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Bulletin No. 147 - The Alkali Content of Irrigation Water

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Utah Agricultural College
EXPERIMENT STATION

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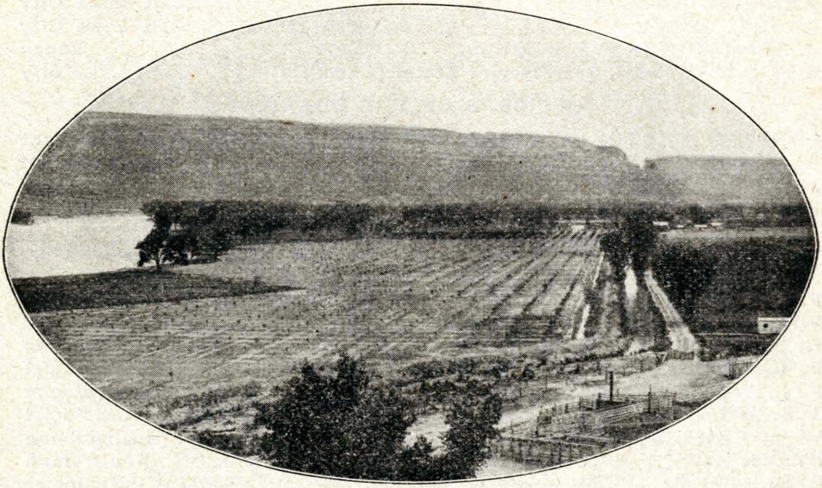

The Alkali Content of Irrigation Water

BY
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THE ALKALI CONTENT OF IRRIGATION WATERS.

By ROBERT STEWART and C. T. HIRST

In certain irrigated districts the alkali problem is a menace. Any controllable factor which tends to increase the alkali content of the soil should be carefully considered in a successful system of soil management. In this connection the quality of the irrigation water is of great importance; the saline content of water has a marked influence upon the method and quantity to be used for irrigation. The factors which will contribute to an increase or decrease of the alkali content of the water must be clearly understood. The amount of the several kinds of alkali salts added to the soil by large or small applications of water must be clearly understood in order that the farmer may utilize the water supply to the best advantage. A knowledge of the quantity and nature of the alkali salts added to the soil will enable him to more systematically plan his crop rotation since crops vary in their power to resist the action of the several kinds of alkali.

The saline content of rivers having their origin entirely in arid regions is usually much higher than that of streams which are derived from the run-off and drainage from an area already thoroughly leached during the past ages, their soluble salt content being thus reduced to a minimum. On the other hand, the arid streams used for irrigating purposes are usually derived from the run-off drainage and seepage from the high mountains and plateaus, the country rock of which is abundantly impregnated with alkali salts. As a result the arid streams have a much higher saline content than do those of a humid region.

As a basis for such a comparison and study the "alkali" or soluble salt composition of four important rivers of the world are recorded below:[1]

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1. Clarke, F. W. Jour. Am. Chem. Soc., Vol. 27, p. 112, 1905.

Parts per 100,000.

	Name of River			
	Yukon	St. Lawrence	Rhine	Baikal
Calcium	2.2	3.1	4.9	1.6
Magnesium	0.4	1.0	1.0	0.3
Sulphuric Acid	1.1	1.7	2.2	0.5
Potassium	....	....	....	0.3
Chlorine	0.04	0.4	0.7	0.16
Bicarbonic Acid	4.5	6.8	8.4	3.4
Nitric Nitrogen	....	....	....	0.004
Total Salts	9.8	14.8	17.8	6.9

Of course the saline content varies in different years and also throughout the year. This is especially true of arid irrigating streams where the variation is much greater, due to a number of factors. The arid streams are derived from the lakes and reservoirs of the uplands where the concentration of the soluble salts by evaporation from a large exposed surface is enormous. Also, during the hot dry summer there is an accumulation of soluble salts due to the concentration by evaporation from the soil surface from the alkali pre-existing in the country rock, and these salts are carried into the irrigating stream by the sudden summer showers. These factors, together with the evaporation from the surface of the river itself, result in a much higher saline content—especially during the dry seasons when irrigation is all the more necessary. Moreover, it is intensified when the irrigation ditch diverts the water from the river below other canals and irrigated farms which contribute large amounts of alkali salts in the drainage and seepage water. Successful irrigation with such water highly impregnated with alkali salts is indeed an art, and any information regarding the composition and methods of using such water should be welcomed.

If definite limits could be placed upon the amount of salinity allowable in irrigation water, the problem of its use would be materially simplified; but the amount of alkali which may be present in irrigation water under some conditions of soil and crop may not be permissible under others. Possibly the greatest uncertainty regarding the limits of salinity permissible is due to inadequate analysis and lack of uniform methods of analysis which fail to differentiate between the harmful and harmless constituents present. The mere determination of total solids is not adequate. It is true that if small amounts of soluble salts are present it is all that is necessary; but where it is shown that amounts approaching the danger point, or very far in excess of it, are present, any method which shows only the total soluble salts present falls short since it does not tell the kind of salts present. Under such conditions, if the salts are all or are largely sodium carbonate or sodium chloride the quality of the water is poor and should be used with the best judgment or not at all—as the case may be. If, on the other hand, the salts present even in excessive quantities are all or largely calcium or magnesium bicarbonate, the water may be suitable for irrigation.

Water of a high saline content may be used on alkali-resistant crops, such as sweet or Egyptian clover, which would be fatal to other crops. Old alfalfa may be irrigated with water of so high a saline content that it would kill young alfalfa. The character of the soil also materially modifies not only the limits which may be placed on the amounts of salts allowable in irrigation water, but also the method of using the water itself. Thus, the use of saline irrigation water on open, well-drained sandy soil might be permissible, and yet it would result in disaster if used on fine-textured, poorly-drained, heavy clay. The method and frequency of cultivation after the application of irrigation water also influences the possibilities of the use of irrigation water of high saline content.

Hilgard[2] makes the following comment upon this phase of the question: "Broadly speaking, the extreme limits of mineral content usually assigned for potable waters, viz., forty grains per gallon (1862 pounds per acre-foot) also applies to irrigation waters. Yet it sometimes happens that all or most all of the solid content is gypsum and Epsom salt, when only a large excess of the latter would constitute a bar to irrigation; while, on the contrary, a large proportion of the solids consists of carbonate of soda or common salt, even a smaller proportion of salts than forty grains might preclude its regular use, depending upon the nature of the soil to be irrigated. In a clay loam or heavy adobe, not only do the salts accumulate nearer to the surface, but sub-drainage being slow and imperfect (unless

2. Hilgard, E. W., California Exp. Sta. Bul. 128, p. 30, 1900.

under-drained), it becomes difficult or impossible to wash out the saline accumulations from time to time, as is feasible in sandy lands. In these, moreover, as already stated, the alkali never becomes as concentrated near the surface as in heavier soils." Elsewhere in the same publication he says: "It may be taken for granted that the waters of all lakes having no regular outflow are unfit for regular irrigation use." Such a lake, he further states, is Lake Elsinore in Riverside County, California, which contains from eighty to one hundred grains to the gallon: three-fifths of sodium chloride and one-fifth each of sodium carbonate and sodium sulphate.

Forbes,[3] in discussing the use of saline irrigation waters says: "This fluctuating percentage of salts in the river is of exceeding interest to those located upon this water supply, for 'alkali' in the Salt River Valley is derived more from the water supply than from the little-affected virgin soils. . ....It is difficult to state the danger point for the soluble salts in the water supply." He feels that 0.25 per cent of salts in the soil is a more or less dangerous quantity of alkali, even when composed of the less harmful salts. Any addition of alkali in the irrigation water should be carefully controlled.

Means[4], however, claims that the amount of alkali salts permissible in irrigation water has been under-estimated by American writers and calls attention to the fact that the Arabs in Sahara, Africa, use irrigation water containing over eight hundred parts per hundred thousand, more than one-half of which is sodium chloride. He also quotes from an earlier publication[5]: "The limit of endurance for most cultivated plants in a water solution is about 1 per cent, or one thousand parts of the readily soluble salts in one hundred thousand parts of water."

In our study of the alkali and nitrate[6] accumulations in arid soils, we became impressed with the necessity of further work being done on the saline content of arid rivers, owing to the unsatisfactory state of the available information. During

3. Forbes, R. H., Arizona Exp. Sta. Bul. 44, p. 165, 1902.
4 Means, T. H., Cir. 10, Bur. Soils, U. S. D. A., 1903.
5. Report 64, Field Operations, Division of Soils, 1899.
6. Stewart and Peterson, Utah Exp. Sta. Bul. 134, 1914.

the summer of 1914, samples of water were collected for us from the Price River, Huntington Creek, Sevier River, and Coal Creek, at various times throughout the irrigating period. These samples were shipped to the chemical laboratory for analysis and were analyzed according to the following methods of analysis:

Methods of Analysis.

Total Solids:

Fifty c.c. of water were evaporated to dryness on an electric hot plate in 100 c.c. beakers, cooled in dessicators and weighed accurately to the fourth decimal place.

Carbon Dioxide:

Fifty c.c. of water were titrated against $\frac{n}{30}$ H_2SO_4 using methyl orange as an indicator.

Chlorine:

Determined by Volhard's method, using $\frac{n}{50}$ $AgNO_3$.

Calcium:

Fifty c.c. of water heated to nearly boiling and a drop or two of NH_4OH added. Then hot solution of Ammonium Oxalate added to complete precipitation. After nearly boiling for about two hours the material was filtered through a 7 c.m. filter by decantation. Most of the precipitate was left in the beaker and after three decantations was dissolved in a few drops of HCl, then returned to hot plate and neutralized with ammonia and a few drops of oxalate added. This was then filtered, washed thoroughly with hot water, and then the beakers containing the filtrate were replaced by the beakers in which the precipitation took place. A small hole was made in the filter paper with a sharp glass rod and the precipitate was washed into the beakers with hot dilute sulphuric acid. About 5 c.c. of con. H_2SO_4 were added to each. The solution was heated nearly to boiling and titrated with $\frac{n}{10}$ $KMnO_4$.

Magnesium:

The filtrate from calcium was concentrated if necessary to about 250 c.c., made only faintly alkaline, and the magnesium precipitated in the cold with microcosmic salts and allowed to stand for twelve hours. The precipitate was thoroughly washed with two and a half per cent ammonia. The filter and precipitate were then burned to a white, or only slightly grey ash in an electric furnace.

Sulphuric Acid:

Was determined by precipitating the sulphuric acid as $BaSO_4$ in the usual way.

Potassium:

Was determined as follows: 500 c.c. were evaporated to dryness, taken up with hot water and filtered. The filtrate was acidified with HCl and platinic chloride added and evaporated almost to dryness. It was allowed to cool and alcohol added, then allowed to stand two hours; filtered, washed about eight times with alcohol, then about four times with ammonium chloride solution, saturated with K_2PtCl_6. Then washed again with alcohol about ten times. The K_2PtCl_6 was then dissolved from the filter with hot water into weighed beakers. This solution was evaporated to dryness and weighed.

Nitric Nitrogen:

Fifty c.c. evaporated to dryness. Treated with 2 c.c. phenoldisulphonic acid. Allowed to stand ten minutes diluted with water. Made alkaline with ammonia and the color compared with a standard solution of potassium nitrate in a Kennicot colorimeter.

The results of the analysis are reported below as ions of the bases and acids as parts per hundred thousand of water. Conventional combinations are also made according to the calculations recommended[7] by the Association of Official Agricultural Chemists. These results are also reported as parts per hundred thousand of water. That is, according to this recommendation the hypothetical combinations are made by calculating the calcium and magnesium to the acid ions in the following order: bicarbonic, sulphuric acid, and chlorine. Any remaining acid ions are calculated to sodium. Calculations are also made as to the amount of these compounds added to the soil by an acre-foot of irrigation water. It must be clearly remembered that our methods of chemical analysis are for ions and not for compounds. We cannot determine directly the amount of sodium chloride in the soil or water, but we can determine accurately the amount of chlorine in solution. The method used in assigning this chlorine to the several basic ions may or may not show the water to be harmful.

7. Bureau of Chemistry, U. S. D. A., Cir. 52, p. 13.

The Waters of Price River, Huntington, Ferron, and Emery Creeks

In Table I are recorded the results of analysis of the waters collected from the Price River, Huntington, Ferron, and Emery Creeks. These streams drain from the same geological formation and are used to irrigate the same kinds of soil; hence they may well be considered together.

TABLE I—ANALYSIS OF WATER FROM PRICE, WELLINGTON, FERRON, HUNTINGTON, AND EMERY, UTAH.

Results Expressed as Parts in 100,000 of Irrigation Water.

			Sample Number					
Constituents	Ferron	Emery	Park Ditch 4	Wellington 2	Price 6	Price	Huntington 1	Huntington 2
Ions								
Calcium (Ca)	9.2	6.2	6.6	8.0	6.8	12.4	5.8	9.0
Magnesium (Mg)	5.6	3.0	8.2	8.7	3.7	8.8	2.5	7.4
Sulphuric Acid (SO_4)	23.3	4.0	12.8	15.3	14.0	54.0	0.9	39.5
Potassium (K)	trace	trace	trace	trace	trace	trace	trace	trace
Chlorine (Cl)	0.14	0.28	0.28	0.14	0.14	0.28	0.14	0.14
Bicarbonic Acid (HCO_3)	30.9	23.2	57.5	30.0	24.5	27.8	25.5	31.3
Nitric Nitrogen (NN)	0.06	0.04	0.006	0.01	0.03	0.03	0.007	0.08
(Conventional Combinations)								
Total Souble Salts	73.2	38.8	72.6	58.4	54.8	126.0	26.00	92.4
Calcium Sulphate ($CaSO_4$)	......	......	......	......	......	11.2	......	......
Calcium Bicarbonate $Ca(HCO_3)_2$	37.3	25.1	26.70	32.40	27.60	37.0	23.50	36.5
Magnesium Sulphate ($MgSO_4$)	24.5	5.1	3.50	19.20	14.40	43.5	1.10	32.9
Magnesium Bicarbonate $Mg(HCO_3)_2$	3.9	6.6	44.90	7.30	4.90	......	9.50	4.6
Magnesium Chloride ($MgCl_2$)	......	0.4	......	1.80	......	......	1.90	......
Sodium Nitrate ($NaNO_3$)	0.4	0.3	0.04	0.07	0.20	0.2	0.04	0.5
Sodium Sulphate (Na_2SO_4)	5.3	......	14.00	......	2.90	15.4	......	18.4
Sodium Chloride (NaCl)	0.23	......	0.47	......	0.24	0.5	......	0.2

These waters all contain salts in such proportion as to approach or exceed the limits set by many American writers. However, the complete analysis furnished enables us to differentiate between the harmful and harmless constituents. In sample Ferron, for example, 52 per cent of the total solids is bicarbonate of calcium, a harmless soluble salt from the point of view of the irrigator. Had this acid ion been calculated as sodium carbonate the water might have been condemned for irrigation purposes.

Traces of potassium are found in all the samples, while rather heavy traces of nitrate nitrogen also are present. The chlorine content is very low.

An examination of Table II showing the pounds per acre added to the soil of the various salts is instructive. If one considered the total salts only, rather serious conclusions must be drawn. The addition of 3426.0 pounds of salts by the water of Price River, such as shown by sample P, is very serious when considered only from this point of view, but when it is observed that one-third of this is bicarbonate of calcium the seriousness is materially decreased. However, the addition of 418.8 pounds of sodium sulphate and 1183.2 pounds of magnesium sulphate per acre to the soils of this area, which are fine-textured, heavy, poorly-drained, and already heavily impregnated with alkali, is a consideration which requires careful thought and soil management.

TABLE II—POUNDS OF ALKALI SALTS APPLIED BY ONE ACRE-FOOT OF IRRIGATION WATER.

			Sodium			Calcium		Magnesium		
Water Sampled	Sample Number	Total Salts	Nitrate	Chloride	Sulphate	Bicarbonate	Sulphate	Bicarbonate	Chloride	Sulphate
Ferron Creek	P 2	1990.0	10.9	6.26	144.1	1014.5	None	106.0	None	666.3
Emery Creek	P 3	1055.0	8.2	None	None	682.7	None	179.0	10.9	138.7
Park Ditch	P. D. 4	1974.0	1.1	12.78	380.8	726.0	None	1221.0	None	95.2
Wellington Ditch	W. D. 5	1588.0	1.6	None	None	881.6	None	198.6	49.0	522.2
Price River	P 6	1490.0	5.4	6.3	78.8	750.6	None	133.2	None	391.7
Price River	P	3426.0	5.2	13.6	418.8	1005.3	304.6	None	None	1183.2
Huntington Creek	H 1	707.0	1.1	None	None	639.6	None	258.4	51.6	29.9
Huntington Creek	H 2	2512.0	13.6	5.44	500.2	992.6	None	125.0	None	895.0
Average										
Price		2119.5	3.3	8.1	219.6	840.9	76.1	388.2	12.2	548.1
Huntington		1609.5	7.35	2.7	250.1	816.1	......	191.7	25.8	462.5

There is a marked variation in the salt content and its nature observed at different parts of the irrigation season. Thus, the Huntington Creek, when first examined (July 14, 1914), contained only 707 pounds of salts in each acre-foot of water, while on the second examination (August 13, 1914), this had increased to 2,512 pounds of salts. There is a variation in the bicarbonate of calcium and magnesium, but not so great as in the sulphates. When it is remembered that an acre-foot of irrigation water is a small application and that frequently three and four acre-feet are used during the year, the amount of sulphate of sodium and magnesium added is a serious consideration and should be carefully controlled.

The country rock which contributes to the soil formation in this area is rich in soluble salts. The analysis of the water-soluble salts, or alkali content of two representative samples of shale from the area—one from Price, the other from Emery, which is south of Huntington—are recorded below as pounds per 2,000,000 pounds of material.[1]

Ions	Price Sample Number 95	Emery Sample Number 130
Total Salts	25720 0	80480.0
Calcium (Ca)	2810.0	11398.0
Magnesium (Mg)	873.0	1048.0
Carbonic Acid (CO_3)	466.0	760.0
Sulphuric Acid (SO_4)	17134.0	63976.0
Chlorine (Cl)	118.2	283.6
Potassium (K)	trace	386.2

	No. 95		No. 130	
Conventional Combinations	Per Cent	Pounds per 2,000,000 Pounds Soil	Per Cent	Pounds per 2,000,000 Pounds Soil
$Ca(HCO_3)_2$	0.05673	1134.6	0.10268	2053.6
$Mg(HCO_3)_2$	0.00569	113.8	....	....
$CaSO_4$	....	....	1.8480	36952.0
$MgSO_4$	0.2115	4230.0	0.260	5200.0
Na_2SO_4	0.9627	19254.0	1.6224	32448.0
NaCl	0.00195	39.0	0.0234	468.0

The soils from these shales are rich in the sulphates of sodium and magnesium, and any addition to these amounts by means of the irrigation water must be controlled as much as possible. The injudicious use of such irrigation water on this kind of soil is bound to result disastrously, while its use on well-

1 An acre to a depth of about 6 2-3 inches is estimated to weigh 2,000,000 pounds.

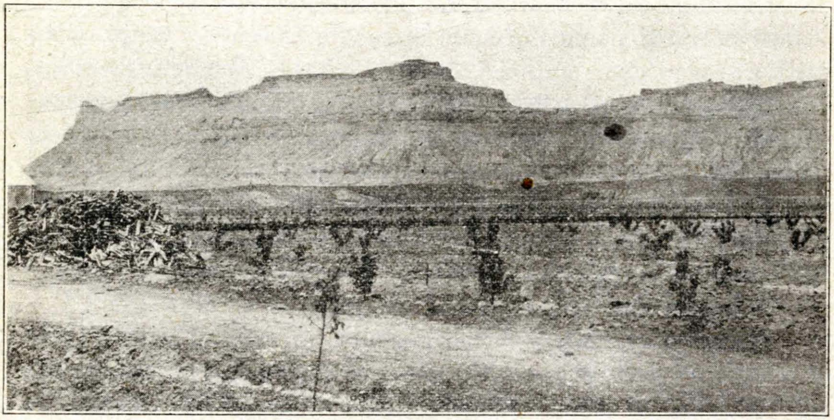

Fig. 1.—Ledge of country rock containing a high percentage of alkali salts.

drained, alkali-free soil would not only be non-injurious but may be beneficial.

The Water of Coal Creek.

The water of Coal Creek, used for irrigation purposes in the vicinity of Cedar City, Utah, is purer than that of the

TABLE III—ANALYSIS OF WATER FROM CEDAR CITY, UTAH.

Results Expressed as Parts per 100,000 of Irrigating Water.

Constituents.	Sample Number 1 (7|24|14)	2 (8|26|14)	3 (9|17|14)
(Ions)			
Calcium (Ca)	6.2	4.8	5.4
Magnesium (Mg)	2.3	2.4	2.9
Sulphuric Acid (SO_4)	3.6	9.3	7.5
Potassium (K)	trace	0.9	1.0
Chlorine (Cl)	0.14	0.14	0.14
Bicarbonic Acid (HCO_3)	20.7	19.3	21.1
Nitric Nitrogen (NN)	0.018	0.016	0.021
(Conventional Combinations)			
Total Soluble Salts	35.0	32.2	32.4
Calcium Sulphate ($CaSO_4$)	....	....	....
Calcium Bicarbonate $Ca(HCO_3)_2$	25.1	19.4	21.9
Magnesium Sulphate ($MgSO_4$)	4.5	7.2	6.3
Magnesium Bicarbonate $Mg(HCO_3)_2$	2.2	5.6	5.6
Magnesium Chloride ($MgCl_2$)	1.8	....	....
Sodium Nitrate ($NaNO_3$)	0.1	0.1	0.1
Sodium Sulphate (Na_2SO_4)	....	5.0	....
Sodium Chloride (NaCl)	....	0.3	0.2

Price-Huntington district. The results of the analysis are recorded in Table III which shows that the amount of the various ions present is small.

The amount of salts present is below the minimum limits set by all American writers upon the subject even when the bicarbonates of calcium and magnesium are included although the larger part of the salts consists of the harmless bicarbonates of calcium and magnesium. There is little variation in the alkali content throughout the period of irrigation as determined by ions.

The number of pounds of the various salts added to the soil by an acre-foot of irrigation water is recorded in Table IV.

TABLE IV—POUNDS OF ALKALI SALTS APPLIED IN ONE ACRE-FOOT OF COAL CREEK WATER.

		Sodium			Calcium		Magnesium		
Sample Number	Total Salts	Nitrate	Chloride	Sulphate	Bicarbonate	Sulphate	Bicarbonate	Chloride	Sulphate
1	952.0	2.7	None	None	682.6	......	59.8	49.0	122.4
2	875.6	2.7	8.16	136.0	527.6	......	152.3	......	195.8
3	881.2	2.7	5.4	92.4	595.6	......	152.3	......	171.3
Average	902.9	2.7	4.5	76.1	601.9	......	121.5	16.3	163.2

While the amount of chlorine present in solution is the same through the season, the form of combination as calculated has changed. On July 24 the chlorine exists as magnesium chloride, while on both the latter dates it is entirely sodium chloride. While the amount of sodium and magnesium sulphate added to the soil by an acre-foot of such irrigation water is materially less than in the case of the waters from Price River and Huntington Creek, the amount of sodium chloride, which is more toxic, is considerably greater. The variation in the sodium chloride content is undoubtedly due to evaporation and concentration of the waters of Coal Creek, intensified by the leaching from the adjacent red shale which is rich in sodium chloride.

The water-soluble salt content of the large shale and gypsum beds over which this stream runs and which contribute to the soil formation is recorded below:

Ions	Shale Sample Number 374	Gypsum Sample Number 376
Total Salts	83200	95680
Calcium	21656	23976
Magnesium	751	1642
Carbonic Acid	800	640
Sulphuric Acid	49944	55040
Chlorine	284	993
Potassium	None	870

	No. 374		No. 376	
Conventional Combinations	Per Cent	Pounds per 2,000,000 Pounds of Soil	Per Cent	Pounds per 2,000,000 Pounds of Soil
$Ca(HCO_3)_2$	0.1081	2162.0	0.0864	172.8
$CaSO_4$	0.1388	2776.0	3.9976	79952.0
$CaCl_2$	0.0224	448.0	....	....
$MgSO_4$	....	....	0.4064	8128.0
Na_2SO_4	....	....	2.528	50560.0

The salts consist essentially of the sulphates of calcium, magnesium, and sodium.

The Waters of the Sevier River.

The data from the waters of the Sevier River form an interesting study. The river traverses and extensive area throughout Utah and receives the run-off from an area of native rock which is heavily impregnated with alkali. Our samples for analysis were obtained near the mouth of the river after much of the fresh water had been diverted and the river enriched with the drainage waters of the Sevier Valley, the soils of which are more or less heavily impregnated with alkali. The results of analysis are recorded in Table V.

The waters are very much richer in the harmful alkali salts than either of the other streams studied. This is undoubtedly due in a large measure to the fact that they represent seepage waters. The calcium and magnesium carbonate content is practically the same as in the waters of Castle Valley, but the sulphate content and especially that of the more harmful chlorides, is very much greater. The nitric nitrogen is also present in comparatively large quantities. The amount of potassium is also appreciable.

TABLE V—ANALYSIS OF WATER FROM DELTA, MILLARD COUNTY, UTAH.

Constituents (Ions)	Sample Number 1	2	3	4	5	6	7	8	9	10
Calcium (Ca)	6.2	7.8	7.4	8.4	8.2	9.2	8.6	7.4	8.4	8.4
Magnesium (Mg)	3.2	7.3	10.0	8.7	8.7	7.9	8.3	7.5	7.4	7.4
Sulphuric Acid (SO_4)	19.9	16.3	22.2	27.2	28.8	25.6	32.9	32.8	33.4	32.6
Potassium (K)	.9	.9	1.0	1.2	.8	1.0	.4	.4	1.1	1.0
Chlorine (Cl)	9.2	8.5	5.8	9.0	11.5	10.1	22.1	21.0	22.3	20.4
Bicarbonic Acid (HCO_3)	27.2	29.2	27.8	29.0	28.4	29.2	26.4	24.9	28.4	29.0
Nitric Nitrogen (NN)	.19	.22	.17	.16	.11	.17	.04	.08	.09	.09
(Conventional Combinations)										
Total Salts	96.8	90.0	95.8	110.4	126.8	119.0	142.6	140.6	143.6	137.6
Calcium Sulphate	......	......	......	......	......	......	......	......	......	......
Calcium Bicarbonate	25.1	31.6	30.0	34.0	33.2	37.2	34.9	30.0	34.0	34.0
Magnesium Sulphate	7.8	20.4	27.8	34.1	36.1	32.1	40.7	34.8	33.7	33.1
Magnesium Bicarbonate	10.0	6.6	5.8	4.1	4.1	1.4	0.2	2.9	3.4	4.2
Magnesium Chloride	......	8.0	7.8	4.4	2.8	......	......	......	......	......
Sodium Nitrate	1.2	1.3	1.0	1.0	1.0	.7	.3	.5	.6	.5
Sodium Sulphate	19.2	......	......	......	......	......	0.6	7.1	9.0	8.6
Sodium Chloride	15.2	41.2	......	9.5	15.5	14.8	36.5	34.6	36.8	33.7

The amount of the various salts added in an acre-foot of irrigation water is recorded in Table VI.

TABLE VI—POUNDS OF ALKALI SALTS APPLIED BY ONE ACRE-FOOT OF IRRIGATION WATER FROM SEVIER.

			Sodium			Calcium		Magnesium		
Water Sampled	Sample Number	Total Salts	Nitrate	Chloride	Sulphate	Bicarbonate	Sulphate	Bicarbonate	Chloride	Sulphate
At Hinckley	1	2632.4	32.6	413.5	522.8	683.2	....	272.0	....	212.1
At Hinckley	2	2448.0	35.4	1121.0	....	860.0	....	179.5	217.6	554.8
At Delta	3	2606.0	27.2	....	....	816.0	....	157.6	212.4	756.0
At Delta	4	3003.0	27.2	258.4	....	924.7	....	111.5	119.7	927.4
At Delta	5	3448.4	27.2	421.6	....	903.0	....	111.5	76.2	981.8
At Delta	6	3236.0	19.1	402.6	....	1012.0	....	38.0	122.4	873.0
At Delta	7	3878.8	8.1	992.8	16.3	949.2	....	5.4	....	1107.0
At Delta	8	3824.0	13.6	940.8	193.6	816.0	....	78.8	....	946.6
At Delta	9	3906.0	16.3	1000.8	244.8	924.7	....	92.5	....	916.6
At Delta	10	3742.0	13.6	916.6	233.9	924.7	....	114.2	....	900.8
Average		3272.4	22.03	646.81	121.14	881.35	....	116.1	74.83	817.6

The amount of such salts varies from one and one-fifth tons in the early part of the irrigation season to nearly two tons in the later part of the season. Roughly speaking, one-third to one-fourth of these salts consists of the harmless bicarbonates of calcium and magnesium. The amounts, however, of the noxious salts—sodium chloride and magnesium sulphate—added by an acre-foot of irrigation water is serious. From three hundred to one thousand pounds of sodium chloride are added by each acre-foot of water. In some cases three or four acre-feet of water are used, thus adding an enormous quantity of this alkali to a heavy soil poorly drained and already highly impregnated with alkali. Equal quantities of magnesium sulphate are also added together with appreciable quantities of sodium sulphate. These results emphasize the necessity of great care in the use of such water, and also the necessity of artificial drainage on the fine-textured heavy soils of Millard County.

The Sevier River rises in and traverses the country rock which is rich in the alkali salts. The analyses of the representative samples of such rock near Richfield are recorded below as pounds per 2,000,000 pounds of soil:

Ions	Red Shale Richfield, Utah. Sample Number 30	Red Shale Sigurd, Utah. Sample Number 31
Total Salts	236200.0	194240.0
Calcium (Ca)	54920.0	25904.0
Magnesium (Mg)	5680.0	3503.0
Carbonic Acid (CO_3)	1200.0	480.0
Sulphuric Acid (SO_4)	132519.0	60800.0
Chlorine (Cl)	12052.0	35876.0

Conventional Combinations	Per Cent	Pounds per 2,000,000 Pounds of Soil	Per Cent	Pounds per 2,000,000 Pounds of Soil
$Ca(HCO_3)_2$	0.1621	3242.0	0.0648	1296.8
$CaSO_4$	9.192	183840.0	4.309	86180.0
$CaCl_2$	0.161	3220.0	0.0284	568.0
$MgCl_2$	0.748	14960.0	0.686	13720.0
$MgSO_4$	....	....	....	....
NaCl	....	....	2.905	58100.0

This material is high especially in sulphate and chloride of sodium and furnishes an excellent explanation of the higher alkali content of the water of Sevier River, especially as regards the sodium chloride and sulphate.

SUMMARY

The average amount of the various salts added by an acre-foot of irrigation water is recorded below as pounds per acre:

Name of Stream	No. of Analyses	Total Salts	Sodium Nitrate	Sodium Chloride	Sodium Sulphate	Calcium Bicarbonate	Calcium Sulphate	Magnesium Bicarbonate	Magnesium Chloride	Magnesium Sulphate
Price River	4	2119.5	3.3	8.1	219.6	840.9	......	388.2	12.2	548.1
Huntington Creek	2	1609.5	7.3	2.7	250.3	816.1	......	191.7	25.8	463.9
Coal Creek	3	902.9	3.1	59.9	76.1	601.9	......	121.6	16.3	286.2
Sevier River	10	3272.4	22.0	646.8	121.4	881.4	......	116.1	74.8	817.6
Ferron Creek	1	1990.0	10.9	6.3	144.1	1014.5	......	106.0	......	666.3
Emery Creek	1	1055.0	8.2	0.0	0.0	688.0	......	179.0	10.3	138.7

From this it may be noted that for every acre-foot of water of Price River practically one ton of mixed salts is added to a soil already rich in soluble salts and one which is very heavy, impervious, and with hardly any natural drainage.

About the same amount of salts, of very similar composition is carried by the waters of Huntington Creek, yet it must be noted that there is more than twice as much both of sodium sulphate and magnesium sulphate, although there is not so much salt in solution. These waters are applied to soils similar to those of Price and the result is to be seen by a visit to Huntington, Cleveland, etc., localities where the Huntington Creek water is used. The heavy sedentary soils are underlain by strata of shales still containing the salts that were deposited with them. The water comes in contact with them, rises to the surface carrying its load of alkali, and the result is the bog lands of these localities. The traveler sees many instances where the bog has claimed the farmhouse, the orchard, and the farm. This is similar to what has been observed in other localities.

In the Sevier region the conditions are even worse, for not only is the average concentration of salts more than fifty per cent higher, but there is also a smaller proportion of the harmless calcium and magnesium bicarbonates, and consequently a higher percentage of the more harmful salts, such as sodium chloride and magnesium sulphate, etc. We might note that whereas in Price and Huntington Creeks we have but 4.5 and 3.1 pounds respectively, of sodium chloride per acre-foot of water, we have in the Sevier River water more than 650 pounds per acre-foot. The same is also true with regard to the magnesium sulphate. There is one mitigating feature, however: each one of these streams carries valuable amounts of sodium nitrate. This is especially true of the waters of the Sevier River.

If we use the water of these streams it must be concluded that where good, natural drainage does not exist, artificial drainage must be supplied; that wherever possible crops should be grown which will shade the ground and thus prevent, as much as possible, surface evaporation, for it must be borne in mind that all surface evaporation results in the concentration of salts at the surface. Mulching and careful methods of irrigation should be practiced in order to minimize evaporation. Some authorities recommend irrigation by soaking from ditches where possible, since in this way the moisture is brought into contact with the plant roots and causes less surface evaporation and also maintains a movement of water downward into the drainage system. Another method is that of using the high flow of the river during the time of melting snows when the water contains least salt to wash out the accumulations of alkali. The drainage waters from alkali regions should be used as little as possible.

CONCLUSIONS

1. The mere determination of the total salts present in irrigation water is not adequate in judging the quality of the water for irrigation. The determination of total salts is valuable as a check on the analysis.

2. A large part of the soluble salts of irrigation water consists of the harmless bicarbonates of calcium and magnesium. In some instances these salts constitute 50 per cent of the total amount present.

3. The soluble salts present in irrigation water vary from time to time due to concentration by evaporation, to drainage from the surface soil during storms, and to seepage from the irrigated lands and canals.

4. The waters of Price River and Huntington Creek are highly charged with harmful alkali salts and must be used very judiciously on the heavy clay soils of Castle Valley, which are already heavily charged with sulphates of sodium and magnesium.

5. The waters of Coal Creek are excellent for irrigation since they contain only minimum quantities of harmful salts. The economical use of such water will not add excessive quantities of harmful alkali salts to the soil.

6. The waters of the Sevier River are heavily impregnated with the harmful chlorides and sulphates of sodium and magnesium. The waters of this stream are such that their continued use without artificial drainage on the heavy clay soils of Millard County is likely to cause trouble.

7. The waters of all the streams examined are free from sodium carbonate, or black alkali, possibly due to the fact that all the streams traverse country rock which is rich in deposits of gypsum.