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Explanation and Interpretation of Analyses of Irrigation Waters

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ACCURATE chemical analyses of irrigation waters give the outstanding qualities, identify the more important substances that are present, and show their concentration.

All waters used for irrigation carry varying quantities of certain chemicals that are referred to as dissolved salts. If their concentration is not too great, some of the constituents of these dissolved salts improve the growth of plants; others are harmful to plant growth and to soils. The total concentration of dissolved salts varies from a few to several thousand parts per million (p. p. m.), most irrigation waters being in the range of 100 to 1,500 p. p. m.

The more important constituents of these waters are calcium, magnesium and sodium, known as cations; and bicarbonate, sulfate, and chloride, known as anions. Potassium, carbonate, nitrate, silica, and boron are usually present, but ordinarily only in low concentration. Small quantities of other substances may be found in some waters, but their effect on the quality of the water for irrigation is not important, and they are usually not considered in an analysis.

The purpose of this circular is to explain, in nontechnical language, the meaning of the several items in an analysis of a water and the interpretation of the analysis in terms of suitability of the water for irrigation use.

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COLLECTION OF WATER SAMPLES

As a detailed analysis of a water is time-consuming and expensive, care should be taken that the sample represents the stream or well from which it is taken. Samples from streams should be drawn from running water well downstream from tributaries. Samples from wells should be taken after the well has been in operation for some time. Clean glass bottles with rubber stoppers are suitable containers. The samples should be transferred to the laboratory promptly after collection.

In order that an analysis may be of greatest use, not only for the immediate purpose but for future reference, the following information should accompany each sample sent to the laboratory.[1]

Collector's Description of Water Sample

Collector's No. ------ Lab. No. ------ Date -------- Collector ---------------
Kind of water (circle one)—Spring, stream, lake, well ----------------------
Name of owner ---
County -------------------- Distance and direction from nearest town -----
Location ------ ¼, Sec. ----, T ----, R ----. U. S. G. S. sheet ------------
Distance and direction from ¼ corner or landmark -------------------------
Other description ---
(Exact location of the sampling site may be shown by a sketch map.)
Depth ------ Depth to upper perforations ------ Casing diameter ----------
Discharge ------ Static level ------ Draws down to --------------------
Temperature (°C. or °F.) ------ Odor ------ Gas ------ Color ----------
Use (circle one)—Irrigation, municipal, industrial, stock, domestic, other ------
Approximate acreage served -------- Crops grown -----------------------
Conditions or symptoms of land or crops ---------------------------------
Owner's opinion of water quality --
Collector's remarks ---

ABBREVIATIONS USED

The following abbreviations and symbols are used in the analysis of water samples:

e. p. m.	Equivalents per million	B	Boron
p. p. m.	Parts per million	Ca	Calcium
t. a. f.	Tons per acre-foot	Mg	Magnesium
c. f. s.	Cubic feet per second	Na	Sodium
s. f.	Second foot	K	Potassium
g. p. m.	Gallons per minute	CO_3	Carbonate
°C.	Degrees Centrigrade	HCO_3	Bicarbonate
°F.	Degrees Fahrenheit	SO_4	Sulfate
cm.	Centimeters	Cl	Chloride
pH	Acidity or alkalinity	NO_3	Nitrate
D. S.	Dissolved solids	SiO_2	Silica
E. C.	Electrical conductivity	$>$	More than
mho/cm.	Electrical conductivity unit	$<$	Less than
$K \times 10^6$	Formerly used as abbreviation for electrical conductivity; see page 8.		

[1] The Bureau of Plant Industry, Soils, and Agricultural Engineering does not analyze waters except in the course of investigations of its own or of other governmental agencies.

EXPLANATION OF AN ANALYSIS

The following is a typical analysis of a sample of river water used for irrigation of thousands of acres of farm land.

ANALYSIS OF RUBIDOUX LABORATORY WATER SAMPLE NO. 18985 [1]

Electrical conductivity ($EC \times 10^6$ at 25° C.)	mho/cm	1, 140
Percent sodium		51
Boron	p. p. m.	. 16
Dissolved solids	t. a. f.	1. 01
pH		7. 9
Silica	p. p. m.	24

Cations:	Equivalents per million	Anions:	Equivalents per million
Calcium	4. 07	Carbonate	([2])
Magnesium	1. 30	Bicarbonate	3. 58
Sodium	5. 87	Sulfate	4. 95
Potassium	. 24	Chloride	3. 08
		Nitrate	. 01
Total	11. 48	Total	11. 62

[1] Abbreviations explained on p. 2. [2] Trace.

A brief explanation of the items shown above follows:

Parts per million.—1 p. p. m. equals 1 part, by weight, of the constituent per 1 million parts by weight of the water.

Tons per acre-foot.—1 t. a. f. equals 1 ton of dissolved salts carried in 1 acre-foot of water.

Equivalents per million.—The unit, "equivalent per million," is defined as 1 equivalent weight of an element, ion, or a salt in 1 million weights of solution. The equivalent, a unit developed by chemists, is particularly useful in water analyses. It is the weight, on a relative scale, of that quantity of an element or compound that will exactly react with another element or compound to complete a certain standard chemical reaction (combine with or be equal to 8 units of oxygen). Thus 23 parts, or 1 equivalent, of sodium combine with 35.5 parts, or 1 equivalent, of chloride to form sodium chloride, ordinary table salt. The two features of importance in connection with this unit (e. p. m.) are: (1) 1 equivalent of any element will exactly combine with, or be equivalent to, 1 equivalent of any other element; and (2) in any solution, such as an irrigation water, the sum of the anions must equal the sum of the cations in terms of equivalents.

Cations.—Calcium, magnesium, sodium, and potassium are the so-called cations, or basic constituents. Calcium, magnesium, and potassium are essential plant foods. Sodium is taken up freely by many plants but may not be essential. Calcium and magnesium are beneficial to the soil, while sodium produces adverse reactions. The cations are reported in equivalents per million.

Anions.—The anions are carbonate, bicarbonate, sulfate, chloride, and nitrate. Carbonate makes a water strongly alkaline; bicarbonate makes it mildly alkaline. The total quantity and relative proportions of the two determine to a great extent the total alkalinity, as well as the pH value, of the water. Sulfate and nitrate are essential plant foods and in an irrigation water are desirable in reasonable quantities. Calcium and sulfate form the sparingly soluble salt known as gypsum, which is beneficial to most soils. The anions are reported in equivalents per million.

pH value.—This is an expression of the intensity of the acid or alkali in a water. The scale extends from 0, strongly acid; through 7, neutral; to 14, strongly alkaline. Most natural waters fall in the mildly alkaline range, 7 to 8.5.

Electrical conductivity.—A water containing dissolved salts will conduct an electric current, the amount of current depending upon the number and kinds of the dissolved salts. This property is used in the electrical conductivity determination, which is a reliable measure of the total salt content of a water.

There is no simple relationship between electrical conductivity and the other measures of total concentration, but the following give approximate values that may be useful. Electrical conductivity ($EC \times 10^6$ at 25° C.) divided by 100 is approximately equal to total anions or cations in equivalents per million. Electrical conductivity multiplied by 0.7 is approximately equal to dissolved solids in parts per million. Referring to the analysis on page 3, $1{,}140 \div 100 = 11.4$ e. p. m. anions or cations, which is approximately equal to the determined values; and $1{,}140 \times 0.7 = 798$ p. p. m. dissolved solids. The determined value of dissolved solids is 1.01 t. a. f., which is equivalent to 742 p. p. m.

Percent sodium.—To find the percentage of sodium of a water, the results of the analysis must be reported in equivalents per million. The quantity of sodium is then divided by the sum of the quantities of calcium, magnesium, sodium, and potassium, and the result expressed as a percentage. To know this is important, because waters of high sodium percentage so react with the soil that it becomes difficult to till and is hard when dry, sticky when wet, and "takes water" very slowly.

Boron.—This is the characteristic element of such well-known compounds as borax and boric acid. It is required in small quantity by all plants but is injurious in higher concentrations. It is reported as parts per million of boron.

Silica.—This constituent is usually present in concentrations below 60 p. p. m., and under such conditions is essentially inert as far as soils and plants are concerned. It is reported as parts per million SiO_2.

Dissolved solids.—The measure of the total quantity of dissolved matter carried by a water is obtained by evaporating a filtered sample of the water and weighing the residue. The results are reported as tons per acre-foot or parts per million.

INTERPRETATION OF THE ANALYSIS

Any method for the interpretation of the analysis of an irrigation water is based on the presumption that the water will be used under average conditions as related to quantity, soil permeability, drainage, climate, and crops. The method of interpretation here proposed, therefore, is not directly applicable under unusual conditions.

Before making an estimate of the quality of a water, an analysis must be made that shows the total concentration of dissolved constituents, the percent sodium, and the concentration of boron. The total concentration may be expressed either in terms of electrical conductivity, of total equivalents per million of anions or cations, or of dissolved solids. If the conductivity is not shown in the analysis, an approximate value can be obtained by multiplying total equivalents per million of anions or cations by 100 or by dividing dissolved solids in parts per million by 0.7, as shown on page 4.

The diagram shown in figure 1 is used in interpreting an analysis of an irrigation water. On the left margin of the diagram are shown values (0 to 100) for percent sodium, and the lower margin is divided in a scale of conductivity (0 to 3,500). To use the diagram, locate the point corresponding to the values for conductivity and percent sodium as shown in the analysis. The position of this point determines the quality classification to which the water is assigned. For instance, the analysis on page 3 shows a percent of sodium of 51 and a conductivity of 1,140. To locate the point on the diagram corresponding to these specifications, follow up the percent sodium scale (left margin) to the value 51, then follow to the right across the diagram for a distance corresponding to 1,140 on the conductivity scale (lower margin). A cross (+) locates the point on the diagram, and the water would be classed as good to permissible.

In judging the quality of an irrigation water, boron must be considered because it is sometimes present in sufficient concentration to be harmful to plants. The permissible limits for boron of several classes of irrigation water are shown in table 1, and the relative tolerance of different crop groups to boron in table 2.

TABLE 1.—*Permissible limits for boron of several classes of irrigation water*

Classes of water	Crop groups		
	Sensitive	Semitolerant	Tolerant
	P. p. m.	*P. p. m.*	*P. p. m.*
Excellent	<0.33	<0.67	<1.00
Good	0.33 to .67	0.67 to 1.33	1.00 to 2.00
Permissible	.67 to 1.00	1.33 to 2.00	2.00 to 3.00
Doubtful	1.00 to 1.25	2.00 to 2.50	3.00 to 3.75
Unsuitable	>1.25	>2.50	>3.75

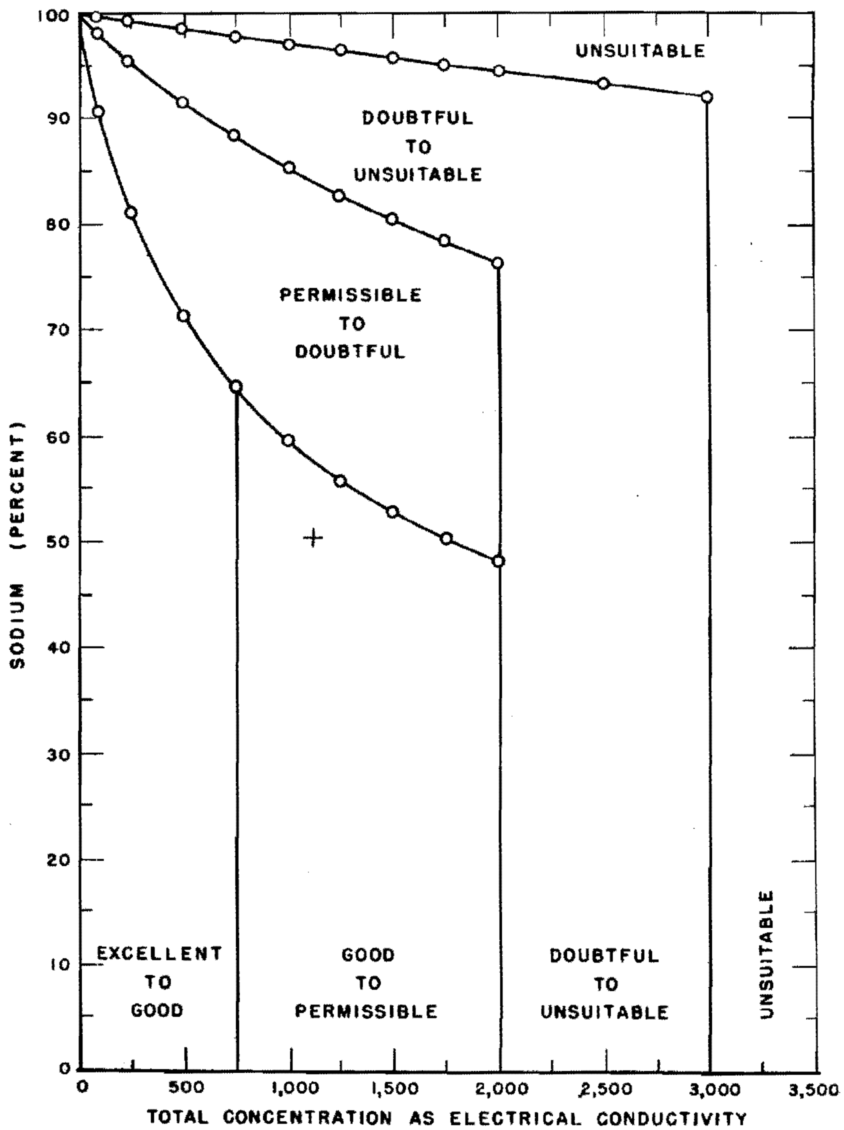

FIGURE 1.—Diagram for use in interpreting the analysis of an irrigation water.

TABLE 2.—*Relative tolerance of crop plants to boron*

[In each group the plants first named are considered as being more sensitive and the last named more tolerant]

Sensitive to boron	Semitolerant to boron	Tolerant to boron
Lemon	Lima bean	Carrot
Grapefruit	Sweetpotato	Lettuce
Avocado	Bell pepper	Cabbage
Orange	Tomato	Turnip
Thornless blackberry	Pumpkin	Onion
Apricot	Zinnia	Broadbean
Peach	Oat	Gladiolus
Cherry	Milo	Alfalfa
Persimmon	Corn	Garden beet
Kadota fig	Wheat	Mangel
Grape (Sultanina and Malaga)	Barley	Sugar beet
Apple	Olive	Palm (*Phoenix canariensis*)
Pear	Ragged Robin rose	Date palm (*P. dactylifera*)
Plum	Field pea	Asparagus
American elm	Radish	Tamarix, or athel (*Tamarix aphylla* and *T. gallica*)
Navy bean	Sweet pea	
Jerusalem-artichoke	Pima cotton	
Persian (English) walnut	Acala cotton	
Black walnut	Potato	
Pecan	Sunflower (native)	

CONVERSION FACTORS AND CONSTANTS

To change an analysis reported in parts per million to equivalents per million, the concentration of each constituent in parts per million is divided by its equivalent weight. The equivalent, or combining, weight of a constituent is the molecular weight divided by its valence. For instance, the molecular weight of calcium is 40.08 and the valence is 2, therefore, the equivalent weight, 40.08÷2 is 20.04. The equivalent weights of the common constituents are:

Cations:	*Equivalent weight*	Anions:	*Equivalent weight*
Calcium	20	Carbonate	30
Magnesium	12.2	Bicarbonate	61
Sodium	23	Sulfate	48
Potassium	39.1	Chloride	35.5
		Nitrate	62

To change an analysis reported in equivalents per million to parts per million, the concentration of each constituent in equivalents per million is multiplied by its equivalent weight.

Total hardness is equal to the calcium carbonate ($CaCO_3$) equivalent of the calcium and magnesium content of a water. It can be calculated as follows:

As $CaCO_3$ in parts per million $= 50 \times$ (Ca + Mg, expressed in equivalents per million), or

As $CaCO_3$ in grains per U. S. gallon $= \frac{50}{17.1} \times$ (Ca + Mg, expressed in equivalents per million).

Grains per U. S. gallon × 17.1 = parts per million.
Parts per million × 0.00136 = tons per acre-foot.
Tons per acre-foot × 735 = parts per million.
1 acre = 43,560 square feet.
Acre-foot = a unit of volume of water that would cover 1 acre to a depth of 1 foot; 43,560 cubic feet.
1 acre-foot of soil weighs 4,000,000 pounds (approximate).
1 acre-foot of water weighs 2,720,000 pounds (approximate).
1 cubic foot of water per second or second foot =
- 50 miner's inches in—
  - Idaho, Kansas, Nebraska, Nevada, New Mexico, North Dakota, South Dakota, Utah, and southern California.
- 40 miner's inches in—
  - Arizona, California (statute), Montana, and Oregon.
- 38.4 miner's inches in Colorado.

Gallons per minute × 0.002228 = cubic feet per second.
1 cubic foot per second for 24 hours = 1.98 acre-feet.
1 U. S. gallon =
- 231 cubic inches,
- 0.1337 cubic foot,
- 8.338 pounds water at 59° F. (15° C.),
- 58,366 grains water at 59° F. (15° C.).

1 cubic foot =
- 7.4805 gallons,
- 62.372 pounds water at 59° F. (15° C.).

1 cubic foot of soil in place weighs 70 to 105 pounds.
Electrical conductivity expressed as $K \times 10^5$ at 25° C. multiplied by 10 = $EC \times 10^6$ at 25° C.

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