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EFFECT OF AGRICULTURAL USE ON WATER QUALITY FOR DOWNSTREAM USE FOR IRRIGATION

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THE EFFECT OF AGRICULTURAL USE ON WATER QUALITY FOR DOWNSTREAM USE FOR IRRIGATION

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ABSTRACT

The effect of irrigation return flow on downstream irrigation use is of increasing concern. Changes that result from irrigation diversions are demonstrated by analyses of three river systems; the Sevier, Colorado and the Rio Grande, and the Imperial Irrigation District in California.

The term quality as used in this paper includes total salt, electrical conductance, composition by major ions, sodium percentage, sodium absorption ratio (SAR), residual sodium carbonate, effective salinity, chloride ion and boron (ppm). A classification is suggested that considers all of these parameters.

Permanent irrigated agriculture depends upon a satisfactory salt balance, especially for the sodium and chloride ions. Good water management will minimize water use and losses but an overall satisfactory salt balance is essential.

Principal conclusions are: Return flows degrade water quality but frequently this does not significantly affect the use of the downstream flow for irrigation. The development of new projects where virgin soils contain large quantities of soluable salts should be carefully considered. Irrigation water quality criteria should be revised. Improved water management will not have a major long time effect on downstream water quality except where subsoils contain slowly soluable salts.

KEY WORDS: Agriculture, Drainage, Evaporation, Evapotranspiration, Irrigation, Return Flow, Rivers, Salinity, Water Management, Water Quality.

EFFECT OF AGRICULTURAL USE ON WATER QUALITY
FOR DOWNSTREAM USE FOR IRRIGATION

by J. E. Christiansen[1]

Introduction

The effect of irrigation return flow on downstream water quality has been of particular concern in recent years. Many writers have dealt with the subject and have been concerned with the gradual deterioration in water quality of some of our major river systems such as the Colorado River and the Rio Grande.

Eldridge et al. (1960) issued a comprehensive report entitled "Return Irrigation Water Characteristics and Effects." This report dealt with all uses of waters receiving irrigation return flow. It summarized much of the available data on quantities and quality of return flow. In their summary they state "Return irrigation water is a major factor affecting the quality of surface and ground waters of large sections of this country..." They also say: "Successful irrigation requires that a 'salt balance' be maintained in the soil which means that the salt (dissolved mineral matter) output by-way-of return flow must equal or exceed the input by-way-of the irrigation water..." They recognize that there is a "shift in the proportion of various cations and anions which make up these salts." Much of this report deals with non-agricultural uses of waters receiving return flow.

Utah State University Foundation prepared a report for the Federal Water Pollution Control Administration entitled, "Pollution Characteristics and Pollution Problems of Irrigation Return Flow" (1969). This report attempted to present an extensive review of the present state of scientific knowledge and technology associated with the practice of irrigation as affecting return flow

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and downstream quality of water. It contained 245 references and a bibliography on the subject with about 700 titles. Many aspects of the problem of water flow from irrigation systems were considered. One of the principal conclusions arrived at was that there were still some points of uncertainty or disagreement, and that additional research on some aspects of the problem was needed. A more recent report by Skogerboe and Law (1971) also emphasizes the need for additional research.

Bagley et al. (1971) prepared a recent report for the National Water Commission entitled "Extending the Utility of Non-Urban Water Supplies" which deals primarily with management techniques for "extending the utility of an existing water supply in any river basin." They suggest that this can be approached "under three general quiding principles: (1) minimizing depletion wherever possible...(2) generally preserve, protect and improve water quality...and (3) make carefully considered allocations..."

Although this report does not deal specifically with the effect of agricultural use on water quality it does cover many aspects of the problem and stresses the fact that "every river basin is different, with different configurations, proportions, and numbers of water using entities. It points out that a "low irrigation efficiency in the Twin Falls region of Idaho provides a return flow supply much more uniform in flow rate and temperature, of high quality, and at a location convenient for other uses including an excellent fish hatching operation. On the other hand, low irrigation efficiencies in the Grand Junction area of Colorado permit large quantities of deep percolation waters to come in direct contact with gypsiferous and other more highly saline formations where substantial pickup of minerals takes place as water makes its way back into the Colorado River." Thus, in the Idaho example, low efficiencies in irrigation may result in greater utility for other uses, while the Colorado example has just the opposite effect.

In discussing the benefits of better water management to the individual user as contrasted with the public good, they pose the question: "What changes

in individual irrigation practices result in the greatest public benefit with respect to making water available to a greater number and variety of uses? Making additional supplies available through increased irrigation efficiencies may be largely illusionary... "since high seepage, deep percolation or surface runoff losses represents water that sill remains in the manageable supply of the basin... except where the irrigator is at the 'end of the ditch.' " They say, however, that "there are several good reasons for generally encouraging higher efficiencies in individual uses."

Another comprehensive study bearing on the subject of return flow by Hyatt, et al. (1970) is entitled, "Computer Simulation of the Hydrologic-Salinity Flow System within the Upper Colorado River Basin." In this study they produced a hybrid analog-digital model of the upper basin including some forty sub-basins wherein they considered all uses of water, stream flows and salt loadings. This report contains data on the characteristics of the sub-basins and considers the effect of actual and proposed irrigation projects on the stream flow and salt burden of the downstream system. They state: "The only water quality parameter considered in the model development was total dissolved solids (TDS) or salinity. In general, this parameter has been most responsible for limiting water re-use in the irrigated and sparsely settled areas of the Western United States."

Although many studies have shown that there is generally a deterioration in water quality along streams where there are diversions for irrigation and the return flows re-enter the stream, this does not mean that detrimental effects of irrigation outweigh the beneficial effects. Quite the reverse is true; irrigation developments in the United States have contributed materially to the overall economy of the country and to the present standard of living in many ways. It has made it possible to enjoy many foods, especially vegetables, fruits, and nuts, which are grown mainly under irrigation and which would not otherwise be available, as indicated by Christiansen (1953).

Objectives and Limitations of this Discussion

One of the principal objectives of this discussion is to take a closer look at

water quality criteria for irrigation with primary consideration being given to the composition including all factors that degrade or enhance water with respect to its use for irrigation.

An historical review of various proposals for classifying irrigation waters is presented with suggestions by the writer. Limitations of some of the more commonly used criteria are mentioned. Salt balance and the need for a favorable salt balance in an irrigated area is explained. Leaching requirement is included in the discussion because of its relationship to the management of irrigation water. A study of the composition of irrigation water along several stream systems in relation to various criteria for classifying water is presented for the Rio Grande, the Sevier River in Utah, the Upper Basin of the Colorado River in Utah, and the Imperial Irrigation District.

The discussion is limited to downstream uses for irrigation. Many other aspects of water quality, especially as they pertain to urban uses are not included because of space limitations. For the same reason, problems pertaining to saline water treatment and mineralized springs are not covered. Suggestions for a more complete system of classifying irrigation waters are given.

Irrigation Water Quality Criteria

In order to discuss intelligently the subject of the effect of agricultural use on water quality as it pertains to reuse for irrigation, it is first necessary to be somewhat specific as to just what is meant by water quality.

Many writers have discussed irrigation water quality criteria. The early writers, including Scofield (1927), Kelley (1937), Eaton (1935), Wilcox and Magistad (1943), and others, generally classified irrigation waters with respect to: (a) total salt content or conductance, (b) sodium, usually expressed as a percentage of total cations, and (c) boron content, usually expressed in parts per million. Eation and others have emphasized the detrimental effect of residual sodium carbonate.

All authorities recognize that it is not the water quality per se that is of most importance, but that it is the salinity and sodium status of the soil

solution within the soil root zone that affects the growth of crops. Soil and drainage characteristics and the amount of water applied have an important bearing on the resulting soil salinity in addition to the quality of the water applied. This discussion, however, is limited to water qaulity for irrigation use; many other factors must also be considered together with the salt tolerance of crops to be grown. Where the drainage is satisfactory; that is where the water table can be maintained well below the root zone, the salinity and often the sodium status of the soil can be materially affected by the amount of water that passes through the soil profile. The salinity of the soil solution may vary from less than twice to possibly more than twenty times that of the water applied under different soil conditions and leaching regimes.

Wilcox (1948) published a diagram for assessing water quality based on total salt content, expressed as conductance or in milliequivalents per liter, and Na percentage. This diagram differed from most of the earlier tables in that it indicated that a water with very low total salinity might have a relatively high sodium percentage and still be rated as an excellent water for irrigation. For example, a water with a salinity of 2.5 me/l. and an Na percentage of 82 would still be considered "excellent." This differed from the classification previously published by Wilcox and Magistad (1943) in which any water with an Na percentage greater than 75 would be considered as class 3 (injurious to unsatisfactory).

Thorne and Thorne (1951) presented another diagram somewhat similar to that of Wilcox's in which waters were given a number 1 to 5 representing conductance and a letter A to E for sodium percentage, Lines were drawn to indicate 25 ratings for 1A to 5E. This diagram likewise indicated that a 1A water might have a high Na percentage if the conductance was low (up to 100 percent for 0 conductance).

The thinking with respect to waters of low salinity but with relatively high Na percentages apparently comes from consideration of the effect of salt concentration and sodium on the ultimate base exchange status and crop responses rather than the effect on soil structure. Evidence is cited where it is shown that low salt high sodium waters produce adverse effects on soil structure, infiltration

rates and soil permeability. This adverse effect of sodium on soil structure is ignored in some classification systems.

Salinity Laboratory Classification

Richards et al. (1954) in the commonly called "Salinity Laboratory Handbook No. 60" proposed a classification based on the sodium adsorption ratio, SAR, and electrical conductance. Waters were assigned values of C1 to C4 for conductance, and S1 to S4 for sodium hazard based on both SAR values and conductance. For example, water with a conductance of 0.1 mmho and SAR of 10 would still be C1-S1, but a water with a conductance of 3 mmhos and SAR of 10 would be C4-S3. This classification was presented in the form of a semi-logrithmic diagram, and it has become the most commonly used criteria for classifying irrigation waters as to quality. Richards et al. discussed the effect of boron and residual sodium carbonate as defined by Eaton. They cautioned against using waters with more than 1 ppm boron for sensitive crops and 3 ppm for tolerant crops, and 'concluded that waters with more than 2.5 meq/l. of residual sodium carbonate are not suitable for irrigation purposes," and that "waters containing 1.25 to 2.5 meq/1. are marginal," and "those with less than 1.25 meq/1. are probably safe."

They also mention that "high bicarbonate" waters are undesirable but fail to define "high bicarbonate." The term appears to be used to indicate "residual sodium carbonate" and not high ratios of HCO_3 to Cl + SO_4. In the "high bicarbonate" experiment cited (Table 11) only those waters with more than 1 meq/1. of residual sodium carbonate produced adverse effects on the soil. Waters with a high ratio of HCO_3 to Cl (85% to 15) but with less than 1 meq/1. of residual Na_2CO_3 did not produce soils with high exchangeable sodium percentages even after 86 applications of irrigation water. Because of the low solubility of Ca $(HCO_3)_2$. The HCO_3 ion in irrigation waters seldom exceeds 4.5 meq/1. except where there are unusually large amounts of Mg, or where residual sodium carbonate is present.

Residual sodium carbonate, as defined by Eaton (1935), means that the sum of the HCO_3 and CO_3 ions exceeds the sum of the Ca and Mg ions and that, therefore,

some of the HCO_3 or CO_3 ions are associated with the Na ions which produces a high pH and undesirable soil structure.

Unfortunately, many people using the Salinity Laboratory Classification diagram fail to read the "fine print" and consider only the SAR and conductance values. They ignore the residual sodium carbonate and high Na percentage and boron.

Effective Salinity, Doneen

Doneen (1959) suggested the term "effective salinity" as a criteria of water quality. Effective salinity is expressed in meq/1. and is computed by subtracting the $Ca(HCO_3)_2$, $Mg(HCO_3)_2$ and $CaSO_4$ in that order, from the total. The remaining salts which are highly soluble comprise the effective salinity. Recognizing that the texture and drainage characterisitics of the soil have a significant effect on the salinity of the irrigation water that might be acceptable, he suggested three classifications, 1, 2, and 3, for each of three soil and drainage conditions which are indicated in Table 1 by A, B, and C (the writer's designation).

Table 1. Effective Salinity, Millequivalents per Liter, Doneen (1959)

Soil and Drainage Conditions	Class		
	1	2	3
A	<7	7-15	>15
B	<5	5-10	>10
C	<3	3-5	>5

A Open soils, good drainage.

B Intermediate textured soils and drainage conditions.

C Low infiltration rates, poor drainage conditions.

This classification recognizes the fact that the salts of low solubility contribute little to the actual salinity of the soil solution. There appears to be considerable merit in the ideas suggested by Doneen with respect to the evaluation of a water for irrigation.

Christiansen and Olsen Suggested Rating

Recently in Guatemala, Christiansen and Olsen (1972) found a case where the Salinity Laboratory Classification had been used, but where the "fine print" regarding Na and residual sodium carbonate had been overlooked. Some time ago, a number of wells were drilled for irrigation in a relatively arid location in the eastern part of the country. These wells were equipped with electric motor turbine pumps and were operated for only a few years before troubles began. Low infiltration rates developed and this created difficulties in irrigating, and yields decreased. This, together with a high cost for power resulted in the abandonment of these wells within a period of about three years. Shortly thereafter a feasibility study for a gravity project for the area was made by an engineering firm, and in their report they included analyses of the water from several of these wells. The analyses for three of these wells are given in Table 2.

Table 2. Analyses of Waters from Three Wells in Guatemala

	Well Number		
	1	4	5
EC-micromhos	595	550	415
Cations: meq/l.			
Ca	1.46	1.60	0.56
Mg	1.13	1.15	0.10
Na	3.90	3.17	3.46
K	0.12	0.15	0.07
Total	6.61	6.07	4.19
Anions:			
HCO_3	4.70	5.23	3.27
SO_4	0.92	0.43	0.47
Cl	0.83	0.44	0.59
NO_3	0.10	0.14	0.04
Total	6.55	6.20	4.37
Na %	59.0	52.2	82.6
SAR	3.41	2.77	6.39
Salinity Lab Classification	C2-S1	C2-S1	C2-S1

The classification C2-S1 indicated a fairly satisfactory water, especially with respect to the sodium hazard. A careful study of the data for these three wells, however, indicated that the Na percentage ranged from 52 to 83 percent and that the residual Na_2CO_3 ranged from 2.11 to 2.61 meq/1. No mention was made in the report about the relatively high Na percentage or the high residual Na_2CO_3. At another location in the same general area there was evidence that a soil had become sodic after being irrigated for a few years with well water that had a conductance of about 500 µmhos/cm. It is assumed that this water may also have contained residual Na_2CO_3, but analyses of the water were not available.

On the basis of this experience, a table entitled "Suggested Ratings for Irrigation Water" was prepared and included in the report. This is given here as Table 3. Comments with respect to this table included "These suggested ratings for irrigation water ... consider all of the important factors which degrade a water with respect to its use for irrigation. Each detrimental factor is considered separately and no attempt is made to combine these factors into a single classification. The factors considered are those that have been proposed by a number of authorities including Eaton, Scofield, Wilcox and Magistad, Thorne and Thorne, Richards et al., and Doneen."

It is emphasized that these are "suggested ratings" and that comments with respect to the merits of this table, and the values suggested will be welcomed by the authors.

Table 3. Suggested Ratings for Irrigation Water, Maximum Values

Rating	EC mmhos	Na+ %	SAR	Na_2CO_3 meq/1.	Cl- meq/1.	Eff. Sal. meq/1.	Boron ppm
1	0.5	40	5	0.5	3	3	0.5
2	1.0	60	10	1.0	6	6	1.0
3	2.0	70	15	2.0	10	12	2.0
4	3.0	80	20	3.0	15	18	3.0
5	4.0	90	30	4.0	20	24	4.0

Salt Balance and Leaching Requirement

The concept of a favorable salt balance in an irrigated area has long been recognized. Scofield (1927) recognized that salts in the soil solution were not taken up by plants in proportion to the water transpired, and that it was necessary to apply water to irrigated lands in excess of actual evapotranspiration in order to leach salts through the root zone. Scofield published another paper entitled "The Salt Balance in Irrigated Areas," (1940). Wilcox analyzed the salt balance of the Rio Grande River and prepared annual reports from 1934 to 1963. A summary report for the thirty-year period was issued by Wilcox (1968).

The term salt balance as commonly used has two rather distinct meanings. The first is with respect to the soil profile, and the second with respect to an irrigated area, project or valley. An irrigated area, such as the Imperial Irrigation District, may have an overall favorable salt balance, and yet many sub-areas, and the soil root zone within such areas, may have an unfavorable salt balance. The concept of a salt balance is of greatest importance where the irrigation water contains appreciable amounts of salt, especially sodium salts, since without adequate drainage from the root zone, salt accumulation will be quite rapid. For example, if a water has a conductance of 1 mmho (approximately 640 ppm salt), and if 3 feet (depth) of water was applied in a season, it would mean that 2.6 tons of salt were being applied to each acre per year in the irrigation water. It would then not take long to accumulate large amounts of salt in the soil if drainage was inadequate.

The term "leaching requirement" has been used for many years to indicate the excess amount of water over actual evapotranspiration that must be applied as irrigation water (including precipitation) in order to maintain a salt balance within the root zone of the crops grown. The leaching requirement is generally estimated from conductance measurements on the irrigation water and an assumed maximum tolerable conductance level for the drainage water. This concept, however, ignores the composition of the irrigation water and the fact that some the calcium and biocarbonate ions precipitate in the soil as lime and are not all removed

by the water passing below the root zone. Magistad and Christiansen (1944) in discussing "Salt Balance" state: "In general, the conception of a salt balance is beneficial because it so clearly demonstrates the need for drainage. The place of some particular salts or ions in such a balance has not been determined. For instance, a considerable proportion of the calcium entering a soil in the irrigation water may precipitate as calcium carbonate, which is almost inert insofar as salinity is concerned." Some of the calcium and sulfate ions may precipitate as calcium sulfate, which has an intermediate solubility (approximately 30 meq/l.). They say: "Actually, a salt that is precipitated is removed almost as effectively as though it disappeared with the drainage water." With respect to a salt balance in the Imperial Valley, they say: "Scofield (1943) has shown that on a small area in the Imperial Valley where an accurate check has been made, only about 6 percent of the quantity applied as irrigation water reappears in the drainage system; the other 94 percent is transpired by the growing plants or is lost by evaporation from the soil surface." Fortunately there are excellent data now available on salt balance conditions in the Imperial Valley which show that a much larger proportion of the water used is accounted for as drainage and waste water leaving the irrigated area.

Salt Balance in the Imperial Valley

It may be of interest to review briefly the salt balance in the Imperial Valley. The fascinating story of the development of irrigation in the Imperial Valley of Southern California was the subject of one of the best-selling novels of its day, "The Winning of Barbara Worth" by Harold Bell Wright, 1911. A more factual account has been prepared by the Imperial Irrigation District (1960) which states: "The first water from the Colorado River reached the Valley in June, 1901, and there followed one of the most rapid irrigation developments, on a large scale, ever witnessed in our nation." This rapid development was brought to a sudden but temporary halt by the failure of the Rockwood Gate at the entrance to the Alamo canal on October 11, 1005, during a high flood on the Colorado and Gila Rivers. From that time until February, 1907, the entire flow of the Colorado

River entered the Valley uncontrolled and created the Salton Sea and the New River. The flow into the Valley was finally brought under control by the Southern Pacific Company which became owner of the irrigation system. The Imperial Irrigation District was organized in 1911 to acquire the main canal system and other properties of the original California Development Company which was actually acquired in 1916. In 1922 the District took over the canals formerly operated by thirteen mutual water companies. Soon it became apparent that drainage would be necessary to control the water table, and the District took over the responsibility of providing a main network of open drains, usually spaced about one-half mile apart. This network of open drains did not prove adequate and farmers were encouraged to install tile drains. The District agreed to provide an outlet for each 160 acres of irrigated land. According to the Districts Annual Reports, 1969 and 1970, from 1929 to 1943, a period of 14 years, a total of 536 miles of the tile drains were installed on 25,000 acres of land. The amount of tile drains installed each year increased from 60 miles in 1944 to a maximum of 1,036.6 miles in 1970, the last year for which a record is available. By that time a total of 14,859 miles of tile had been installed in 362,252 acres.

A salt balance study was begun in 1944. For that year, 2,342,420 tons of salt entered the District in the irrigation water and 2,102,938 left in the drainage water, leaving a net of 239,482 tons in the soil. A deficit continued every year until 1949 when 145,217 tons more salt left the area than came in via the irrigation water. Since 1949, there has been a favorable salt balance every year, and through 1970 a total of 8,212,000 tons more salt has left the area than came in with the irrigation water, an average of 357,000 tons per year. In 1970, 2,755,000 acre feet of water entered the Imperial Irrigation District carrying 3,488,000 tons of salt, and 1,020,500 acre feet left the District as drainage effluent carrying 3,780,700 tons of salt, an excess of 292,700 tons. This emphasizes the large amount of salt carried by irrigation and drainage waters. Fortunately, there are no downstream irrigated areas affected by the drainage water from the Imperial Irrigation District.

Salt Balance by Constituents

A most interesting part of this study, however, was the balance of the specific ions in the water. For 1969 and 1970, the results are given in Table 4 which shows that while there was a favorable salt balance for both years, there was a negative balance for Ca, HCO_3, and SO_4, and a large positive balance for Na and Cl. This means that some $CaCO_3$ and $CaSO_4$ was precipitated and that NaCl was leached from the soil. Part of the NaCl removed may have resulted from an improvement in the exchangeable cation status. Calcium probably replaced some of the exchangeable sodium which was leached from the soil as NaCl and $NaHCO_3$.

Table 4. Salt Balance by Constituents, Imperial Irrigation District Reports, 1969 and 1970

	Tons of Constituents					
	1969			1970		
	Influent	Effluent	Balance	Influent	Effluent	Balance
Cations						
Ca	386,006	279,952	-106,054	400,766	288,198	-112,568
Mg	129,521	141,518	+ 12,006	132,590	142,127	+ 9,537
Na + K	541,655	811,694	+270,039	556,897	793,791	+236,894
Total	1,057,173	1,233,164	+175,991	1,090,253	1,224,116	+133,863
Anions						
HCO_3	351,798	169,180	-182,618	361,773	169,728	-192,045
SO_4	1,274,753	1,109,495	-165,258	1,352,862	1,149,401	-203,461
Cl	538,834	1,132,483	+593,649	532,633	1,098,826	+566,193
Total	2,165,385	2,411,158	+245,773	2,247,268	2,417,955	+170,687
Na + K + Cl	1,080,489	1,944,177	+863,688	1,089,530	1,892,617	+803,087
Total tons of salt	3,222,558	3,644,322	+421,764	3,337,521	3,642,071	+304,550
Acre feet	2,675,833	962,639	-1,713,194	2,754,898	1,020,503	-1,734,395
Tons per acre foot	1.20	3.79		1.21	3.57	
Effluent as % of influent		36.0			37.0	

The history of most irrigation projects is somewhat similar to that of the Imperial Valley. The water table usually is at an adequate depth below the ground surface when irrigation water is first applied. Unless there is adequate natural

drainage, or unless groundwater is being pumped from wells, there is a fairly rapid rise in the water table until it nears the surface and salinity appears. By this time, a large quantity of natural salts has been deposited in the soil. Drainage systems are then installed, and the salt balance changes from a negative to a positive quantity. Many years may elapse, however, before the average soil salinity of the area is reduced to a balance and where the soil salinity is at a desirable level and the outflow of salt is equal to the inflow of salt.

When the soil salinity has been reduced to an acceptable level, a balance of the Na and/or Cl ions might then be considered as an adequate salt balance. This might be achieved by more efficient irrigation practices with less drainage outflow. If the same amount of water was diverted from the stream, however, and a larger area was irrigated because of the more efficient use of the water, the higher efficiency would not improve the quality of the downstream water.

Leaching Requirement

The leaching requirement was defined by Richards et al. (1954) as "the fraction of the irrigation water that must be leached through the root zone to control soil salinity at any specified level," and also as "the minimum amount of water required to be drained." They presented the following equation for estimating this leaching requirement:

$$LR = EC_{iw}/EC_{dw} \qquad (1)$$

in which

LR is the leaching requirement as a ratio of the water

EC_{iw} and EC_{dw} are the corresponding mean value of the electrical conductances of the irrigation and drainage water, respectively.

They also state, "For field crops where a value of EC_{dw} = 8 mmhos/cm can be tolerated...and for irrigation waters with conductivities of 1,2 and 3 mmhos/cm respectively, the leaching requirements will be 13, 25 and 38 percent. These are maximum values, and since properly taken into account, other factors all would enter in such a way as to reduce the predicted value of the leaching requirement."

In spite of this precaution, Equation 2, often with assumed EC_{dw} values of 6 to 7.5 mmhos/cm, is used to estimate leaching requirements. The writer suggests that a simple correction to Equation 1 would give more realistic values of the leaching requirements for most irrigation waters, especially those with relatively good quality. The modification suggested may be written

$$LR = (EC_{iw} - EC_{bc})/EC_{dw} \quad (2)$$

in which EC_{bc} is the estimated conductance of the calcium bicarbonate in the which which can be estimated from an analysis by the equation

$$EC_{bc} = 0.1\ Ca(HCO_3)_2 \quad (3)$$

where $Ca(HCO_3)_2$ is expressed in meq/l. For waters with large amount os $CaSO_4$, such as the Pecos River, one might modify Equation 1 to read

$$LR = EC_{iw} - EC_{bc} - EC_{cs}/(EC_{dw} - EC_{csdw}) \quad (4)$$

in which EC_{cs} is the electrical conductance of the $CaSO_4$ in the irrigation water after correction for the $Ca(HCO_3)_2$, and EC_{csdw} is the estimated conductance of the $CaSO_4$ in the drainage water, with a maximum value of 2 mmhos. EC_{cs} and EC_{csdw} can be estimated from the equation

$$EC_{cs} = 0.09\ CaSO_4 \quad (5)$$

Equation 2 and 4 are only approximations, but they are believed to give more realistic values of LR than Equation 1 for most irrigation waters. A comparison of the estimated values of LR from the three equations, using data from Richards et al., (Table 12) and a value of $EC_{dw} = 8$ is given in Table 5.

Table 5. Comparison of LR Values Estimated from Equations,1, 2 and 4

River and Location	EC_{iw} mmhos	Eq. 1	Eq. 2	Eq. 4
Colorado, Yuma, Ariz.	1.060	13.2	10.0	9.9
North Platte, Wyo-Neb.	0.828	10.3	5.9	5.9
Arkansas, Colo.	1.210	15.2	10.2	8.3
Rio Grande, El Paso	1.160	14.5	10.0	10.0
Pecos, New Mexico	3.210	40.0	36.1	24.6
Sevier, Central Utah	0.580	7.3	4.1	4.1
Sevier, Delta, Utah	2.400	30.0	26.1	26.1
Snake, Idaho	0.410	5.1	2.4	2.4

This table gives a rough estimate of the leaching required to maintain a salt balance, but which, for some of the waters, may be more than taken care of by precipitation and the unavoidable over-irrigation under the best of irrigation practices.

Effect of Irrigation Efficiency and Water Management on Downstream Water Quality

Differences in the estimation of leaching requirement and its effect on overall water management should not materially affect downstream water quality. More efficient water management with higher irrigation efficiencies will have for the long term relatively little effect on downstream water quality, assuming that the same total acreage is irrigated and that a balance of Na and Cl ions must be maintained to insure the permanence of the irrigation development. With less leaching and return flow, there will be a higher percentage of the less soluble salts precipitated in the soil, with very little detriment to the project. There will, therefore, be less drainage effluent and total salt entering the downstream flow. The drainage effluent will have a higher percentage of Na and Cl ions. For a satisfactory salt balance, however, it will be necessary for the total quantity of the highly soluble Na and Cl salts entering in the irrigation water to leave the area, either in the natural return flow seepage to the stream or via drainage channels, assuming that there will be a favorable balance of Na and Cl ions at an acceptable soil salinity level.

This more highly concentrated return flow may have just as much adverse effect on the downstream water quality as a more dilute effluent with a higher percentage of Ca, HCO_3 and SO_4 ions. The resultant Na and Cl percentages in the downstream flow would be higher, although the total salinity may be slightly lower.

With less efficient management and correspondingly a lower irrigation efficiency and a greater return flow, there would be a greater outflow of total salts until a new balance is reached. This effluent would contain lower Na and Cl percentages and higher Ca, HCO_3 and SO_4 percentages. The actual "quality" of the downstream flow would be affected very little, except tempemporarily until a new balance is reached.

If, however, the irrigation enterprise diverted the same amount of water, and if with more efficient management of the water a greater acreage was irrigated, there would be less total effluent and consequently less total downstream flow with a higher concentration (same total amount) of Na and/or Cl ions. More efficient management would, under these conditions, actually degrade the downstream flow rather than improve it.

Release of Minerals from Soil Weathering and the Effect on Downstream Water Quality

Many soils of the semi-arid West contain unweathered minerals in addition to lime, gypsum, and the more soluble salts. These minerals are primarily unstable Ca and Mg silicates which break down upon leaching releasing soluble salts in addition to those applied in the irrigation water. The effect of this soil mineral weathering on the sodium hazard (SAR) of irrigation water was studied by Rhodes, Kruger and Reed (1968) and Rhodes (1968). They found that these released salts produced a higher (2 to 4 me/l), concentration of Ca + Mg than Na (0.4 to 1.3 me/l), regardless of the SAR value and concentration of salts in the leaching water. When an equilibrium was obtained, the SAR value of the leachate was always less than the SAR value of the leaching water. Some of the released Ca and Mg ions were absorbed on the exchange complex which also had the effect of reducing the exchangeable sodium percentage (ESP) of the soil solution. This effect is opposite that of the precipitation of $CaCO_3$ in the soil which increases the percentage of Na in solution as well as the ESP. The net effect of leaching with $CA(HCO_3)_2$ waters also was to lower the SAR and ESP of the leachate.

Effect of Precipitation of $CaCO_3$ on the Quality of Return Flow

Many investigators have discussed the precipitation of $CACO_3$ in the soil from $Ca(HCO_3)_2$ in irrigation waters. Generally, soil solutions and drainage waters have concentrations of HCO_3 in the range of 3 to 5 me/l, and may be said to be saturated with $Ca(HCO_2)_2$. The solubility of $Ca(HCO_3)_2$ is somewhat dependent on other constituents, temperature and pH.

When irrigation water is applied to the soil, the soil solution passing through the root zone usually will be saturated with respect to $Ca(HCO_3)_2$. The relative amount of $CaCO_3$ precipitated will depend primarily on the ratio of amount of water applied to that which passes through the root zone. This precipitation of $CaCO_3$ increases the Na percentage and SAR value of the return flow and is the principal reason why the NA percentage of river waters increases as one progresses downstream as shown in Table 6 for the Rio Grande. Here the Na percentage increased from 26 to 63 between Otowi Bridge and Fort Quitman.

Under some conditions the precipitation of $CaCO_3$ may contribute to an unbalanced nutrient condition and result in chlorosis in some plants.

Irrigation of Gypsiferous Soils

One special condition where efficient irrigation practices and better overall management of the irrigation project through reduction in canal seepage losses and higher irrigation efficiencies, etc., might affect downstream water quality is where the subsoils contain relatively large amounts of gypsum. As irrigation water passes through the root zone or seeps from canals into the subsoils, it will dissolve some of this gypsum which will find its way back into the river system and increase the total salt content of the downstream flow. There are some areas in the upper basin of the Colorado River where subsoils are highly gypsiferous, or where they contain minerals that are continuously breaking down to yeild soluble salts. Under such conditions, there may be a greater outflow of total salt, including $CaSO_4$, than inflow. Efficient irrigation practice will, inder these conditions, decrease the total salt outflow, but it should not be decreased to the point where there is an unfavorable balance of Na and Cl ions. The additions of Ca and SO_4 ions to the downstream water may in some instances be beneficial in that it would reduce the Na percentage and SAR values of the water and actually improve the water quality for irrigation but not for municipal or industrial use. Again, if the more efficient management of the water diverted resulted in a greater acreage being irrigated, there would be a net adverse affect on the downstream flow both in quantity and quality.

Development of an Irrigation Project on Virgin Soils of High Salt Content

Another special condition where the downstream water quality may be adversely affected is the development of new irrigation projects along river systems where the virgin soils contain appreciable quantities of salt. In the past, many irrigation projects have been developed where the virgin soils were quite salty, but after a few years, especially where the soils had good natural drainage the more soluble salts were largely leached from the root zone and the soils became non-saline and fertile. Successful irrigation practices in such areas necessitated the application of sufficient amounts of water to leach large amounts of salt from the virgin soil. On river systems where the stream flow is already largely used and where the downstream quality may be at a point where it is becoming undesirable for irrigation, additional upstream developments on salty soils might be unwise and should be very carefully considered before being approved for construction.

If a considerable amount of water in the river is unused, and the downstream water is of reasonably good quality, the irrigation of such salty soils might not be unduly harmful. The leaching of the more soluble salts from such an area may be of a temporary nature, as the quality of the return flow should improve with time.

Changes in Water Quality Along River Systems

Because of the wide range of soil and water characteristics, a conclusion regarding the effect of irrigation use and return flow on downstream water quality may not be warranted. In general, however, there is a degradation in quality as one proceeds downstream along a river system where there are irrigated areas which divert water and return drainage effluent to the stream. This change is generally one of increased total salt content together with an increase in the sodium and chloride percentages and a corresponding decrease in the calcium and bicarbonate percentages. The magnitude of the changes varies greatly from stream to stream and depends on many factors. In some basins where there are gypsiferous or salty

subsoils, or where minerals are continuously yielding soluble salts, there may be a degradation in water quality even though there is no irrigation development.

Rio Grande System

The principle that there will be a degradation in water quality along a stream system where water is diverted for irrigation and return flow re-enters the stream, and the magnitude of the changes are well illustrated by the salt balance studies of Wilcox (1968) for the Rio Grande. He presents complete analyses of the water at seven stations along the river for each of the thirty years of the study. Six of these stations for the last year of the study, 1963, were selected for the presentation given in Table 6. There are irrigated areas along the river between each of these six stations.

The changes in composition that occur on the Rio Grande with respect to sodium, chloride, calcium and bicarbonate ions are believed to be typical of many rivers. There is some decrease in the percentage of Mg and a small increase in SO_4 to Station 5, then a decrease at Station 6. There was no residual Na_2CO_3 at any station.

In this instance, the deterioration in quality is primarily with respect to salinity rather than sodium hazard, although the Na percentage had increased from 26 percent at the first station to 63 percent at the sixth station. It will be noted that there was a relatively greater increase in the Cl ion from 5 to 63 percent probably due to the fact that Cl is not involved in the exchangeable cation status.

Because of the relatively long period of complete records (30 years) on this stream, it may be of interest to determine what changes have taken place during this period. Because of the presence of storage reservoirs along the stream, the changes in water quality from year to year are somewhat erratic because of the salt storage and releases that occur from year to year. In order to determine whether there are trends or changes in water compositions with time, the 30-year period was broken into three 10-year periods and means were determined for each period. The results of this analysis is given in Table 7.

Table 6. Water Analyses - Rio Grande, 1963 Annual Means

Station[1]	1		2		3		4		5		6	
EC, mmhos/cm	0.37		0.63		0.69		0.80		1.32		5.82	
Dissolved solids, tons per acre foot	0.32		0.53		0.60		0.70		1.19		5.43	
Boron, ppm	--		0.11		0.13		0.12		0.23		0.62	
SAR	0.8		1.9		2.1		2.3		4.1		12.0	
Cations	meq/l.	%	meq/l.	%	meq/l.	%	meq/l.	%	meq/l.	%	meq/l.	%
Ca	2.18	58	2.73	44	2.94	43	3.43	43	4.65	35	15.62	25
Mg	0.60	16	0.91	15	0.94	14	1.09	14	1.51	11	6.95	11
Na	1.00	26	2.55	41	2.90	43	3.45	43	7.15	54	39.70	64
Total	3.78		6.19		6.78		7.97		13.31		62.27	
Anions												
$HCO_3 + CO_3$	2.31	61	2.64	42	2.77	41	2.96	37	3.71	27	4.94	8
SO_4	1.31	34	2.56	41	2.62	38	3.22	40	5.88	43	18.64	30
Cl	0.19	5	1.05	17	1.46	21	1.89	23	3.99	30	39.22	62
NO_3	0.01	0	tr	0	tr	0	0.02	0	0.01	0	0.03	0
Total	3.82		6.25		6.85		8.09		13.54		62.83	
Computed values:												
Salinity Lab Classification	C2-S1		C2-S1		C2-S1		C3-S1		C3-S1		C5-S4	
Effective Salinity	1.47		3.56		3.84		4.54		8.26		46.64	
Suggested rating (2) with respect to: EC	1		2		2		2		3		5	
Na %	1		2		2		2		2		3	
SAR	1		1		1		1		1		2	
Na_2CO_3	1		1		1		1		1		1	
Cl	1		1		1		1		2		5	
Eff. Sal.	1		2		2		2		3		5	
Boron	1		1		1		1		1		2	
Na, % of cations	26		41		43		43		54		63	
Cl, % of anions	5		17		21		23		29		63	

[1]Stations: 1. At Otowi Bridge, New Mexico 2. Below Elephant Butte Reservoir, New Mexico 3. Below Caballo Dam, New Mexico 4. Above Leasburg Dam, New Mexico 5. At El Paso, Texas 6. At Fort Quitman, Texas

Table 7. Changes in Water Composition with Time, Rio Grande 1934-43.

(Mean values at Stations 1, Otowi Bridge and 5, El Paso)

Decade	Flow 1000 AF	EC µmhos	Dissolved Solids TAF	Dissolved Solids 1000 tons	Cations - Ton equiv. Ca	Mg	Na	Total	Anions - Ton equiv. HCO_3	SO_4	Cl	NO_3	Total	Composition - % Na	HCO_3	SO_4	Cl
AT EL PASO, TEXAS																	
1934-43	620	1237	1.13	664	3691	1314	5178	10183	2850	4596	2887	15	10348	50.8	27.5	44.4	27.9
1944-53	431	1214	1.08	466	2388	914	3806	7108	2004	3006	2102	8	7120	53.5	28.1	42.2	29.5
1954-63	246	1294	1.16	275	1514	519	2181	4214	1145	1955	1179	3	4282	51.8	26.7	45.6	27.5
Mean	432	1249	1.13	468	2531	916	3722	7169	2000	3185	2056	9	7250	51.9	28.4	43.9	27.6
AT OTOWI BRIDGE, NEW MEXICO																	
1934-43	1234	338	.32	375	3163	1059	1416	5638	3134	2026	373	20	5553	25.1	56.4	36.5	6.7
1944-53	1482	327	.30	261	2306	687	1000	3993	2450	1357	216	17	4040	25.0	60.6	33.6	5.3
1954-63	868	354	.31	233	2259	552	883	3694	2405	1124	190	16	3735	23.9	64.4	30.1	5.1
Mean	1195	340	.31	290	2576	766	1099	4441	2663	1502	260	18	4443	24.7	59.9	33.8	5.8
DIFFERENCE - OTOWI BRIDGE TO EL PASO *																	
1934-43	-614	899	.81	289	528	256	3762	4546	-284	2570	2514	-5	4795	25.7	-28.9	7.9	21.2
1944-53	-1051	887	.78	205	82	227	2806	3115	-446	1649	1886	-9	3080	28.5	-32.5	8.6	24.2
1954-63	-622	940	.85	42	-845	-33	1298	420	-1260	831	989	-13	547	27.9	-37.7	15.5	22.4
Mean	-763	909	.82	178	-78	150	2622	2693	-663	1682	1796	-9	2806	27.2	-32.3	10.1	22.6

* Negative sign indicates less ions at El Paso than at Otowi Bridge.

This table shows that there has been an improvement in the quality of the water at El Paso during the 30-year period. The monthly data indicate that there are fairly well-defined relationships between the total monthly flows and the dissolved solids or conductance values. A comparison of the data for 1934 and 1935 with 1962 and 1963 shows that during the summer when the flow is in the range of 40 to 50 thousand acre feet per month, the dissolved solids ranged from 1.30 to 1.24 tons per acre foot for 1934 and 1935. For 1962 and 1963, for the same range in flow, the dissolved solids ranged from 1.02 to 0.90 tons per acre foot, or about 80% as much. There does not appear to have been any significant change in the composition of the water in terms of the percentages for each ion. There was, however, a significant reduction in the total amount of salt, and especially for the Na and Cl ions passing El Paso in the last decade as compared with the first decade. Over the entire period, there has been a favorable overall salt balance and especially for the Na and Cl ions. The total outflow of the Na ion for the third decade was only 42% as much as for the first decade. For the Cl ion, the outflow for the third decade was 41% as much as for the first decade. In terms of total dissolved solids, the comparative percentage was 41.5%.

Between Otowi Bridge and El Paso, there were significant increases in the total amount of Na, Mg, SO_4 and Cl ions, and some decreases in HCO_3 and NO_3 ions. For the entire period, there was an approximate balance for the Ca ion, but for the first and second decades, there was a small pickup of Ca, and for the third decade, a deposition of Ca.

For individual years, the total salt inflow at Otowi Bridge ranged from 115,000 tons in 1956 to 726,000 tons in 1941. At El Paso, the range was from 82,200 tons in 1956 to 1,321,800 tons in 1942. Over the 30-year period, 8,700,000 tons of salt passed Otowi Bridge and 14,040,000 tons passed El Paso. For the Na ion, 32,970 ton equivalents entered and 111,660 ton equivalents left this reach of the river. For the Ca ion, 77,280 ton equivalents entered and 75,930 ton equivalents left. There was, therefore, a favorable balance for all ions except Ca, HCO_3 and NO_3.

For individual years, there was a positive balance (more leaving than entering) for Ca for 16 of the 30 years; for Mg, for 20 years; for Na for 29 years; for HCO_3 for only 11 years; for SO_4, for 28 years; and for Cl for all 30 years. For the NO_3 ion the balance was positive for only 5 of the 30 years. For total salt, the balance was positive for 24 of the 30 years.

Overall, it would appear that with more efficient water management, and with less leaching and a balance of Na and Cl ions, there could be a significant reduction in the total salt load at El Paso, and probably a greater average flow.

Sevier River System, Utah

Similar changes occur along the Sevier River in Utah, Thorne and Thorne (1951). Here there are many tributaries, especially in the upper reaches of the river, and irrigated areas along the middle and lower reaches. The changes that occur in the composition and quality of the water are summarized in Table 8.

The Sevier River water is relatively higher in Mg than most streams. Since the $Mg(HCO_3)_2$ solubility is between that of $Ca(HCO_3)_2$ and $CaSO_4$, the percentage of Mg remains relatively constant. The SO_4 percentage increases from Stations 1 to 3 then decreases somewhat. Other ions follow the same trend as the Rio Grande. The boron and residual sodium carbonate would not be considered detrimental at any station. Because of the high salinity, the water at Station 6 would be suitable for irrigation only under favorable conditions and good management.

The changes that occur along this river reflect differences in tributary inflow, evapotranspiration and return flow. Since this stream had been used for irrigation for about eighty years before date of sampling, one might assume that a fairly stable situation had developed.

Most of the drainage effluent from the area irrigated between Stations 5 and 6 does not re-enter the Sevier River between these stations. The increase in salt concentration between these stations is probably due mostly to evaporation losses from the reservoir and river under low flow conditions.

Table 8. Quality of Water Changes Along the Sevier River, Utah, 1949

Station[1]	1		2		3		4		5		6	
Date	5/6		5/6		5/6		5/6		6/3		8/20	
Total salt, tons per acre foot	.23		.44		.78		2.26		2.46		4.50	
EC, mmhos/cm	.28		.49		.91		2.50		2.70		4.50	
Cations	meq/l.	%	meq/l.	%	meq/l.	%	meq/l.	%	meq/l.	%	meq/l.	%
Ca	1.55	60	2.20	41	3.84	38	6.49	24	4.14	14	8.18	17
Mg	0.74	29	2.06	39	3.70	36	6.90	26	7.56	26	13.64	29
Na+K	0.28	11	1.06	20	2.62	26	13.41	50	17.04	59	25.39	54
Total	2.57		5.32		10.16		26.80		28.74		47.21	
Anions												
$HCO_3 + CO_3$	2.62	93	3.75	76	4.62	48	6.47	25	5.11	18	4.88	10
Cl	0.06	2	0.34	7	1.22	13	10.82	42	14.65	50	28.51	58
SO_4	0.15	5	0.85	17	3.81	39	8.74	33	9.44	32	15.62	32
Total	2.83		4.94		9.65		26.03		29.20		49.01	
Computed values:												
SAR	.12		.44		.87		3.54		5.07		5.30	
Effective Salinity	.28		.51		5.0		20.3		23.6		42.3	
Boron, ppm	.05		.08		.11		.48		.42		.26	
Salinity Lab Classification	C2-S1		C2-S1		C3-S1		C4-S1		C4-S2		C4-S2	
Suggested rating (2) with respect to EC	1		1		2		4		4		5	
Na %	1		1		1		2		2		2	
SAR	1		1		1		1		2		2	
Cl	1		1		1		4		4		5	
Eff. Sal.	1		1		2		5		5		5	

[1]Stations: 1. Panguitch near S Fork 2. Kingston near E Fork 3. Richfield at Glenwood Road 4. Salina at Highway Bridge 5. Gunnison Bend Reservoir at outlet 6. Conk's Diversion S. of Deseret

Upper Basin of the Colorado River Within Utah

Another stream where there is concern over the water quality is the Upper Basin of the Colorado River. An analysis was made of the USGS data for 1965 for the part of the Basin within Utah but including a small part of Wyoming below Green River, Wyoming, and a small part of Arizona between the state line and Lees Ferry. To make the presentation similar to that of Table 6 and 8, the data given in ppm were converts to equivalents per million, epm, (essentially the same as millequivalents per liter). Where data on Ca and Mg were not given, except for a few specific analyses, these analyses were used to estimate the effective salinity as indicated. The results of this study are given in Table 9. The irrigated acreage between stations and total irrigated area above each station is reported by Hyatt et al. (1970) is given in Table 10.

Table 10. Estimated Irrigated Areas in Upper Colorado River Basin, Hyatt et al. (1970)

Station	River	Location	Area Between Stations (acres)	Total Area Above Station (acres)
9-2170	Green	Green River, Wyo.		65,100
			107,000	
9-2345	Green	Below Flaming Gorge Dam		172,100
			92,800	
9-2610	Green	Near Jensen, Utah		264,900
			23,000	
9-3020	Duchesne	Near Randlett, Utah		133,500
			85,200	
9-3150	Green	Green River, Utah		506,600
9-1635.3	Colorado	Below Colo-Utah State Line		448,800
			2,500	
9-1800	Dolores	Below Colo-Utah State Line		39,800
9-1805	Colorado	Below Junction with Dolores		491,100
9-3795	San Juan	Near Bluff, Utah		209,100
			38,500	
9-3800	Colorado	At Lees Ferry, Ariz.		738,700

Tables 9 and 10 reveal several things that were somewhat surprising to the writer. First, there is a relatively small increase in total salinity in the Green River Basin from the station at Green River, Wyoming, to the station near Green River, Utah, the last point at which the water is sampled before the confluence with the Colorado River (EC 711 to 813 μmhos), in spite of the fact that the conductance of the waters of the Duchesne River is much higher (EC 1320 μmhos).

Table 9. Water Quality--Colorado River and Tributaries, Upper Basin--Mean Values 1965, USGS Data.

Station[1]	9-2170		9-2345		9-2610		9-3020		9-3150		9-1635		9-1800		9-1805		9-3795		9-3800	
Basin	Green River										Colorado River						San Juan		UBCR	
River	Green		Green		Green		Duchesne		Green		Colorado		Dolores		Colorado		San Juan		Colorado	
Area - Sq. Mi.	10,000		15,100		25,400		3,920		40,600		17,900		4,580		24,100		23,000		107,900	
Mean Q - cfs	2,550		2,227		4,797		1,132		7,091		7,893		1,104		8,845		2,801		14,940	
EC µmhos/cm	711		809		605		1,320		813		1,240		2,590		1,278		815		819	
T.D.S. ppm	489		573		399		961		552		871		1,620		889		573		587	
SAR	1.4		1.7		1.4		2.7		1.8		2.3		7.7		2.5		1.6		1.9	
Cations	epm	%	epm	%	epm	%	epm	%	epm	%	epm	%	epm	%	epm	%	epm	%	epm	%
Ca	----	45*	3.64	41	----	52*	----	42*	3.40	38	----	42*	----	24*	4.90	36	4.10	45	3.90	42
Mg	----	24*	2.30	26	----	15*	----	17*	2.30	26	----	20*	----	8*	3.37	25	2.14	23	1.81	20
Na+K	2.40	31	2.86	33	2.18	33	6.14	41	3.17	36	5.18	38	18.0	68	5.43	39	2.96	32	3.34	37
Total	----		8.80		----		----		8.87		----		----		13.7		9.20		9.05	
Anions																				
HCO_3	3.15	41	3.15	35	2.80	43	4.60	31	3.34	38	3.10	23	2.48	9	2.98	22	2.77	30	2.52	28
SO4	4.23	55	5.09	57	3.12	48	8.55	56	4.67	53	7.54	55	6.27	24	6.78	50	5.85	64	5.06	55
Cl	0.31	4	0.73	8	0.62	9	1.92	13	0.85	9	3.05	22	17.5	67	3.81	28	0.53	6	1.55	17
Total	7.67		8.97		6.54		15.1		8.86		13.7		26.3		13.6		9.15		9.13	
Sal. Lab Class.	C2-S1		C3-S1		C2-S1		C3-S1		C3-S1		C3-S1		C4-S2		C3-S1		C3-S1		C3-S1	
Effective Salinity	4.2*		5.16		3.1*		8.7*		5.47		7.9*		20.0*		8.80		5.10		5.15	
Suggested Rating:																				
EC	2		3		2		3		2		3		4		3		3		3	
Na%	1		1		1		2		1		1		3		1		1		1	
SAR	1		1		1		1		1		1		2		1		1		1	
Cl	1		1		1		1		1		2		5		2		1		1	
Eff. Sal.	2*		2		2*		3*		2		3*		5*		3		2		2	

[1]Stations: 9-2170 Green River, Wyoming; 9-2345 Below Flaming Gorge Dam; 9-2610 Jensen, Utah; 9-3020 Randlett, Utah; 9-3150 Green River, Utah; 9-1635.3 4 miles below Utah-Colorado State Line; 9-1800 13.5 miles below Utah-Colorado State Line; 9-1805 1 mile below Dolores River; 9-3795 20 miles SW of Bluff, Utah; 9-3800 at Lees Ferry, Arizona, 16 miles below Glenn Canyon Dam.

*Estimated from specific analyses.

A total of 440,500 acres was reported as irrigated in the Green River Basin between these stations. Also, it will be noted that there was an increase in mean flow from 2550 to 7091 cfs due mostly to the inflow from the Yampa, White and Duchesne Rivers.

The mean conductance of the Colorado River below the Utah-Colorado state lines was 1240 µmhos, and the Dolores River had a conductance of 2590 µmhos with a Na percentage of 68, much higher than for any other stream. The conductance of the water at Lees Ferry averaged only 819 µmhos. The quality of the water at this station was probably affected appreciably by the storage in Lake Powell. One of the effects of storage in Flaming Gorge Reservoir and Lake Powell is indicated by the range in conductance values at the stations above and below these reservoirs as given in Table 11. Although these reservoirs have an overall effect of increasing the mean salinity of the water due to evaporation from the water surface, they have a very beneficial effect in reducing the maximum conductance values.

The conclusions from this study of the Upper Colorado River Basin in Utah may not be competely valid because data for only one year, 1965, (which was readily available to the writer) was ocnsidered. Because of the large volumes of storage in the reservoirs, a study of this kind should be made on data for a period of several years. Time limitations did not permit such a study.

Table 11. Effect of Reservoirs on Range in Conductance Values Above and Below the Reservoirs, 1965.

Station	Reservoir	EC µmhos	Ratio max/min
	Flaming Gorge		
9-2170	Above reservoir	360-1160	3.2
9-2345	Below reservoir	643-944	1.5
	Lake Powell		
9-3150	Above reservoir	429-1280	3.0
9-1805	Above reservoir	404-1890	4.4
9-3795	Above reservoir	326-1350	4.1
9-3800	Below reservoir	472-1120	2.4

Conclusions

The principal conclusions arrived at from this study are:

1. That the development of irrigation projects along any river system where return flow enters the river results in some deterioration in the quality of downstream flow.
2. There appears to be relatively little change in the composition of the waters of the Green River and the Colorado River within the State of Utah.
3. More efficient management of irrigation water should, at least temporarily, provide some improvement in the downstream water quality and possibly increase the downstream flow.
4. From the long-term point-of-view, however, relatively little can be done in the way of more efficient management of the water resources on developed projects to improve the downstream water quality.
5. Although, the weathering of arid soils releases soluble minerals which adds a small amount to the total salt load of the downstream flow it also has the effect of reducing the Na percentage and SAR value. The net effect may be an improvement in water quality.
6. Careful consideration should be given to the development of new projects on lands that are high in residual salts and to the elimination of areas where subsoils contain large quantities of soluble salts.
7. Some consideration might be given to updating or improving irrigation water quality criteria. Some suggestions are included in this discussion.

References

Bagley, J. M. etal. 1971. Extending Utility of Non-Urban Water Supplies, Parts I and II, Summary and Recommendations. Prepared for the National Water Commission by Utah State University Foundation, Logan, Utah. PB-207 115, 245 p.

Christiansen, J. E. 1953. Irrigation in Relation to Food Production, Agricultural Engineering, Vol. 34, No. 6, pp. 400-406, 410.

Christiansen, J. E. and Edwin C. Olsen, III. 1972. Irrigation Projects in Guatemala--Observations and Recommendations. Utah State University-USAID/ Guatemala (in manuscript).

Doneen, L. D. 1959. Evaluating the Quality of Irrigation Waters. State Department of Water Resources, Sacramento, California. Bulletin 75, Vol. II, pp. F1-33.

Eaton, F. M. 1935. Significance of Carbonates in Irrigation Waters, Soil Science 69-123-133.

Eaton, F. M. 1935. Boron in Soils and Irrigation Waters and Its Effect on Plants, with Particular Reference to the San Joaquin Valley of California. U.S. Department Agricultural Technical Bulletin 448. 132 pp. illus.

Eldredge, Edward F. et al. 1960. Return Irrigation Water, Characteristics and Effects. Research and Technical Consultation Project, U. S. Department of Health, Education and Welfare, Public Health Service, Region IX, Portland, Oregon. 120 pp. Processed.

Hyatt, M. Leon et al. 1970. Computer Simulation of the Hydrologic-Salinity Flow System Within the Upper Colorado River Basin. Utah Water Research Laboratory/ College of Engineering, Utah State University. PR WG-54-1. 125 pp + Appendices, Approx. 125 pp.

Imperial Irrigation District. 1960. Reprinted 1966. Historic Salton Sea and Imperial Irrigation District. Imperial Irrigation District, Imperial, California, 33 pp.

Imperial Irrigation District. 1969 and 1970. The Colorado River and Imperial Valley Soils. Imperial Irrigation District, Imperial California, 25 pp. each.

Kelley, W. P. 1937. The Reclamation of Alkali Soils. California Agricultural Experiment Station Bulletin 617.

Magistad, O. C. and J. E. Christiansen. 1944. Saline Soils, Their Nature and Management. U. S. Department of Agriculture, U. S. Salinity Laboratory, Bureau of Plant Industry and Agricultural Engineering, 32 pp.

Pillsbury, A. F. and Harry F. Blaney. 1966. Salinity Problems and Management in River Systems. Journal of Irrigation and Drainage. ASCE paper 4733, IR 1, pp. 77-90.

Reitemeier, R. F., J. E. Christiansen, R. E. Moore and W. W. Aldrich. 1948. Effect of Gypsum, Organic Matter and Drying on Infiltration of a Sodium Water into a Fine Sandy Loam. U. S. Department of Agriculture, Technical Bulletin 937. 36 pp.

Rhoades, J. D., D. B. Krueger, and M. J. Reed. 1968. The Effect of Soil-Mineral Weathering on the Sodium Hazard of Irrigation Waters. Soil Science Society of American Proceedings, Vol. 32, No. 5, pp. 643-647.

Rhoades, J. D. 1968. Mineral Weathering Correction for Estimating the Sodium Hazard of Irrigation Waters. Soil Science Society of American Proceedings, Vol. 32, No. 5 pp. 648-652.

Richards, L. A., et al. 1954. Diagnosis and Improvement of Saline and Alkali Soils. Handbook 60. U. S. Department of Agriculture, U. S. Salinity Laboratory. 160 pp.

Scofield, C. S. 1927. The Effect of Absorption by Plants on the Concentration of the Soil Solution. Journal of Agricultural Research 35:745-756.

Scofield, C. S. 1940. Salt Balance in Irrigated Areas. Journal of Agricultural Research, Vol. 61, No. 1. pp. 17-40.

Scofield, C. S. 1943. Unpublished Analyses. Division of Irrigation Agriculture, U. S. Bureau of Plant Industry, Soils and Agricultural Engineering.

Skogerboe, Gaylord V. and James P. Law, Jr. 1971. Research Needs for Irrigation Return Flow Quality Control. Environmental Protection Agency, Project 13030, 99 pp. multilith.

Thorne, J. P. and D. W. Thorne. 1951. Irrigation Waters of Utah. Utah Agricultural Experiment Station Bulletin 346. 64 pp.

U. S. Geological Survey, Department of Interior. 1965. Water Resources Data for Utah, Part 2, Water Quality Records. 136 pp.

Utah State University Foundation. May 1969. Characteristics and Pollution Problems of Irrigation Return Flow. U. S. Department of the Interior, Federal Water Pollution Control Administration, Robert S. Kerr Water Research Center, Ada, Oklahoma.

Wilcox, L. V. 1948. The Quality of Water for Irrigation Use. U. S. Department of Agriculture, Technical Bulletin 962. 40 pp.

Wilcox, L. V. 1968. Discharge and Salt Burden of the Rio Grande above Fort Quitman, Texas, and Salt-Balance Conditions on the Rio Grande Project. U. S. Salinity Laboratory Research Report No. 113, U. S. Salinity Laboratory, Soil and Water Conservation Research Division, USDA, Riverside, California. Processed, 200 pp.

Wilcox, L. V. and O. C. Magistad. 1943. Interpretation of Analyses of Irrigation Waters and the Relative Tolerance of Crop Plants. U. S. Bureau Plant Industry, Soils, and Agricultural Engineering. Processed, 8 pp.

Wilcox, L. V. and W. R. Resch. 1963. Salt Balance and Leaching Requirement in Irrigated Lands. Technical Bulletin No. 1290, Agricultural Research Service in Cooperation with Bureau of Reclamation. 23 pp.

Appendix

Comments on the Salinity Laboratory C - S Classification

As previously mentioned, the Salinity Laboratory C - S classification for irrigation waters is the most commonly used criteria for evaluating water quality for irrigation. The writer believes that this classification has the following defects:

1. It is often misused in that the "fine print" in the handbook regarding the effect of residual sodium carbonate (mentioned under headings "Bicarbonate" and "Effect of Bocarbonate Ion--", etc. is often overlooked.
2. The adverse effect of sodium is tied directly to the SAR value which may be very low for low salt waters with a relatively high Na percentage, as for example, the Coachella Valley, California, well water, reported by Reitemeier et al. (1948). The use of this well water had caused difficulty in obtaining adequate infiltration of irrigation water in a fine sandy loam. The infiltration rates were very low. Analysis of this water is given in Table 12. The water would be classified C1-S1.

Table 12. Analysis of Well Water, Coachella Valley

Cations	epm	Anions	epm
Ca	0.30	$CO_3 + HCO_3$	1.57
Mg	0.08	SO_4	0.50
Na	1.98	Cl	0.33
K	0.06	NO_3	0.04
Total	2.42	Total	2.44
EC umhos	250	pH	8.30
Na percent	82	Na_2CO_3	1.19
SAR	4.55		

according to the suggested rating by Christiansen and Olsen (1972) this water would have been rated No. 5 on basis of Na percentage, and No. 3 on basis of residual sodium carbonate. On all other factors it would be No. 1.

3. The C classification for many irrigation waters is misleading. In Utah and in some of the other western states, mountain waters containing mostly $Ca(HCO_3)_2$, and having conductances in the range of 300 to 500 umhos/cm, have been used successfully for more than 100 years with no apparent detrimental effects. These waters are classed C2. Logan River water, for example, as an Ec value of 350 umhos, Na percentage of 2.66, effective salinity of only 0.24 meq/l. and no residual sodium carbonate. It would have a C2-S1 rating. When a sample of this water was concentrated 300 times (to 1/300 of the initial volume) by evaporation at 80° C, the conductance was only 4120 µmhos, or only 11.8 times that of the river water. According to the suggested ratings, it would be No. 1 in all categories. The writer believes that any water with a conductance value of 500 µmhos or less should be given the top rating as far as conductance is concerned, especially when most of the salt present is $Ca(HCO_3)_2$. It is also of interest to note that not one of the 22 water analyses given in Tables 5 and 6 had a C1 rating. Seven would rate C2; ten, C3; four, C4; and one, C5. With respect to sodium hazard, eighteen would rate S1; three, S2; and one, S4. Even though return flow increases the Na percentage it would appear that it does not create a "sodium hazard" according to the SAR rating in most instances.

4. The cautions regarding "high bicarbonate" waters should be more specifically directed to waters with "residual sodium carbonate." No evidence has been found where waters with a high ratio of HCO_3 to other anions, but with no residual sodium carbonate, have been determined to be detrimental. For example, the Logan River water has a ratio of HCO_3 to SO_4+ Cl of 13.0. This water has been referred to as a high bicarbonate water by Pillsbury and Blaney (1966). It has been used on well-drained soils for more than 100 years and the soils are now more fertile than when originally reclaimed.