.

< 250 μS/cm	Safe for salt-sensitive crops with some leaching
251-750 μS/cm	Plants with moderate salt tolerance can be grown without special management practices
751-2250 μS/cm	Plants with good salt tolerance can be grown with adequate drainage, but may require special management practices
> 2250 μS/cm	Only suitable for very salt-tolerant plants with adequate drainage and considerable leaching

Table 2. Classification of irrigation waters based on EC (U.S. Salinity Laboratory Staff 1954, p. 79-81)

The EPA and a predecessor agency produced a series of ambient water quality criteria documents beginning with the 1968 *Water Quality Criteria* (FWPCA, "Green Book"), followed by the *Water Quality Criteria 1972* (NAS/NAE 1973, "Blue Book"), 1976 *Quality Criteria for Water* (USEPA, "Red Book"), and 1986 *Quality Criteria for Water* (USEPA, "Gold Book"). The discussion related to EC and SAR in these documents is summarized below. Today, a summary table containing recommended water quality criteria for the protection of aquatic life and human health in surface water for approximately 150 pollutants is available on the EPA's website, but does not include recommendations for the protection of agricultural uses.[10]

< 750 μS/cm	No detrimental effects
750 - 1500 μS/cm	Can have detrimental effects on sensitive crops
1500 - 3000 μS/cm	May have adverse effects on many crops and require careful management practices
3000 - 7500 μS/cm	Can be used for tolerant plants on permeable soils with careful management practices

Table 3. EC Hazard for Irrigation Water (adapted from the Gold Book (USEPA 1986, Solids (Dissolved) and Salinity section)

The EC values in Table 3 are also included in the Green Book (FWPCA 1968, p. 170), Blue Book (NAS/NAE 1973, p. 335), and Red Book (USEPA 1976, p. 208) based on the 1954 *Diagnosis and Improvement of Saline and Alkali Soils* (U.S. Salinity Laboratory Staff) as the primary reference.

[8] For example, see https://archive.org/details/useofalkalinesal10mean.

[9] Available at http://www.ars.usda.gov/sp2UserFiles/Place/53102000/hb60_pdf/hb60complete.pdf.

[10] http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm.

Ayers and Westcot's (1985)[11] guidelines for salinity classified waters with an EC of less than 700 μS/cm as having no restriction on use, 700 - 3000 μS/cm as a slight to moderate restriction on use, and greater than 3000 μS/cm as a severe restriction on use.[12] Although these guidelines are dated, they are still recommended by USDA's Natural Resources Conservation Service (NRCS),[13] state university Extension Services,[14] the Western Fertilizer Handbook (Western Plant Health Association 2002/2010, p. 40), and standard textbooks (e.g., Gardiner and Miller 2008, p. 416).

The most recent review of the salinity effects on plants is the 2012 *Agricultural Salinity Assessment and Management*, published by the American Civil Engineering Society (Wallender and Tanji) and is the standard reference for this area of science around the world. Although this book (over 1,000 pages) offers no simple guidelines, below is a summary of the major variables to consider.

Variables That Can Affect Whether EC Criteria are Protective of Irrigated Agriculture

Many variables influence the EC level necessary to protect irrigated agriculture, including the salt tolerance of target crops and desired yield, irrigation method, attainable leaching fraction, and soil solution salinity.

Plant Salt Tolerance

Definitions of plant salt tolerance vary based on intended use. For agricultural crops, the goal may be maximizing economic yield, whereas for landscapers it may be maintaining aesthetic qualities without excessive growth, and for ecologists the goal may be plant survival (Grieve et al. 2012). This section will focus on the plant salt tolerance for agricultural crops, which can be described as the yield decline across a range of salt concentrations.

Salt tolerance varies by crop type, variety, and growth stage. Maas and Hoffman (1977) conducted an extensive literature review and compiled salt tolerance data for over 70 crops. They created a crop salt tolerance table that included a threshold above which there is yield loss, as compared to yields under nonsaline conditions, and a slope describing the percentage of expected yield reduction per unit increase in salinity above the threshold. These salt tolerance tables have been adapted over the years (e.g., Ayers and Westcot 1985 (See Table 4), Maas and Grattan 1999), and are still widely used today (e.g., Table 13-1 in Grieve et al. 2012).[15]

[11] Available at http://www.fao.org/DOCReP/003/T0234e/T0234e00.htm (see section 1.4).

[12] No restriction on use is defined as full production capability for all crops without use of special practices. Restriction on use indicates a limitation on choice of crop or special management practices are necessary to maintain full production.

[13] For example, see http://www.nrcs.usda.gov/wps/portal/nrcs/detail/az/technical/?cid=nrcs144p2_065177.

[14] For example, see http://extension.colostate.edu/topic-areas/agriculture/irrigation-water-quality-criteria-0-506/.

[15] See also http://www.nrcs.usda.gov/Internet/FSE_PLANTMATERIALS/publications/azpmstn10485.pdf.

Crop	100% Yield EC_{iw}	90% Yield EC_{iw}	75% Yield EC_{iw}
Sugarbeet	4700	5800	7500
Sorghum	4500	5000	5600
Wheat	4000	4900	6300
Soybean	3300	3700	4200
Rice	2000	2600	3400
Alfalfa	1300	2200	3600
Corn & Potato	1100	1700	2500
Lettuce	900	1400	2100
Onion	800	1200	1800
Bean	700	1000	1500
Strawberry	700	900	1200

Table 4. Estimated crop tolerance and yield potential of selected crops as influenced by irrigation water salinity (EC_{iw} in µS/cm) (adapted from Ayers and Westcot 1985, adapted from Maas and Hoffman 1977 and Maas 1984)

Often the salt tolerance of a crop species is based on data from a few varieties. Varietal differences are common among field and garden crops, but the differences vary. For example, Al-Khatib et al. (1993) and Cornacchione and Suarez (2015) described varietal differences in alfalfa. In addition, dormant varieties of alfalfa appear to be less salt tolerant than non-dormant varieties (Cornacchione and Suarez 2015). For example Steppuhn et al. (2012) determined a relative yield (cumulative fresh weight over multiple cuttings) ranging from 30 to 38% for 9 dormant alfalfa varieties grown at EC 15,500 µS/cm relative to the EC 1500 µS/cm control. In contrast, Cornacchione and Suarez (2015), determined cumulative relative yields ranging from 70 to 93% at EC 12,700 µS/cm and 42 to 74% at EC 18,400 µS/cm for 4 non-dormant alfalfa varieties. Other crops with known varietal differences include barley, wheat, tomatoes, soybean, lettuce, melons, and fruit trees (Shalhevet 1994).

The scientific literature indicates that most plants are more sensitive to salinity during emergence and seedling establishment and become more tolerant as they mature (Läuchli and Grattan 2012). However, Cornacchione and Suarez (2015) found comparable salt tolerance for alfalfa during emergence, seedling, and growth stages. Shalhevet (1994) highlighted difficulties in establishing the relative sensitivity of crops at different growth stages, since effects on growth during one stage may influence the response during the following stages. This work suggested plants respond to the time-weighted salinity exposure. Most salt tolerance experiments irrigate with non-saline water during plant establishment and apply salinity treatments to later growth stages. Therefore, for plants that are more sensitive to salinity at emergence or seedling establishment, or plants that are exposed to saline water during their entire life cycle, the majority of published salt tolerance studies may underestimate the adverse effects of salinity. In addition, salt tolerance studies are often conducted with frequent applications of saline water at a constant concentration, which may not represent field conditions (Grieve et al. 2012).

In the scientific literature, there are two main approaches to describing plant salt tolerance: (1) the piece-wise linear threshold-slope model (e.g., Maas and Hoffman 1977); and (2) nonlinear models (e.g., Steppuhn et al. 2005a, b). Both approaches are based on experimental plant yield data, but use different theoretical methods to describe the data.

Irrigation Method

The irrigation method used affects salt distribution in the soil. Irrigation water is applied by three main methods: (1) surface; (2) sprinkler; and (3) drip (Ayars 2012). In surface irrigation, water flows over the surface of the field and some of the water infiltrates. Types of surface irrigation include furrow or flood, border, and basin irrigation. Sprinkler irrigation can be set, spray water from a fixed location, or mobile, move continuously while applying water in a straight line (linear) or a circle (center pivot). Sprinkler-irrigated crops, including alfalfa, are susceptible to foliar injury when the plant absorbs salts in the irrigation water through the leaves (Maas et al. 1982). Microirrigation includes surface drip, subsurface drip, bubbler, and microsprinkler, but are commonly all referred to as drip irrigation. Water is delivered near plants through a network of tubing with small holes (emitters) at a slow application rate.[16] The distribution of salts in the soil is affected by the method of irrigation, seed placement, and bed size and shape, as illustrated in Figures 2 and 3.

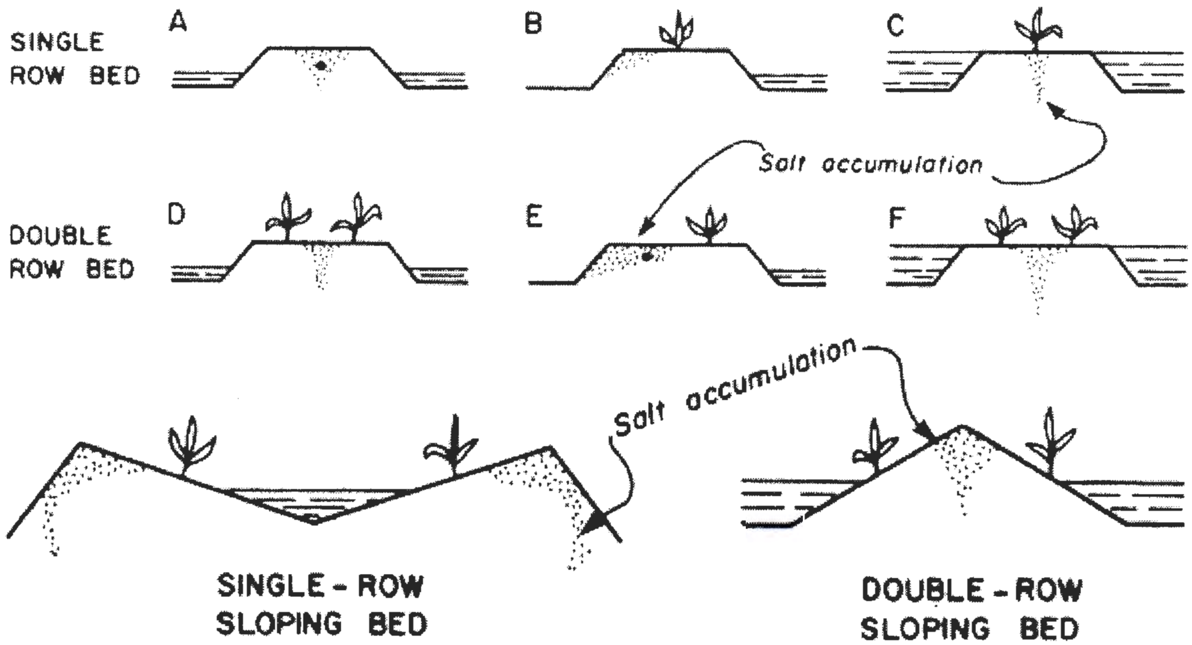

Figure 2. Salt accumulation patterns under furrow irrigation (from Ayers and Westcot 1985)

[16] For pictures of different irrigation methods, see http://water.usgs.gov/edu/irmethods.html.

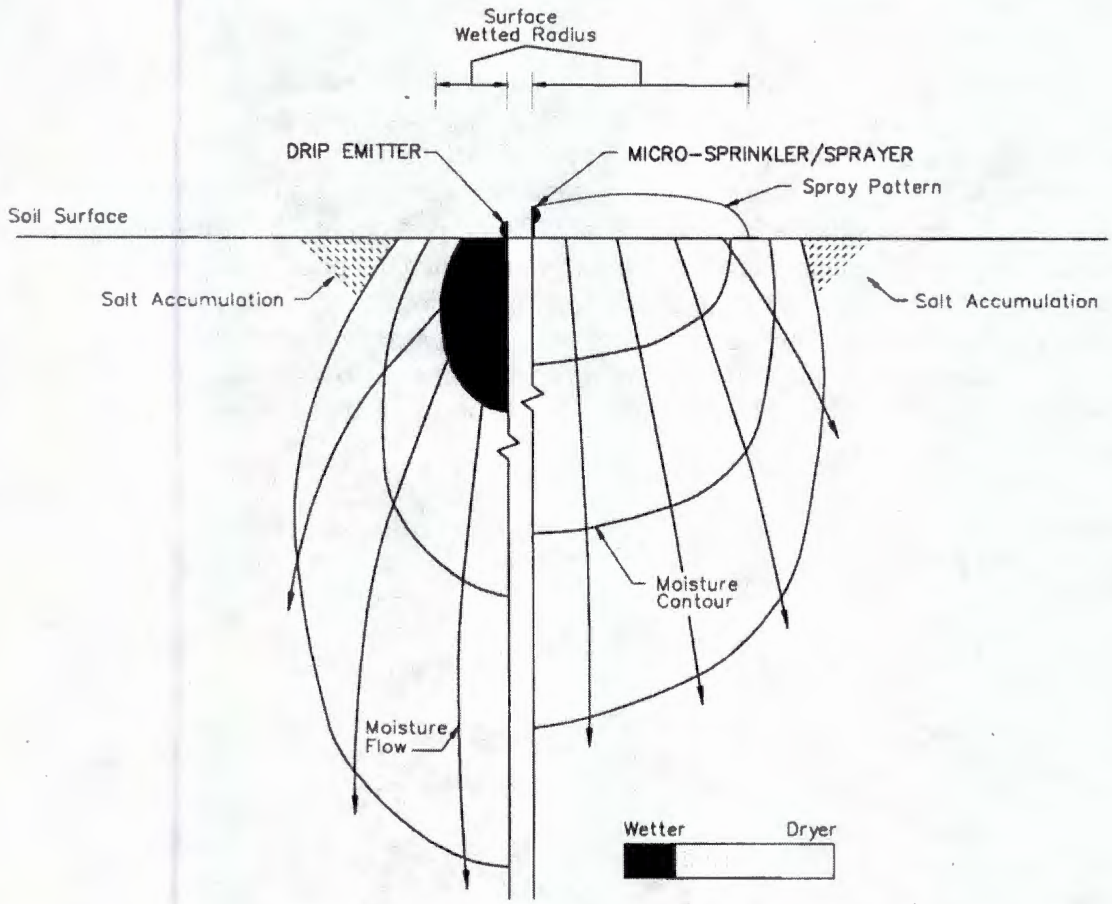

Figure 3. Salt accumulation patterns with surface drip and microsprinkler irrigation (Fipps 2003)

Leaching Fraction

Leaching fraction (LF) was defined by the U.S. Salinity Laboratory (1954) as the fraction of applied water that moves (leaches) beyond the root zone. The higher the leaching fraction, the less salt will accumulate in the soil. The U.S. Salinity Laboratory also developed the concept of leaching requirement (LR), or the minimum leaching fraction a crop can tolerate without yield reduction, assuming steady-state conditions. A steady-state analysis does not include a time variable and assumes the water content and salt concentration at a given point remains constant with time, however true steady-state conditions rarely exist in the field within the rootzone (Rhoades 1974, Letey et al. 2011, Ayars et al. 2012). Rootzone salt concentrations vary at individual field scales, and within a field, throughout the wetting-drying cycles in any given irrigation season.

Today LF and LR can be calculated using a variety of approaches, including steady-state and transient-state computer models. Transient-state analyses allow simulations that include variables such as crop rotations, changes in crop salt tolerance during different growth stages, precipitation, changes in irrigation water quality, and mineral precipitation-dissolution reactions. Letey et al. (2011) summarize the literature regarding comparisons of transient-state models with field data. Comparisons of transient-state models to steady-state models are summarized by Letey et al. (2011) and Corwin et al. (2012).

Soil Solution Salinity

EC is used as a measure of the salinity of irrigation water (EC_{iw}), a soil solution extract (EC_e), and the soil solution (EC_{ss}). Direct measurement of soil solution salinity is difficult, especially when the soil is not saturated. In addition, because the soil salinity depends on the water content at the time of sampling, direct measurement makes comparisons with other studies difficult (Suarez 2012). The U.S. Salinity Laboratory scientists (1954) standardized the estimation of soil salinity using the following procedure: (1) demineralized water is added to a soil sample until the soil paste glistens and slightly flows when the container is tipped; (2) the soil paste is left overnight; (3) the next day the soil paste is filtered and extracted under vacuum, and the solution (saturation extract) obtained is analyzed (Suarez 2012). The results are reported as EC_e.

Plant response to salinity is related to EC_{ss}, and there are various recommendations for calculating EC_{ss}. Historically, EC_{ss} at field capacity[17] was estimated by the average root zone EC_e. This method assumes decreasing water uptake with depth and averages the measured or calculated EC_e of several depths (e.g., Ayers and Westcot 1985). More recent literature concludes that the average root zone EC_e method overestimates the negative impact of soil salinity on crop yield and recommends use of water uptake-weighted salinity (Letey et al. 2011, Suarez 2012). The differences between these two approaches increase with decreasing LF.

Whether the EC of the irrigation water (EC_{iw}) is protective of the target crops can be assessed by relating EC_{iw}, the leaching fraction (LF), and EC_{ss} at field capacity (See Figure 4).

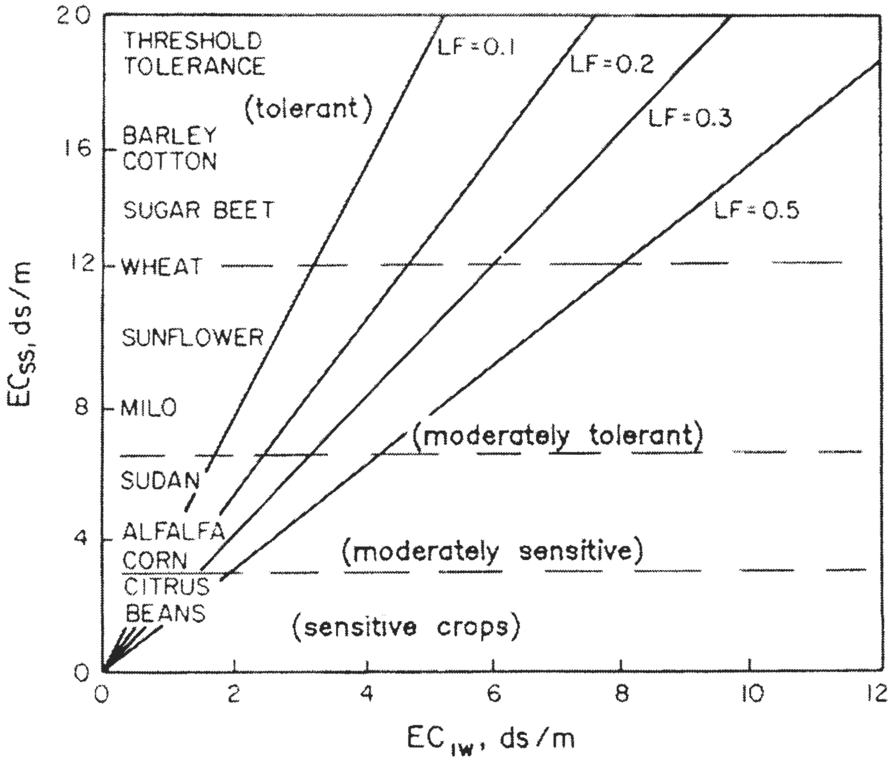

Figure 4. Relationship between EC_{ss} at field capacity, EC_{iw}, and LF required to avoid yield loss (Suarez 2012, p. 351)

[17] Field capacity is a measure of the greatest amount of water that a soil can store under conditions of complete wetting followed by free drainage, normally reached about one day after heavy rain or irrigation (Gardiner and Miller 2008).

Summary

The most recent guidelines for salinity effects on plants indicate that EC less than 700 μS/cm is protective of most crops. However, laboratory studies indicate EC less than 500 μS/cm may not be protective of some soils (see the *Interactive Effects of Salinity* section below). The range of EC 700 – 3000 μS/cm is protective of a general agricultural water supply use, but there is increased risk of detrimental effects as EC increases (e.g., reduced yields for crops start above 700 μS/cm). Greater than 3000 μS/cm is not protective of many crops. However, many variables influence the EC level necessary to protect irrigated agriculture, including the salt tolerance of target crops and desired yield, irrigation method, attainable leaching fraction, and soil solution salinity estimation method. The EPA's action under CWA Section 303(c) on EC numeric criteria adopted by states or tribes will depend on site-specific circumstances.

Sodicity Effects on Soil

The previous section on salinity effects was related to salt concentration. This section will focus on the effects of sodicity, which is related to salt composition. SAR, the ratio of sodium concentration compared to calcium and magnesium, is one way to measure sodicity.

Sodicity indicates a high ratio of exchangeable sodium in relation to other exchangeable cations (Rhoades 2012). Sodicity can cause soil swelling and dispersion in soils, reducing pore size or plugging of soil pores, and surface crusting (Mace and Amrhein 2001, Shainberg and Singer 2012). As a result, infiltration[18] is reduced and it is difficult for seeds to germinate, for roots to penetrate the soil, and for plants to obtain adequate water and nutrients. However, similar reductions in infiltration in different soils may result in very different impacts on crop yield. For example a 25% loss in infiltration in a well-drained sandy-loam soil may have little effect on crop production, whereas the same infiltration reduction in a poorly-drained clay soil could significantly affect crop yield.

Most clays are crystalline, with a plate-like shape, and are made up of layers of oxygen atoms held together by silicon and aluminum atoms (Gardiner and Miller 2008). Due to their chemical structure, most clays have a net negative charge. Cations in the soil water are attracted to the negatively charged clay surface in proportion to their charge (i.e., calcium and magnesium are attracted to the surface with twice the force of sodium) (Shainberg and Letey 1984, Rhoades 2012).

Cations attached to clay platelets in soil can be exchanged, meaning one cation can be removed and replaced with another. Cation exchanges must be of equivalent charge, therefore, one calcium ion (Ca^{2+}) would be exchanged for two sodium ions (Na^+) (Gardiner and Miller 2008). If calcium is the dominate cation on clay surfaces, clay platelets can form aggregates (flocculation). If sodium becomes the dominate cation on clay surfaces, aggregates can breakdown into subaggregates (slaking) and individual clay platelets can separate from aggregates (dispersion), and both the subaggregates and clay platelets can lodge in soil pores (Rhoades 2012).[19] This chemical dispersion can also result in the formation of a surface crust which can significantly reduce infiltration rates (Oster and Schroer 1979).

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[18] Infiltration is the movement of rain or irrigation water on the soil surface into the upper layer of soil (Gardiner and Miller 2008). Infiltration rate is the volume of water entering a specified cross-sectional area of soil per unit time (Soil Science Society of America 2008).

[19] See http://vro.depi.vic.gov.au/dpi/vro/vrosite.nsf/pages/soilhealth_dispersion-animation for a short animation of this process.

The cation exchange capacity (CEC) is the sum total of exchangeable cations that a soil can adsorb, and the portion of the CEC occupied by sodium is the exchangeable sodium percentage (ESP), reported in centimoles of charge per kilogram (Gardiner and Miller 2008). The greater the proportion of sodium, the higher the sodicity hazard. SAR, the ratio of sodium concentration compared to calcium and magnesium, is easier to calculate from a soil extract than is ESP (Shainberg and Letey 1984, Gardiner and Miller 2008). ESP and SAR are numerically equivalent in the range of 3 to 30 for most practical purposes (Shainberg and Letey 1984, Läuchli and Grattan 2012). The greater the SAR value, the higher the sodicity hazard.

There is scientific uncertainty about whether the adverse effects of sodicity are reversible, but the effects of swelling are generally considered reversible, whereas the effects of dispersion are not (Shainberg and Letey 1984, Bauder and Brock 1992, Mace and Amrhein 2001, Levy and Shainberg 2004). Part of this uncertainty stems from the fact there is no standardized test method to quantify sodicity effects on infiltration or hydraulic conductivity,[20] making comparison of research results difficult.

Guidelines

Some of the guidelines for SAR and irrigated soils are summarized below. These guidelines represent a wide range of agricultural soils, and experimental methods. The assumptions of these guidelines can make them over- or under-protective when applied site-specifically. Therefore, the guidelines are a good first step in evaluating water quality for irrigation, but should be considered in combination with local research and field experience whenever possible. The summary below demonstrates that over time, the guidelines for SAR have become more stringent as the scientific literature documented effects at lower SAR levels.

The EPA and a predecessor agency produced a series of ambient water quality criteria documents beginning with the 1968 *Water Quality Criteria* (FWPCA, "Green Book"), followed by the *Water Quality Criteria 1972* (NAS/NAE 1973, "Blue Book"), 1976 *Quality Criteria for Water* (USEPA, "Red Book"), and 1986 *Quality Criteria for Water* (USEPA, "Gold Book"). The discussion of SAR in these documents indicated SAR 8 – 18 was usable for general crops and forages, but emphasized that specific soil conditions existing in a given locale should be considered. Today, a summary table containing recommended water quality criteria for the protection of aquatic life and human health in surface water for approximately 150 pollutants is available on the EPA's website, but does not include recommendations for the protection of agricultural uses.[21]

Although dated, the Ayers and Westcot (1985) guidelines for infiltration in the table below are still used throughout the world, state university Extension Services, and standard textbooks (e.g., Gardiner and Miller 2008, p. 416). The Western Fertilizer Handbook (Western Plant Health Association 2002/2010) includes the Ayers and Westcot guidelines below (p. 40), but provides the general guideline that if the SAR is less than 3, there should be no problems, in the range of 3-9 there are increasing problems, and above 9 severe problems can be expected (p. 43).

[20] Hydraulic conductivity is the ability of soil to conduct water through the soil profile (Soil Science Society of America 2008).
[21] http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm.

SAR	Use Restriction (EC in μS/cm)		
	None	**Slight to Moderate**	**Severe**
0-3	> 700	200-700	< 200
3-6	> 1200	300-1200	< 300
6-12	> 1900	500-1900	< 500
12-20	> 2900	1300-2900	< 1300
20-40	> 5000	2900-5000	< 2900

Table 5. Ayers and Westcot (1985, section 1.4) guidelines for infiltration

The most recent guidelines appear in the 2012 *Agricultural Salinity Assessment and Management*, published by the American Civil Engineering Society (Wallender and Tanji) which is the standard reference for this area of science around the world. Unlike previous guidelines, Figure 5 is based on experiments that considered soil effects in the presence of rain as well as irrigation water.

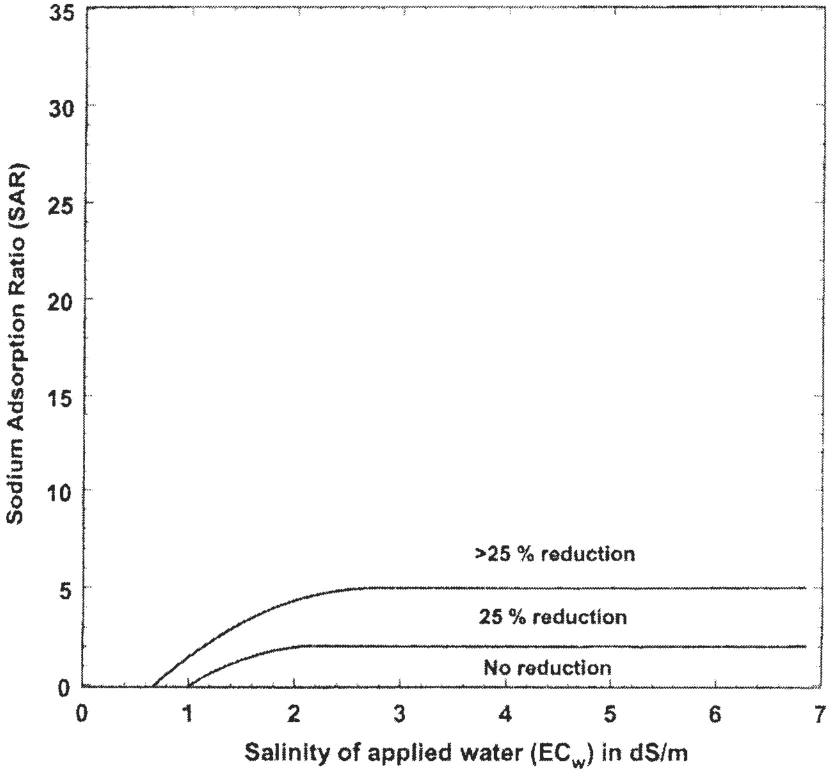

Figure 5. Relationship between SAR and EC at which 25% reduction in infiltration is expected when irrigating in the presence of rain (Suarez 2012, p. 357)

These guidelines indicate a > 25% reduction in infiltration above about SAR 2 at EC 1000 μS/cm, and above SAR 5 regardless of EC. However, a 25% loss in infiltration in a well-drained sandy-loam soil may have little effect on crop production, whereas the same infiltration reduction in a poorly-drained clay soil could significantly affect crop yield. SAR > 10 is not protective of most soils when irrigating in the presence of rain.

Sodicity adversely affects soil physical properties such as structural stability, infiltration rate, and hydraulic conductivity (Shainberg and Singer 2012). As discussed above, the sodicity guidelines for irrigation waters are usually based on the combined interactive effects of EC and SAR. Each soil responds differently to the same combination of EC and SAR, therefore each soil has a unique threshold (Shainberg and Letey 1984, Oster 1994, Shainberg and Singer 2012). This diversity reported in the scientific literature is partly due to differences in experimental design. In addition, scientists have also demonstrated that variables such as soil texture (see Figure 6), clay mineralogy, clay content, organic matter, oxide content, exchangeable Mg, and pH affect soil response to saline and sodic conditions (e.g., McNeal and Coleman 1966, McNeal et al. 1968, Frenkel et al. 1978, Oster and Schroer 1979, Suarez 1981, Ben-Hur et al. 1985, Stern et al. 1991, Suarez et al. 2006, Browning et al. 2007). However, the data on these variables are for specific groups of soils and the effects of these variables have not been quantified (Suarez 2012). Therefore, this section will focus on the existing guidelines and scientific literature related to the interactive effects of EC and SAR and how the general thresholds for EC and SAR can help identify areas of concern that may warrant more site-specific investigation.

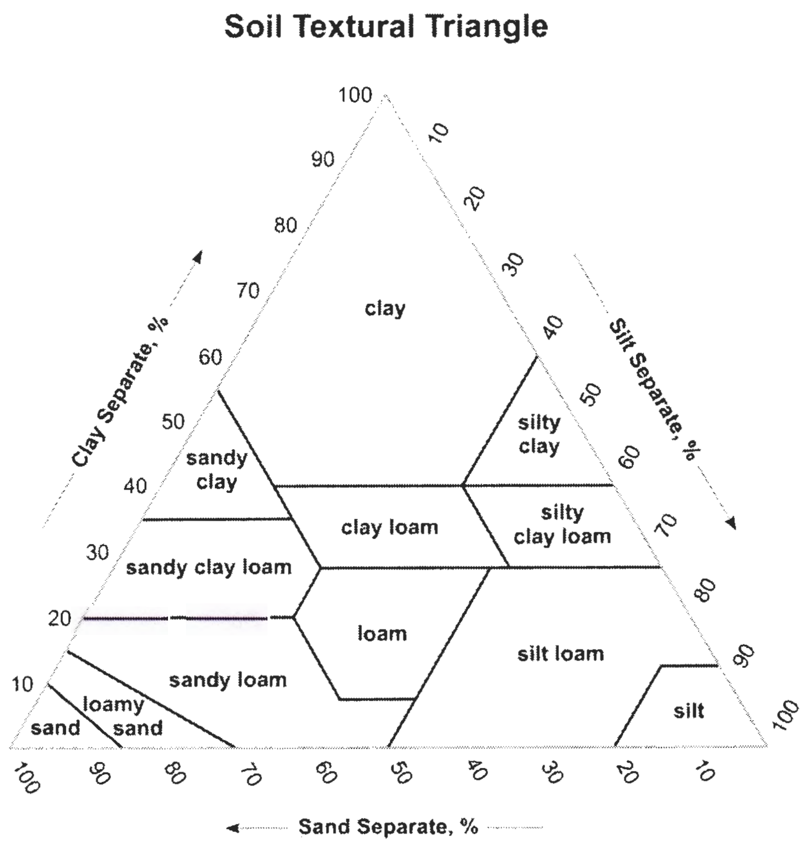

Figure 6. Soil textural triangle (USDA)[22]

[22] See http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/edu/kthru6/?cid=nrcs142p2_054311.

Interactive Effects of Salinity

The salinity of the percolating water (irrigation or rain) affects how a soil responds to sodicity (Quirk and Schofield 1955). Elevated salinity has a flocculating effect on soil, whereas elevated sodicity has a dispersive effect on soil (McNeal 1968, Shainberg and Letey 1984). Therefore, the adverse impacts of sodicity may be reduced with increasing salinity. Part of the challenge for states and tribes in determining what level of salinity is protective of their irrigated agriculture use is balancing the positive effect of increasing salinity on soil physical properties and the negative effect of increasing salinity on plants discussed in the previous section.

The Ayers and Westcot (1985) guidelines only considered the effects of irrigation water (i.e., did not consider rain). These guidelines indicate that with SAR 0 – 3, there should be no impacts on infiltration if the EC is greater than 700 µS/cm, and the thresholds for SAR 3 – 6 and 6 – 12 are greater than 1200 µS/cm and 1900 µS/cm, respectively. Slight to moderate impacts are predicted with EC 500 – 1900 µS/cm. Mace and Amrhein (2001) found no significant reductions in hydraulic conductivity below EC 2500 µS/cm and no significant differences in clay dispersion between EC 500 and 2500 µS/cm. Shainberg et al. (1981) reported reduced hydraulic conductivity if SAR > 6 at EC 1000 µS/cm and SAR > 9 at EC 2000 µS/cm. Clay dispersion increased if SAR > 5 at EC 1000 µS/cm and SAR > 9 at EC 2000 µS/cm. McNeal and Coleman (1966) tested seven soils of varying mineralogy and found hydraulic conductivity was reduced 25% at EC 2000 µS/cm and SAR 5 for the most sensitive soil. In summary, at EC > 1000-1900 µS/cm some research shows limited hydraulic conductivity impacts at SAR 6-9, and at EC > 2000-2500 µS/cm some studies show limited impacts at SAR 6-12.

Application of low EC water (< 500 µS/cm) from irrigation or rain may result in a significant reduction in EC at the soil surface (reduced flocculation), leading to dispersion (Oster 1994, Suarez et al. 2006, Suarez 2012). This is because salts present in the soil water solution will be leached (reducing EC), but sodium ions attached to the surface of clay platelets will only leach if calcium and magnesium ions are available (e.g., from dissolution of calcite or from the irrigation water) in the soil solution to replace exchangeable sodium (reducing SAR) (Oster 1994, Shainberg and Singer 2012). Depending on the quantity of low EC water introduced, these effects tend to be concentrated at or near the soil surface, with diminishing effects deeper in the soil horizon. In addition to chemical dispersion, studies have demonstrated that physical dispersion also results from the impact of rain drops on the soil surface, which can contribute to seal/crust formation and the resultant decreased infiltration and increased runoff (McIntyre 1958, Agassi et al. 1981, Morin et al. 1981).

The Ayers and Westcot (1985) guidelines indicate that with SAR 0 – 3, severe impacts on infiltration can occur with EC less than 200 µS/cm, and the thresholds for SAR 3 – 6 and 6 – 12 are less than 300 µS/cm and 500 µS/cm, respectively. Laboratory studies have found impacts on soil physical properties even in the SAR 1-6 range when EC is 500 µS/cm or less. Oster and Schroer (1979) reported reduced infiltration rates in the range of SAR 2 – 4.6 at EC 500 µS/cm relative to infiltration rates at EC 1200 µS/cm. Mace and Amrhein (2001) treated clay loam soil with water of SAR 1, 3, 5, and 8, and EC 0, 250, 500, 1000, 2500, and 10,000 µS/cm. They found clay dispersion increased significantly below 500 µS/cm with increasing dispersion as SAR increased from 1 to 8. Kazman et al. (1983) leached soils with EC 50 µS/cm and found infiltration rates decreased as SAR increased in the range of 1.0 – 6.4. When leached with distilled water, Shainberg et al. (1981) treated soil-sand mixtures with SAR 10, 15, 20, 30 and EC 3000, 2000, 1000 µS/cm & distilled water. They reported hydraulic conductivity decreased 20% of its initial value at SAR 5, but reductions in hydraulic conductivity and dispersion even occurred at SAR 1 – 2. Agassi et al. (1981) observed decreased infiltration rates, clay dispersion, and crust formation even at low SARs (4.6 and 6.4) when distilled water was applied by rain simulator. They also reported that increasing EC to 500 μS/cm significantly reduced dispersion and increased infiltration rates at SAR 4.6 and 6.4. Recognizing that the test methods and soil types used varies among these studies, taken together they demonstrate the potential hazards of SARs in the range 6-12, especially in combination with EC 500 μS/cm or less.

Almost all research on the effects of EC and SAR on soil was conducted on arid soils using only irrigation water (Suarez et al. 2006). These studies also used disturbed soil columns under continuously saturated conditions. Shainberg and Singer (2012) note that these studies used laboratory methods that do not reflect field conditions (e.g., dry, disturbed soils exposed to fast wetting rates, followed immediately by flooding or high-intensity simulated rain) and they suggest that these conditions overestimate the effects of sodicity. Conversely, the fact much of the previous research did not consider the effects of rain could result in an underestimation of sodicity effects (Suarez et al. 2006 and 2008, Bauder et al. 2008). The few rainfall simulation studies did demonstrate that infiltration rate is more sensitive to the effects of sodicity than hydraulic conductivity in saturated soil experiments (Agassi et al. 1981, Kazman et al. 1983). Bauder et al. (2008) simulated repeated flood irrigation wetting regimes, and found significant increases in EC_e and SAR from single and multiple wettings, especially in soils with >33% clay content. Subsequent simulated single rainfall events produced proportionately greater reductions in EC_e than SAR.

Although useful, these studies only examined short-term effects and did not include wetting and drying cycles representative of field conditions. The only experiment on soil response to EC and SAR in a combined rain and irrigation system with surface wetting and drying was funded by the EPA and the results were published by Suarez et al. in 2006 and 2008. Uncropped clay and loam soils were flood irrigated with SAR 2, 4, 6, 8, 10 and EC 1000 and 2000 μS/cm, with alternating rain and irrigation and drying between irrigations. For the loam soil, during the last rain event the infiltration rate decreased above SAR 2 for both EC 1000 and 2000 μS/cm, with the largest decrease between SAR 4 and 6. For the clay soil, the infiltration rate generally decreased above SAR 2 for both EC 1000 and 2000 μS/cm, with the largest decrease (about 30%) between SAR 2 and 4 (Suarez et al. 2006). The results for both soils suggest that in the range of EC 1000 – 2000 μS/cm, SAR is the limiting parameter. These results also indicate soils exposed to irrigation and rain during the cropping season are more sensitive to SAR compared to irrigation alone.

The EC of surface waters used for irrigation will vary throughout the year based on factors such as flow, but rapid changes in EC for rain are possible. For example, Jonsson and Vonnegut (1991) reported real-time EC measurements for 7 rain events in Albany, New York, that varied from 5 - 230 μS/cm. They found significant variations in EC during a single rain event, up to a factor of 5, as well as from one rain event to another. The EC of applied water in the scientific literature is almost always at a constant concentration. The EPA is not aware of any studies that examined the soil effects of rain with variable EC such as that described by Jonnson and Vonnegut (1991).

Summary

The guidelines and scientific literature for sodicity effects on soil indicate that SAR < 2 is protective of most soils. The range of SAR 2 – 5 is protective of a general agricultural water supply use, but may not protect all soils. Within the range of SAR 5 – 10 there is increased risk of detrimental effects as SAR increases. Greater than SAR 10 is not protective of most soils, particularly when irrigating in the presence of rain. However, the SAR level that protects irrigated agriculture depends on many variables, including target soils and crops. The EPA's action under CWA Section 303(c) on SAR numeric criteria adopted by states or tribes will depend on site-specific considerations.

Livestock Water Supply

Salinity Effects on Livestock

Excessive salinity in livestock drinking water can decrease production. Detrimental effects vary by species, age, body size, amount of water ingested through drinking and feed, and ambient air temperature and humidity. Even within a species, such as cattle, effects vary for dairy cattle as compared to beef cattle. The most recent review of the scientific literature pertaining to water quality effects on livestock, Raisbeck et al. 2007, recommends thresholds for various elements in water, but does not recommend relying on TDS to evaluate water quality for livestock. Most of the data available on livestock effects is reported as TDS in mg/L, which for purposes of this review was converted to EC in µS/cm by dividing by 0.64 (see discussion in Background section above).

Guidelines

The Green Book (FWPCA 1968) section on livestock water supplies includes the following table of standards developed in Australia as safe maximum limits for livestock.

Animal	Maximum Limit (µS/cm)
Poultry	4468
Swine	6703
Horses	10,054
Dairy cattle	11,171
Beef cattle	15,625
Sheep	18,750

Table 6. The Green Book (FWPCA 1968, p. 134)

In the Blue Book (NAS/NAE 1973), the table above was replaced with the following table.

< 1562 µS/cm	Relatively low level of salinity. Excellent for all classes of livestock and poultry.
1562 – 4686	Very satisfactory for all classes of livestock and poultry. May cause temporary and mild diarrhea in livestock not accustomed to them or watery droppings in poultry.
4687 – 7811	Satisfactory for livestock, but may cause temporary diarrhea or be refused at first by animals not accustomed to them. Poor waters for poultry, often causing water feces, increased mortality, and decreased growth, especially in turkeys.
7812 – 10,936	Can be used with reasonable safety for dairy and beef cattle, for sheep, swine, and horses. Avoid use for pregnant or lactating animals. Not acceptable for poultry.
10,937 – 15,625	Unfit for poultry and probably for swine, Considerable risk in using for pregnant or lactating cows, horses, or sheep, or for the young of these species. In general, use should be avoided although older ruminants, horses, poultry, and swine may subsist on them under certain conditions.
Over 15,625	Risks with these highly saline waters are so great that they cannot be recommended for use under any conditions.

Table 7. The Blue Book (NAS/NAE 1973, p. 308)

The Food and Agriculture Organization of the United Nations also uses a table similar to Table 7 in their guidance (Ayers and Westcot 1985).[23]

The Natural Resources Conservation Service (NRCS) National Range and Pasture Handbook (2003)[24] recommends the following:

Parameter	**Limit to Maintain Production**	**Maximum Limit**
TDS	3906 µS/cm	7812 µS/cm
Salinity	–	Horses 10,054 µS/cm Dairy Cattle 11,171 µS/cm Beef Cattle 15,652 µS/cm Sheep 20,156 µS/cm

Table 8. NRCS National Range and Pasture Handbook (2003) water quality standards for livestock

In 2007, Raisbeck et al. published a review of the scientific literature pertaining to water quality effects on livestock.[25] This report does not recommend relying on TDS to evaluate water quality for livestock because it is a poor predictor of animal health. However, the report discusses detrimental effects such as decreased water & food intake, weight gain, and milk production in cattle, swine, sheep, and horses in the range of 3187 – 23,434 µS/cm. The authors note they have seen toxicity in animals from water with TDS as low as 500 mg/L (~ 781 µS/cm), but the scientific literature indicates EC less than 3000 µS/cm protects a livestock water supply use.

Summary

In the most recent review of the scientific literature, EC is not recommended for evaluating water quality for livestock, but if other metrics are not available, the scientific literature indicates EC less than 3000 µS/cm protects a livestock water supply use. The effects of EC in the literature vary widely and depend on variables such as livestock species and assumed water intake through water and feed. The EPA's action under CWA Section 303(c) on EC numeric criteria adopted by states or tribes will depend on site-specific considerations.

[23] Available at http://www.fao.org/DOCReP/003/T0234e/T0234E07.htm#tab28 (Table 28).
[24] Available at http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1043065.pdf, see Table 6-8.
[25] Available at http://www.uwyo.edu/uwe/pubs/b1183/.

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APPENDIX 2
TO THE EPA'S APPROVAL OF MONTANA'S WQS FOR EC AND SAR

USDA
United States Department of Agriculture

Research, Education, and Economics
Agricultural Research Service

May 8, 2014

Martin Hestmark
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Office of Ecosystems Protection and Remediation
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Reference: USDA IA Identification Number 60-5310-7-747
EAP IA Identification Number DW-12-92329501-0

Dear Mr. Hestmark:

The comments below represent our evaluation of the Montana water quality standards for electrical conductivity (EC) and sodium adsorption ratio (SAR), as presented in the Review of Rationale dated August 5, 2011, "Review of the Rationale for EC and SAR Standards", prepared by Montana Department of Environmental Quality, as specified in the Interagency Agency Agreement Number: 60-5310-7-747. Under this agreement, the EPA requested assistance from the U.S. Salinity Laboratory (USDA-ARS) in evaluating the technical merit of water quality standards (WQS) and/or effluent limits for EC and SAR.

General Comments

The basis of the rationale for the Electrical Conductivity (EC) standard stems from the loss in crop yield associated with elevated salinity in the soil. The adverse effect of salinity (represented by EC) is a well-documented field observation reinforced by a very large number of published scientific papers that quantify this yield loss for a very extensive list of crops. The basis of the rationale for a SAR (sodium adsorption ratio) standard stems from the adverse impact of elevated SAR on soil physical properties, with loss of infiltration rate of water being the primary

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consideration. This process is very well known and has also been extensively studied, and documented to result in loss of soil productivity (decreased crop production).

The relationships to convert EC of the irrigation water to EC of the soil extract and EC of the soil water presented in this Review of Rationale are those relationships in common use by University extension specialists, and consultants. These conversion factors are widely accepted, but it is pointed out in the specific comments that these are not exact relationships but rather average values. In a similar manner the EC standards depend on estimates of leaching fractions in the various irrigated regions because leaching affects the soil water EC, and this is the factor that determines salinity damage. These estimates of leaching fraction cannot be exact but again they appear to be reasonable estimates and consistent with the information from published studies cited in the Review of Rationale.

The standards for average EC and SAR are in line with the bulk of the scientific literature on the subject and with the current consensus of experts in this area of research. What is not adequately addressed is the rationale for the maximum levels of EC and SAR, which are part of the standards.

Overall, the Review of Rationale provides detailed justification of the water quality standards listed in the numeric criteria adopted by Montana. However, there are a number of assumptions and simplifications that were not addressed. Details are provided below.

2.0 Need for Standards

2.1 Electrical Conductivity

The electrical conductivity is a measure of the electrical conductance of a water sample under specified conditions, and typically corrected to the conductance at 25°C. The EC is related to the amount of salts in the solution, but the relationship depends on the salt composition (Robinson and Stokes 1959). The EC has been used to assess salinity damage to crops (Maas and Hoffman 1977), but it is considered as a proxy for the more difficult to measure osmotic potential.

The statement that plants do not remove salts is not correct; plants remove small amounts of the total salt applied in the irrigation water, typically 5-7% of the total applied.

Leaching fraction is not properly defined (bottom of page 2). The leaching fraction is the fraction of applied water that leaches beyond the rootzone. The applied water volume equals ET + leached water volume (the leaching fraction term is defined in Ayers and Westcot 1985, among others). The term ET refers to the combined water quantities of soil evaporation and plant transpiration.

Leaching can and does occur even when the soil is not saturated and water stored in the soil need not leach. A better statement than that used in the Review of Rationale (page 3 top) would be to say that little leaching occurs when the soil water content at the bottom of the root zone is below "field capacity" for that soil.

2.2 Sodium Adsorption Ratio

SAR is not properly defined in the Review of Rationale. It is the concentration of Na/((Ca + Mg)/2)$^{0.5}$ where concentration is expressed in meq/L or mmoles$_c$/L. There is a useful empirical relationship that links the SAR to the exchangeable sodium percentage (ESP) of the soil (U.S. Salinity Laboratory Staff, 1954).

The SAR and EC of the irrigation water do not necessarily equilibrate with the SAR and EC of the soil water. The soil water *in situ* will be of higher EC than the irrigation water since plants extract mostly water and only a small amount of salt. If the soils contain gypsum or other soluble salts the EC of the soil water will also increase from mineral dissolution, relative to the EC of the irrigation water. Since gypsum readily dissolves, soils containing gypsum almost always result in gypsum saturated soil water and an increase in EC. Also the SAR of the soil water may be equal or greater than that of the irrigation water, especially if the irrigation water is supersaturated with respect to calcite or at elevated CO_2, such as the case with ground water when extracted. The need to "adjust" the SAR to account for precipitation or dissolution of calcium carbonate was noted by Bower et al. (1968), however the initial Bower method was not correct. The method developed by Suarez (1981) addressed this error and has been widely accepted (see Ayers and Westcot 1985, among others).

3.0 Derivation of EC standards

EC_e is used but not defined at this point (see US Salinity Laboratory Staff, 1954, for a definition of this term and details on how it is obtained). It should have been indicated that this section is based on a salt tolerance model that assumes that the data can be represented by a threshold and linear slope response to salinity.

A large data base of scientific publications exists describing the salt tolerance of various crops. The original work providing numerical values was that of Mass and Hoffman (1977) who compiled salt tolerance data for a large number of crops and represented the yield loss associated with salinity in terms of a threshold level above which there is yield loss and a slope relating yield loss per unit salinity above the threshold. This research has been widely accepted and is convenient to apply. These salt tolerance tables appear in many publications, including the Ayers and Westcot (1985) FAO publication, also in the recommendations of Hanson et al. (1999) and numerous others, including the Am. Soc. Civil Engineers "Salinity Assessment and Management", Manual 71, edited by K.K. Tanji (1990) and the revised edition, Am. Soc. Civil Engineers "Salinity Assessment and Management", Manual 71 edited by W.W. Wallender and K.K. Tanji (2012).

Some salt tolerance data may show an initial increase in yield with increasing salinity or even no threshold value, with yield decreasing with any increase in salinity. Other models may represent the entire yield salinity relationship better than this threshold model (see Steppuhn et al. 2005). The response model used by Montana in this Review of Rationale is a simplified model of plant response developed by Maas and Hoffman (1977) that has been widely used, as it is convenient and reasonably accurate.

The assumptions used to develop Table 1 are not described. This Table and other similar tables and graphical relationships are calculated with simplifying assumptions. They utilize average root zone salinity rather than water uptake weighted salinity. Most scientists consider that it is the salinity of the water taken up by the plant that matters not the salinity in the soil. Typically the roots are closer to the surface where most of the water is taken up, while salinity is greatest deeper in the soil where less water is extracted by the plant. Plant water uptake decreases with increasing soil depth. Thus the average rootzone salinity overestimates the plant response to soil salinity. This error is especially large at low leaching fractions (see Letey et al. 2011). The differences in these two models (average root zone salinity and water uptake weighted salinity) are measurable at 15% leaching and increase with decreased leaching fraction.

There is a switch at the bottom of page three of the Review of Rationale from a discussion of EC_e, the EC of a soil water extract, to EC_w, the EC of the irrigation water. The relationship between these two is not explained here nor in the Table but is addressed in the next section. The permissible irrigation water EC discussed is thus based on leaching fraction, rainfall inputs, rootzone salinity distribution, as well as the assumed relationship used to convert EC_e and EC of soil water *in situ*.

The section that describes determination of the irrigation water EC values at which there is no yield loss should follow the 3.1 Leaching Fractions section, as it is dependent on the assumptions described in that section.

The irrigation water values shown in Table 1 depend on leaching fraction; essentially all irrigation districts are improving irrigation efficiency and scarcity of water is moving the technology to more efficient irrigation systems, such as drip and sprinkler, and away from flood and furrow. It is likely advantageous to better utilize available water and thus decrease leaching fractions, as is occurring in almost all irrigated areas. These standards (assuming 0.15 leaching fractions) would underestimate salinity impacts if there were to be future implementation of decreased leaching fractions, as the EC_e and EC of water taken up by the plants would increase if leaching fraction is decreased.

When discussing salt tolerance it is important to consider that most salt tolerance studies that the Mass and Hoffman (1977) and all subsequent salt tolerance data bases utilize, consisted of experiments where initial irrigation was with non-saline water and then salinity treatments imposed after the plants were established. It is known that salt tolerance varies according to stage of growth and the extent of variation in sensitivity at different stages is different for different crops. For many crops the salt tolerance is lower at emergence and seedling establishment than it is for subsequent growth stages.

Lucerne (alfalfa), *M sativa* L., is stated by Smith (1994) as well as Al-Khatib et al. (1993) as being more sensitive to salinity at the germination and seedling stages than at the subsequent growth stage. Five supporting references are provided by Al-Khatib et al. (1993) including studies by Uhvits (1946), Ayers and Hayward (1948), Fosberg (1953), and Chang (1961). However, Steppuhn et al. (2009 and 2012) and Cornacchione and Suarez (in review) found that mortality at emergence for alfalfa in sand media was either less affected or equally affected by salinity than was subsequent biomass production. Assadian and Miyamoto (1987) found that increased depth of seed placement in saline soil increased alfalfa sensitivity to salinity in the early growth stages, perhaps providing a partial explanation to conflicting reports in the literature regarding sensitivity at various stages of growth. Consideration should be given that there is uncertainty on relative sensitivity to salinity at various stages of growth and that it may be variety dependent or dependent on depth of seeding. If germination and seedling stages are the most sensitive stages then the salt tolerance tables used in the Review of Rationale under-estimate the adverse impact of irrigating with saline water because they do not consider this sensitive stage of growth. Allen (1984) did not find a relation between varietal tolerance of alfalfa at germination and at seedling stage. Furthermore, Johnson (1990) did not find a relation between tolerance at germination and mature stage (cited in Johnson et al. 1992), hence it is not possible to estimate seedling or germination salinity tolerance from mature plant salt tolerance, i.e. using the salt tolerance tables in Ayers and Westcot (1985), or Mass and Hoffman (1977). This is an important uncertainty in determination of the EC irrigation water standard, as response to germination and seedling growth is not considered.

It is also known that there are important varietal differences in salt tolerance of alfalfa (Al-Khatib et al. 1993) as well as other crops. The alfalfa varieties used in Montana are unknown to us and not described in the Review of Rationale of Montana Standards so we don't know the possible yield losses of the varieties used. It is also likely that the salt tolerance of the varieties currently used is not well characterized. Within the last ten years a number of alfalfa varieties suitable for hot arid climates have been released that are purported to be salt tolerant. Cornacchione and Suarez (in review) determined that several new alfalfa varieties are considerably more salt tolerant than indicated by the alfalfa listing in the literature (Mass and Hoffman 1977). In Montana, dormant varieties of alfalfa are presumably utilized, while Maas and Hoffman and subsequently the Review of Rationale listed salt tolerance data from experiments with non-dormant varieties. Dormant varieties appear to be less salt tolerant than non-dormant varieties, based on comparison of data in Steppuhn et al. (2012), to data of Maas and Hoffman (1977) and Cornacchione and Suarez (in review). For example Steppuhn et al. (2012) reported a relative yield of 62% and 33% with corresponding EC_e values of 4.0 and 7.8 dS m^{-1}, respectively while Cornacchione and Suarez (in review) report a relative yield of 68% and 30% with corresponding EC_e values of 8.7 and 11.3 dS m^{-1}, respectively. This is likely one of the most important uncertainties in establishing EC standards, thus Montana officials should determine the varieties used under their climatic conditions and consider information on these varieties, if available, under comparable climatic conditions.

It should be considered that most salt tolerance studies are conducted with frequent applications of the saline water to avoid drought stress. The salinity of the irrigation water in published studies is also almost always of constant concentration. Under field conditions in Montana, farmers experience fluctuating salinity and intermittent irrigation (depending on water availability). It is assumed in the Review of Rationale that the fluctuations are not important and that the plant response can be represented by the mean salinity over the growing season, however this assumption is questionable.

Many of the uncertainties discussed above could be resolved by conducting a salt tolerance study from germination to mature stage using local alfalfa varieties under local climatic conditions. It is not clear why the Rationale does not consider the impact of water quality on the 13 acres of beans grown in the area. At what acreage level does the yield loss of a crop become sufficient to affect the standard? Is a standard developed without consideration of this acreage fully protective? It should also be considered that future fluctuations in farm prices and markets may make expanded bean production, and production of other high value salt sensitive crops, feasible.

3.1 Leaching Fraction

The leaching fraction assumptions are important to the estimation of the EC of the irrigation water that can be utilized without yield loss because the published salt tolerance information is expressed in terms of EC_e. The value of 15% leaching (or 0.15 leaching fraction, not 15% leaching fraction as stated in the Review of Rationale), is based on Oster, personal communication. Documentation or justification of this value is not provided, but is needed. This is an important uncertainty in evaluating adequacy of EC irrigation water standards.

Figure 1 is based on the average rootzone salinity (EC) which has been the conventional way of evaluating salt tolerance. However, researchers, currently consider that the salt tolerance should be reported in terms of water uptake weighted salinity, and indicated that average rootzone salinity overestimates salinity damage (Letey et al. 2011, among others). The differences between these two calculation methods increase with decreasing leaching fraction. This error overestimates salinity yield loss; but if we assume that the leaching fraction estimates are correct, the error is relatively minor.

The relationship between EC_w and EC_e shown in equation 1 is not exact, rather only a rough approximation. There are two relationships imbedded in this approximation. First, consider the relationship between EC of the irrigation water and EC of the soil water. The assumption is that the EC of the soil water is inversely proportional to the volume of water, i.e. if the volume is reduced by half due to plant water extraction, then the soil water EC is doubled. This assumption does not consider that the EC increase is not linear with the increase in concentration of salts. This is a minor error that overestimates yield loss. More importantly, for soils containing gypsum, the relationship underestimates soil water EC and thus yield loss. The other assumption in equation 1 relates to changes in water content. The salt tolerance data and soil salinity are generally reported in terms of the water extract from a saturation paste (U.S. Salinity Laboratory Staff 1954). It is assumed in the Review of Rationale that the water content of the saturation paste is twice the water content of the soil water (as assumed in Ayers and Westcot 1985). This approximation depends on the soil type, for example the relationship for a loamy sand was determined to be 2.2, and it would be below 2.0 for a clay soil. Use of the relationship assumes that the EC_w=2.0 EC_e relationship is correct for the published experiments. This assumption can generate errors of up to 20% in soil water salinity (either higher or lower). The relationship also depends on leaching fraction as noted.

The discussion on page 4 bottom, regarding leaching fraction indicates that these are averages. As pointed out in the discussion, the calculation assumes a uniform irrigation. Any non-uniformity in irrigation means that some areas of the field have lower leaching fractions and thus higher salinity. Thus, in a field with non-uniform irrigation, the yields will be lower than under a field with uniform irrigation. As uniformity decreases, the average yields decrease. Undoubtedly the impact can be reduced by use of best management practices, such as switching to a more uniform application system, but this would require costly investment in new irrigation systems. The assumption of uniform irrigation results in significant underestimation of salt damage to crop production. With flood and furrow irrigation there is considerable variation in water intake by the soil and thus leaching across the field. The spatial distribution of water in a field is beyond the scope of the Rationale but it directly impacts the crop response to a given irrigation water salinity. An indication of the extent of spatial distribution of salinity in irrigated fields is seen in Figures 58, 60, and 70 in Rhoades et al. (1999), where measured salinity varies more than three-fold across furrow irrigated fields. Realistic estimates of yield loss or the threshold irrigation water salinity at which yield loss occurs must consider non-uniformity of water application and infiltration. Estimates on non-uniformity can be made from literature studies of irrigation uniformity as related to irrigation system, slope and soil texture. The uniform irrigation assumption likely results in a significant underestimation of salt damage.

Hanson et al. (1999) is not the authoritative source on leaching fraction, contrary to the statement on the top of page 6; actually this reference is relatively unknown outside California. Ayers and Westcot (1985) and Tanji (1990, the ASCE Salinity Manual) are the main sources generally utilized. Hanson et al. (1999) is mostly taken from Ayers and Westcot (1985).

3.2 Precipitation Correction Factor

The fraction of rainfall that infiltrates is variable depending on slope, soil type, management practices, as well as rainfall intensity and antecedent soil moisture. The estimates provided in this Review of Rationale, in the absence of specific data, are likely suitable for the estimations of average input EC (rain+ irrigation). The water quality levels are "corrected" with an assumed effective rainfall and subsequent dilution of salts in the soil. A factor that is not addressed in this discussion is "What is the variability in the rainfall pattern?" As an approximation it could be assumed that 50% of the years (assuming a normal distribution in the annual rainfall) there is less rain than the average used in the calculations. In dry years the soil salinity will be greater and salt damage greater. Consideration of rain variability from year to year results in prediction of increased sensitivity to irrigation water salinity. This consideration can be made by evaluation of the variability in annual rain in this region and applying this probability relation to the calculation of average EC for each year in a 10-20 year interval and then calculating yield loss at various EC concentrations.

On the Powder River a flood irrigation leaching fraction of 0.3 is assumed (rather than the 0.15 used in the Tongue River discussion). One of the reasons flood irrigation (less efficient) has higher leaching fractions is that growers understand that the water application is highly variable (poor water distribution) and that more water overall must be applied to the entire field to get a sufficient quantity to the areas that get less water. It is thus especially questionable with flood irrigation to assume 100% uniformity in application and then calculate salinity impacts based on an average leaching fraction of 0.3. In this instance the Review of Rationale should have considered a distribution of leaching fractions and salinity, based on the non-uniformity of irrigation. This Review of Rationale might also consider the possibility that leaching fractions may be lower in the future. Both of these factors suggest the need for lower values for the salinity standards.

3.4 Derivation of the Standards for Non-Irrigation Season

The arguments used regarding seedling sensitivity to salinity for plants in the riparian zone are also valid for many field crops and should have been considered in the standards for the non-irrigation season.

3.5 Maximum EC Standards

Using the guidelines for acute toxicity to aquatic life is likely not the best criteria to set the maximum for EC standards. The maximum value might be related to either osmotic shock (which would be expected to be at least 200% of the typical current value) or more reasonably, to be related to some EC value at which permanent damage is incurred by the plant. Data on this effect is likely minimal, but I am not aware of any information that indicates an adverse effect when the salinity is increased 150% over a short time period. The justification is lacking for the 150% maximum value.

4.0 Derivation of SAR Standards

The Review of Rationale provides information on SAR standards from water quality criteria (Ayers and Westcot 1984, and Hanson et al. 1999), and cites a series of publications relating SAR to infiltration and hydraulic conductivity. The Review of Rationale demonstrates that the consensus SAR at which adverse effects may occur is at or below 5, most likely in the range of SAR 3 when we consider the interaction of irrigation water quality with rain. In addition to the studies discussed (which are the most pertinent), there are a large number of additional studies not cited, that provide support for the standards selected.

The statement that the higher the clay content the greater the soil's vulnerability to dispersion (middle of page 6) is not documented, and many would take issue with that generalization. For example, Suarez et al. (2006) found two Montana soils of differing clay content to have a similar relative response to SAR regarding loss of infiltration. However it is correct to consider that comparable reductions in infiltration of a clay and sandy soil do not result in comparable impacts. Soils with ample infiltration rates could experience 20-30% losses in infiltration without a likely adverse effect on crop yield, while comparable losses in a clay soil could have a large adverse impact on crop production. It should also be considered that losses in infiltration caused by swelling of montmorillonitic clays may be reversible while losses due to dispersion of clays may be almost irreversible. There are also studies that document differences in soil dispersion and hydraulic conductivity sensitivity to SAR as related to clay mineralogy (Frenkel et al. 1978). Clay mineralogy is not addressed in the Review of Rationale.

4.1 The Rainfall Effect

The Review of Rationale concludes the SAR irrigation season discussion on page 13 with the remark that Schaefer et al. (2001) citing Ayers and Westcot (1985) consider that for irrigation water with a low salinity (EC between 200 and 700 μS/cm) the lowest SAR required to protect soil permeability is 3.0. They state that for these reasons the average SAR of 3.0 during the irrigation season was adopted for tributary streams. There is no mention here that the adopted criteria (Montana Numeric Criteria for EC and SAR) list SAR 5 as the average allowed for the Powder and Little Powder River. The reason why this value is different for these two rivers is not presented here. These rivers both have greater EC standards than the tributaries, thus it could be argued that the Ayers and Westcot (1985) graph allows greater SAR at greater EC, but Ayers and Westcot (1985) and Hanson et al. (1999) did not consider the effects of rainfall on dispersion of sodic soil. The discussion in the Rationale makes it clear that under rainfall the SAR is generally buffered and the EC drops. Thus with inputs of rain, SAR criteria either are not to be adjusted upwards or adjusted only slightly when EC of the irrigation water increases. Thus the selection of a SAR above 3 (value of 5 is given) may be reasonable but the rationale is not presented. The discussion should have noted that the Ayers and Westcot (1985) graph (Figure 2) is only a guideline estimate of when problems may develop. There is great variability in reported stability among soils relative to SAR (McNeal and Coleman 1966, and Lebron and Suarez 1992) and the standards should be based at least in part on data from Montana soils, as some information is available, and cited in the study.

4.2 SAR During The Non-Irrigation Season

The discussion does not mention the adverse effect of rainfall on soil structural stability of soils with elevated SAR. With rain the surface soil EC decreases dramatically while the SAR decreases only slightly. This has been mentioned by several studies over the years and more recently, computer model simulations have quantified this effect as presented in Suarez et al. (2008).

4.3 Maximum SAR Standards

This section lacks justification because the EPA aquatic life (biological) ratios are not applicable to chemical effects on soil physical properties. The maximum standard should be based on short term effects of SAR on infiltration or hydraulic conductivity. The literature on this topic is mixed with some studies reporting that the adverse effects are reversible and others reporting the effects to be irreversible, likely related to the effects of swelling (reversible) and dispersion (irreversible). Comparison of different studies is also difficult because there is no standardized test method to examine SAR effects on infiltration or hydraulic conductivity. Most published studies are based on a single irrigation event thus it is difficult to predict the level of protection afforded by consideration of a 30-day average SAR value. The 30-day average value may not be appropriate if the soil type is such that the infiltration changes are irreversible (such as soils containing illitic clay.)

5.0 Decline in Produced Water Quality between Discharge and Ultimate Use

The change in chemistry of CBM (coal bed methane) water is related to known and predictable processes. The degassing of carbon dioxide from CBM water as it is discharged to the surface, results in an increase in pH and precipitation of calcium carbonate, reducing the calcium concentration in solution and increasing the SAR. An adjustment in the SAR can be made to account for this change, typically from computer modeling or from tables or equations adjusting SAR (Suarez 1981, Ayers and Westcot 1985).

Appendix 1

In paragraph 3 of this section the statement is made that leaching of salts will occur when the total infiltrated water exceeds ET by about 14 inches. This statement would require further explanation as leaching can potentially occur whenever infiltrated water exceeds ET. Perhaps the authors are referring to an initially dry soil at the time of the infiltration event and consider leaching to mean complete flushing of salts from the rootzone.

Calculations of salinity impacts on crop production in this section are based on average rootzone salinity as described in Ayers and Westcot (1985), rather than the more realistic method of water uptake weighted salinity.

The calculations appear to assume that there is either no leaching of salts or periodically, every 8-10 years, a complete flushing of the rootzone. This simplification likely overestimates salt damage as some leaching may occur in years with less than 14 inches of infiltration in excess of ET. This estimation of yield loss would be better calculated using a dynamic salt transport computer model such as UNSATCHEM (Suarez and Simunek 1997) that enables detailed calculation of water and salt transport with input of daily ET and infiltration events. A realistic analysis would also require as input a probability distribution of the frequency of leaching events, rather than the assumption of 8-10 year leaching events. In the absence of computer simulations the simple calculations used likely overestimate salinity.

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Sincerely,

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