Chapter 5

DRAINAGE WATER CHARACTERISTICS

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Chapter 5: Drainage Water Characteristics

I. Introduction

Water quality determines if, how and where the water can be used. Constituents in drainage water may include salts, toxic trace elements and nutrients. Water quality also can limit potential uses, as well as increase the costs of operation and maintenance of equipment and facilities. As salinity, measured either as total dissolved solids (TDS) or electrical conductivity (EC) increases, water quality decreases.

II. Units of Measurement

Water quality is assessed by evaluating the concentrations of, and relationships amongst, its constituents. This may include measuring the concentrations of salt ions such as sodium and chloride and trace elements such as boron and selenium, the sum of the dissolved salts which is salinity, or the ratio of sodium to calcium and magnesium which is sodicity. Water quality regulations establish standards for these constituents by which all must abide. Units of water quality are typically expressed as parts per million (ppm), parts per billion (ppb), or parts per trillion (ppt).

For dissolved salts and trace elements in water, volume-based units are most commonly employed. The measurement will be given as either milligrams per liter (mg/L) or milli-equivalents per liter (meq/L). The SI unit is millimoles of charge per liter (mmolc/L) which is primarily used in research. The following will help to explain these units, their equivalents, and conversions amongst them.

III. Characteristics of Agricultural Drainage Waters

A. "Tail Water" and Subsurface Drainage Water ("tile water")

There are two types of water that farmers routinely deal with on the Westside, "tail water" and subsurface drainage water.

- "Tail water" is surface water that was applied to irrigate crops but does not infiltrate into the soil and is collected as runoff.
- Subsurface drainage water as used in this manual refers to the water collected by the subsurface drainage system. The drains may collect or intercept irrigation and rain water that has moved through the soil profile as well as subsurface flows of groundwater. Hence, it is difficult to predict the composition, or trace the origin, of water collected by a subsurface drainage system.

1 ppm = 1 mg/L, the measurement most commonly used to characterize agricultural water on the Westside of the San Joaquin Valley.
1 ppb = μg/L, commonly used for trace elements
1 ppm = 1,000 ppb = 1,000,000 ppt
%C = 10,000 ppm

*Constituent	ppm → meq/L	meq/L → ppm
	multiply by	
Na (sodium)	0.043	23
Ca (calcium)	0.050	20
Mg (magnesium)	0.083	12
Cl (chloride)	0.029	35
SO_4 (sulfate)	0.021	48
HCO_3 (bicarbonate)	0.016	61
CO_3 (carbonate)	0.033	30

*from Hanson, Grattan, & Fulton, 1999, Agricultural Salinity & Drainage)

> Subsurface drainage water usually empties into a sump or some other type of collector from which it can be used to sequentially irrigate salt-tolerant crops.

Subsurface drainage water is usually of lower quality than the irrigation water applied to the soil surface. The drainage water has traveled through the soil profile and has picked up various compounds and substances, such as salts, soil particles, inorganic trace elements, and organic compounds. Subsurface drainage water from different locations has different compositions and characteristics. For example, in the Westside San Joaquin Valley, sodium sulfate is generally the predominant salt as compared to other salt-affected regions in the world where sodium chloride tends to predominate. Similarly, within the Valley, trace element composition in drainage water can differ greatly. At Red Rock (Five Points area) selenium concentrations in drainage water are much higher than at AndrewsAg (southern Kern Co.) or at Westlake Farms (near Stratford). However, at Westlake Farms, molybdenum concentrations are much higher than at the other two locations. These trace element compositions have implications, especially for forage production using drainage water.

B. Salts

The three primary sources of salts are irrigation water, soils and groundwater.

The primary source of imported irrigation water for the Westside is surface water from the Sacramento-San Joaquin Delta. Although it is extremely low in salts, each year an average of 800,000 tons of salt are imported to the northern San Joaquin Valley by surface water deliveries; 335,000 tons leave by way of the San Joaquin River. Another 2 million tons of salt are imported into the southern San Joaquin Valley by way of the water delivery system, where it remains because Tulare Basin is a hydrologically closed system (DWR, 2001). Moreover, in one hour alone, the salt accumulation in the San Joaquin Valley totals about 11 semi-truck trailers, at about 25 tons of salt per truck, according to the DWR (See Figure 1)

Because Westside soils are of a marine origin, they and the groundwater naturally contain salts. Irrigation adds more salts to the soil and groundwater. Additional sources of salt include local precipitation and runoff, pesticides, fertilizers, manure and other soil amendments, such as gypsum and lime.

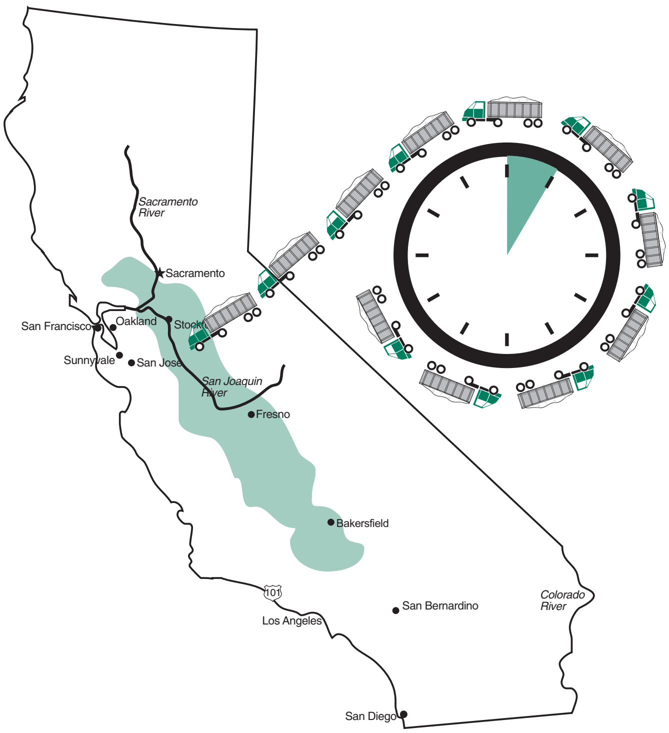

Figure 1. Salt accumulation in the San Joaquin Valley totals about 11 semi-trailers an hour at 25 tons per truck. From Salt balance in the San Joaquin Valley. 2001. *Water Facts*, Department of Water Resources.

Due to the variation in salts that are found in soils and irrigation waters, it is therefore logical that salt composition and concentrations in drainage water would also vary greatly. Salts that are commonly found in subsurface drainage water include sulfates, chlorides, carbonates, and bicarbonates of sodium, calcium, and magnesium. Tail water also may contain these salts, but generally in much lower concentrations than in drainage water. To summarize:

- Subsurface drainage water generally contains high levels of salts.
- Tail water contains slightly more salts than the applied water, but much less than drainage water.
- The salts present in subsurface drainage water may make the water unsuitable for domestic or industrial uses.

C. Water Salinity

Common units for water salinity are **EC** (electrical conductivity) expressed in deciSiemens per meter (dS/m), or in **TDS** (total dissolved solids) expressed in parts per million (**ppm**), or its equivalent mg/L. The conversion factors for these units are slightly different for San Joaquin Valley drainage waters than for other waters, and they increase as salinity of the water increases (Table 1).

Table 1. Conversion Factors for drainage waters in the San Joaquin Valley (from Agricultural Salinity and Drainage by Hanson, Grattan and Fulton, 1999).

TDS (ppm) = 740 x EC (dS/m); when EC is less than 5 dS/m
TDS (ppm) = 840 x EC (dS/m); when EC is between 5 and 10 dS/m
TDS (ppm) = 920 x EC (dS/m); when EC is greater than 10 dS/m
TDS (meq/l) = 10 x EC (dS/m)

An older unit for EC is millimhos per centimeter (mmhos/cm) which equals ds/m.

D. Water Sodicity (sodium in the water)

Sodicity refers to the amount of sodium (Na) present in the water. This can be expressed as the exchangeable sodium percentage (ESP). More often, however, the sodium level is expressed in relation to calcium and magnesium levels in the water. The measurement is called the sodium adsorption ratio or SAR. The equation is as follows:

$$\text{SAR in (meq/L)} = \frac{Na}{\div (Ca + Mg) / 2}$$

High SAR waters pose special problems for soil management. This is because sodium breaks down (disperses) the clays in soil, which leads to a loss of soil structure, and reduced infiltration.

Irrigation water having a SAR > 10 or an ESP of 13 may infiltrate poorly when applied to a medium or fine-textured soil, particularly if the salinity of the water is low. However, it is actually the combination of both SAR and EC that determines how well a water will infiltrate into soil. This is sometimes called the "permeability hazard."

Many of the Westside drainage waters are saline-sodic, therefore proper soil management will be essential in the drainage water-irrigated areas of the IFDM system to offset soil degradation caused by sodium in the water.

E. Toxic Trace Elements

Westside soils originated from marine sediments and contain salts and potentially toxic trace elements (selenium, molybdenum, arsenic, uranium and boron). The presence and concentration of these trace elements can vary greatly within the Valley. These trace elements can be concentrated by agricultural practices as the crop uses water and leaves behind the salt and trace elements. As irrigation water dissolves existing soil salts, the trace elements can potentially leach into groundwater.

Major trace elements include:

- **Selenium –** an essential trace element for animals and humans than can cause reproductive failure and teratogenic effects in birds. The water and wildlife water quality limit for selenium is 2 mg/L (ppb) (Table 2).
- **Molybdenum** – an essential trace element for plants and some animals, but can be toxic to ruminant animals. The CVRWQCB's recommended limit and irrigation guideline limits for molybdenum in water for agricultural use is 10 mg/L (ppb) (Table 2).
- **Arsenic** – a mammalian toxin.
- **Uranium** – radioactive element found in specific locations throughout the Valley.
- **Boron** – an element that may cause a reduction in the growth rate of chicks. Many agronomic crops are sensitive to boron.

Most of the elements originate naturally from the soils, but imported irrigation water may also contain some trace elements. These elements are classified as "substances of concern" because of their potential to negatively impact water quality, public health, agricultural productivity, and/or fish and wildlife (San Joaquin Valley Drainage Program, 1990). For crop production, boron is generally of greatest concern. For wildlife, selenium poses the greatest hazard. Table 2 lists irrigation water guidelines and target water quality concentrations for wildlife.

Table 2. Irrigation guideline limits for various constituents and water quality targets for wildlife. Irrigation guidelines taken from Ayers and Westcot (1985). For wildlife targets, a more complete table and reference are given in Chapter 7.

Constituent	Irrigation guideline limits (mg/l)	Targeted Wildlife and Water Quality (mg/l)
Arsenic (As)	100	<5
Boron (B)	—	<0.3
Cadmium (Cd)	10	—
Chromium (Cr)	100	—
Copper (Cu)	200	—
Iron (Fe)	500	—
Lead (Pb)	5,000	—
Manganese (Mn)	200	—
Mercury (Hg)	—	—
Molybdenum(Mo)	10	<10
Nickel (Ni)	10	—
Selenium (Se)	20	<2
Uranium (U)	—	—
Vanadium (V)	100	—
Zinc (Zn)	2,000	—

F. Nutrients

If too much water is added to leach salts from the soil, nutrients may also be leached, potentially resulting in reduced growth and yields. The leached nutrients could be considered an asset if the subsurface drainage water containing the nutrients is collected and applied to other crops in the IFDM system.

For example, most Westside San Joaquin Valley drainage waters are high in nitrate. Drainage water from Red Rock Ranch and AndrewsAg may contain more than 80 ppm NO_3-N (Table 3). In most cases, forages or halophytes produced with this water do Not need nitrogen fertilizer applications. For salt tolerant field crops, the rate of applied nitrogen fertilizer could be greatly reduced.

G. Methods for Using Saline Drainage Water for Irrigation

Several methods exist for utilizing a saline water source, such as subsurface drainage water, in an irrigation program. These methods differ regarding where, when or how the saline water is applied to the grower's field, and whether non-saline water is included in the cropping system. The IFDM system described in this manual is primarily a sequential reuse system

1. Sequential Reuse

In this practice, part of the farm or sub-region is designated as the reuse area. The area consists of a sequence of fields within the boundaries of a farm, or an irrigation district, that are irrigated with saline water of increasingly higher concentrations (Grattan and Rhoades, 1990). That is, the drainage collected under one field – which is more saline than the irrigation water – is used to irrigate the next field in the sequence and so on. The main purpose is to obtain an additional economic benefit from the available water resources, to minimize the area affected by shallow water tables, and to reduce the volume of drainage water that requires disposal.

An IFDM system implements sequential reuse, as described above, with a solar evaporator at the terminal end.

The existing sequential reuse systems are the 4-stage system at Red Rock Ranch and 3-stage system at AndrewsAg. The number of stages includes the area irrigated with fresh water, hence the 4-stage system at Red Rock Ranch involves

Table 3. Composition of drainage water used to irrigate salt-tolerant forages and halophytes in drainage water reuse projects on the Westside of the San Joaquin Valley.

Location & Year	Plants irrigated	EC (dS/m)	SAR	Boron (ppm) (mg/L)	Selenium (ppb) (ug/L)	Molybdenum (ppb) (ug/L)	Sodium (meq/L)	Calcium (meq/L)	Magnesium (meq/L)	Chloride (meq/L)	Sulfate (meq/L)	Bicarbonate (meq/L)	Nitrate-N (ppm) (mg/L)	pH
Red Rock Ranch														
(5/22/03)	**Forages†**	13.7	26.8	24	980	< 50	122	26.9	14.2	61.5	102	3.9	84.6	7.2
(1/29/03)	(2nd reuse)	13	41.7	23	990	.	134	26.8	13.2	57.1	101	4	83	7.8
(5/22/03)	**Halophytes††**	12.7	25.1	21.8	720	< 50	116.5	29.2	13.9	62.6	83.6	5.74	75.6	7.5
(1/29/03)	(3rd reuse)	17.8	37	33	1380	.	171	27.3	17.8	94.5	121	6.7	98.9	7.8
Andrews Ag														
(1/02/03)	**Halophytes** (2nd reuse)	10.6	26.8	14.1	260	.	126	21.3	24.5	24.9	142	3.6	83.3	8.3
Panoche/ SJRWQIP	**Forages** (only 1 reuse)	5 - 8	.	6 - 8	60 - 120	.	.	.	.	.	.	.	.	.
Mendota (1997)	**Halophytes** (3rd reuse)	29	44	48	700	.	323	31	82.7	106	225	.	64	8
Mendota (San Luis Drain†††)														
(1990)		10.7	19.2	14.4	325	88	95.9	27.7	22.4	.	.	48	.	

† Water from Sump B at Red Rock Ranch
†† Water from Sump C at Red Rock Ranch
††† Water sampled from the San Luis Drain near Mendota, CA (ASCE, 1990)

three reuses of the drainage water and in the 3-stage system at AndrewsAg, the drainage water is reused twice. The term "stage" is only applied to the cropping areas; the terminal solar evaporation area is not included.

2. Single Reuse

A few examples exist, such as the San Joaquin River Water Quality Improvement Project (SJRIP) operated by Panoche Drainage District, where subsurface drainage water is used once for the irrigation of salt-tolerant crops and forages. When this project started, only a small portion of the 4,000-acre reuse area had subsurface drainage and the main objective was to displace some of the subsurface drainage water being discharged to the San Joaquin River under a special agreement (Grasslands Bypass Project) so as to meet water quality objectives.

Although not the preferred system for long-term sustainability, single use can be used in the initial stages of a subsurface drainage water reuse project, for example, when a means of drainage water disposal is needed and a long-term commitment and funds for installing a complete drainage system have not been secured.

However, in order to control soil salinization and maintain both soil permeability to water and maintain plant productivity in the reuse area, it is likely that a subsurface drainage system would be needed in the reuse area. This would result in the conversion of a single reuse system to a multiple stage, sequential reuse system, similar to IFDM.

3. Blending

Blending involves mixing saline water and good quality water together to achieve an irrigation water of suitable quality based on the salt tolerance of the chosen crop. The blended water is used for irrigation. The AndrewsAg IFDM system blends fresh water and drainage water for its "Stage 2" cotton, as described below. Blending is not attractive if saline water does not supply at least 25 percent of the total irrigation water requirement. That is, the costs and risks of the increased management associated with adding salts to the irrigation supply will likely outweigh the benefits from increasing the total water supply by only a slight to modest amount.

4. Cyclic Use

The "cyclic" method was first introduced and tested by Rhoades (1984). Saline drainage water is used solely for certain crops and only during certain portions of their growing season. The objective of the cyclic strategy is to minimize soil salinity during salt-sensitive growth stages, or when salt-sensitive crops are grown. With a cyclic strategy, the soil salinity profile is purposefully reduced by irrigation with good quality water, thereby facilitating germination and permitting crops with lesser tolerances to be included in the rotation. The cyclic strategy keeps the average soil salinity lower than that under the blending method, especially in the upper portion of the profile, which is critical for emergence and plant establishment (Grattan and Rhoades, 1990).

5. Combining Strategies

These strategies are not mutually exclusive. In fact, a combination may be most practical in some cases. For example, within a sequential reuse scheme such as IFDM, blending and/or cyclic methods may be used occasionally to germinate and establish the salt-tolerant crops. This is also true for the establishment of salt-tolerant perennial forages, some of which require at least a full year of fresh water irrigation prior to applying the saline subsurface drainage water.

Another example would be the AndrewsAg IFDM which is a sequential reuse, but for the Stage 2 cotton, fresh water and drainage water are often blended. The ratio ranges from 1/3 fresh water and 2/3 drainage water to 2/3 fresh water and 1/3 drainage water, depending on subsurface drainage water supply.

In general, the blending and cyclic strategies are suitable for subsurface drainage water that is relatively low in salinity (< 8 dS/m= 6700 ppm TDS). Both require an ample supply of both good quality and saline water to be available for irrigation throughout the season. These methods have been successful in field tests (Rhoades et al., 1988; Grattan & Oster, 2003).