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Managing Irrigation Water Quality

for crop production in the Pacific Northwest

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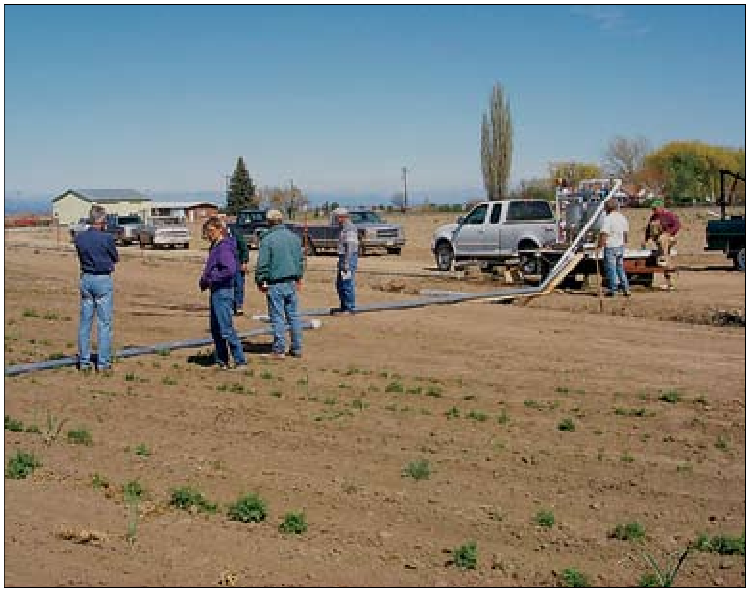
Managing Irrigation Water Quality for Crop Production in the Pacific Northwest

Water quality is a concern to everyone who uses water. How to manage water in a specific situation can be both a practical and financial challenge.

This publication focuses on analyses used for typical agricultural irrigation water sources. Water originating from an industrial, livestock, or municipal source may require additional analyses and care.

Some irrigation waters can damage plants directly, while others damage soil structure. The impact of irrigation water on soil and plants depends on the water, soil, crop, and environmental conditions. The tables and guidelines in this publication are not all-encompassing and may not be appropriate for some situations. Experimentation and consultation with experts will help establish a water management program for a particular situation.

After deciding on a water treatment method (e.g., adding gypsum or acid), make sure the water treatment system is working properly by monitoring the resulting water quality.



What's in this publication?

This publication focuses on using water analyses to choose appropriate water treatment and water management practices for irrigated agriculture. It will help determine:

- What tests are needed to characterize water quality
- How to collect water samples
- How to interpret analytical data from a laboratory
- How to use water analyses to identify water use limitations
- How to determine the amount of salts and nutrients applied by irrigation
- Options for managing irrigation water to avoid:
    - Salt accumulation
    - Excess sodium and soil surface sealing
    - Lime deposition on fruits and vegetables
    - Emitter and nozzle plugging
    - Chloride and boron toxicity
    - Excessive nutrient application

The examples on pages 21–23 provide information on how to evaluate water quality and choose appropriate management practices. Definitions are found in the glossary (page 20). A companion publication, *Managing Saline and Sodic Soils for Crop Production* (in press), will provide guidance for managing irrigated soils.

Irrigation water analyses

The first step in assessing irrigation water is to test the water. Although past experience with an irrigation water is valuable, a water analysis is essential to prevent irrigation-induced problems.

When sampling for legal or regulatory purposes, consult a laboratory or water analysis expert for sampling guidance.

Sampling procedures

Sampling irrigation water starts with a clean container. A clean 1-quart plastic or glass container is suitable for routine agricultural irrigation water analysis. Plastic containers may be shipped, but glass containers must be hand delivered to the laboratory. Laboratories often provide sample containers, and some laboratories collect samples themselves. Label the container with sample identification, contact information, sample date, and location.

Before sampling, pump the water long enough to clear residual impurities from the irrigation system. (When sampling during an irrigation cycle, this is not an issue.)

Rinse the container at least three times with the water to be tested and fill it all the way to the top. Immediately submit samples to a laboratory for analysis. If possible, samples should remain cool during shipping (below 40°F).

Wastewater containing high concentrations of suspended organic materials (such as raw manure) requires special handling. Ask the laboratory about its requirements.

How often should I sample?

Testing frequency is based on water use and source. Surface waters are subject to seasonal weather and flow patterns and may need frequent monitoring. The chemical composition of groundwater changes slowly and usually needs to be tested only every few years. Deep basalt aquifers are less likely to change than shallow alluvial aquifers, which are influenced by land practices. As long-term aquifer levels subside, incorporate the resulting changes in water quality into an irrigation water monitoring program.

Analyze water before purchasing or leasing new ground. Also analyze water when a new well or other water source becomes available.

Wastewater sampling frequency, such as for dairy effluent, should be based on the farm's circumstances. Sampling may be dictated by a permit from a regulatory agency. Agricultural wastewaters are less regulated than industrial and municipal sources, but analysis is recommended for proper management.

What analyses should be performed?

Irrigation water samples should be tested for at least the analytes listed in Table 1. Analyzing for iron (Fe) and manganese (Mn) concentration may also be beneficial. Consider the water source when determining what analyses should be performed. Water originating from industrial,

Table 1. Cations, anions, and other measurements recommended for characterizing irrigation water quality.

Cations		Anions		Other	
Calcium	Ca^{2+}	Chloride	Cl^-	Total dissolved solids or electrical conductivity	TDS or EC
Magnesium	Mg^{2+}	Boron	BO_3^{3-}	Residual sodium carbonate	RSC[b]
Sodium	Na^+	Carbonate	CO_3^{2-}	Lime deposition potential	LDP[b]
Potassium	K^+	Bicarbonate	HCO_3^-	Sodium adsorption ratio or sodium hazard	SAR[b]
		Sulfate	SO_4^{2-}(a)	Acidity/alkalinity	pH
		Nitrate	NO_3^- (a)		

[a] See Table 2 for conversions to nutrient basis for sulfate (S) and nitrate (N).

[b] RSC, LDP, and SAR are calculated from concentrations of anions and cations present in the water.

livestock, or municipal sources generally requires additional analyses.

Choosing a laboratory

A list of laboratories is available from most local Extension offices or from the state Department of Agriculture. Or, see "References" (page 18) for how to obtain a list of laboratories (OSU Extension publication EM 8677) that provide analyses of irrigation waters in the Pacific Northwest.

A laboratory should have a quality control (QC) program sufficient to ensure that the analytical results are precise and accurate. A lab should use a third-party laboratory proficiency testing QC program, such as NAPT (North American Proficiency Testing).

Analysis units

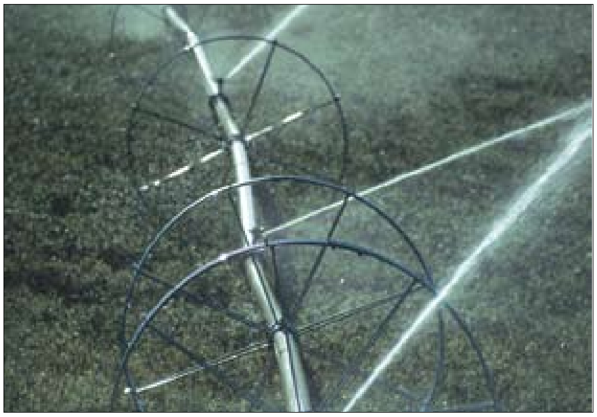
Most laboratories report cation and anion concentrations in water as parts per million (ppm, mg/L, or μg/mL). For the following calculations, milliequivalents per liter (meq/L) is needed, and results must be converted from ppm to meq/L: residual sodium carbonate (RSC), sodium adsorption ratio (SAR), lime deposition potential (LDP), and cation:anion balance. For these analyses, it is useful to know the amount of charge (- or +) contributed by different ions. A meq of charge from any cation balances a meq of charge from any anion. Table 2 gives conversion factors for converting ppm to meq/L.

Sulfur, nitrogen, and boron exist most commonly in irrigation water as sulfate, nitrate, and borate compounds, respectively. Therefore, laboratories commonly report these elements in terms of concentration of these compounds. However, as these elements are also essential nutrients, it is helpful to know the concentration of each in terms of the nutrient alone (without the added weight of the attached oxygen). This enables a crop manager to adjust fertilizer recommendations by subtracting the amount of nutrient being applied in the irrigation water directly from the fertilizer recommendations (see "Crediting N and other nutrients in irrigation water," page 9).

Table 2. Conversion factors for irrigation water cation and anion concentrations.

Measurement	Symbol	To convert from ppm (mg/L) to meq/L[a] divide by
Calcium	Ca^{2+}	20
Magnesium	Mg^{2+}	12.2
Sodium	Na^{+}	23
Potassium	K^{+}	39.1
Chloride	Cl^{-}	35.5
Carbonate	CO_3^{2-}	30
Bicarbonate	HCO_3^{-}	61
Sulfate	SO_4^{2-}	48
Sulfate-sulfur	SO_4^{2-}-S	32.1
Nitrate	NO_3^{-}	62
Nitrate-nitrogen	NO_3^{-}-N	14
Borate	BO_{33}^{-}	19.6
Boron	B	10.8

[a] To convert from meq/L to ppm, multiply by the conversion factor.



Making sure the pieces fit

One way to evaluate analysis quality is to compare the sum of the cations (+) with the sum of the anions (-) in units of meq/L. These two sums should differ by no more than 20 percent when a water analysis is done correctly. Table 3 is an example of a water sample with 6.3 meq/L cations and 6.1 meq/L anions, demonstrating acceptable cation:anion balance.

Salts

What is salt?

A salt is a combination of positively charged elements (cations) and negatively charged elements (anions). Cations include calcium, magnesium, sodium, and potassium. Anions that will dissolve in water include carbonate, bicarbonate, nitrate, sulfate, chloride, and boron (Table 1).

Salt accumulation

Salts accumulate in soil when inputs exceed outputs. Salts are supplied to soil by irrigation water, geologic sources (soil parent material), fertilizers, manures, composts, or any other amendment. Salts are removed by leaching and crop removal. When irrigation water is high in salt, leaching is the only effective way to remove salt.

What problems are caused by excess salt?

Excess salts affect crop production and soil quality. Salt has the following effects on crop yield and quality.

- Soluble salts (those that dissolve in water) damage plants through an osmotic effect; water moves from the area of lower salt concentration (the plant root) to an area of higher salt concentration (the soil). This causes plants to be stressed for water and wilt even though the soil may be wet.
- Soluble salts in irrigation water can desiccate (burn) leaf tissue when applied to foliage.
- Salts deposited on crops can cause leaf and fruit discoloration, reducing market value.
- Irrigation water that supplies nitrogen in excess of crop need may reduce yield and/or quality.

Table 3. Example: Assessing laboratory salt analyses by calculating sums of cations and anions.

Cations	Water analysis		Anions	Water analysis	
	(ppm or mg/L)	(meq/L)		(ppm or mg/L)	(meq/L)
Calcium	80	4.0	Chloride	80	2.3
Magnesium	5	0.4	Carbonate	0	0.0
Sodium	36	1.6	Bicarbonate	125	2.0
Potassium	11	0.3	Sulfate-sulfur[a]	22	0.7
			Nitrate-nitrogen[a]	15	1.1
			Boron[b]	0.2	0.02
Sum cations		**6.3**	**Sum anions**		**6.1**

[a] Nitrate-N and sulfate-S are presented on a nutrient basis (as N and S). See Table 2 for appropriate conversions if the lab reports on an ion basis (S as sulfate, N as nitrate).

[b] Boron has several anionic forms and is reported as elemental.

Salt has the following effects on soil quality.

- Irrigation water with a high ratio of sodium to calcium + magnesium (high SAR) limits water movement into the soil (infiltration) and through the soil (percolation).
- Salts supplied by irrigation water can accumulate in soil, reducing cropping options and increasing management costs.

A common misconception is that salt damage is associated with sodium and/or sodium chloride (table salt). In fact, salt damage results from the sum of all soluble cations and anions present. Problems caused specifically by sodium are discussed on pages 10–14.

Assessing salt hazard

Salts in a water sample are measured by total dissolved solids (TDS) or electrical conductivity (EC). The higher the TDS or EC, the higher the salt hazard. Irrigation water is classified by its salt hazard in Table 4.

For example, water with an EC of 1.0 contains 640 ppm salt. When irrigating with 3 acre-feet of this water, approximately 2.6 tons of salt per acre are applied every year.

(640 ppm salt x 2.7 [million lb water per acre-foot] x 3 acre-feet water) ÷ 2,000 lb per ton = 2.6 tons salt per acre

TDS and EC are reported in a variety of units. If necessary, use Table 5 to convert units to those used in Table 4.

Salt management

Salt removal from irrigation water

Unfortunately, desalinization, the removal of salt from water, is not cost-effective because of the energy required to distill water or the amount of filtration needed. For example, reverse osmosis will remove salt, but 90 percent of the water is wasted and only 10 percent is usable after filtration.

Dilution

When a nonsaline water source is available, but in insufficient quantity to meet all of the crop's needs, it can be mixed with saline water to dilute the salt. Dilution is the only economical way to reduce the salt concentration in irrigation water.

Table 4. General hazard from salinity of irrigation water.

Water electrical conductivity (EC)	Water total dissolved solids (TDS)	Salinity hazard and effects on management
(mmhos/cm or dS/m)	**(ppm)**	
below 0.25	below 160	Very low hazard. No detrimental effects on plants, and no soil buildup expected.
0.25–0.75	160–480	Low hazard. Sensitive plants may show stress; moderate leaching prevents salt accumulation in soil.
0.75–2.0	480–1,280	Medium hazard. Salinity may adversely affect plants. Requires selection of salt-tolerant plants, careful irrigation, good drainage, and leaching.
2.0–3.0	1,280–1,920	Medium-high hazard. Will require careful management to raise most crops.
Above 3.0	Above 1,920	High hazard. Generally unacceptable for irrigation, except for very salt-tolerant plants where there is excellent drainage, frequent leaching, and intensive management.

Table 5. Conversion factors for measurements of salinity of irrigation water.

Measurement	Symbol	To convert	Divide by	To obtain
Total dissolved solids	TDS	mg/L or ppm or µg/mL	640	EC (dS/m or mmhos/cm)
Electrical conductivity	EC	dS/m	1	mmhos/cm
Electrical conductivity	EC	µmhos/cm	1,000	mmho/cm

Crop tolerance to salinity

The following factors are important to keep in mind when managing salts for crop production.

- Salt damage is related to crop sensitivity (Table 6). For example, high-EC irrigation water significantly reduces potato yields, but might not affect wheat as severely.
- Crop tolerance changes with crop growth stage. Plants are most sensitive to elevated salt levels at germination and as immature seedlings. For example, sugarbeets are sensitive to salt as seedlings, but are more tolerant to salt at later growth stages. Seed size also affects salt sensitivity; smaller seeds usually are more sensitive to salts.
- High air temperature, intense sunlight, and/or low humidity can worsen leaf burn from irrigation water salts.
- Leaching need increases with increased water EC.
- As irrigation efficiency increases (less water is applied to grow the crop), leaching decreases, and the likelihood of salt accumulation increases. Regardless of the irrigation system, salts need to be leached from the soil profile periodically via irrigation and/or precipitation.

- A number of crop, soil, and irrigation management practices can be used to maintain productivity when using high-salt irrigation water. These practices are discussed in *Managing Saline and Sodic Soils for Crop Production* (in press).

Too little salt in irrigation water

Water with an EC below 0.2 mmhos/cm can also cause problems. Very low EC water dilutes and/or leaches calcium and makes soil aggregates susceptible to disintegration, causing water infiltration problems.

Adding a calcium salt, such as gypsum or calcium chloride, to the irrigation water and raising the EC to 0.2 to 0.3 mmhos/cm can

Table 6. Potential crop yield reduction due to saline irrigation water.

	Estimated crop yield reduction			
Crop	**0%**	**10%**	**25%**	**50%**
	Electrical conductivity (EC) of water (dS/m or mmhos/cm)			
Barley	4.3	6.7	8.7	12
Wheat	4.0	4.9	6.4	8.7
Sugarbeet[a]	4.7	5.8	7.5	10
Alfalfa	1.3	2.2	3.6	5.9
Potato	1.1	1.7	2.5	3.9
Corn (grain)	1.1	1.7	2.5	3.9
Corn (silage)	1.2	2.1	3.5	5.7
Onion	0.8	1.2	1.8	2.9
Beans	0.7	1.0	1.5	2.4

[a] Especially sensitive during germination. EC should not exceed 3 dS/m for garden beets and sugarbeets during germination.

Source: Adapted from Ayers (1977).

prevent infiltration problems. See “Calculating rate of gypsum addition to irrigation water” to determine the amount of gypsum or calcium chloride needed to increase EC.

Calculating rate of gypsum addition to irrigation water

Example: Irrigation water has an EC of 0.1 mmhos/cm. A grower needs to know how much gypsum (75 percent purity) to add to 1 acre-foot of water to increase EC to 0.25 mmhos/cm.

Step 1. Determine how much the EC of the irrigation water needs to increase.

Equation: Target EC – present EC

Calculation: *0.25 mmhos/cm (target) – 0.10 mmhos/cm (present) = 0.15 mmhos/cm*

Step 2. Calculate the rate of pure gypsum addition.

Equation: Target EC increase (from Step 1) x 640 (ppm salt per unit of EC) x 2.7 (million lb water per acre-ft)

Calculation: *0.15 x 640 x 2.7 = 259 lb gypsum/acre-ft*

Step 3. Calculate the application rate based on the purity of the gypsum.

Equation: Pure gypsum needed x (100 ÷ % purity of material)

Calculation: *259 lb x (100 ÷ 75) = 345 lb of 75% pure gypsum/acre-ft*

Note: Other soluble calcium sources can substitute for gypsum. Adjust for Ca percentage, and use care to avoid materials detrimental to plants and soils.

Individual nutrients

Excess amounts of some nutrients in irrigation water may damage crops and limit crop rotation options. Irrigation waters differ widely in concentrations of nutrients (see “Examples,” pages 21–24).

High concentrations of chloride (Cl) or boron (B) can damage crops. Nitrogen in irrigation water should be subtracted from the recommended fertilizer N to be applied to avoid excessive vegetative growth and succulence and to minimize nitrate leaching to groundwater. Nitrogen supplied by irrigation water can substitute for fertilizer N. Other nutrients supplied by irrigation waters may also satisfy or exceed crop needs.

Chloride

Excess chloride deposited on leaves causes foliar burn. Some plants are more susceptible to chloride than others (Table 7).

Damage caused by high-chloride irrigation water can be minimized by planting a less sensitive crop; avoiding foliar contact by using furrow, flood, or drip irrigation; and rinsing the plants at the end of each irrigation event if a source of high-quality water is available.

Table 7. Chloride classification of irrigation water.

Chloride (mg/L or ppm)	Effect on crops	Susceptible plants
below 70	Safe for most plants	Rhododendron, azalea, blueberry, dry beans
70–140	Sensitive plants show injury	Onion, mint, carrot, lettuce, pepper, grape, raspberry
140–350	Moderately sensitive plants show injury	Potato, alfalfa, sudangrass, squash, wheat, sorghum, corn, tomato
above 350	Can cause severe problems	Sugarbeet, barley, asparagus, cauliflower

Source: Adapted from Ayers and Westcot (1985).

Boron

Boron is toxic to many crops at levels only slightly above those required for growth. Boron concentrations in water of 1 ppm can damage sensitive fruit crops, while other crops may not be damaged until B exceeds 4 ppm (Table 8). High B concentrations in the Pacific Northwest are more common in water from deep basalt wells than in water from shallow alluvial wells.

Preventing buildup of Cl and B in soil

Long-term accumulation of Cl and B in soil can be assessed by soil testing. Buildup of excessive amounts is prevented by periodic leaching. Time leaching events to minimize nitrate-N leaching. See *Managing Saline and Sodic Soils for Crop Production* for more information.

Nitrogen and other nutrients

Irrigation water may supply substantial amounts of nitrogen and other nutrients. Recycled surface irrigation waters (example in Table 9) often are rich in nutrients. Irrigation water diverted directly from streams usually contains lower nutrient concentrations.

Credit nutrients in irrigation water when determining amounts of nutrients to supply from other sources (fertilizers, manures, etc.). Calculate credits from irrigation water analyses (See “Crediting N and other nutrients in irrigation water,” page 9.)

Application of excessive amounts of N can reduce crop quality through several mechanisms.

- Excess N generates excess vegetative growth at the expense of crop yield and impacts maturity, quality, and/or storability, which is

Table 8. Tolerance of plants to boron (B) in irrigation water.

Boron	Rating	Susceptible plants
(mg/L or ppm)		
below 0.5	Extremely sensitive	Blackberry
0.5–0.75	Very sensitive	Peach, cherry, plum, grape, walnut, beans
0.75–1	Sensitive	Wheat, barley, lima bean, garlic, onion, lupine, strawberry, walnut
1–2	Moderately sensitive	Pepper, pea, carrot, radish, potato, cucumber,
2–4	Moderately tolerant	Lettuce, cabbage, turnip, Kentucky bluegrass, oats, corn, mustard, clover, squash, muskmelon
4–6	Tolerant	Sorghum, tomato, alfalfa, vetch, sugarbeet, table beet
6–15	Very tolerant	Asparagus

Table 9. Example: Nutrients supplied by sprinkler application of 1 acre-foot of irrigation water.

Nutrient	Concentration in irrigation water	Nutrient supplied[a]
	(ppm)	**(lb/acre-ft)**
Calcium	80	216
Magnesium	5	14
Sodium	36	97
Potassium	11	30
Chloride	80	216
Sulfate-S	22	59
Nitrate-N	15	41
Boron	0.2	0.5

[a] Convert ppm to lb/acre-ft in irrigation water by multiplying by 2.7.

important for crops such as potatoes, grass seed, sugarbeets, and apples.

- Excess N results in a more succulent plant, which may be more susceptible to insects, pathogens, and frost damage.

Crediting N and other nutrients in irrigation water

Example: A grower applies 30 inches of water via sprinkler irrigation during the growing season. The irrigation water contains 10 mg nitrate-N/liter. Calculate nitrate-N applied in lb/acre.

Equation: Nutrient applied (lb/acre) = A x B x C x 0.227

A = irrigation water applied (in/acre)

B = nutrient concentration in water (mg/L or ppm)

C = decimal fraction of applied water retained in the field (for sprinkler or drip irrigation, C = 1; for furrow irrigation systems, C = 0.5)

0.227 is the factor for converting ppm to lb/acre-inch of water

Calculation: *Nitrate-N applied (lb/acre) = 30 x 10 x 1.0 x 0.227 = 68 lb/acre*

Note: The calculation above assumes that the lab reports in units of ppm (mg/L). If the lab reports nutrients in other units, use the following equations to convert to ppm:

ppm nitrate (NO_3) ÷ 4.4 = ppm nitrate-N (NO_3-N)

ppm sulfate (SO_4) ÷ 3.0 = ppm sulfate-S (SO_4-S)

meq/L nutrient x its equivalent weight (conversion factor in Table 2) = ppm nutrient (for example: meq/L potassium [K] x 39.1 = ppm potassium [K])

Water pH, sodium, and carbonates

In this section we explain the following:

- How water pH, sodium, and carbonate concentrations can limit water use options
- Options for adjusting water chemistry
- How to calculate the quantity of amendments needed to correct water chemistry

Decisions about water chemistry corrections require irrigation water analyses for pH, electrical conductivity, cations (sodium, calcium, and magnesium), and anions (carbonate and bicarbonate) in units of meq/L. To convert water analysis values from ppm to meq/L, see Table 2.

Water pH

Water pH generally is not a problem itself, but it is an indicator of other problems such as sodium and carbonates. Irrigation water tends to be alkaline, commonly in the range of pH 7.2 to 8.5. As irrigation water pH increases above 8.2, the potential for sodium problems increases.

Other management issues related to water pH include the following.

- Water pH can affect performance and persistence of some herbicides.
- High-pH water can reduce the effectiveness of some N fertilizers applied through irrigation.
- Long-term irrigation with high-pH water may cause soil pH to increase.

Sodium and soil structure

Too much sodium relative to calcium + magnesium in water can damage soil structure. (See "Soft water makes hard ground," page 12.) To understand the potential effects of irrigation water on soil structure, several irrigation water characteristics need to be evaluated (Table 10).

Sodium adsorption ratio (SAR): A tool for evaluating sodium hazard

An equation used to predict irrigation water sodium hazard is the sodium adsorption ratio (SAR). SAR is the ratio of sodium to calcium and magnesium. The higher the SAR, the greater the sodium hazard. SAR is calculated as:

$$\text{SAR} = \frac{[\text{Na}^+]}{\sqrt{0.5([\text{Ca}^{2+}] + [\text{Mg}^{2+}])}}$$

In other words, SAR equals the sodium concentration (meq/L) divided by the square root of half of the sum of calcium + magnesium concentrations (meq/L).

When an irrigation water analysis has cations in ppm or mg/L, they must be converted to meq/L, as shown in Table 2, before calculating SAR.

The SAR is not enough by itself to predict the impact of irrigation water on soil. Other components of a water analysis also affect sodium hazard (Table 10). Using EC and SAR to assess the sodium hazard is discussed on page 11. Residual sodium carbonate, another measure of sodium hazard, is discussed on page 14.

Table 10. Water quality tests used to predict irrigation water effects on soil structure.

Water quality test	**Effect of chemical property on soil structure**
Relative concentrations of calcium, magnesium, and sodium (sodium adsorption ratio or SAR)	The higher the SAR, the greater the risk of damaging soil structure.
Dissolved salt (electrical conductivity or EC)	Increased salt concentration (higher EC) in water helps maintain soil structure. (Note, however, that a higher EC increases the salt hazard; see Table 4, page 5.)
Residual sodium carbonate (RSC)	When RSC is positive, calcium is lost from the soil solution via the following chemical reaction: carbonates in water + soil calcium ⟹ calcium carbonate (lime deposit in soil) This loss of calcium from the soil solution increases SAR in the soil solution, thereby increasing the sodium hazard.
Alkalinity (pH)	As pH increases above 8.2, the risk of destroying soil structure increases because of sodium accumulation. Soil with a pH above 8.4 is an indication of sodium predominance.

Using EC and SAR to assess potential for water infiltration problems

Because both SAR and EC affect water infiltration, both must be considered in estimating water infiltration hazard (Table 11). In general, sodium hazard increases as SAR increases and EC decreases.

Table 11 is only a general guide because it gives one interpretation for all soils. Table 11 indicates ranges of interpretive values, rather than absolute values, to reflect variation in how different soils respond to sodium.

In practice, the severity of water infiltration problems depends partly on soil texture. At a given EC and SAR, water infiltration problems are greater with higher soil clay content. The kind of clay also is important. Soils that contain shrink-swell, 2:1 clays have greater water infiltration problems than do 1:1 clays.

To use Table 11, find water SAR in the left column and water EC in one of the other columns. For example, if a water has an SAR of 5 and an EC of 1.5, the risk of water infiltration problems due to sodium is low.

Waters with low risk of water infiltration problems can be used without amendment to adjust SAR or EC. A water with moderate risk (center column) may or may not result in a significant problem with water infiltration. When the risk is high, management practices are needed to prevent loss of soil structure.

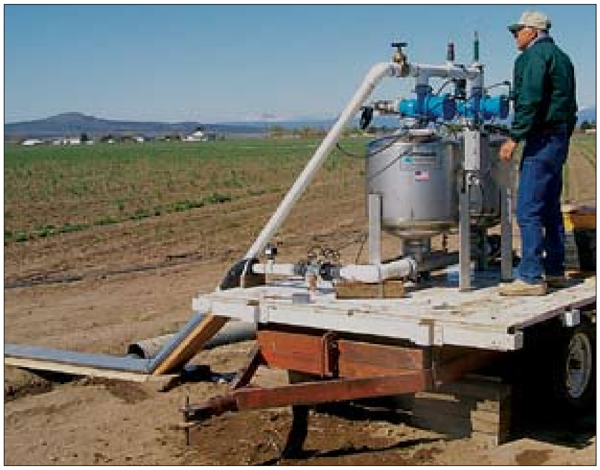


Table 11. Evaluating the risk of sodium in irrigation water causing a water infiltration problem in soil.

Use both the sodium adsorption ratio (SAR) and the electrical conductivity (EC) of the irrigation water to estimate the likelihood of a water infiltration problem.

	Risk of water infiltration problem		
	Low	Moderate	High
SAR	EC of water (dS/m or mmhos/cm)		
0–3	above 0.7	0.7–0.2	below 0.2
3–6	above 1.2	1.2–0.3	below 0.3
6– 12	above 1.9	1.9–0.5	below 0.5
12–20	above 2.9	2.9–1.3	below 1.3
20–40	above 5.0	5.0–2.9	below 2.9

Source: Ayers and Westcot (1985).

Example

Situation: A grower has two water sources and wants to know how the waters compare in terms of sodium hazard.

Water analysis

Water source A has SAR of 5.0 and EC of 0.5.

Water source B has SAR of 5.0 and EC of 1.5.

Interpretation from Table 11

Water A: Water infiltration problems may occur. Severity of problem will depend on soil characteristics.

Water B: Unlikely to cause a water infiltration problem.

Treating water to reduce SAR and increase EC

Water infiltration problems caused by excess sodium are easier to prevent than to remedy. Prevention is accomplished by continually adding soluble calcium to the irrigation water or soil and by leaching the sodium. In the case of saline soil, water infiltration problems caused by excess sodium should be addressed before leaching salts and correcting saline conditions. (See *Managing Saline and Sodic Soils for Crop Production.*)

Water is treated to reduce sodium hazard by injecting calcium into the water. Calcium injection reduces sodium hazard by reducing water SAR and increasing water EC. Calcium also prevents the formation of sodium bicarbonate (an additional water infiltration hazard). Magnesium injection is not usually used to treat water because it is more expensive than calcium and less effective at improving soil structure.

Gypsum or other sources of soluble calcium (e.g., calcium chloride) can be used to treat water. Approximately 20 pounds of 100 percent pure gypsum must be added per acre-inch of water (approximately 27,000 gallons) to increase calcium by 1 meq/L. Gypsum is rarely pure, and the recommended amount must be adjusted for purity. How much gypsum or other calcium source is needed depends on soil texture and other characteristics of the irrigation water (Table 10, page 10).

Soft water makes hard ground

Household water softeners work by replacing calcium and magnesium with sodium, making the water "soft." Soft water is good for preventing lime deposits in plumbing, but it is bad for maintaining good soil structure.

- Soft water (water high in sodium) makes hard ground.
- Hard water (water high in calcium and magnesium) makes soft ground.

See *Managing Saline and Sodic Soils for Crop Production* for more information on soil management practices.

Table 12. How hard irrigation water makes "soft ground" and soft irrigation water makes "hard ground."

Concentration of cations in water	Household water term	Resulting soil structure when this water is used for irrigation
Low sodium relative to calcium + magnesium (low SAR)	hard water	"Soft ground," good soil structure. Water moves into and through soil easily.
High sodium relative to calcium + magnesium (high SAR)	soft water	"Hard ground." Dissolution of soil organic matter ("slick spots") and dispersion of clays results in poor soil structure. Soil surface seals. Water moves very slowly into and through soil.

Example. Calculating gypsum requirement for SAR amendment

Situation: A grower wants to reduce water SAR from 10 to 5, using 75 percent pure gypsum. He also wants to know how much the water EC will increase after adding gypsum.

Water analysis:

1.0 meq/L calcium (Ca)
7.5 meq/L sodium (Na)
0.1 meq/L magnesium (Mg)

Step 1. Solve the SAR equation for soluble calcium needed at the target SAR value.

Units: Ca, Mg, and Na in water in units of meq/L

Equation

$$\text{SAR} = \frac{[\text{Na}^+]}{\sqrt{0.5([\text{Ca}^{2+}] + [\text{Mg}^{2+}])}}$$

First, insert the target SAR (in this case 5.0) and the concentrations of Na and Mg into the equation:

$$5 = \frac{7.5}{\sqrt{0.5([Ca^{2+}] + 0.1)}}$$

Divide both sides by 5:

$$1 = \frac{7.5}{5} \times \frac{1}{\sqrt{0.5([Ca^{2+}] + 0.1)}}$$

Solve for $[\text{Ca}^{2+}]$ by multiplying both sides by $\sqrt{0.5([\text{Ca}^{2+}] + 0.1)}$

$$\sqrt{0.5([Ca^{2+}] + 0.1)} = \frac{7.5}{5}$$

Square both sides:

$$0.5(Ca + 0.1) = \left(\frac{7.5}{5}\right)^2$$

Divide both sides by half:

$$Ca + 0.1 = 2\left(\frac{7.5}{5}\right)^2$$

Subtract 0.1 from both sides:

$$\text{Ca} = 2\left(\frac{7.5}{5}\right)^2 - 0.1$$

Solve for Ca:

$$\begin{aligned} Ca &= 2\,(1.5)^2 - 0.1 \\ &= 2 \times 2.25 - 0.1 \\ &= 4.5 - 0.1 \\ &= 4.4 \end{aligned}$$

Step 2. Determine the amount of Ca needed.

Units: meq/L

Equation: Target Ca - Initial Ca in water

Calculation: *4.4 - 1.0 = 3.4 meq/L Ca*

This is the amount of calcium that needs to be added.

Step 3. Determine the amount of gypsum to add.

Units: lb gypsum/acre-inch of water

Conversion factor: 20 lb of pure gypsum (23% Ca, $CaSO_4 \cdot 2H_2O$) is needed to add 1 meq/L of calcium to 1 acre-inch of water.

Equation: (Ca needed [from Step 2] x 20 x 100) ÷ % purity of gypsum

Calculation: *(3.4 x 20 x 100) ÷ 75% = 91 lb gypsum/acre-inch*

This is the amount of gypsum needed to lower SAR to 5.0.

Step 4. Calculate the increase in EC of water following gypsum addition.

Equations: To convert lb/acre-inch to ppm, multiply by 4.4; to convert ppm to EC, divide by 640

Calculation: *(91 x 4.4) ÷ 640 = 0.63 dS/m (or mmhos/cm)*

This is how much the conductivity of the irrigation water will theoretically increase from the gypsum addition, assuming the gypsum is 100% soluble.

Note: Depending on the initial salt content of the irrigation water, adding gypsum may make water too salty, creating other problems. Adding calcium to water may be incompatible with some fertilizers, especially those containing phosphorus.

Residual sodium carbonate (RSC)

What is RSC?

Another predictor of sodium hazard is the residual sodium carbonate (RSC) of water. RSC is the sum of carbonates (bicarbonate + carbonate) minus the sum of the divalent cations (calcium and magnesium). To calculate RSC, a water analysis with units in meq/L is needed (see Table 2, page 3, for conversion factors).

Why are high-RSC waters a problem?

As RSC increases above zero, so does sodium hazard to soil structure (Table 13) because the water adds more carbonates than divalent cations to the soil. When RSC is positive, calcium is lost from the soil solution via the following chemical reaction:

carbonates in water + soil calcium ⇒ calcium carbonate (lime deposit in soil)

As water RSC increases, so does the need for monitoring soil pH and the rate of water infiltration into soil (Table 13). Waters with an RSC above 1.0 usually require amendment to decrease RSC.

Treating water to decrease RSC

There are two ways to decrease water RSC: add acid or add gypsum. Both acid and gypsum reduce the sodium hazard to soil structure posed by high-RSC water.

- Gypsum adds calcium to reduce RSC and SAR. However, gypsum also increases lime deposition potential, which might be a problem (see below).
- Acid reacts with carbonates to form carbon dioxide gas, thereby lowering water RSC and pH. Acid addition does not affect water SAR. Acid also decreases lime deposition potential. Adding enough acid to decrease water pH to near 7.0 will change a positive RSC to a negative RSC.

Example. Calculating RSC for a water sample

Water analysis:

bicarbonate (HCO_3): 4 meq/L
carbonate (CO_3): 1 meq/L
calcium (Ca): 2 meq/L
magnesium (Mg): 1 meq/L

Equation: carbonate anions - divalent cations: $(HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})$

Calculation: *(4 + 1) - (2 + 1) = RSC of 2*

Table 13. Suggested limits for irrigation water based on residual sodium carbonate (RSC).

RSC class	RSC (meq/L)	RSC irrigation hazard
Class 1, Low	below 0	No RSC-associated problems.
Class 2, Medium	0–1.0	Monitor infiltration and soil pH; amendment may or may not be necessary; check SAR.
Class 3, High	1.0–2.5	Monitor infiltration and soil pH; amendment with acid or gypsum likely is necessary.
Class 4, Very high	above 2.5	Monitor infiltration and soil pH; amendment with acid or gypsum is necessary.

Source: Stevens (1994).

Lime deposition potential

What is lime deposition potential?

Lime deposition occurs when calcium or magnesium carbonates (lime) precipitate out of irrigation water, leaving white residues or deposits. Lime deposition from irrigation water occurs because environmental factors such as evaporation of water, loss of carbon dioxide as a gas, increased temperature, and increased pH act to reduce the solubility of lime in water. These environmental factors change as water moves through an irrigation system and lime is deposited on vegetation, irrigation equipment, or the soil.

When is lime deposition a problem?

Lime deposition can cause the following problems.

- Lime deposited in irrigation distribution systems (e.g., pipes, tubes, or emitters) causes plugging. Microirrigation systems and drip irrigation systems are more prone to plugging than are pivot sprinkler systems.
- For fruit and vegetable crops, the presence of lime residue reduces marketability, because consumers often associate white residues with pesticide contamination.
- The presence of high concentrations of lime in irrigation water can precipitate phosphorus or micronutrient fertilizers that are injected into the water.
- Irrigation water can apply a significant amount of lime to soil. The presence of lime deposits in soil can reduce the solubility of some plant nutrients such as phosphorus, zinc, manganese, and iron.

Assessing lime deposition potential

The lime deposition potential of water is calculated as the lesser of carbonates (carbonate + bicarbonate) or divalent cations (calcium + magnesium) present in water. The higher the number, the higher the risk of lime deposition. To calculate lime deposition potential, a water analysis with units of meq/L is needed (see Table 2, page 3, for conversion factors).

Example. Calculation of lime deposition potential for a water sample

Water analysis

bicarbonate (HCO_3): 4 meq/L
carbonate (CO_3): 1 meq/L
calcium (Ca): 2 meq/L
magnesium (Mg): 1 meq/L

Equation: lesser of (bicarbonate + carbonate) or (calcium + magnesium)

Calculation: *lesser of (4 + 1) or (2 +1) equals lime deposition potential of 3*

Table 14. Irrigation guidelines for overhead sprinkling to avoid lime deposits on leaves and fruit.

Lime deposition potential of water (meq lime/L)[a]	Suggested water application rate (in/hr)
below 2	No limitations
2–3	More than 0.2
3–4	More than 0.2; irrigate only when evaporation rates are low (at night or on cloudy days)
above 4	Not recommended for overhead irrigation

[a] The amount of lime formed is equivalent to the lesser of carbonates (bicarbonate + carbonate) or divalent cations (calcium + magnesium) in the water, expressed in units of meq/L.

Source: Stevens (1994).

Reducing lime deposition on fruits and vegetables

Lime residues on fruit and vegetables can be minimized by managing irrigation practices (Table 14, page 15). Irrigation management practices include the following:

- Avoiding contact of high-lime water with leaves and fruit by irrigating under the crop canopy
- Applying overhead sprinkler irrigation when less evaporation takes place (at night or on cloudy days)
- Irrigating with more water per irrigation and decreasing frequency to reduce deposition events

Water used for over-tree cooling (water applied as mist to cool fruit on hot days) usually must be treated with acid to remove lime and lower pH to 6.5.

Removing lime from water

Lime residues can be minimized by lowering water pH to below 6.5. Lowering pH is accomplished by injecting acid (Table 15) or by using a sulfur burner to generate acidifying sulfur compounds. Lime deposition potential is reduced as bicarbonate is converted to carbon dioxide. When sulfuric acid is used, calcium carbonate/bicarbonate (lime) in the water is converted to calcium sulfate (gypsum). Calcium, magnesium, and sodium sulfates are more soluble and less likely to form residues on fruit or clog microirrigation systems.

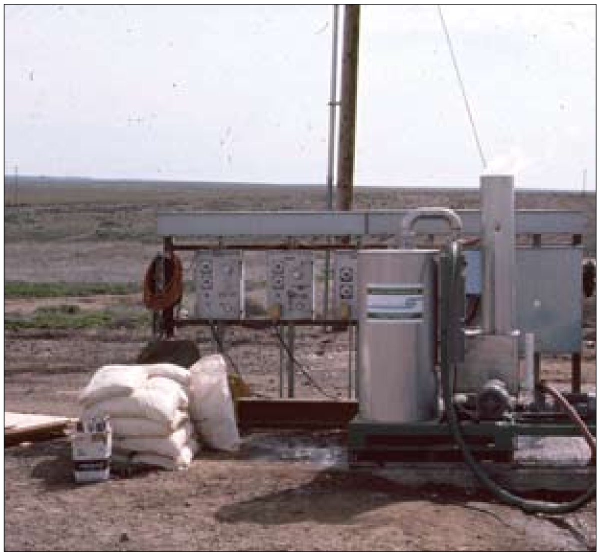


Table 15 shows how much sulfuric acid is required to neutralize bicarbonate in irrigation water. Other acids can be used; adjust rates based on acid strength, using product information from the supplier.

When acids are used, it is critical to monitor water pH after acid addition. When water pH is too low (below 5.5), excessive corrosion of the irrigation system occurs. When water pH is too high (above 6.5), not enough bicarbonate may have been removed, and lime deposition problems may persist. Test strips that change color in response to changes in pH have adequate sensitivity for water pH monitoring.

Table 15. Amount of 95 percent sulfuric acid (H_2SO_4) required to neutralize 90 percent of the bicarbonate in irrigation water.[a]

Bicarbonate in water	Sulfuric acid required per acre-inch of water		
(mg/L or ppm)	(meq/L)	(lb)	(gal)
50	0.8	8.6	0.6
100	1.6	17.2	1.1
200	3.3	34.3	2.3
400	6.6	68.7	4.6

[a] Additional acid is required for waters containing carbonate (CO_3^{2-}).

Source: Adapted from Stroehlein and Halderman (1975).

Water quality for microsprinkler and drip irrigation

Several water characteristics besides lime deposition potential (Table 14, page 15) can cause clogging in irrigation systems. Water pH, salts (EC), manganese, and iron are the most important chemical tests for irrigation water quality for microsprinkler irrigation systems (Table 16).

Other water characteristics can also cause clogging but are not discussed in detail here. For example, hydrogen sulfide in water sometimes causes clogging, but analyses for this compound often are unreliable because sulfides are chemically unstable in a water sample (they can rapidly convert to other forms of sulfur). Biological slimes caused by bacteria or algae can also cause irrigation system clogging. Biological slimes are prevented by injecting chlorine or acid. Suspended sediment (turbidity) can also clog irrigation systems. Filtering is the standard practice used to minimize sediment clogging problems.

Table 16. Plugging potential of irrigation water used in microsprinkler irrigation systems.

	Restriction on use		
Water analysis	**Low**	**Slight to moderate**	**Severe**
pH	below 7	7–8	above 8
EC	below 0.8	0.8–3.1	above 3.1
Manganese (Mn)	below 0.1	0.1–1.5	above 1.5
Iron (Fe)	below 0.1	0.1–1.5	above 1.5

Source: Ayers and Westcot (1985).

References

Ayers, R.S. 1977. Quality of irrigation water. *Journal of the Irrigation and Drainage Division*. ASCE. Vol. 103, No. IR2, June 1977, p.140.

Ayers, R.S. and D.W. Westcot. 1985. *Water Quality for Agriculture*. FAO Irrigation and Drainage Paper 29. http://www.fao.org

Hart, J. Revised 2006. *Laboratories Serving Oregon: Soil, Water, Plant Tissue, and Feed Analysis.* EM 8677. Oregon State University. Corvallis, OR.

Hopkins, B.G., J.W. Ellsworth, D.A. Horneck, R.G. Stevens, and D.M. Sullivan. In press. *Managing Saline–Sodic Soils for Crop Production*. Pacific Northwest Extension publication. Oregon State University. Corvallis, OR.

Stevens, R.G. 1994. Water quality and treatment considerations. pp. 115–125. In: K.E. Williams and T.W. Ley (eds.). *Tree Fruit Irrigation: A Comprehensive Manual of Deciduous Tree Fruit Irrigation Needs.* Good Fruit Grower Publishing (Washington State Fruit Commission). Yakima, WA.

Stroehlein, J. and A.D. Halderman. 1975. *Sulfuric Acid for Soil and Water Treatment.* Arizona Agri-File Q-357. College of Agriculture, University of Arizona. Tucson, AZ.

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Appendix A. Putting it all together

A methodical approach to interpreting analytical results will help you evaluate water quality and make sound management decisions.

1. Consider the quality of the laboratory data

- Did the laboratory perform all of the needed tests (Table 1, page 2)?
- Verify that cations and anions in the water sample are roughly balanced. See Table 3 (page 4) for an example of how to calculate cation:anion balance.

2. Determine water limitations

- Determine water hazards (summarized in Table 17, below) for the following:
  - **Salt** (Tables 4 and 6). EC indicates how much salt is in the water, but not what kind. Water pH will help identify the salt form.
  - **Sodium** (Tables 10, 11, and 13). SAR and RSC, in combination with EC, will help you evaluate whether water infiltration is likely to be a problem.
  - **Lime deposition** (Table 14)
  - **Microirrigation system plugging** (Table 16)
  - **Specific ion toxicity**, e.g., chloride and boron (Tables 7 and 8). Boron can be high when EC is low, so look at boron results separately.
  - **Nutrients**, e.g., nitrate-N, sulfate-S, phosphorus, and potassium (Table 9)
- Determine limitation(s) for agricultural use based on the hazards identified.
- Determine which limitation(s) impose significant restriction(s).

3. Weigh management options

- Does the water have too many limitations for the intended use?
- What water treatment or water management options exist? See the following sections:
  - Salts (pages 4–7)
  - Sodium (pages 9–14)
  - Lime deposition (pages 15–16)
  - Microirrigation system plugging (page 17)
  - Specific ion toxicity (pages 7–8)
  - Nutrients (pages 8–9)
- What will it cost to treat or manage the water to overcome limitations?
- Is the planned water management system sustainable? Will the same crop rotation be feasible in 5, 10, or 30 years?
- Treating irrigation water problems directly is more cost-effective than treating or correcting the problem that occurs from using water with significant limitations.
- Fertigation influences irrigation water properties. Caution is needed to ensure that fertigation does not significantly decrease water quality.
- Remember to take into account nutrients supplied by irrigation water. Analytical results for nitrate and other elements, such as S and K, will allow calculation of the fertilizer value of applied nutrients (see page 9).

Table 17. Interpretation of water quality tests to determine major water quality limitations.

Water limitation	Test	Where to find interpretive information in this publication
Salt hazard	Electrical conductivity (EC)	Tables 4 and 6 (pages 5 and 6)
Sodium hazard (potential to destroy soil structure)	Sodium adsorption ratio (SAR) and residual sodium carbonate (RSC)	Tables 10, 11, and 13 (pages 10, 11, and 14)
Lime deposits on leaves and fruit	Lime deposition potential	Table 14 (page 15)
Potential for plugging of microirrigation systems	Lime deposition potential, electrical conductivity (EC), pH, iron (Fe), manganese (Mn)	Table 16 (page 17)
Specific ion toxicity to plants	Chloride (Cl) and boron (B)	Tables 7 and 8 (pages 7 and 8)
Nutrients supplied by irrigation water	Nitrate-N, sulfate-S, potassium (K), etc.	"Crediting N and other nutrients in irrigation water" (page 9) and Table 9 (page 8)

Appendix B. Glossary

Acid: pH less than 7.0.

Alkaline: pH greater than 7.0.

Anion: A negatively charged ion such as chloride (Cl^-), sulfate (SO_4^{2-}), carbonate (CO_3^{2-}), or bicarbonate (HCO_3^-).

Cation: A positively charged ion such as calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), or ammonium (NH_4^+).

Dispersion: Breaking up of "clumps" of soil particles or aggregates into individual soil particles (sand, silt, and clay). Soil aggregates form larger, more continuous soil pores than do individual soil particles. The larger pores provide better water and air movement.

Drainage: Unimpeded downward movement of water beyond the root zone.

Electrical conductivity (EC): The ease with which electrical current passes through water. EC is proportional to the salt concentration in the water. Consequently, total salt concentration in a soil or irrigation water can be estimated by measuring EC. The higher the EC, the greater the salt concentration.

Elemental sulfur (S^0): A yellow, inert crystalline mineral that is finely ground. In soil, elemental S is oxidized to sulfate via microbial activity. The rate of elemental S oxidation in soil is most rapid in warm, moist soils. Complete oxidation of elemental S to sulfate often takes months or years.

Evapotranspiration (ET): Combined water use by plants and water evaporated from the soil surface in a given time period. Usually expressed as inches of water or millimeters of water per day.

Flocculation: The aggregation or clumping together of smaller individual particles of soil, especially clay, into larger clumps or aggregates.

Gypsum: $CaSO_4{\bullet}2H_2O$, the common name for calcium sulfate. Applied as a source of calcium to reclaim sodic and saline–sodic soils.

Infiltration: Entry of water into soil.

Leaching: The removal of soluble minerals from one soil zone to a lower zone by the downward movement of water through the soil profile.

Lime: Calcium carbonate and magnesium carbonate minerals common in alkaline soil and water.

Lime deposition potential (LDP): The lesser of carbonates (carbonate + bicarbonate) or divalent cations (calcium + magnesium) present in water. The higher the LDP, the higher the risk of lime deposition.

meq/L: Milliequivalents per liter.

Osmotic potential: The water pressure exerted across a cell wall or semipermeable membrane caused by an unequal concentration of salts or sugars on the two sides of the cell wall or membrane. Water will move from the side with the lower salt or sugar concentration through the membrane into the area with the higher salt or sugar concentration.

pH: A measure of the acidity or basicity of a material or solution. Less than 7 is acidic, more than 7 is basic, and 7 is neutral. pH is measured with an electrode pH meter or colored dyes.

ppm: Parts per million.

Residual sodium carbonate (RSC): The sum of carbonates (bicarbonate + carbonate) minus the sum of calcium and magnesium. RSC is a predictor of sodium hazard; the higher the RSC, the higher the sodium hazard.

Sodium adsorption ratio (SAR): The SAR of a saturated paste extract or irrigation water is a relationship between the concentrations of sodium (Na^+) and calcium + magnesium (Ca^{2+} plus Mg^{2+}). SAR predicts the Na^+ status. It is calculated as:

$$\text{SAR} = \frac{[Na^+]}{\sqrt{0.5([Ca^{2+}] + [Mg^{2+}])}}$$

where calcium, magnesium, and sodium concentrations are expressed in units of milliequivalents per liter (meq/L).

Soil structure: The combination or arrangement of primary soil particles into secondary particles, units, or peds.

Soil texture: The relative proportions of the three soil separates (sand, silt, and clay) in a soil.

Appendix C. Examples: Evaluating water quality

This section presents examples of five typical irrigation waters in the Pacific Northwest. The examples highlight some of the most frequently encountered irrigation water quality problems in this region. Analytical results for the sample waters are shown in Tables 18a and b.

We will interpret these results using the tables in this publication. Analysis follows the step-by-step approach outlined below (based on Appendix A, "Putting it all together," page 19).

Step-by-step interpretation of analytical results

1. Do the data make sense? Does the sum of cations approximately equal the sum of anions?
2. What are the pH and EC? EC indicates how much salt is in the water, but not what kind. Water pH will help identify the salt form.

3. SAR and RSC, in combination with EC, will help in evaluating whether water infiltration is likely to be a problem.
4. Boron could be high when EC is low, so look at boron results separately.
5. Levels of nitrate and other elements, such as S and K, will allow calculation of fertilizers being applied.

Table 18a. Examples: Analyses of different sources of water in the Pacific Northwest.

Water source	pH	EC	SAR	RSC	Lime deposition potential	Carbonate	Bicarbonate
		(dS/m)		(meq/L)	(meq/L)	(ppm)	(ppm)
1. Stream (snow melt)	7.7	0.04	0.1	-0.1	0.3	0	7
2. Canal	8.1	0.5	1.1	-2.4	2.0	0	125
3. Well #1	8.5	0.8	5.6	2.7	2.2	0	296
4. Lagoon water	8.5	3.1	8.7	7.0	8.9	121	720
5. Well #2	8.5	13.1	27.9	23.2	30.3	105	3,050

Table 18b. Examples: Analyses of different sources of water in the Pacific Northwest.

Water source	Ca	Mg	Na	K	Cl	Sulfate-S	Nitrate-N	B
	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
1. Stream (snow melt)	5	2	1	1	2	1	1	0.1
2. Canal	80	5	36	11	80	22	15	0.2
3. Well #1	40	2	135	4	89	25	3	0.1
4. Lagoon water	118	36	419	176	343	89	36	0.4
5. Well #2	410	120	2,500	4	2,550	99	19	5.1

Sample 1 (stream/snow melt)

Assessment

This exceptionally pure surface water is located not far downstream from its mountainous source (snow melt). The water is rated very low for salts, creating a risk of soil structure problems. This water also has the potential to cause a problem with drip irrigation systems; the soil may seal at the point of contact with irrigation water (below or at the emitter), causing runoff.

This water does not present any other hazards, such as problems with lime deposition or mixing with fertilizers for fertigation.

Management

This water would benefit from Ca additions such as gypsum, calcium nitrate, or calcium chloride. Inject calcium and/or other fertilizer salts into the water to raise the salt load to about 0.2 to 0.25 dS/m. Approximately 20 to 30 lb of pure gypsum per acre-inch of water (27,155 gal) is equivalent to about 0.2 dS/m. This amount should be adequate to prevent soil structure problems. Applying fertilizer (especially nitrogen and potassium) through the irrigation water can reduce the gypsum requirement, as any nutrients injected into the water will increase its EC.

Monitor EC to ensure that the injection rate is correct and that the proper EC is achieved. Raising the EC too high is wasteful, but not raising it enough will not solve the water penetration problem.

Three acre-feet of water would add 8.1 lb nitrogen as nitrate, an inconsequential amount in terms of fertilizer value.

Sample 2 (canal water)

Assessment

As a general rule, irrigation water derived from surface bodies has lower concentrations of dissolved materials than groundwater and, thus, less hazard. The water in this sample is safe without restrictions.

Management

This water does not require special management and is safe for virtually all situations. The water does have significant fertilizer value. Each 3 acre-feet of water applied will add 122 lb N, 178 lb S, and 89 lb K. Account for these nutrients in a nutrient management plan.

Sample 1. Snowmelt.

Salt (EC) (Table 4)	Sodium (SAR) (Table 11)	Water infiltration hazard	Residual sodium carbonate (RSC) (Table 13)	Lime deposition potential (Table 14)	Chloride (Table 7)	Boron (Table 8)	Nitrate-N
(dS/m)			(meq/L)	(meq/L)	(ppm)	(ppm)	(ppm)
0.04	0.1		-0.1	0.3	2	0.1	1
Very low	Low	High	None	Low	None	None	

Sample 2. Canal.

Salt (EC)	Sodium (SAR)	Water infiltration hazard	Residual sodium carbonate (RSC)	Lime deposition potential	Chloride	Boron	Nitrate-N
(dS/m)			(meq/L)	(meq/L)	(ppm)	(ppm)	(ppm)
0.5	1.1		-2.4	2.0	80	0.2	15
Low	Low	Moderate	Low	Low	Low	None	

Sample 3 (well water #1)

Assessment

This type of water is common in the Pacific Northwest. It is not too high in salt, relatively high in pH and sodium, and low in calcium. These factors may combine to cause an infiltration problem. Salt accumulation will be a problem only if internal soil drainage is minimal and rainfall is low. Although this particular water has low B content, it is not uncommon for such waters to have moderate to high B as an additional hazard.

Management

This water will require some management, depending on the crop grown, soil type, and irrigation system. At least occasional gypsum applications will be needed. Monitor soil water infiltration to decide when gypsum is needed. Sulfuric acid will help lower the pH of the water and minimize lime deposition. This may be the most cost-effective management tool for this water.

Sulfur is the only nutrient applied in large quantities (202 lb per 3 acre-feet) by this water.

Sample 4 (lagoon water)

Assessment

This sample is high in salts, sodium, and chloride, and it has very high residual sodium carbonate. It would supply large amounts of nutrients and would best be used for fertilizer.

Management

Do not use this water for irrigation without diluting it with high-quality water. The dilution percentage depends on the cropping system and other available management tools. To lower salinity, SAR, and RSC, dilute with 50 percent low-salt water (such as the water in Sample 1), making sure sufficient calcium is present. With 50 percent dilution, plant only crops moderately tolerant to salts and chloride. Further dilution with high-quality water can make the water suitable for use with all crops.

Credit the nutrients supplied by this water in a nutrient management plan. The nitrate alone will apply almost 300 lb N for 3 acre-feet of water. However, for most lagoon waters, nitrate analysis alone is inadequate for predicting the amount of nitrogen supplied by the water. An analysis for total nitrogen and possibly ammonium is needed to account for all of the nitrogen in the water. Each 3 acre-feet of water applied also supplies 1,425 lb K, 720 lb S, and 3.2 lb B.

Sample 3. Well #1

Salt (EC)	**Sodium (SAR)**	**Water infiltration hazard**	**Residual sodium carbonate (RSC)**	**Lime deposition potential**	**Chloride**	**Boron**	**Nitrate-N**
(dS/m)			**(meq/L)**	**(meq/L)**	**(ppm)**	**(ppm)**	**(ppm)**
0.8	5.6		2.7	2.2	89	0.1	3
Medium	Low	Moderate	Very high	Moderate	Low	None	

Sample 4. Lagoon

Salt (EC)	**Sodium (SAR)**	**Water infiltration hazard**	**Residual sodium carbonate (RSC)**	**Lime deposition potential**	**Chloride**	**Boron**	**Nitrate-N**
(dS/m)			**(meq/L)**	**(meq/L)**	**(ppm)**	**(ppm)**	**(ppm)**
3.1	8.7		7.0	8.9	343	0.4	36
High	Moderate	Low	Very high	High	High	None	

Sample 5 (well water #2)

Assessment

This sample is extremely high in salts, sodium, boron, chloride, and RSC.

Management

Do not use this water for irrigation without substantial dilution. Unfortunately, it would have to be diluted more than 15-fold to make it suitable as irrigation water, most likely an uneconomical solution.

Sample 5. Well #2

Salt (EC)	Sodium (SAR)	Water infiltration hazard	Residual sodium carbonate (RSC)	Lime deposition potential	Chloride	Boron	Nitrate-N
(dS/m)			**(meq/L)**	**(meq/L)**	**(ppm)**	**(ppm)**	**(ppm)**
13.1	27.9		23.2	30.3	2,550	5.1	19
Severe	Severe	Low	Severe	Severe	Severe	High	

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