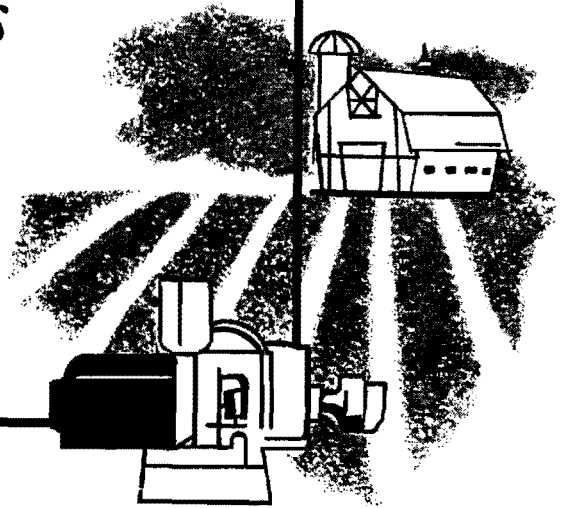# Classification and Use of

Irrigation Waters

By L. V. Wilcox
United States
Salinity Laboratory

Circular No. 969

UNITED STATES DEPARTMENT OF AGRICULTURE
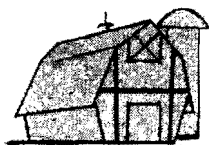Washington, D. C.   NOVEMBER 1955

CONTENTS

Classification
and Use of
Irrigation Waters [1]

By L. V. WILCOX,[2] *senior soil scientist, Soil and Water Conservation Research Branch, Agricultural Research Service*

Irrigation waters, whether diverted from surface streams or pumped from wells, carry certain chemical substances in solution, dissolved from the rocks or soils over which the waters have passed. The concentration and nature of these dissolved constituents determine the quality of the water for irrigation use.

Accurate chemical analyses of irrigation waters identify the more important substances that are present and show their concentration. From such analyses it is possible to classify waters in terms of their suitability for irrigation and to anticipate with some assurance the effect of the water on crops and on soils. The purpose of this circular is to explain the analysis and classification of irrigation waters and the special problems involved in their use.

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 collected 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 cork or 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:[3]

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[1] Report of a study in which certain phases were carried on under the Research and Marketing Act of 1946.

[2] Mr. Wilcox is Assistant Director of the United States Salinity Laboratory, Riverside, California.

[3] The United States Salinity Laboratory does not analyze waters except in the course of its own investigations or those conducted for other Government agencies.

COLLECTOR'S DESCRIPTION OF WATER SAMPLE

Collector's No........; Lab. No........; Date........; Collector..........

Owner..

....
<div align="center">Spring, Stream, Lake, Well? (circle one)</div>

....
County   Miles—distance nearest town   USGS sheet

Location.... ¼, Sec....; T.... ....; R.... ....; ....
<div align="right">Distance and direction from
section corner or landmark</div>

Other description..

Depth......; Depth to upper perforations......; Casing diameter............

Discharge......; Static level......; Draws down to........................

Temp............; Odor......; Gas......; Color........................
   ° C. or ° F.

Use: Irrig., Municipal, Ind., Stock, Domestic.............................

Approximate acreage served, crops..

Condition or symptoms of land or crops...................................

Owner's opinion of water quality..

Collector's remarks..

....

....

Report to: ....

....

....

(Please draw a map on the reverse side, if necessary, to show the exact location of the sampling site.)

ANALYSIS OF IRRIGATION WATERS

Methods of Analysis

The procedures that are recommended for the analysis of irrigation waters are given in detail in chapter 8, United States Department of Agriculture Handbook 60.[4] These methods are reasonably rapid and yield results of satisfactory accuracy, but any set of procedures of comparable accuracy may be substituted.

Explanation of an Analysis and Its Items

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

ANALYSIS OF WATER SAMPLE No. 22431 [1]

Electrical conductivity ($EC\times10^6$ at 25° C.) _____ micromhos/cm__ 1, 010
Soluble-sodium percentage (SSP) _____ 41
Sodium-adsorption-ratio (SAR) _____ 2. 5
Residual sodium carbonate (RSC) _____ 0
Boron (B) _____ parts per million__ 0. 15
Dissolved solids _____do____ 701
pH_____ 7. 8

Cations:	meq./l.	Anions:	meq./l.
Calcium (Ca)	3. 54	Carbonate (CO_3)	0. 12
Magnesium (Mg)	2. 43	Bicarbonate (HCO_3)	1. 88
Sodium (Na)	4. 30	Sulfate (SO_4)	5. 92
Potassium (K)	. 10	Chloride (Cl)	2. 40
		Nitrate (NO_3)	. 01
Total	10. 37	Total	10. 33

[1] For definitions, abbreviations, and symbols, see "Glossary" and subsequent sections.

The items of an analysis are explained as follows.

UNITS.—It is customary to express the concentrations of cations and anions either in parts per million (p. p. m.) or in milliequivalents (milligram equivalents) per liter (meq./l.); the latter unit is preferred. Both units are defined and factors for converting p. p. m. to meq./l. are given on pages 16 to 18. The unit meq./l. has at least 2 advantages that the unit p. p. m. does not have: 1 milliequivalent of any ion will exactly combine with or be equivalent to 1 milliequivalent of any other ion; and in any solution, such as an irrigation water, the sum of the cations should equal the sum of the anions in terms of equivalents. Differences between cations and anions signify that there are undetermined constituents present or that there are errors in the analysis.

The expression "electrical conductivity" is synonymous with "specific electrical conductance." The standard unit for conductivity, mho/cm., is so large that most natural waters have a value of much

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less than 1 unit. For purposes of convenience in recording or expressing such results, the value in mho/cm. is multiplied by 10^6 (decimal point moved 6 places to the right) and reported as micromhos/cm. or $EC \times 10^6$ at $25°$ C. The several methods of reporting conductivity are as follows. (The conductivity from the foregoing analysis is used as an example.)

$$EC \quad = 0.00101 \text{ mho/cm.}$$
$$EC \times 10^3 = 1.01 \text{ millimhos/cm.}$$
$$EC \times 10^5 = 101 \text{ (K} \times 10^5)$$
$$EC \times 10^6 = 1,010 \text{ micromhos/cm.}$$

ELECTRICAL CONDUCTIVITY.—Electrical conductivity is commonly used for indicating the total concentration of the ionized constituents of a natural water. It is closely related to the sum of the cations (or anions) determined by chemical analysis, and it correlates well with the value for dissolved solids. In the classification of waters, discussed in the next section, conductivity is the measure of the salinity hazard involved in the use of the water for irrigation.

SOLUBLE-SODIUM PERCENTAGE (SSP).—This term is also referred to as the percent sodium, or sodium percentage. It is a calculated value and is defined by the following equation in which the concentrations are in meq./l.:

$$SSP = \frac{\text{Soluble sodium concentration}}{\text{Total cation concentration}} \times 100$$

It is useful in characterizing a water, since a high value indicates a soft water and a low value indicates a hard water. It is indicative of the sodium (alkali) hazard but is not as satisfactory a measure of this hazard as is the sodium-adsorption-ratio.

SODIUM-ADSORPTION-RATIO (SAR).—This is a calculated value and is defined by the equation

$$SAR = \frac{Na^+}{\sqrt{\dfrac{Ca^{++} + Mg^{++}}{2}}}$$

in which the concentrations are expressed in meq./l. A nomogram for determining the SAR value of an irrigation water is shown (fig. 1).

An exchangeable-sodium-percentage (ESP) scale is included in the nomogram opposite the SAR scale. This ESP scale is based on an empirical equation that relates ESP to SAR. For a more detailed discussion of this relationship, see United States Department of Agriculture Handbook 60, cited previously. After the SAR value of an irrigation water is determined by use of the nomogram, it is possible to estimate from the central scale the ESP value of a soil that is at equilibrium with this irrigation water. Under field conditions, the actual ESP may be somewhat higher than the estimated equilibrium value. This is because the concentration of the soil solution is increased by evaporation and plant transpiration, resulting in a higher SAR and a correspondingly higher ESP. The ESP estimated from the central scale of the nomogram can therefore be regarded as a minimum value that is often exceeded in the field.
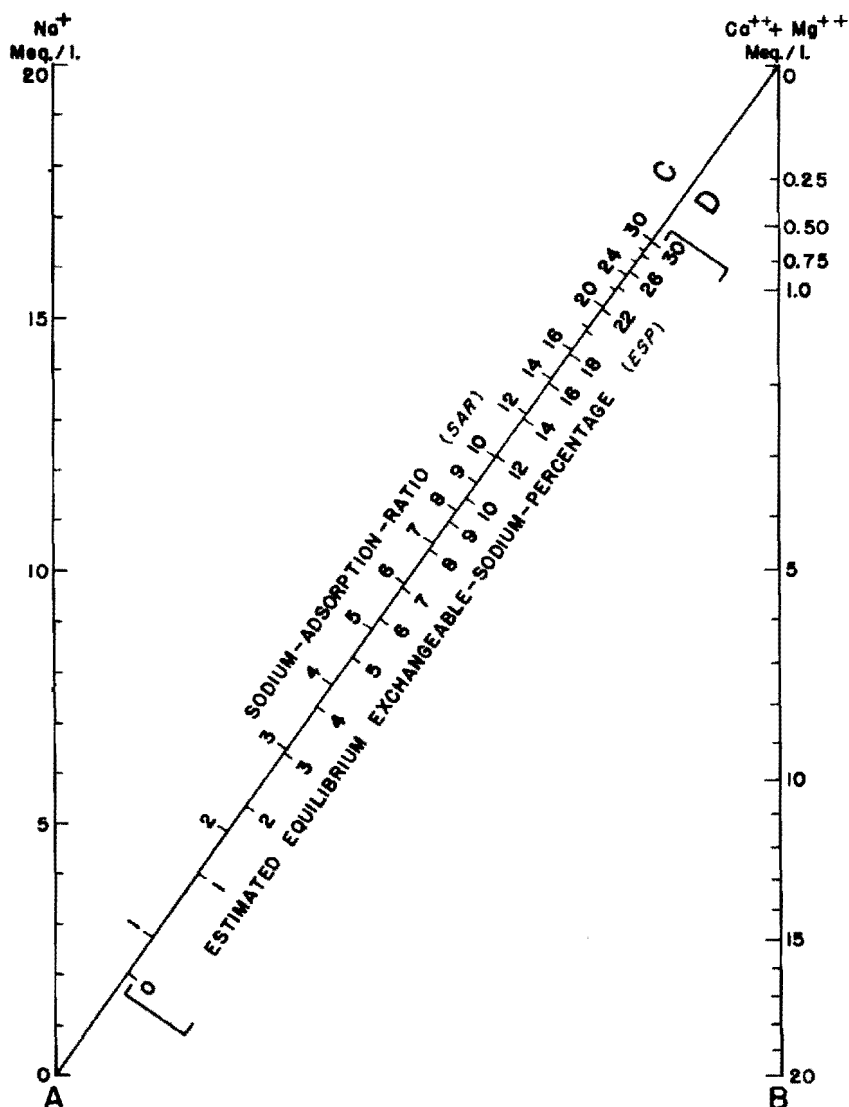
FIGURE 1.—Nomogram for determining the *SAR* value of irrigation water and for estimating the corresponding *ESP* value of a soil that is at equilibrium with the water.

RESIDUAL SODIUM CARBONATE (*RSC*).—This term was proposed by Eaton [5] and defined as

$$RSC = (CO_3^+ + HCO_3^-) - (Ca^{++} + Mg^{++})$$

in which the concentrations are expressed in meq./l. The chemistry involved is discussed under "Anions," and its significance in the section "Classification of Irrigation Waters."

[5] EATON, F. M. SIGNIFICANCE OF CARBONATES IN IRRIGATION WATERS. Soil Sci. 69: 123–133. 1950.

Boron (B).—This is the characteristic element of such well-known compounds as borax and boric acid. It is found in practically all natural waters, the concentration ranging from traces to several p. p. m. It is essential to plant growth, but is exceedingly toxic at concentrations only slightly above optimum. Plants usually show no symptoms of boron deficiency if irrigated with water containing at least 0.1 p. p. m. of B, but injury may develop on the more sensitive plants when irrigated with water containing boron in excess of 1 p. p. m. Permissible limits of boron in irrigation waters and a relative tolerance list of plants are given later in this circular (see table 1).

Dissolved solids.—This is a measure of the total quantity of dissolved matter carried by a water. It is determined by evaporating to dryness a filtered sample of the water and weighing the residue. Dissolved solids can be estimated from the electrical conductivity by using the relationship given on page 17.

pH reading.—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 western irrigation waters fall in the mildly alkaline range, 7 to 8.5.

Cations.—Calcium, magnesium, sodium, and potassium are the cations or basic constituents ordinarily present in significant concentrations in irrigation waters. Calcium, magnesium, and potassium are essential plant foods. Sodium is taken up freely by many plants, but it probably is not essential in the same sense as the other nutrients and it may be actually toxic to some plants.

The sodium or alkali hazard involved in the use of a water for irrigation is determined by the absolute and relative concentrations of the cations. If the proportion of sodium is high, the alkali hazard is high; conversely, if calcium and magnesium predominate, the hazard is low. Alkali soils are formed by the accumulations of exchangeable sodium and are often characterized by poor tilth and low permeability. The *SAR*, as discussed previously, provides an estimate of the sodium or alkali hazard and is used for this purpose in the classification of irrigation waters.

Anions.—The more important anions found in irrigation waters are carbonate, bicarbonate, sulfate, chloride, and nitrate. Sulfate and nitrate are essential plant nutrients and are desirable in reasonable concentrations. Chloride in higher concentrations is undesirable, as it is toxic to some plants.

Carbonate waters are strongly alkaline, but bicarbonate waters are only mildly so. The total quantity and relative proportions of the two determine, to a great extent, the total alkalinity as well as the pH reading of a water. In waters containing high concentrations of these ions, there is a tendency for calcium and possibly magnesium to precipitate as carbonates when the water is concentrated by transpiration and evaporation. With the removal of calcium and magnesium from the soil solution, the relative proportion of sodium is increased with the attendant increase in alkali hazard. The residual sodium carbonate (*RSC*), as previously defined, is a measure of the hazard involved in the use of high-bicarbonate waters. Permissible limits for *RSC*, based on field observations and greenhouse tests, are given in the section "Classification of Irrigation Waters."

CLASSIFICATION OF IRRIGATION WATERS

In classifying an irrigation water, it is assumed that the water will be used under average conditions with respect to soil texture, infiltration rate, drainage, quantity of water used, climate, and salt tolerance of the crop. Large deviations from the average for one or more of these factors may make it unsafe to use a water that would be safe under average conditions. Similarly, under some unusual circumstances it may be possible to use a water that would be considered unsafe under average conditions. This relationship to average conditions must be kept in mind in connection with the use of any general method for the classification of irrigation waters.

Salinity Hazard

Under average conditions, as already mentioned, there is a close relationship between the conductivity of an irrigation water and the conductivity of the saturation extract of the soil. The growth of plants, in turn, is inhibited or prevented by higher saturation-extract concentrations and is not affected seriously by lower concentrations.[6] Electrical conductivity therefore becomes a satisfactory measure of the salinity hazard involved in the use of water for irrigation.

Waters are divided into 4 groups with respect to conductivity, the dividing points between classes being at 250, 750, and 2,250 micromhos/ cm. (see fig. 2). These class limits were selected in accordance with the relationship between electrical conductivity of irrigation waters and the electrical conductivity of saturation extracts.

From a review of the analyses of water samples from more than 1,300 irrigation water sources of the West, representing both surface and ground waters, it is apparent that more than half of the waters have conductivity values below 750 micromhos/cm. and that less than 10 percent have conductivity values above 2,250 micromhos/cm.

Control of salinity is discussed on p. 12.

Sodium (Alkali) Hazard

The establishment of water-quality classes from the standpoint of the sodium hazard is more complicated than for the salinity hazard. The problem can be approached from the viewpoint of the probable extent to which soil will adsorb sodium from the water and the rate at which such adsorption will occur as the water is applied.

Consider the simple case where a nonalkali soil is leached continuously with a high-sodium irrigation water and an increase in concentration of the salts in the solution is prevented by the absence of plant growth and of surface evaporation. Under these conditions, the exchangeable-sodium-percentage (ESP) which the soil will eventually attain when it and the water are in equilibrium can be predicted closely from the sodium-adsorption-ratio (SAR) of the water; the rate at which the equilibrium condition will be attained will depend on the total cation concentration or electrical conductivity of the water. Thus, for this situation, application of waters having the same sodium-

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[6] Plant response and crop selection for saline and alkali soils is discussed in chapter 4, U. S. Department of Agriculture Handbook 60, previously cited.

adsorption-ratios and variable electrical conductivities would ultimately result in about the same exchangeable-sodium-percentages, but the amount of water required to bring the soil to this ultimate exchangeable-sodium-percentage would vary inversely with the electrical conductivity.

In actual practice, the SAR of the soil water increases, owing to the increase in concentration of all salts and the possible precipitation of calcium and magnesium salts, as the moisture content is decreased by plant extraction and surface evaporation. This results in a somewhat higher ESP than would be predicted directly from the SAR of the water. Although the SAR is the best available index of the equilibrium ESP of soil in relation to irrigation water, total cation concentration or conductivity is an additional factor and is taken into account in the classification of sodium hazard given in the next section.

Control of exchangeable sodium (alkali) in soil is discussed on p. 14.

Diagram for Classifying Irrigation Waters

The diagram for the classification of irrigation waters (fig. 2) is based on electrical conductivity in micromhos/cm. and on the sodium-adsorption-ratio.

The curves are given a negative slope to take into account the dependence of the sodium hazard on the total concentration. Thus, any water with an SAR of 9 and a conductivity of less than 168 is classed, insofar as sodium hazard is concerned, as an S1 water. With the same SAR and a conductivity between 168 and 2,250, it becomes an S2 water; and with a conductivity greater than 2,250, the water is rated S3. This system, by which waters at a constant SAR value are given a higher sodium-hazard rating with an increase in total concentration, is arbitrary and tentative, but it seems to be supported by field and laboratory observations.

To use the diagram, the electrical conductivity and the concentrations of sodium and calcium plus magnesium for the irrigation water are required. If only the concentration of calcium plus magnesium is known, sodium can be estimated as follows:

$$Na^+ = (EC \times 10^6/100) - (Ca^{++} + Mg^{++})$$

Conversely, if only sodium is known, calcium plus magnesium can be estimated by the equation

$$(Ca^{++} + Mg^{++}) = (EC \times 10^6/100) - Na^+$$

The ionic concentrations are expressed in milliequivalents per liter (meq./l.).

The SAR can be calculated from the defining equation or estimated from the nomogram (fig. 1). Using SAR and the $EC \times 10^6$ as coordinates, locate the corresponding point on the diagram. The position of the point determines the quality classification of the water. This is illustrated by the analysis of the irrigation water already given, in which calcium plus magnesium equals 5.97 meq./l; sodium, 4.30 meq./l; and electrical conductivity ($EC \times 10^6$), 1,010 micromhos/cm. The SAR, calculated from the defining equation or estimated from the nomogram (fig. 1), is found to be 2.5. The point on the dia-
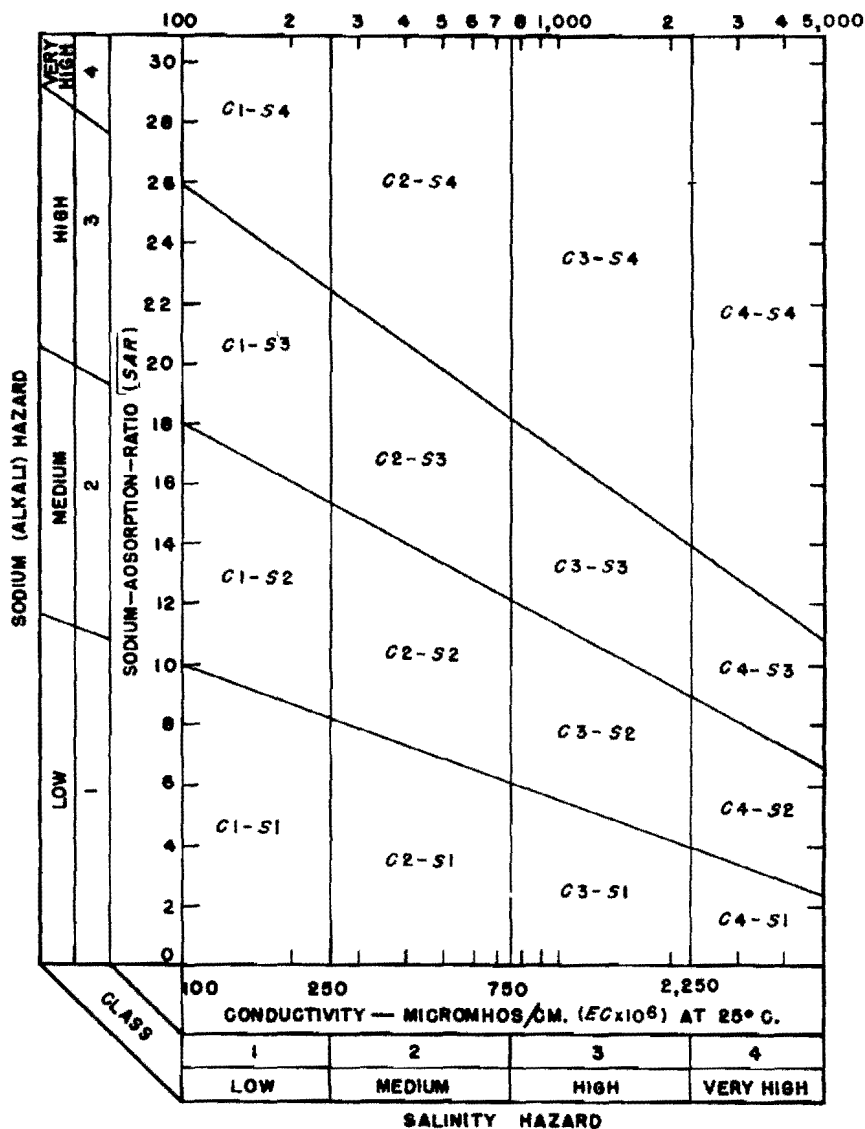
FIGURE 2.—Diagram for the classification of irrigation waters.

gram corresponding to these coordinates ($SAR=2.5, EC\times10^6=1{,}010$) classifies the water as $C3$–$S1$.

The significance and interpretation of the quality ratings on the diagram (fig. 2) are summarized as follows:

CONDUCTIVITY

Low-salinity water ($C1$) can be used for irrigation with most crops on most soils, with little likelihood that a salinity problem will de-

velop. Some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability.

Medium-salinity water (*C*2) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most instances without special practices for salinity control.

High-salinity water (*C*3) cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required, and plants with good salt tolerance should be selected.

Very high salinity water (*C*4) is not suitable for irrigation under ordinary conditions but may be used occasionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and very salt-tolerant crops should be selected.

SODIUM

The classification of irrigation waters with respect to SAR is based primarily on the effect of exchangeable sodium on the physical condition of the soil. Sodium-sensitive plants may, however, suffer injury as a result of sodium accumulation in plant tissue when exchangeable sodium values are lower than those effective in causing deterioration of the physical condition of the soil.

Low-sodium water (*S*1) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium-sensitive crops, such as stone-fruit trees and avocados, may accumulate injurious concentrations of sodium.

Medium-sodium water (*S*2) will present an appreciable sodium hazard in fine-textured soils of high cation-exchange-capacity, especially under low-leaching conditions, unless gypsum is present in the soil. This water may be used on coarse-textured or organic soils that have good permeability.

High-sodium water (*S*3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management—good drainage, high leaching, and additions of organic matter. Gypsiferous soils may not develop harmful levels of exchangeable sodium from such waters. Chemical amendments may be required for replacement of exchangeable sodium, except that amendments may not be feasible with waters of very high salinity.

Very high sodium water (*S*4) is generally unsatisfactory for irrigation purposes except at low and perhaps medium salinity where the solution of calcium from the soil or use of gypsum or other amendments may make the use of these waters feasible.

Sometimes the irrigation water may dissolve sufficient calcium from calcareous soils to decrease the sodium hazard appreciably, and this should be take into account in the use of *C*1–*S*3 and *C*1–*S*4 waters. For calcareous soils with high pH values or for noncalcareous soils, the sodium status of waters in classes *C*1–*S*3, *C*1–*S*4, and *C*2–*S*4 may be improved by the addition of gypsum to the water. Similarly, it may be beneficial to add gypsum to the soil periodically when *C*2–*S*3 and *C*3–*S*2 waters are used.

Effect of Boron Concentration on Quality

The occurrence of boron in toxic concentrations in certain irrigation waters makes it necessary to consider this element when assessing the quality of water. Scofield[7] proposed the limits shown (table 1).

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

Boron class	Sensitive crops	Semitolerant crops	Tolerant crops
	P. p. m.	*P. p. m.*	*P. p. m.*
1	<0. 33	<0. 67	<1. 00
2	0. 33 to . 67	0. 67 to 1. 33	1. 00 to 2. 00
3	. 67 to 1. 00	1. 33 to 2. 00	2. 00 to 3. 00
4	1. 00 to 1. 25	2. 00 to 2. 50	3. 00 to 3. 75
5	>1. 25	>2. 50	>3. 75

Plant species differ markedly in their tolerance to high concentrations of boron. In areas where boron occurs in excess in the soil or irrigation water, the boron-tolerant crops may grow satisfactorily, whereas sensitive crops may fail. The relative boron tolerance of a number of crops as determined by Eaton,[8] with only minor modifications based on more recent field observations, are shown (table 2).

Differences of a few places in the position of a crop in the boron-tolerance list may not be significant, and there is no sharp division between successive classes. Climate and variety may also be factors in altering the indicated tolerance of a given species.

Effect of Bicarbonate Ion Concentration on Quality

Laboratory and field studies have resulted in the conclusion that waters with more than 2.5 meq./l. residual sodium carbonate (*RSC*) are not suitable for irrigation purposes. Waters containing 1.25 to 2.5 meq./l. are marginal, and those containing less than 1.25 meq./l. *RSC* are probably safe. It is believed that good management practices and proper use of amendments might make it possible to use successfully some of the marginal waters for irrigation.

Summary of Classification Requirements

In appraising the quality of an irrigation water, first consideration should be given to the salinity and alkali hazards by referring to figure 2 and the quality-class ratings that accompany the diagram.

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[7] SCOFIELD, C. S. THE SALINITY OF IRRIGATION WATER. Smithsn. Inst. Ann. Rpt. 1934–35: 275–287, illus. 1936.

[8] EATON, F. M. BORON IN SOILS AND IRRIGATION WATERS AND ITS EFFECT ON PLANTS, WITH PARTICULAR REFERENCE TO THE SAN JOAQUIN VALLEY OF CALIFORNIA. U. S. Dept. Agr. Tech. Bul. 448, 131 pp., illus. 1935.

TABLE 2.—*Relative boron tolerance of certain plants*

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

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

Consideration should then be given to the independent characteristics, boron or other toxic elements, and bicarbonate, any one of which may change the quality rating. Finally, recommendations as to the use of a water must take into account such factors as drainage and management practices.

USE OF IRRIGATION WATERS

Control of Salinity

Plant roots take in water but absorb very little salt from the soil solution. Similarly, water but no salt is lost by evaporation from the soil surface. Both processes result in a concentration of salts in the soil water. If irrigation water is applied so sparingly that leaching is ineffectual, or if drainage is inadequate, the soil will become saline and the growth of crops will be inhibited or prevented.

The leaching necessary to maintain a favorable salt balance can be accomplished in several ways provided soil drainage is satisfactory. Water can be applied in excess with each irrigation or in very heavy irrigations at intervals. In many areas, rainfall is sufficient to effect some leaching. If salinity is high at the start, reclamation may require leaching by ponding water on the surface.

The leaching requirement is defined as the percent of the applied irrigation water that must pass through and beyond the root zone to maintain the salt content of the water draining from the root zone at a specified value. Assuming that it is desired to maintain the soil
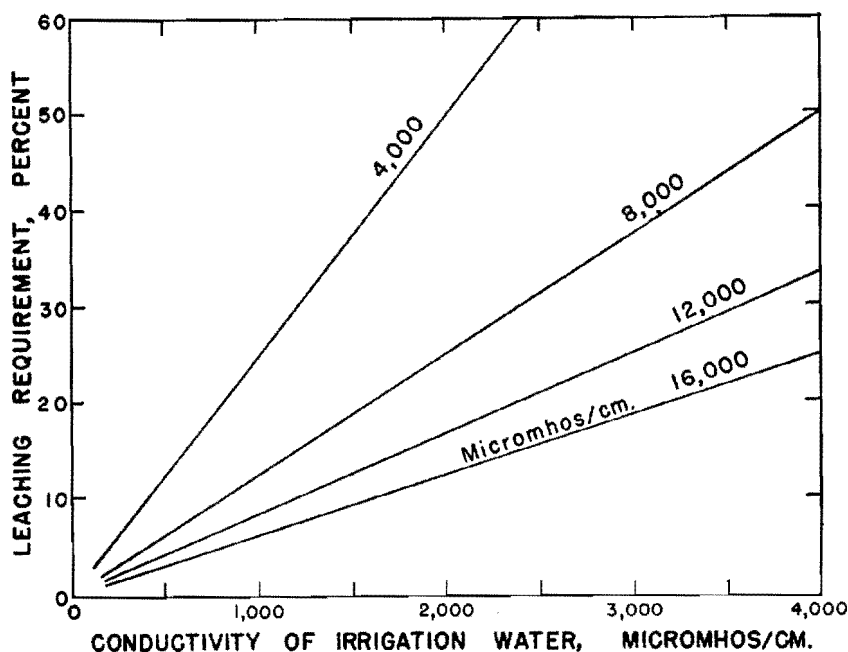
FIGURE 3.—Graphical estimate of the leaching requirement for an irrigation water of known conductivity if the conductivity of the soil water at the bottom of the root zone is to be maintained below values indicated on curves.

water at the bottom of the root zone at a conductivity of 4,000 when using an irrigation water having a conductivity of 1,000, it is possible to estimate the leaching requirement by referring to figure 3.

In this instance the indicated leaching requirement is 25 percent. This means that to prevent the salinity of the soil water from building up a conductivity higher than 4,000, the irrigation water with conductivity of 1,000 must be applied in such excess that 25 percent of it will leach on through the root zone. Obviously, this procedure can give only an estimate of the excess water required, but it should be in the right order of magnitude, and it does emphasize the necessity for leaching the root zone in order to control salinity.

The permissible level of salinity in the soil water passing below the root zone is related primarily to the salt tolerance of the crops to be grown.   The subject of salt tolerance is discussed in detail in chapter 4, United States Department of Agriculture Handbook 60, previously cited.

As a guide in determining the leaching requirement that may be necessary, a scale of conductivity and related crop response is shown in the following tabulation; this material is from Handbook 60.   The conductivity is expressed in terms of micromhos/cm. of the saturation extract of the soil in the root zone.   The corresponding conductivity values for the soil water at the bottom of the root zone would be higher, in many instances 1½ to 2 times as great   Thus, if the conductivity values shown in the tabulation are used as a guide in deciding the per-

missible level of salinity in the drainage water, the value selected would be conservative and the estimated leaching requirement should be ample.

Conductivity, $EC \times 10^6$ at 25° C. of the saturation extract (*micromhos/cm.*)	Related crop response
0–2,000	*Salinity effects mostly negligible.*
2,000–4,000	*Restricted yields of the more sensitive crops, such as:* Avocado, citrus, strawberry, peach, apricot, almond, plum, prune, apple, pear. Beans, celery, radish. Most clover species, meadow foxtail.
4,000–8,000	*Yields of many crops restricted.* The more sensitive crops in this group include: Grape, cantaloup. Cucumber, squash, peas, onion, carrot, bell pepper, potato, sweet corn, lettuce. The more tolerant crops in this group include: Olive, fig, pomegranate. Cauliflower, cabbage, broccoli, tomato. Oats, wheat, rye, alfalfa, Sudan grass, Dallis grass, strawberry clover, perennial ryegrass, sweetclovers. Flax, corn, rice.
8,000–16,000	*Only salt-tolerant crops yield satisfactorily. These include:* Date palm. Asparagus, kale, garden beets. Birdsfoot trefoil, barley, many species of wheatgrasses and wild ryes, Rhodes grass, Bermuda grass, saltgrass. Some varieties of cotton. Sugar beet.
More than 16,000	*Satisfactory yields from only a few very salt-tolerant species:* Certain native range plants.

Control of Exchangeable Sodium (Alkali) in Soil

Waters high in sodium affect soils differently than saline low-sodium waters and may require special management practices. Sodium in the water tends to be fixed or adsorbed by the soil in an exchangeable form. As the proportion of exchangeable sodium (alkali) increases, adverse physical and chemical conditions develop in the soil that limit or prevent the growth of plants.

Reclamation involves the replacement of the exchangeable sodium by calcium or magnesium and the removal of the sodium by leaching. It is often possible to prevent the formation of harmful levels of exchangeable sodium by the addition of calcium, usually in the form of gypsum, to the water or to the soil.

The sodium status of the water is expressed in terms of sodium-adsorption-ratio (SAR). Using figure 4 as a guide, it is possible to estimate the quantity of gypsum required to reduce the soluble sodium content of the water to a level that will not produce adverse soil conditions. For instance, if the SAR of the irrigation water is 22 and the conductivity is 1,000, the gypsum required to reduce the SAR to 8 would be 0.29 tons per acre-foot of water. The selection of the value
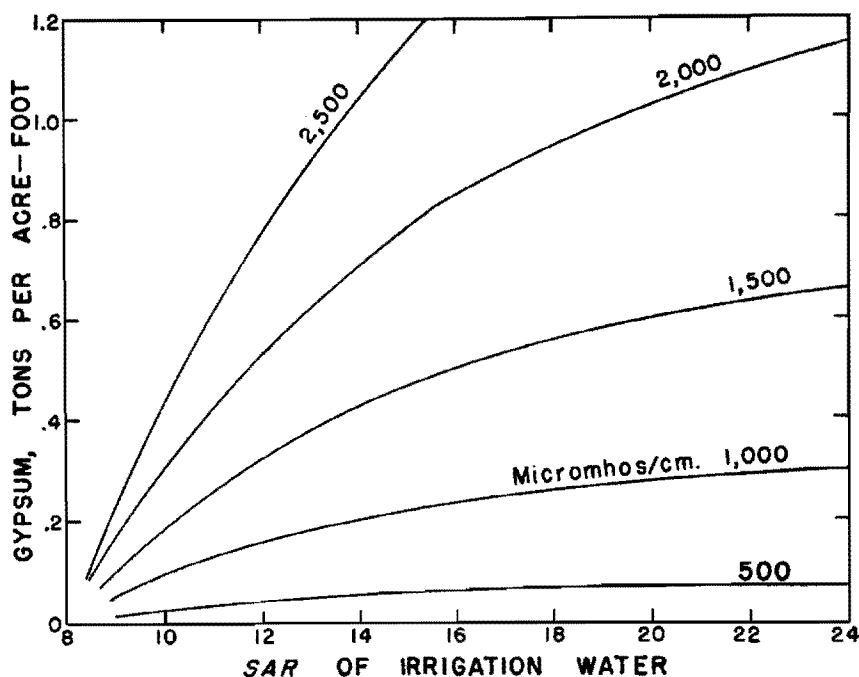
FIGURE 4.—Graphical estimate of the quantity of gypsum to be added to an irrigation water to reduce the sodium-adsorption-ratio (*SAR*) to 8, for waters having conductivity values indicated on curves.

8 for the *SAR* of the irrigation water after treatment with gypsum is arbitrary but is in the range that should be satisfactory.

SUPPLEMENTAL IRRIGATION

Until comparatively recently, irrigation in the United States was confined almost entirely to the arid West; during the past two decades, however, the use of irrigation water, on a supplemental basis, has increased rapidly in the humid regions. The 1950 Census of Agriculture [9] reported a total of 1,516,889 acres under irrigation in the 31 Eastern States.

This type of irrigation presents problems in quality and use of water that are new and different from those encountered in the areas of less abundant rainfall. The classification of irrigation waters, presented in a previous section, is not directly applicable to supplemental waters used in areas of relatively high rainfall; and the information and experience avaliable are so meager that a satisfactory classification cannot be developed at this time.

Certain general statements can be made, however, that may be useful. The following statements are based on the assumption that leaching of the root zone by rainfall takes place at least every year and probably more often.

[9] UNITED STATES BUREAU OF THE CENSUS. UNITED STATES CENSUS OF AGRICULTURE: 1950. 5 v., illus. Washington, D. C. 1952.

Class $C3$ waters can probably be used on a supplemental basis with little danger to crops, while $C4$ waters can be used occasionally on all but the most salt-sensitive crops. Similarly, it is assumed that the sodium concentration can be higher under some conditions; that $S3$ waters would result in very little damage to crops or soils; and that infrequent applications of an $S4$ water might be permissible.

If the irrigation water contains industrial wastes, the concentrations of boron or other substances toxic to plants should be determined.

In some areas the application of saline irrigation waters by means of sprinklers has resulted in serious leaf burn. As insufficient information is available at present to determine when such injury may occur, trials on limited areas are recommended.

Many of the waters of the East are corrosive to metal pipes. In addition to the injury to the sprinkler system, metal ions brought into solution may be toxic to plants.

GLOSSARY

ELECTRICAL CONDUCTIVITY.—The reciprocal of the electrical resistivity. The resistivity is the resistance in ohms of a conductor, metallic or electrolytic, which is 1 cm. long and has a cross-sectional area of 1 sq. cm. Hence, electrical conductivity is expressed in reciprocal ohms per centimeter, or mhos per centimeter. The terms "electrical conductivity" and "specific electrical conductance" have identical meaning.

EQUIVALENT; EQUIVALENT WEIGHT; GRAM EQUIVALENT WEIGHT.—The weight in grams of an ion or compound that combines with or replaces 1 gm. of hydrogen. The atomic weight or formula weight divided by its valence.

EQUIVALENT PER MILLION.—An equivalent weight of an ion or salt per 1 million gm. of solution or soil. For solutions, equivalents per million (e. p. m.) and milliequivalents per liter (meq./l.) are numerically identical if the specific gravity of the solution is 1.0.

EXCHANGEABLE-SODIUM-PERCENTAGE.—The degree of saturation of the soil exchange complex with sodium. It may be calculated by the formula:

$$ESP = \frac{\text{Exchangeable sodium (meq./100 gm. soil)}}{\text{Cation-exchange-capacity (meq./100 gm. soil)}} \times 100$$

LEACHING.—The process of removal of soluble material by the passage of water through soil.

LEACHING REQUIREMENT.—The fraction of the water entering the soil that must pass through the root zone in order to prevent soil salinity from exceeding a specified value. Leaching requirement is used primarily under steady-state or longtime average conditions.

MILLIEQUIVALENT; MILLIGRAM EQUIVALENT.—One thousandth of an equivalent.

MILLIEQUIVALENT PER LITER; MILLIGRAM EQUIVALENT PER LITER.—A milliequivalent of an ion or a compound in 1 liter of solution.

RESIDUAL SODIUM CARBONATE.—The excess of carbonate plus bicarbonate over calcium plus magnesium in a water.

$$RSC = (CO_3^{--} + HCO_3^-) - (Ca^{++} + Mg^{++})$$

where the ionic concentrations are expressed in milliequivalents per liter.

SODIUM-ADSORPTION-RATIO.—A ratio for soil extracts and irrigation waters used to express the relative activity of sodium ions in exchange reactions with soil.

$$SAR = \frac{Na^+}{\sqrt{(Ca^{++} + Mg^{++})/2}}$$

where the ionic concentrations are expressed in milliequivalents per liter.

SOLUBLE-SODIUM PERCENTAGE.—A term used in connection with irrigation waters and soil extracts to indicate the proportion of sodium ions in solution in relation to the total cation concentration. It may be calculated by the formula:

$$SSP = \frac{\text{Soluble sodium concentration (meq./l.)}}{\text{Total cation concentration (meq./l.)}} \times 100$$

SYMBOLS AND ABBREVIATIONS

EC _____ Electrical conductivity in mhos/cm. unless otherwise specified.

$EC \times 10^3$ _____ Electrical conductivity in millimhos/cm. (value in mhos/cm. $\times 10^3$).

$EC \times 10^6$ _____ Electrical conductivity in micromhos/cm. (value in mhos/cm. $\times 10^6$).

mho _____ Reciprocal ohm (ohm spelled backward).

mmho _____ Millimho.

μmho _____ Micromho.

ESP _____ Exchangeable-sodium-percentage.

SAR _____ Sodium-adsorption-ratio.

RSC _____ Residual sodium carbonate.

meq. _____ Milliequivalent.

meq./l. _____ Milliequivalent per liter.

p. p. m. _____ Parts per million. As commonly measured and used, parts per million is numerically equivalent to milligrams per liter.

C2–S3 _____ Example of classification of irrigation water; C denotes conductivity (electrical); S denotes sodium (SAR); numbers denote respective numerical quality classes.

CONVERSION FORMULAS AND FACTORS

Conductivity to milliequivalent per liter:

meq./l. $= 0.01 \times EC \times 10^6$ for irrigation waters in the range 100–5,000 micromhos/cm.

Conductivity to parts per million:

p. p. m. $= 0.64 \times EC \times 10^6$ for irrigation waters in the range 100–5,000 micromhos/cm.

Parts of salt per million parts of irrigation water to tons of salt per acre-foot of water:

Tons per acre-foot (t. a. f.) $= 0.00136 \times$ p. p. m.

Grains per gallon to parts per million:

p. p. m. $= 17.1 \times$ grains per gallon.

Milliequivalents per liter (from chemical analyses) to parts per million:

Multiply meq./l. for each ion by its equivalent weight.

Parts per million to milliequivalents per liter:

Divide p. p. m. for each ion by its equivalent weight.

1 mile=5,280 feet.

1 inch=2.54 cm.

1 foot=30.48 cm.

1 pound=453.59 gm.

1 acre=43,560 sq. ft.

1 acre-foot of soil weighs 4,000,000 pounds, approximately.

1 acre-foot of water weighs 2,720,000 pounds, approximately.

Gallons per minute to cubic feet per second:

c. f. s.=0.002228×g. p. m.

1 cubic foot per second (c. f. s.) =

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.

1 c. f. s. for 24 hours=1.98 acre-feet.

1 U. S. gallon=231 cubic inches,

8.345 pounds of water.

0.1337 cubic foot.

58,417 grains of water.

1 cubic foot=7.48 gallons.

1 cubic foot of water weighs 62.43 pounds.

1 cubic foot of soil in place weighs 68 to 112 pounds. Bulk density 1.1–1.8 gm./cc.

Average particle density for soils low in organic matter=2.65 gm./cc., approximately.

CHEMICAL SYMBOLS, EQUIVALENT WEIGHTS, AND COMMON NAMES

Chemical symbol or formula	Equiva- lent weight	Common name
Ions:		
Ca^{++}	20. 04	Calcium ion.
Mg^{++}	12. 16	Magnesium ion.
Na^+	23. 00	Sodium ion.
K^+	39. 10	Potassium ion.
CO_3^{--}	30. 00	Carbonate ion.
HCO_3^-	61. 01	Bicarbonate ion.
SO_4^{--}	48. 03	Sulfate ion.
Cl^-	35. 46	Chloride ion.
NO_3^-	62. 01	Nitrate ion.
Salts:		
$CaCl_2$	55. 50	Calcium chloride.
$CaSO_4$	68. 07	Calcium sulfate.
$CaSO_4.2H_2O$	86. 09	Gypsum.
$CaCO_3$	50. 04	Calcium carbonate.
$MgCl_2$	47. 62	Magnesium chloride.
$MgSO_4$	60. 19	Magnesium sulfate.
$MgCO_3$	42. 16	Magnesium carbonate.
$NaCl$	58. 45	Sodium chloride.
Na_2SO_4	71. 03	Sodium sulfate.
Na_2CO_3	53. 00	Sodium carbonate.
$NaHCO_3$	84. 01	Sodium bicarbonate.
KCl	74. 56	Potassium chloride.
K_2SO_4	87. 13	Potassium sulfate.
K_2CO_3	69. 10	Potassium carbonate.
$KHCO_3$	100. 11	Potassium bicarbonate.
Chemical amendments:		
S	16. 03	Sulfur.
H_2SO_4	49. 04	Sulfuric acid.
$Al_2(SO_4)_3.18H_2O$	111. 07	Aluminum sulfate.
$FeSO_4.7H_2O$	139. 01	Iron sulfate (ferrous).