WATER QUALITY CRITERIA FOR IRRIGATION IN CBM AREAS
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Abe Horpestad

Numeric water quality standards have been adopted in Montana for many toxic substances that could affect agricultural uses. However, numeric water quality standards have not been adopted for salinity, generally expressed as electrical conductivity (EC), and sodium adsorption ratio (SAR) or for some other substances, which could affect irrigation. This paper discusses the process and considerations that will be used to develop numeric water quality standards for these parameters. These standards may be different for different basins or streams. If you are interested in this standards development process, notify the department to insure that you are notified of department activities related to the development of water quality standards for EC and SAR. The department will post its activities dealing with the development of these standards on its web site at HTTP://WWW.DEQ.STATE.MT.US/COALBEDMETHANE/EVENTS.ASP.

The process that must be used to develop water quality standards is part of state law. The Montana Water Quality Act (MCA) directs the Board of Environmental Review (BER) to establish a water classification system, designate beneficial uses classification and adopt standards that will protect those uses. The Department of Environmental Quality (DEQ) acts in an advisory capacity for the BER. DEQ may develop the criteria that will protect uses and prepare draft rules for the BER but only the BER has the authority to adopt rules (i.e., numeric or narrative standards).

Several pieces of legislation govern the rule writing and adoption process for water quality standards. A key element of the process is public participation and notice of proposed actions. Initial public meetings are not required. In this case, they are being held to provide additional information that the DEQ can use in its development of draft rules. DEQ will compile the comments received during this public process and present them to BER along with the draft rule (SAR and EC standards) in the necessary format. DEQ will then request permission to "initiate rulemaking." If BER agrees, the formal process begins. Additional public notice is required and a public hearing will be held where oral and written comments will be taken. DEQ will compile these comments and prepare draft responses for BER. The result may be recommended changes to the proposed standards. At a BER meeting, usually four months after the request to initiate rulemaking, the BER may decide to accept DEQ's draft responses, modify the responses, accept or modify the proposed standards or direct DEQ to re-notice the process and begin again with additional direction from BER.

After BER adopts the rule and it is published in the Montana Administrative Record it becomes part of the state water quality standards and has the effect of law.

The department is attempting to determine the levels of EC and SAR that will not affect the use of the waters in the Powder River Basin for irrigation. The first step in the adoption of water quality standards is the development of criteria. Criteria describe the scientific relationship between a use of water and the concentration or level of a parameter that could affect that use. Except for the Tongue River, the quality of the water used for irrigation in the CBM area varies a good deal. Some of this variation is related to flow but other factors are also important. In addition, the effects of EC and the SAR of the irrigation water on soils and crop production are dependent on the interaction of several factors other than the water. These factors and their interactions are briefly discussed below and the information that the department needs from the irrigators is described.

Most of the material given here is copied or summarized from two sources. They are, Hansen, B.R., S. R. Gratton, and A. Fulton. *AGRICULTURAL SALINITY AND DRAINAGE*. University of California Irrigation Program. University of California, Davis. Revised 1999, and, Ayers, R. S. and D. W. Westcot, 1985. Water Quality for Agriculture. FAO Irrigation and Drainage paper 29 (Rev 1), Food

and Agriculture Organization of the United Nations.

Table 1, adapted from from Ayers and Westcot, gives guidelines for EC and SAR for irrigation. The reader should bear in mind that these are guidelines and not absolute values. The reader should also read the footnotes and the basic assumptions carefully.

Table 1

GUIDELINES FOR INTERPRETATIONS OF WATER QUALITY FOR IRRIGATION[1]

Potential Irrigation Problem	Units	Degree of Restriction on Use: None	Slight to Moderate	Severe
Salinity *(affects crop water availability)*[2]				
EC_w	dS/m	< 0.7	0.7 - 3.0	> 3.0
(or) TDS	mg/l	<450	450 - 2000	> 2000
Infiltration *(affects infiltration rate of water into the soil . Evaluate using EC_w and SAR together)*[3]				
SAR = 0 - 3 and EC_w =		>0.7	0.7 - 0.2	< 0.2
SAR = 3 -6 and EC_w =		>1.2	1.2 - 0.3	< 0.3
= 3 - 6		1.2		
SAR = 6 - 12 and EC_w =		>1.9	1.9 - 0.5	< 0.5
		1.9		
SAR = 12-20 and EC_w =		>2.9	2.9 - 1.3	< 1.3
SAR = 20-40 and EC_w =		>5.0	5.0 - 2.9	< 2.9

[1]Adapted from University of California Committee of Consultants 1974.

[2]ECw means electrical conductivity, a measure of the water salinity, reported in deciSiemens per meter at 25°C (dS/m) or in units millimhos per centimeter (mmho/cm). Both are equivalent. TDS means total dissolved solids, reported in milligrams per liter (mg/1).

[3]SAR means sodium adsorption ratio. SAR is sometimes reported by the symbol RNs. See Figure 1 for the SAR calculation procedure. At a given SAR, infiltration rate increases as water salinity increases. Evaluate the potential infiltration problem by SAR as modified by ECw. Adapted from Rhoades 1977, and Oster and Schroer 1979.

The water quality guidelines in Table 1 are intended to cover the wide range of conditions encountered in irrigated agriculture. Several basic assumptions (given below) have been used to

define their range of usability. If the irrigation water is used under significantly different conditions, the guidelines may need to be adjusted. Wide deviations from the assumptions might result in wrong judgements about the usability of a particular water supply, especially if it is a borderline case. Where sufficient experience, field trials, research or observations are available, the guidelines may be modified to fit local conditions more closely.

The basic assumptions in the guidelines are:

Yield Potential: Full production capability of all crops, without the use of special practices, is assumed when the guidelines indicate no restrictions on use. A "restriction on use" indicates that there may be a limitation in choice of crop, or special management may be needed to maintain full production capability. A "restriction on use" does not indicate that the water is unsuitable for use.

Site Conditions: Soil texture ranges from sandy-loam to clay-loam with good internal drainage. The climate is semi-arid to arid. Rainfall does not play a significant role in meeting the crop's water demand or leaching requirement. (In a monsoon climate or areas where precipitation is high for part or all of the year, the guideline restrictions are too severe. Under the higher rainfall situations, infiltrated water from rainfall is effective in meeting all or part of the leaching requirement.) Drainage is assumed to be good, with no uncontrolled shallow water table present within 2 meters of the surface.

Methods and Timing of Irrigations: Normal surface or sprinkler irrigation methods are used. Water is applied infrequently, as needed, and the crop utilizes a considerable portion of the available stored soil-water (50 percent or more) before the next irrigation. At least 15 percent of the applied water percolates below the root zone (leaching fraction [LF]=15 percent). The guidelines are too restrictive for specialized irrigation methods, such as localized drip irrigation, which results in near daily or frequent irrigations, but are applicable for subsurface irrigation if surface applied leaching water satisfies the leaching requirements.

Water Uptake by Crops: Different crops have different water uptake patterns, but all take water from wherever it is most readily available within the rooting depth. On average about 40 percent of water is assumed to be taken from the upper quarter of the rooting depth, 30 percent from the second quarter, 20 percent from the third quarter, and 10 percent from the lowest quarter. Each irrigation leaches the upper root zone and maintains it at a relatively low salinity. Salinity increases with depth and is greatest in the lower part of the root zone. The average salinity of the soil-water is three times that of the applied water and is representative of the average root zone salinity to which the crop responds. These conditions result from a leaching fraction of 15-20 percent and irrigations that are timed to keep the crop adequately watered at all times.

Salts leached from the upper root zone accumulate to some extent in the lower root zone but a salt balance is achieved as salts are moved below the root zone by sufficient leaching. The higher salinity in the lower root zone becomes less important if adequate moisture is maintained in the upper, "more active" part of the root zone and long-term leaching is accomplished.

Restriction on Use: The "Restriction on Use" shown in Table 1 is divided into three degrees of severity: none, slight to moderate, and severe. The divisions are somewhat arbitrary since change occurs gradually and there is no clear-cut breaking point. A change of 10 to 20 percent above or below a guideline value has little significance if considered in proper perspective with other factors affecting yield. Field studies, research trials and observations have led to these divisions, but management skill of the water user can alter them. Values shown are applicable under normal field conditions prevailing in most irrigated areas in the arid and semi-arid regions of the world.

Salinity

Salinity refers to the amount of dissolved solids in water and is generally expressed as parts per million (ppm) total dissolved solids (TDS). Electrical Conductance (EC) can also be used as a measure of salinity and is considerably cheaper and easier to measure and monitor. EC will be used in this discussion.

It is important to note that soil scientists express EC in terms of deciSiemens per meter (dS/m) while water quality results are expressed as microSiemens per centimeter (μS/cm). One dS/m equals 1000 μS/cm. Thus, when the water of the Tongue River has an EC of 700 μS/cm it also has an EC of 0.7 dS/m.

The general effects of salts will be described first and then some of the many complicating factors will be discussed. Please bear in mind that this is just the start of the standards setting process. After the department develops draft criteria to protect water uses the Board of Environmental Review will, after considering public comments, determine what standards, if any, will be adopted.

Background

Plants expend energy to extract water from soil. As the salinity of the water in the soil increases the energy needed to extract water also increases. At some point, which varies with the type of crop, further increases in salinity will result in a decrease in crop production.

The composition of the soil, the salinity of the irrigation water, and the amount of irrigation water (and precipitation) that passes through the soil determine the salinity of the water in the soil. In the Powder River Basin the effects of precipitation on leaching in the irrigated areas are generally insignificant and these effects will not be discussed.

Salts in the water may be precipitated out of solution in the soil and salts in the soil may be dissolved by the water in the soil. These processes are determined primarily by the composition of the soil. However, due to the complexities and site specific nature of these processes they will not be discussed here except to note that overall, the total concentration of salts in the water are likely to be increased by contact with the soil.

The percentage of applied water that passes through the soil is called the leaching fraction. The salinity of the irrigation water and the leaching fraction are the most important factors affecting the salinity of the soil water. The salinity of the soil water is important because it, and not the salinity of the irrigation water is responsible for any decrease in crop yield. Continued irrigation will result in the salinity of the soil water coming into equilibrium with the salinity of the irrigation water. The actual relationship will be dependent on the average salinity of the irrigation water and the actual leaching fraction. The characteristics of the soils, especially the amount of clay present in the soils affect the leaching fraction. Significant amounts of clay restrict the amount of leaching that can occur which cam make it difficult to maintain low levels of salts in the soil water.

The relationship between soil water salinity and crop yield will be discussed first and then the relationship between irrigation water salinity and soil water salinity will be discussed.

Crop yield

Table 4 from Ayers can be used to estimate the expected yields for selected crops that are grown using water with differing levels of salinity. The example discussed after the table will help clarify how to use this information.

Table 4 CROP TOLERANCE AND YIELD POTENTIAL OF SELECTED CROPS AS INFLUENCED BY IRRIGATION WATER SALINITY (EC_w) OR SOIL SALINITY (EC_e)[1]

YIELD POTENTIAL[2]

FIELD CROPS	100%		90%		75%		50%		0% "maximum"[3]	
	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w
Barley *(Hordeum vulgare)*[4]	8.0	5.3	10	6.7	13	8.7	18	12	28	19
Cotton *(Gossypium hirsutum)*	7.7	5.1	9.6	6.4	13	8.4	17	12	27	18
Sugarbeet *(Beta vulgaris)*[5]	7.0	4.7	8.7	5.8	11	7.5	15	10	24	16
Sorghum *(Sorghum bicolor)*	6.8	4.5	7.4	5.0	8.4	5.6	9.9	6.7	13	8.7
Wheat *(Triticum aestivum)*[4,6]	6.0	4.0	7.4	4.9	9.5	6.3	13	8.7	20	13
Wheat, durum *(Triticum turgidum)*	5.7	3.8	7.6	5.0	10	6.9	15	10	24	16
Soybean *(Glycine max)*	5.0	3.3	5.5	3.7	6.3	4.2	7.5	5.0	10	6.7
Cowpea *(Vigna unguiculata)*	4.9	3.3	5.7	3.8	7.0	4.7	9.1	6.0	13	8.8
Groundnut (Peanut) *(Arachis hypogaea)*	3.2	2.1	3.5	2.4	4.1	2.7	4.9	3.3	6.6	4.4
Rice (paddy) *(Oriza sativa)*	3.0	2.0	3.8	2.6	5.1	3.4	7.2	4.8	11	7.6
Sugarcane *(Saccharum officinarum)*	1.7	1.1	3.4	2.3	5.9	4.0	10	6.8	19	12
Corn (maize) *(Zea mays)*	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10	6.7
Flax *(Linum usitatissimum)*	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10	6.7
Broadbean *(Vicia faba)*	1.5	1.1	2.6	1.8	4.2	2.0	6.8	4.5	12	8.0
Bean *(Phaseolus vulgaris)*	1.0	0.7	1.5	1.0	2.3	1.5	3.6	2.4	6.3	4.2
VEGETABLE CROPS										
Squash, zucchini (courgette) *(Cucurbita pepo melopepo)*	4.7	3.1	5.8	3.8	7.4	4.9	10	6.7	15	10
Beet, red *(Beta vulgaris)*[5]	4.0	2.7	5.1	3.4	6.8	4.5	9.6	6.4	15	10
Squash, scallop *(Cucurbita pepo melopepo)*	3.2	2.1	3.8	2.6	4.8	3.2	6.3	4.2	9.4	6.3
Broccoli *(Brassica oleracea botrytis)*	2.8	1.9	3.9	2.6	5.5	3.7	8.2	5.5	14	9.1
Tomato *(Lycopersicon esculentum)*	2.5	1.7	3.5	2.3	5.0	3.4	7.6	5.0	13	8.4
Cucumber *(Cucumis sativus)*	2.5	1.7	3.3	2.2	4.4	2.9	6.3	4.2	10	6.8
Spinach *(Spinacia oleracea)*	2.0	1.3	3.3	2.2	5.3	3.5	8.6	5.7	15	10
Celery *(Apium graveolens)*	1.8	1.2	3.4	2.3	5.8	3.9	9.9	6.6	18	12
Cabbage *(Brassica oleracea capitata)*	1.8	1.2	2.8	1.9	4.4	2.9	7.0	4.6	12	8.1
Potato *(Solanum tuberosum)*	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10	6.7
Corn, sweet (maize) *(Zea mays)*	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10	6.7
Sweet potato *(Impomoea batatas)*	1.5	1.0	2.4	1.6	3.8	2.5	6.0	4.0	11	7.1
Pepper *(Capsicum annuum)*	1.5	1.0	2.2	1.5	3.3	2.2	5.1	3.4	8.6	5.8
Lettuce *(Lactuca sativa)*	1.3	0.9	2.1	1.4	3.2	2.1	5.1	3.4	9.0	6.0
Radish *(Raphanus sativus)*	1.2	0.8	2.0	1.3	3.1	2.1	5.0	3.4	8.9	5.9
Onion *(Allium cepa)*	1.2	0.8	1.8	1.2	2.8	1.8	4.3	2.9	7.4	5.0
Carrot *(Daucus carota)*	1.0	0.7	1.7	1.1	2.8	1.9	4.6	3.0	8.1	5.4
Bean *(Phaseolus vulgaris)*	1.0	0.7	1.5	1.0	2.3	1.5	3.6	2.4	6.3	4.2
Turnip *(Brassica rapa)*	0.9	0.6	2.0	1.3	3.7	2.5	6.5	4.3	12	8.0

Table 4 (continued)

YIELD POTENTIAL

FORAGE CROPS	100%		90%		75%		50%		0% "maximum"[3]	
	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w
Wheatgrass, tall *(Agropyron elongatum)*	7.5	5.0	9.9	6.6	13	9.0	19	13	31	21
Wheatgrass, fairway crested *(Agropyron cristatum)*	7.5	5.0	9.0	6.0	11	7.4	15	9.8	22	15
Bermuda grass *(Cynodon dactylon)*[7]	6.9	4.6	8.5	5.6	11	7.2	15	9.8	23	15
Barley (forage) *(Hordeum vulgare)*[4]	6.0	4.0	7.4	4.9	9.5	6.4	13	8.7	20	13
Ryegrass, perennial *(Lolium perenne)*	5.6	3.7	6.9	4.6	8.9	5.9	12	8.1	19	13
Trefoil, narrowleaf birdsfoot[8] *(Lotus corniculatus tenuifolium)*	5.0	3.3	6.0	4.0	7.5	5.0	10	6.7	15	10
Harding grass *(Phalaris tuberosa)*	4.6	3.1	5.9	3.9	7.9	5.3	11	7.4	18	12
Fescue, tall *(Festuca elatior)*	3.9	2.6	5.5	3.6	7.8	5.2	12	7.8	20	13
Wheatgrass, standard crested *(Agropyron sibiricum)*	3.5	2.3	6.0	4.0	9.8	6.5	16	11	28	19
Vetch, common *(Vicia angustifolia)*	3.0	2.0	3.9	2.6	5.3	3.5	7.6	5.0	12	8.1
Sudan grass *(Sorghum sudanense)*	2.8	1.9	5.1	3.4	8.6	5.7	14	9.6	26	17
Wildrye, beardless *(Elymus triticoides)*	2.7	1.8	4.4	2.9	6.9	4.6	11	7.4	19	13
Cowpea (forage) *(Vigna unguiculata)*	2.5	1.7	3.4	2.3	4.8	3.2	7.1	4.8	12	7.8
Trefoil, big *(Lotus uliginosus)*	2.3	1.5	2.8	1.9	3.6	2.4	4.9	3.3	7.6	5.0
Sesbania *(Sesbania exaltata)*	2.3	1.5	3.7	2.5	5.9	3.9	9.4	6.3	17	11
Sphaerophysa *(Sphaerophysa salsula)*	2.2	1.5	3.6	2.4	5.8	3.8	9.3	6.2	16	11
Alfalfa *(Medicago sativa)*	2.0	1.3	3.4	2.2	5.4	3.6	8.8	5.9	16	10
Lovegrass *(Eragrostis sp.)*[9]	2.0	1.3	3.2	2.1	5.0	3.3	8.0	5.3	14	9.3
Corn (forage) (maize) *(Zea mays)*	1.8	1.2	3.2	2.1	5.2	3.5	8.6	5.7	15	10
Clover, berseem *(Trifolium alexandrinum)*	1.5	1.0	3.2	2.2	5.9	3.9	10	6.8	19	13
Orchard grass *(Dactylis glomerata)*	1.5	1.0	3.1	2.1	5.5	3.7	9.6	6.4	18	12
Foxtail, meadow *(Alopecurus pratensis)*	1.5	1.0	2.5	1.7	4.1	2.7	6.7	4.5	12	7.9
Clover, red *(Trifolium pratense)*	1.5	1.0	2.3	1.6	3.6	2.4	5.7	3.8	9.8	6.6
Clover, alsike *(Trifolium hybridum)*	1.5	1.0	2.3	1.6	3.6	2.4	5.7	3.8	9.8	6.6
Clover, ladino *(Trifolium repens)*	1.5	1.0	2.3	1.6	3.6	2.4	5.7	3.8	9.8	6.6
Clover, strawberry *(Trifolium fragiferum)*	1.5	1.0	2.3	1.6	3.6	2.4	5.7	3.8	9.8	6.6
FRUIT CROPS[10]										
Date palm *(Phoenix dactylifera)*	4.0	2.7	6.8	4.5	11	7.3	18	12	32	21
Grapefruit *(Citrus paradisi)*[11]	1.8	1.2	2.4	1.6	3.4	2.2	4.9	3.3	8.0	5.4
Orange *(Citrus sinensis)*	1.7	1.1	2.3	1.6	3.3	2.2	4.8	3.2	8.0	5.3
Peach *(Prunus persica)*	1.7	1.1	2.2	1.5	2.9	1.9	4.1	2.7	6.5	4.3
Apricot *(Prunus armeniaca)*[11]	1.6	1.1	2.0	1.3	2.6	1.8	3.7	2.5	5.8	3.8
Grape *(Vitus sp.)*[11]	1.5	1.0	2.5	1.7	4.1	2.7	6.7	4.5	12	7.9
Almond *(Prunus dulcis)*[11]	1.5	1.0	2.0	1.4	2.8	1.9	4.1	2.8	6.8	4.5

Table 4 (continued)

YIELD POTENTIAL

FRUIT CROPS [10]	100%		90%		75%		50%		0% "maximum"[3]	
	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w
Plum, prune *(Prunus domestica)*[11]	1.5	1.0	2.1	1.4	2.9	1.9	4.3	2.9	7.1	4.7
Blackberry *(Rubus sp.)*	1.5	1.0	2.0	1.3	2.6	1.8	3.8	2.5	6.0	4.0
Boysenberry *(Rubus ursinus)*	1.5	1.0	2.0	1.3	2.6	1.8	3.8	2.5	6.0	4.0
Strawberry *(Fragaria sp.)*	1.0	0.7	1.3	0.9	1.8	1.2	2.5	1.7	4	2.7

[1] Adapted from Maas and Hoffman (1977) and Maas (1984). These data should only serve as a guide to relative tolerances among crops. Absolute tolerances vary depending upon climate, soil conditions and cultural practices. In gypsiferous soils, plants will tolerate about 2 dS/m higher soil salinity (ECe) than indicated but the water salinity (ECw) will remain the same as shown in this table.

[2] ECe means average root zone salinity as measured by electrical conductivity of the saturation extract of the soil, reported in deciSiemens per metre (dS/m) at 25°C. ECw means electrical conductivity of the irrigation water in deciSiemens per metre (dS/m). The relationship between soil salinity and water salinity (ECe = 1.5 ECw) assumes a 15-20 percent leaching fraction and a 40-30-20-10 percent water use pattern for the upper to lower quarters of the root zone. These assumptions were used in developing the guidelines in Table 1.

[3] The zero yield potential or maximum ECe indicates the theoretical soil salinity (ECe) at which crop growth ceases.

[4] Barley and wheat are less tolerant during germination and seedling stage; ECe should not exceed 4-5 dS/m in the upper soil during this period.

[5] Beets are more sensitive during germination; ECe should not exceed 3 dS/m in the seeding area for garden beets and sugar beets.

[6] Semi-dwarf, short cultivars may be less tolerant.

[7] Tolerance given is an average of several varieties; Suwannee and Coastal Bermuda grass are about 20 percent more tolerant, while Common and Greenfield Bermuda grass are about 20 percent less tolerant.

[8] Broadleaf Birdsfoot Trefoil seems less tolerant than Narrowleaf Birdsfoot Trefoil.

[9] Tolerance given is an average for Boer, Wilman, Sand and Weeping Lovegrass; Lehman Lovegrass seems about 50 percent more tolerant.

[10] These data are applicable when rootstocks are used that do not accumulate Na^+ and Cl^- rapidly or when these ions do not predominate in the soil. If either ions do, refer to the toxicity discussion in Section 4.

[11] Tolerance evaluation is based on tree growth and not on yield.

Alfalfa, a forage crop, will be used as an example to help explain the information in this table. In the column title 100% and subtitled EC_e (the EC of the soil water), the value for alfalfa is 1.3. This means that as long as the average EC of the soil water does not exceed 1.3 dS/m (or 1300 μS/cm) the salinity of the water will not cause a decrease in yield. Likewise when the average EC of the soil water (EC_e) reaches 2.2 dS/m the salinity by itsself will cause a 10 percent decrease in yield and an EC_e of 5.9 will cause a 50% decrease in yield.

Table 4 also contains values for EC_w (the EC of the irrigation water). These values are the average concentration of the irrigation water that will result in the corresponding EC_e. Footnote 2 points out that these EC_w values or irrigation water electrical conductance values are based on an assumed leaching fraction of 15 to 20 percent. This means that, for alfalfa, if the EC of the irrigation water is 1,300 μS/cm or less and the leaching fraction is 20 percent, the salinity of the soil water would be 2,000 μS/cm and there would be no decrease in yield.

To this point things are fairly simple. If the crop is alfalfa and the EC of the irrigation water (EC_w) is near 1,300 μs/cm (1.3 dS/m) then the leaching fraction must be 15 to 20 percent. In other words, if the crop needs 24 inches of water per season then 24 inches plus 20 percent (4.8) or a total of 28.8 inches of water must be applied in order to maintain maximum yield. If the irrigation water salinity is greater than 1,300 μs/cm or the leaching fraction is less than 20 percent yields will be decreased. There would be a 10 percent yield decrease if the average irrigation water conductivity were 2,200 μs/cm (2.2 dS/m) and a 25 percent yield decrease if the average irrigation water conductivity is 3,600 μs/cm (3.6 dS/m). In order to determine the effects of changing the leaching fraction an extra step is required.

Figure 1, from Hansen, gives the relationship between the EC of the irrigation water and the EC of the soil water at various leaching fractions. Note that an irrigation water EC of 1.3 dS/m and a leaching fraction of 20% results in an "average root zone" EC of 2 dS/m. The "average root zone" EC is the same as the salinity of the soil water. By using Figure 1 it can be seen that if the EC of the irrigation is 1.3 dS/m and the leaching fraction is 5% the resulting soil water salinity will be about 3.6 dS/m. According to Table 4 this corresponds to about a 25% reduction in yield. If the leaching fraction is 40% then the irrigation water EC could be as high as 2 dS/m without causing decreases in yield.

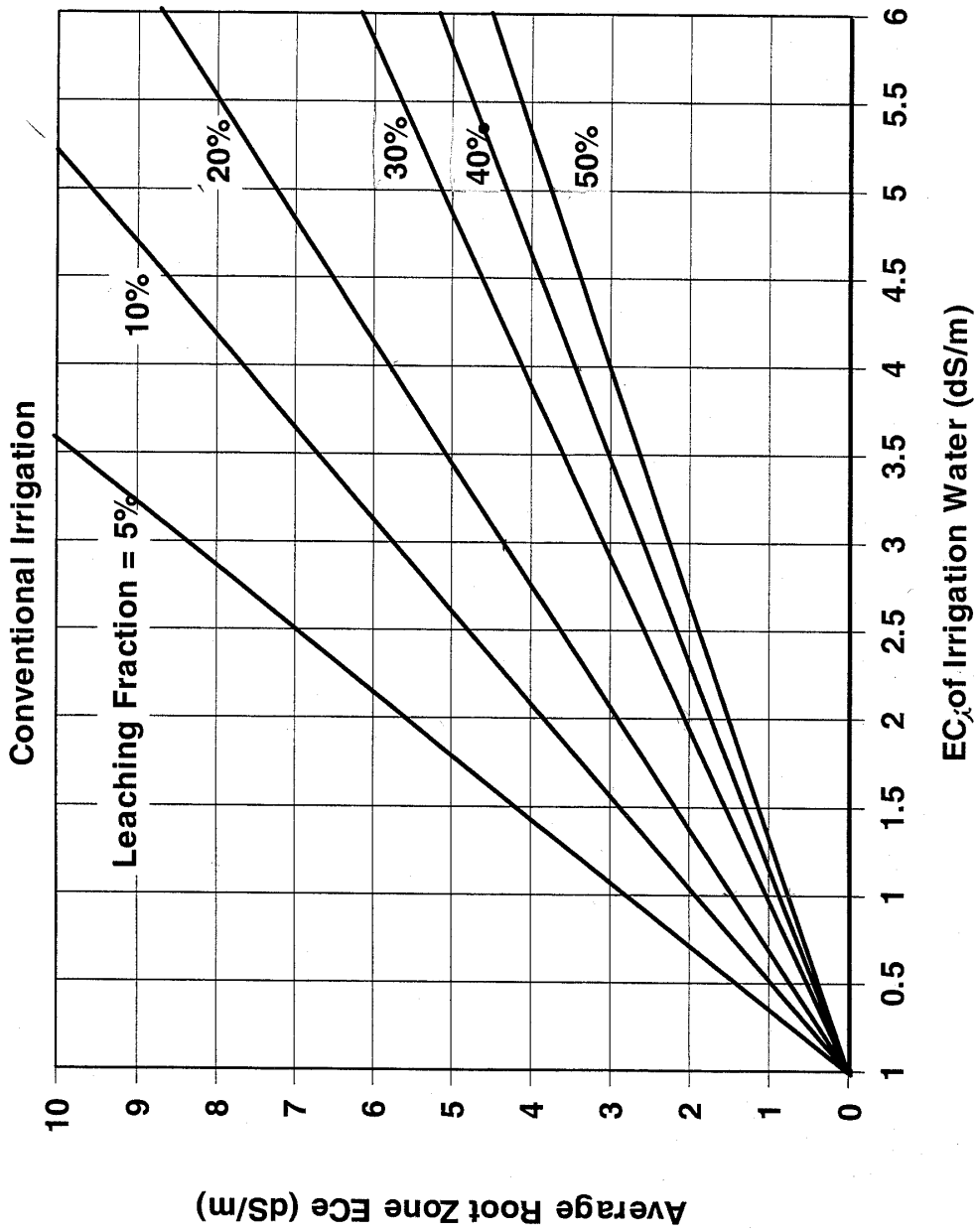

Figure 1. Assessing the maintenance leaching fraction under conventional irrigation methods.

These are all approximate values and assume that sufficient water can pass through the root zone of the irrigated soils. This should not be a problem for most soils for the lower leaching requirements. However, it may be difficult to pass sufficient water through the root zone to achieve the higher leaching fractions, especially in "heavy soils " (soils with a high content of clay). In addition, these tables assume that sufficient water is physically and legally available for the increased leaching. Increasing the leaching fraction from 20 to 40 percent would require 20% more water. All of the information presented to date assumes that leaching is uniform throughout a field.

With conventional irrigation, the leaching fraction is not uniform throughout a field. First of all, there are usually differences in the soil characteristics in a field. Thus, there is likely to be differences in the rate at which water flows through the root zone in different parts of a field because the soil texture and thus the permeability of the soils vary. Secondly, the rate at which water enters the soil at a particular point is partially determined by the water pressure or depth of water at that point. Fields are seldom level. Less water will enter the soils in the "high spots" (a few inches can make a difference) of the field where the depth of water will be least. Most importantly, the amount of leaching that occurs is dependent on the time that excess water is applied to the soil. During conventional flood irrigation, the soils in the upper part of a field near the ditches will be covered with water much longer than the soils at the bottom or tail end of a field.

The problems of low permeability, high spots, differences in the length of time water is applied to different parts of a field can be overcome by dikeing an entire field (like a rice paddy) and covering it with water for as long as necessary to achieve the desired leaching. This assumes that the crop can tolerate being submerged for a sufficient length of time and that it is physically possible to flood the entire field.

Development of salinity criteria

The following information would be useful for the development of salinity criteria. This is not a complete list. Any information dealing with salinity problems in the basin will be useful.

Current irrigation practices in each sub-basin. This includes the amount of each of type irrigation, conventional flood, "complete dikeing", and sprinkler.

The crops that are grown in each sub-basin and the relative amounts of each.

The EC of the soil water prior to coal bed methane development.

The EC of the irrigation water.

Evidence of salinity problems now. This includes salt spots in fields, decreased production at the tail end of fields, and salt buildup in fields with heavy clay soils. It also includes fields that were abandoned in the past due to salinity problems.

Sodium Adsorption Ratio (SAR)

Background

The clay portion of soils consists of very small plate-like structures stacked like decks of cards. Water in soil moves, and it enters soils, by flowing between the "stacks." The plates are held together primarily by calcium ions and to a lesser degree by magnesium ions. Replacement of the calcium ions between the plates with sodium ions tends to force the plates apart and in effect to breakup the "stacks" or "decks."

As the stacks are broken apart, or dispersed, the rate at which water enters the soil (the infiltration rate) decreases. In some cases the rate may become very close to zero. This makes production of crops impractical. This effect does not occur in soils that have very little clay. The size of the effect also depends on the amount (and type) of clay in the soils. Most of the soils in the Powder and Tongue River Basins contain some clay and some of the soils have a lot of clay.

The effect of sodium on soils is related to the abundance, or ratio, of sodium to the abundance of calcium and magnesium. This is called the sodium adsorption ratio or SAR. The effects are also directly related to the total abundance of all of the ions. As the EC of water increases a given SAR becomes less harmful. This relationship is shown in Table 1.

In the Infiltration section of Table 1 the restrictions on use are given for various combinations of SAR and EC. These restrictions are actually caused be reductions in infiltration. For instance if the SAR ranges from 0 - 3 and the EC is less than 0.2 dS/m (remember this corresponds to 200 μS/cm) there will be severe reductions in infiltration. If the EC is between 0.2 and 0.7 dS/m at the same SAR there will be slight to moderate reductions in infiltration. If the EC is greater than 0.7 dS/m will there be no reductions in infiltration. Figure 3 (from Hansen et al) shows these relationships in a graphical format. It is possible to derive the mathematical relationships of the lines in this figure and the resulting formula can be used to calculate the SAR values that would result in reductions in infiltration at any EC.

The relationship between EC and the SAR that will result in no reduction in infiltration is:
SAR = (EC times 0.0071)-2.4754 where EC is expressed as μS/cm[8].

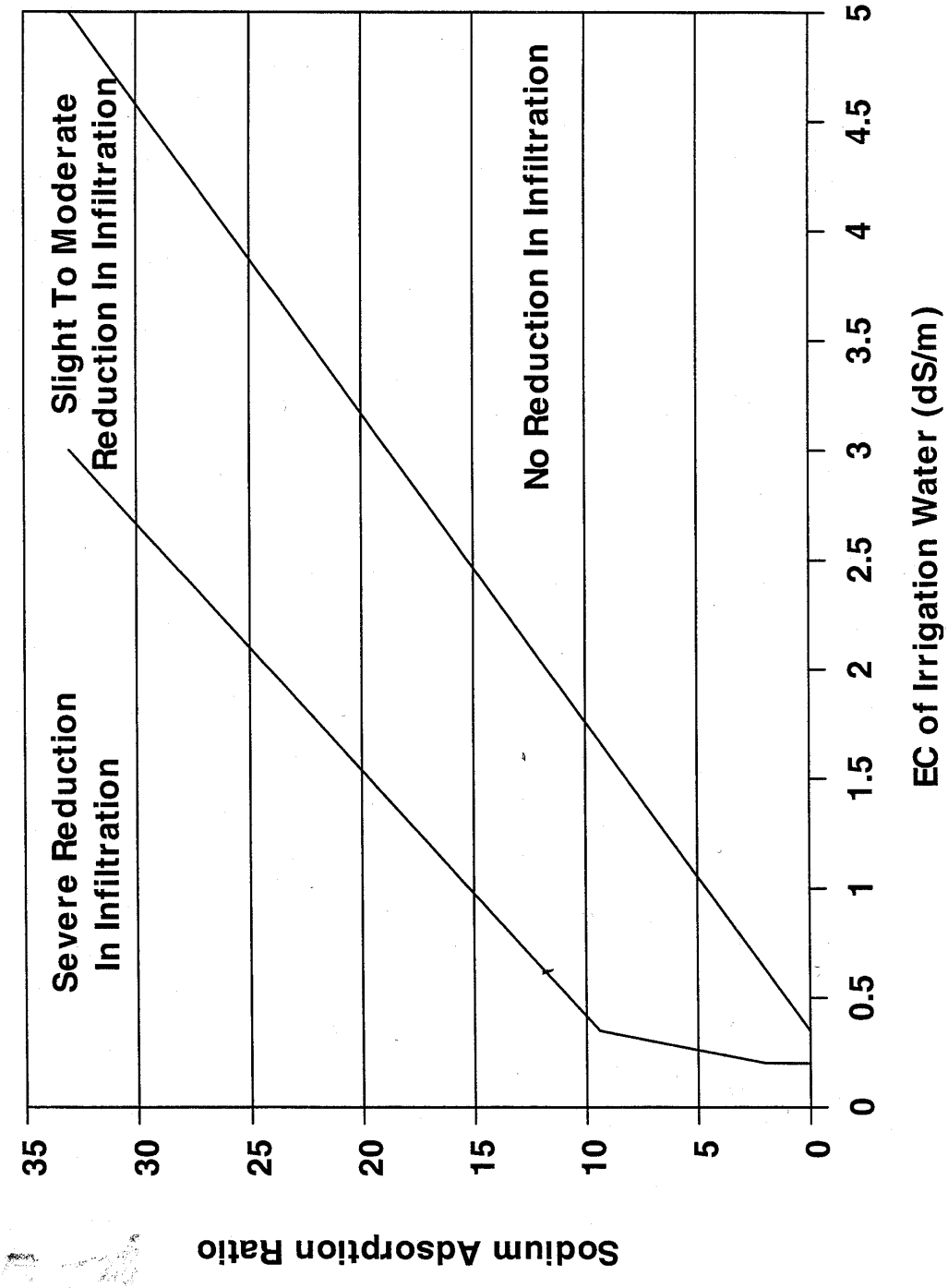

Figure 3. Assessing the effect of salinity and sodium adsorption ratio on infiltration rate.