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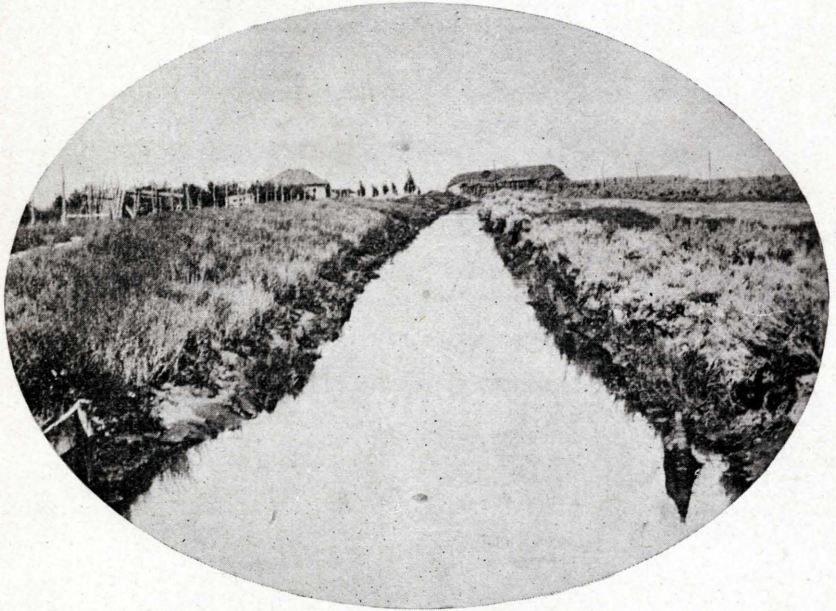
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COMPOSITION OF THE IRRIGATION WATERS OF UTAH

By

J. E. GREAVES and C. T. HIRST



BULLETIN NO. 163

Utah Agricultural College
EXPERIMENT STATION

Logan, Utah

June, 1918

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INTRODUCTION

Analytical work which has so far been published on the composition of the irrigation waters of the Intermountain Region indicates a wide variation in their composition. Some are exceptionally pure, being nearly free from alkali, and may be used without fear of injury to soils; others contain larger quantities of alkali and must be used with care; still others are so heavily charged with soluble salts that they must be used with extreme caution, otherwise the growing crop will be injured and in time the soil rendered unfit for agricultural purposes. The land then must be either reclaimed or abandoned, either of which will entail an enormous expense to the landowner and indirectly to the State. Much of this unnecessary loss can be prevented if definite and complete information be available on the composition of the irrigation waters.

There has been a constant demand for further information concerning the composition of the irrigation waters of the State, but it has been impractical to undertake the analysis of samples sent in by private individuals, for such samples often represent but one canal system. They are collected with no relation to other samples and under varying conditions; hence these would not represent even the water of the one specific system. Furthermore, such a method of procedure would necessitate the analysis of an enormous number of samples and the data so obtained would not be a complete record of the composition of the irrigation waters of the state. Therefore, in this work we have undertaken during various seasons and under careful supervision the collecting of samples from the principal sources of irrigation waters. Although the results herein reported do not necessarily give the composition of water in the specific canals of the state, it does give definite information on the water which enters the various canals. Moreover, it clearly indicates that some of the waters being used are above suspicion and no more work need be done upon them. In other cases, however, it merely opens the way for future and more specialized studies to be carried on to find means of preventing or combating the threatened injury.

WATER AS A SOIL FORMER

A clear understanding of the problem before us demands a brief consideration of the part played by water in soil formation, for it is of first magnitude in the formation of agricultural soils. It works in various ways. All natural rocks are more or less porous; water enters these spaces, and later freezes. In so doing, it breaks off larger or smaller particles, at times causing the whole rock to crumble. The particles by continuous weathering are ever being made finer. Many reach the small and eventually the large stream where they are carried onward. Rock, sand, and soil grind against each other and scour out the bottoms or sides of the stream, often cutting through solid rock at times to an enormous depth, as is witnessed by the fact that at places the Colorado river has cut to a depth of 5000 feet through solid granite. The speed with which this is accomplished varies with the volume of water and the speed of the current. Large, swift streams are able to carry large rocks and quickly scour out their beds, whereas slow streams may carry sand or only clay. But they are ever busy carrying sand, rock, and soil from higher to lower levels. Some natural barriers may act as retainers to the water, under which condition there is formed a lake. This acts as a natural settling basin, the rock debris being deposited on the bottom of the lake. If this be continued long enough the lake becomes filled with soil and the water flows on over the plain only to continue its work of soil formation in some other place. Most of our best agricultural soils of the state have been formed in just such a manner. Hence, we would expect to find within our soils the same constituents as are found within the mountainous rock from which they are being formed.

The quantity of material which may be so transported by water is enormous, as is seen from a few examples. The Mississippi carries annually into the Gulf of Mexico four hundred and six millions tons, or sufficient to cover one square mile to a depth of two hundred and forty-one feet. The Ganges adds to its delta annually two hundred and ninety-one million tons which is sufficient to cover one square mile to a depth of two hundred and nine feet. Turning to a small sluggish stream, we find the Thames carries daily to the sea one thousand and eight hundred tons of sediment. Although the streams of the intermountain district do not carry such enormous quantities of sediment as those cited, they play an appreciable part in soil formations. The soils of this district owe in a large measure their great fertility

to this very factor.

In the early geological periods, huge sheets of ice covered many parts of North America. They flowed slowly from the highlands into the lowlands. On their downward journey there became fixed within their bases huge boulders which were slowly dragged along, grinding themselves and the underlying rocks into fine powder. Rocks from the overhanging cliffs were caught up by the surface of the glacier and as they were carried along, the extremes of temperature often caused their breaking up with explosive violence. This agent probably played an insignificant part in soil formation of the intermountain region, although in the Great Lakes district it has played an important one.

The wind lashes the water of lakes against their banks and in so-doing rolls rocks up and down their banks. These, together with the various suspended material in the surf, slowly wear away the rock. Throughout the Great Basin one may read the history of the extinct lakes by the wearing effect their waters have had on the surrounding mountains.

Even pure water may be considered as a universal solvent, as is witnessed by the fact that pure water is never found outside the laboratory. Even the more resistant substances are soluble to a slight extent in it. When water becomes charged with substances from the soil and atmosphere, its solvent powers are greatly increased. Especially is this true when it becomes filled with carbon dioxide either from the atmosphere or from the decay of plants and animals. Substances so dissolved are deposited when the water evaporates, sometimes adding to the fertility of the soil, but at other times rendering it an unfit home for growing plants. This plays no small part in determining the nature of soil in the intermountain region, for in many basins enormous quantities of water have evaporated, leaving behind their soluble constituents. The native rocks and shales through which the streams flow are often exceptionally rich in soluble salts and these have been dissolved out and concentrated by the water.

Common limestone is one of the rocks most actively attacked by carbonated water, but none are wholly resistant to its action. Even quartz is slowly dissolved. Granite and related rock are rather quickly acted on by water due to the feldspar minerals which it contains. The bases—potash, soda, lime and alumina—are dissolved out. The last is deposited as clay, the first as beneficial or injurious soil constituents, depending on the kind

and the concentration left in a particular soil.

The quantity of the various substances taken up by water varies not alone with the composition of the water, but with the temperature and pressure to which it is subjected. It is well known that warm water more readily dissolves most substances than does cold; furthermore water charged with carbon dioxide under pressure is a wonderful solvent as is witnessed by the large deposits surrounding many natural springs.

We may therefore define soils as the earthy material in which plants have their anchorage and from which they obtain their water and part of their food. They are in reality disintegrated rock intimately mixed throughout with varying quantities of decaying plant and animal residues. Since soils are derived from the native rocks, we may expect to find within them the same constituents as are found in the rock from whence they are derived varying only in quantity of each ingredient. In the intermountain district are great deposits of gypsum, phosphates, and other minerals all of which have contributed to soil formation.

For the present soils may be classified as alkali soils and non-alkali soils. The former are those in which water-soluble salts have accumulated to such an extent that they have become injurious to vegetation. All other soils may be considered as non-alkali. Thus a soil which contains a fairly large quantity of soluble salt may be considered as non-alkali this year, whereas the addition of more may make of it an alkali soil next year. Moreover, a soil which contains enough salts to be injurious to one group of plants may favor the growth of others. Soils may contain fairly large quantities of soluble salts distributed throughout a number of feet and yet produce good crops, but if these salts be concentrated in the first foot they may be injurious. Hence, alkali soils may originate by the addition of salts or by the concentration of salts already present.

As the rocks in the humid regions disintegrate the heavy rains leach much of the soluble material from the soil and carry it to the ocean. Fortunately, it is the non-essential elements which are washed out; the essential, with the exception of nitrates, are held tenaciously by the soil. In the arid regions the rainfall is not sufficient to bring this about and the soluble substances accumulate in the soil in sufficient quantities to become injurious to vegetation, under which condition the soils become "alkali soil." Often our attention is first directed to the condition through the injudicious use of irrigation water which has ag-

gravated a natural condition in one of two ways. First, it may be that the water when applied to the soil is fairly free from soluble salts and as it passes down through the larger pores of the soil dissolves small amounts, but as it reaches the lower levels it is in contact with the soil particles for considerable time with the result that it becomes laden with soluble constituents. Now, as the water at the surface evaporates, the lower layer gradually rises, by the process of capillarity, to the surface carrying with it its soluble salts. On the evaporation of the water these are deposited at times in sufficient quantity to form a crust of alkali. Thus, the soluble salts in from three to five feet of soil may be concentrated mainly in the first foot, giving rise to an alkali condition. At other times the soluble salts in the soil are not excessive, but the use of irrigation water heavily charged with soluble salts increases that already in the soil, thus giving rise to an alkali soil. These conditions are greatly hurried by the excessive and injudicious use of irrigation water.

Furthermore, many of our soils are old lake bottoms in which great quantities of soluble salts were deposited when the lake waters evaporated. Many of our streams which are used for irrigation purposes originate and flow through rock, shale, and clays which are heavily charged with alkali salts, with the result that considerable of the alkali is being leached out by the water only to be deposited on the agricultural lands, and often with disastrous results.

Alkali soils nearly always contain an abundance of plant food, but after the excessive salts have been removed, the physical condition is usually bad. After this is corrected and time has been given for a normal bacterial flora to establish itself in the soils, they are usually exceptionally fertile. So it is with many of the soils to which irrigation waters are being applied. The addition of small quantities of soluble salts may do no harm and often increase the plant growth on such soils. Excessive quantities, however, are not only injurious but in time render the soil sterile.

The main injurious constituents occurring in water and alkali soils are sodium chloride, or common salt, sodium sulfate, or Glauber's salts, and sodium carbonate, or salsoda. Soils which have been the beds of seas or lakes contain, in addition to the above constituents, magnesium chloride, or bittern, magnesium sulfate, or epsom salts, and calcium sulfate, or gypsum. In addition to the above constituents, spots in Utah, Colorado, Wyoming, and California contain quantities of nitrates sufficient to

be injurious to plants, but these are always accompanied by some or all of the other constituents. Hence, the effect in most cases is due to the combined action of a number of salts. Where there is a large amount of any or all of the above salts, except sodium carbonate or nitrate, it is known as "white alkali." It is not necessarily white in color, but is nearly free from sodium carbonate. Where there is considerable of the sodium carbonate or nitrate present it is spoken of as "black alkali." This is due to the dark color which these constituents impart to the soil when they come in contact with organic matter. Although probably not directly so injurious to plants as are some other constituents, sodium carbonate tends to puddle the soil and even after removal by washing it leaves the soil in an extremely bad physical condition. Moreover, it clings tenaciously to the soil particles and is therefore hard to wash out. In short, this is successfully accomplished only by converting it into the sulfate.

The quantity of alkali which plants can withstand varies greatly with the soil and the plant. In general, where the soil is a loam or heavier, the amount of alkali required to injure the crop is greater than where the soil is of a lighter class. Old alfalfa and beets are fairly resistant to alkali, whereas wheat, barley and celery are sensitive. In the following table is given the quantity of the various salts which have been found by Hilgard to be injurious to some of the more common plants. The results are given as pounds per acre to a depth of four feet.

Table I. Quantity of "alkali salts" tolerated by various plants.

Total Alkali		Sodium Sulfate Glauber's Salt	
Salt Grass.....	381,110	Salt Brush.....	125,640
Salt Brush.....	156,720	Alfalfa — old.....	102,480
Alfalfa — old.....	110,328	Sugar Beets.....	52,640
Sugar Beets.....	59,840	Salt Grass.....	44,000
Wheat.....	17,240	Wheat.....	15,120
Apples.....	16,120	Apples.....	14,240
Alfalfa — young.....	13,120	Alfalfa — young.....	11,120
Mulberry.....	5,760	Mulberry.....	3,360
Sodium Carbonate Salsoda		Sodium Chloride Common Salt	
Salt Grass.....	136,270	Salt Grass.....	70,360
Salt Brush.....	18,560	Salt Brush.....	12,520
Sugar Beets.....	4,000	Sugar Beets.....	10,240
Alfalfa.....	2,360	Apples.....	1,240
Wheat.....	1,480	Mulberry.....	1,240
Apples.....	640	Wheat.....	1,160
Mulberry.....	160		

The results of more recent work which has been done at the Utah Experiment Station are given in Figure I.

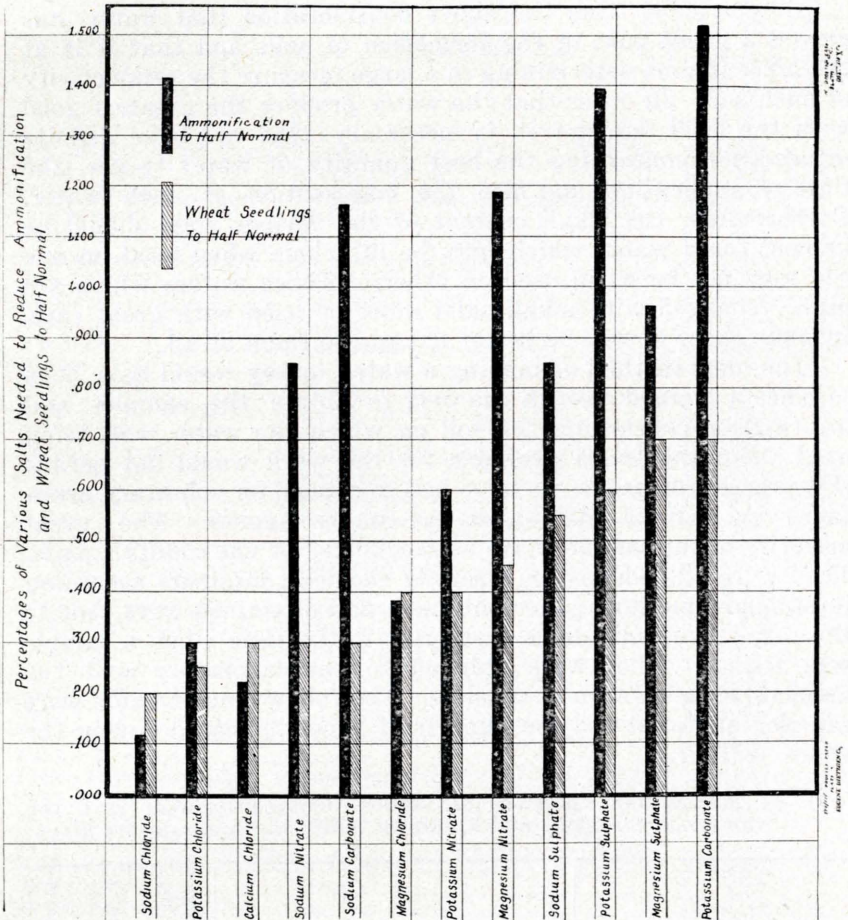


Fig. 1. Percentage of various salts needed to reduce ammonification and wheat seedlings to half normal.

They represent the percentages of the various salts which must be added to calcareous loam soil to reduce the growth of wheat seedling and the beneficial bacterial activity of the soil to one-half normal. The results clearly indicate that though the white alkali is not as injurious to the physical conditions of the soil, it is extremely toxic to plants. Moreover, this figure is of

especial interest in that it indicates that at times beneficial bacteria may be injured before the plants are. This in itself would often mean plant starvation.

It is evident from the above consideration that water has played a great part in the formation of soils and that it is at the present time determining in a large measure the productivity of such soil. In order that the water produce the greatest good with the least damage it is necessary that we have definite information concerning the best quantity of water to use, the time of application, and also the composition of such water. Furthermore, the alkali content of the various soils should be known, for a water which may be injurious when used on one soil may not be when used on others. Those waters which are highly charged with alkali salts must be used with great care. In some cases it may be better not to use them at all.

The ideal method of making a water survey would have been to place a trained man in the field to obtain the samples and information concerning the soil on which the water was being used. But the funds available for the work would not permit this procedure; hence, we have had to depend on voluntary assistance by private individuals or county agents. The great majority of the samples have been collected by the county agents. They were all collected in carefully cleaned containers according to standard methods; the containers and directions were sent to the respective individuals just prior to the time when a sample was desired. They were shipped to the laboratory and the analysis made as soon as possible. The following streams were sampled and analyzed the number of times indicated during the years 1916-17.

Table II. Names and Locations of Water Analyzed together with the Number of the Table and Figure in Which the Analyses are given:

Streams:	Where Sampled	No. of Analyses.....	No. of Table Giving Analyses.	No. of Graph Giving Analyses.
American Fork.....	American Fork, Utah.....	3	IX	4
Ashley River.....	Vernal.....	3	XVII	4
Beaver River.....	Bridge west of Milford.....	1	XVI	2
Beaver River.....	Minersville.....	5	XIV	3
Beaver River.....	Milford.....	4	XIV	2
Beaver River.....	City Power Plant.....	6	XIV	5
Bingham Creek.....	Grace Bros. Ranch.....	1		2
Bear River (Little).....	Mendon-Logan Bridge.....	4	III	2

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Streams:	Where Sampled	No. of Analyses.....	No. of Table Giving Analyses.....	No. of Graph Giving Analyses.....
Box Elder Creek.....	Brigham City.....	1	III	
Clear Creek.....	Sevier Station.....	5	XII	5
Cedar Creek.....	Diversion Dam.....	4	XVI	4
Cottonwood.....	Above Orangeville.....	6	XIV	3
Cottonwood (Big).....	At mouth of canyon.....	6	VII	5
Cottonwood (Little).....	At mouth of canyon.....	5	VII	5
Cub River.....	Franklin.....	1	III	5
Duchesne.....	Randlett.....	3	XVII	4
Duchesne.....	Tabby.....	2	XVII	5
Duchesne.....	Duchesne.....	4	XVII	5
Drains				11
Dry Creek.....	Crescent Ditch.....	1	V	5
Emigration Canyon.....	Mouth of Canyon.....	3	VII	3
Emery Canal.....	Petty Ranch.....	4	XIX	2
Ferron Creek.....	Mouth of Canyon.....	6	XIX	3
Green River.....	Near City.....	3	XIX	3
Huntington River.....	At Bridge.....	5	XIX	2
Hobble Creek.....	Above Springville.....	2	IX	5
Indian Creek.....	Upper Manderfield.....	5	XIV	5
Jordan River.....	Jordan Narrow.....	4	X	2
Lake Fork.....		4	XVII	2
Logan River.....	State Dam.....	2	III	4
Mill Creek.....	Canyon.....	7	VII	3
Maple Creek.....	Near Springville.....	2	IX	5
North Creek.....	Beaver below Stamp Mill.....	3	XIV	5
North Creek.....		4	XIV	5
Ogden River.....	Mouth of Canyon.....	5	XIV	4
Parowan.....	At Diversion Dam.....	4	XVI	4
Parley Creek.....	Canyon.....	5	VII	4
Provo River.....	Olmstead.....	6	IX	4
Price River.....	Near Price.....	6	XIX	2
Paragonah.....	Paragonah.....	1	XVI	4
Reservoir				10
Rock Creek.....	At Utahn.....	4	XVII	15
Red Creek.....	Paragonah.....	3	XVI	5
Strawberry Creek.....	Duchesne.....	4	XVII	3
Sevier River.....	Sigurd Bridge.....	6	XII	2
Sevier River.....	Delta, Delta Land & Water Co.....	4	XII	2
Santa Clara Creek.....	Santa Clara.....	3	XXI	4
Santa Clara Creek.....	West of town Santa Clara.....	3	XXI	4
Summit Creek.....	Santaquin.....	4	IX	4
Summit Creek.....	Summit.....	4	XVI	4
Salt Creek.....	Nephi.....	7	IX	3
Spanish Fork.....	Spanish Fork Canyon.....	4	IX	3
Springs				9
Spring Creek.....	Mendon-Logan Bridge.....	4	III	3
Spanish Fork.....	Thistle.....	1	IX	3
Uinta River.....	Randlett.....	3	XVII	3
U. S. Reclamation Servic.....	Spanish Fork.....	3	IX	3
Utah Lake.....	Pumping Plant.....	2	X	2
Wells				6-7-8
Weber River.....	Riverdale.....	5	V	4
White River.....	Stage road crossing.....	1	XVII	2
West Cache Canal.....	Smithfield Sugar Factory.....	1	III	

METHODS OF ANALYSIS

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

Carbon Dioxide:—Fifty cc. of water were titrated against thirtieth normal sulphuric acid using methyl orange as an indicator.

Chlorine:—Determined by Volhard's method, using fiftieth normal silver nitrate.

Calcium:—Fifty cc. of water were heated to nearly boiling and a drop or two of ammonium hydroxide added. The hot solution of ammonium oxalate was added to complete precipitation. After nearly boiling for about two hours the material was filtered through a 7 cm. filter by decantation. Most of the precipitate was left in the beaker and after three decantations was dissolved in a few drops of hydrochloric acid, then returned to hot plate and neutralized with ammonia and a few drops of oxalate added. This was then filtered, washed thoroly 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 cc. of concentrated sulphuric were added to each. The solution was heated nearly to boiling and titrated with tenth normal potassium permanganate.

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

Sulphuric Acid:—Was determined by precipitating the sulphuric acid as barium sulfate in the usual way.

Nitric Nitrogen:—Fifty cc. were evaporated to dryness and treated with 2 cc. 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 analysis of the water would give the basic and acidic ions in the water. But in reporting the results conventional combinations have been made according to the calculations

recommended* by the Association of Official Agricultural Chemists. These results are reported as parts per million 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. The amount of sodium chloride in the soil or water cannot be determined directly but the amount of chlorine in solution can be determined accurately. The method used in assigning this chlorine to the several basic ions may or may not show the water to be harmful.

STREAMS OF THE SALT LAKE SYSTEM

Eighty-two samples were taken from the Salt Lake system representing the following streams: Bear River, Logan River, Cub River, Little Bear, Spring Creek, Boxelder Creek, Ogden River, Weber River, Emigration Creek, Parley's Creek, Mill Creek, Little Cottonwood, Big Cottonwood Creek, Jordan River, Utah Lake, American Fork, Provo River, Maple Creek, Hobbler Creek, Spanish Fork, U. S. Reclamation Service Power Canal, Summit Creek, and Salt Creek.

Bear, Logan, Cub, Little Bear, Spring Creek, and Boxelder Creek are closely related and the average results obtained from the analysis of these waters are given in Table III.

The total salts found in Bear River water is considerably greater than those found in any of the other streams given in this table. However, over 47 per cent of the total is in the form of the non-injurious calcium and magnesium bicarbonate, whereas the remainder of the salts are in the form of the sodium chloride and magnesium sulphate and chloride, all toxic salts when present in excessive quantities. But this toxic action would be greatly reduced by the calcium salts present. The quantity of soluble salts in Bear River at Corinne is much greater than they are in the West Cache Canal. The gain is mainly in sodium chloride, due to a number of springs which flow into Bear River below the intake of the West Cache Canal. Considering the results as a whole, one would conclude that harm will result from the use of Bear River water only when used in excessive quantities or on land which is already heavily charged

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

Table III. Average Composition of the Waters of Bear, Logan, Cub, Little Bear, Spring Creek, and Boxelder Creek. (Stated as parts per million)

Stream.....	Where Sampled.....	No. of Samples.....	Total Salt.....	Calcium Bicarbonate.....	Magnesium Bicarbonate.....	Magnesium Chloride.....	Magnesium Sulphate.....	Sodium Bicarbonate.....	Sodium Nitrate.....	Sodium Sulphate.....	Sodium Chloride.....
Bear River	Corinne	1	805.0	146.0	234.0	4.2	106.0	0.0	0.0	0.0	357.2
Logan River	State Dam	3	152.0	144.3	77.9	3.2	7.4	7.9	0.4	2.3	1.9
Cub River	Franklin	1	152.0	105.4	21.0	0.0	0.0	64.8	0.7	4.4	0.0
Little Bear River	Mendon (Logan Bridge)	5	316.0	189.2	157.3	4.4	7.1	9.4	0.6	6.2	25.6
Spring Creek	Logan Bridge	5	330.0	187.7	139.2	5.6	37.1	2.8	0.4	15.4	13.6
Boxelder Creek	Brigham City	1	205.0	190.4	101.2	14.2	11.8	0.0	0.0	0.0	0.0
West Cache Canal	Sugar Factory	1	346.0	183.2	183.8		24.6			19.6	76.0

with soluble salts.

Logan River contains less than one-fifth as much soluble salts as Bear River contains, and nine-tenths of this is in the form of the bicarbonates of magnesium and calcium. The composition of this stream varies with the season, as it contained 133 parts per million on June 16, 1917, and 180 parts on the corresponding date in 1916. This variation may be due in part to the stage of the stream, for on June 16, 1917, the flood waters were near their greatest height, whereas on the same date the previous year the high water season was past. Since in neither case is the quantity of salt high, and this, and also Cub River, should be classed as streams very low in soluble salts. Cub River differs in that it contains 64.8 parts per million of the caustic alkali sodium bicarbonates, but the quantity of this present is not sufficient to do injury.

Little Bear contains less than one-half the soluble salts found in Bear River, and this is nearly all in the form of the bicarbonates of calcium and magnesium. Moreover, the remainder is composed of a number of salts and not three—as is the case with the water from Bear River. There is a slight

variation in composition of the water of Little Bear from month to month, being lowest with 212 parts per million of soluble salts in June and highest in July with 409; but at either time the water could be used with impunity.

Spring Creek contains slightly larger quantities of soluble salts than does Little Bear and differs further from this latter in that it contains more sulphates and less chlorides and carbonates. The seasonal fluctuation is from 242.0 parts per million in September to 386 in July, but at either season the water is well within the limits of safety.

Boxelder Creek is low in soluble salts and contains nearly all in the form of the bicarbonates of calcium and magnesium. It is markedly different from all the other waters in its sodium content. None of the waters in this group would add large quantities of salts to the soil, as may be seen from Table IV, in which is given the pounds per acre which would be added by one acre-foot of water.

Table IV. Pounds of Salts in One Acre-foot of Water from Bear, Logan, Cub, Little Bear River, Spring and Boxelder Creek.

Stream.....	Total Salts.....	Calcium Bicarbonate.....	Magnesium Bicarbonate.....	Magnesium Chloride.....	Magnesium Sulphate.....	Sodium Bicarbonate.....	Sodium Nitrate.....	Sodium Sulphate.....	Sodium Chloride.....
Bear River.....	2189.0	397.1	636.5	11.4	288.3	0.0	0.0	0.0	971.6
Logan River.....	413.4	392.5	211.9	8.7	20.1	21.5	1.1	6.3	5.2
Cub River.....	413.5	286.7	57.1	0.0	0.0	176.3	1.9	12.0	0.0
Little Bear River.....	859.6	514.7	427.9	12.0	19.3	25.6	1.6	16.9	69.6
Spring Creek.....	897.6	510.6	378.6	15.5	100.9	7.6	1.1	41.9	37.0
Boxelder Creek.....	558.0	517.0	275.0	39.0	32.0	0.0	0.0	0.0	0.0

The only water concerning which there could be a question is the water of Bear River which carries over one ton of soluble salts in an acre-foot, 57.5 per cent of which is sodium chloride and magnesium sulphate. But this is a higher concentration than is found in most of the irrigations taken from this stream as it receives considerable drainage water before it reaches Corinne.

In Table V is given the average composition of the waters of Ogden and Weber Rivers.

Table V. Composition of Water of Ogden and Weber Rivers. (Stated as parts per million).

Stream.....	Where Sampled.....	No. of Sample.....	Total Salts.....	Calcium Bicarbonate.....	Magnesium Bicarbonate.....	Magnesium Chloride.....	Magnesium Sulphate.....	Sodium Bicarbonate.....	Sodium Nitrate.....	Sodium Sulphate.....	Sodium Chloride.....
Ogden River	Mouth of Canyon	6	256.3	149.3	87.5	5.2	7.2	5.3	0.5	8.7	48.6
Weber River	Riverdale	6	256.6	163.1	91.6	3.6	17.9	3.5	0.3	9.5	5.6

Both streams are low in salts and of nearly the same composition. The main difference is in that the Ogden River contains more common salt and has less magnesium chloride than does the Weber. The quantity of common salt present in the Ogden River varies from traces to 139.6 parts per million, being lowest in June and highest in September. The sodium nitrate present in July is 2.5 parts per million, while in September there are only traces. The total salts vary from 128 parts in May to 408 in September. The variation in the Weber River water is not quite so great, being 174.0 parts per million in May and 293.0 parts per million in September. It is quite evident that

Table VI. Pounds of Soluble Salts per Acre-foot of Water from the Ogden and Weber Rivers.

Stream.....	Total Salts.....	Calcium Bicarbonate.....	Magnesium Bicarbonate.....	Magnesium Chloride.....	Magnesium Sulphate.....	Sodium Bicarbonate.....	Sodium Nitrate.....	Sodium Sulphate.....	Sodium Chloride.....
Weber River.....	698.0	443.4	249.1	9.8	48.7	9.5	0.8	25.8	15.2
Ogden River.....	697.2	406.2	338.0	14.2	19.6	14.4	1.4	23.7	132.2

neither stream is carrying sufficient salts in solution to be injurious to agricultural soils as may be seen from Table VI, in which is given the pounds per acre-foot of water.

One acre-foot of the water from Bear River would increase the salts of the soil to about the same extent as would three acre-feet of water from either the Ogden or Weber Rivers. Hence, should alkali injury result from the use of these latter streams, it must in every case be due to the water bringing it up from lower strata of soil and not from the composition of the water. Although these two waters carry the same quantity of soluble salts, there is a great qualitative difference, as the Ogden river contains over nine time the chloride occurring in the Weber River.

The composition of Emigration Creek, Parley's Creek, Mill Creek, Little Cottonwood, and Big Cottonwood are given in Table VII. Geographically, Jordan River and the Utah Lake should be included in this table, but the greater quantity of soluble salts in the two latter makes it appear better to consider them separately.

Table VII. Average Composition of the Waters of Emigration, Parley's Creek, Mill Creek, Little Cottonwood and Big Cottonwood Creeks. (Stated as parts per million).

Stream.....	Where Sampled.....	No. of Samples.....	Total Salts	Calcium Bicarbonate.....	Magnesium Bicarbonate.....	Magnesium Chloride.....	Magnesium Sulphate.....	Sodium Nitrate.....	Sodium Sulphate.....	Sodium Chloride.....
Emigration Creek	1 mi. above mouth	4	331.3	194.5	98.2	12.9	45.4	0.2	28.6	12.6
Parley's Creek 3	Canyon	5	259.6	176.6	39.4	17.3	32.3	0.0	13.2	10.0
Mill Creek 1.....	mouth of Canyon	7	349.8	227.1	35.2	4.7	105.6	0.2	23.9	9.7
Little Cottonwood 2	mouth of Canyon	5	104.4	69.7	11.4	2.2	24.6	0.4	3.0	0.7
Big Cottonwood....	mouth of Canyon	6	172.8	115.8	45.4	3.7	33.2	0.2	11.0	3.1

1 In September, 1916, contained 9.0 parts per million calcium.
 2 In October, 1916, contained 14.8 parts per million calcium sulphate.
 3 contained 11.2 parts per million sodium bicarbonate.

The water from Mill Creek is slightly higher in salts than any of the others. The greater portion of it is in the form of the calcium bicarbonate. It is, however, important to note that the permanent hardness of this water is considerably greater than any of the water so far considered.

The water from Little Cottonwood contains considerably less salts than do any of the others, but when we deduct the bicarbonates in each, the remaining salts are less in Big Cottonwood than they are in Little Cottonwood. Moreover, the nitrates which may indicate pollution are twice as high in the latter as in the former.

It is clear from an examination of Table VIII that the quantity of salts carried to the soil by any of these waters is not sufficient to be injurious to plants.

Table VIII. Pounds of Salts per Acre-foot of Water in Emigration, Parley's, Mill, Little Cottonwood and Big Cottonwood Creeks.

Stream.....	Total Salts.....	Calcium Bicarbonate.....	Magnesium Bicarbonate.....	Magnesium Chloride.....	Magnesium Sulphate.....	Sodium Nitrate.....	Sodium Sulphate.....	Sodium Chloride.....
Emigration Canyon.....	901.3	529.2	267.2	35.1	123.5	.5	77.8	34.3
Parley's Creek.....	706.0	480.4	107.2	47.1	87.9	.0	35.9	27.2
Mill Creek.....	949.2	617.5	95.0	12.7	287.3	.5	64.7	26.4
Little Cottonwood.....	284.0	189.7	31.1	6.1	66.9	.9	8.1	2.0
Big Cottonwood.....	470.0	315.0	123.5	10.1	90.9	.5	29.9	8.4

The seasonal variation in the composition of the waters of Emigration Creek is large. The highest was in October when an acre-foot contained 1202.0 pounds of salts and the lowest in September when there were 683.0 pounds. Although the quantity of salts found in Parley's Creek is not as great as those found in Emigration, the monthly variation is greater in the former, as there was nearly three times as much in the water during September as during July. The extreme variation in the composition of the waters of Mill Creek is 197.0 pounds per acre-foot, there being that much more in the water during October than during September of the same year. The alkali content of both

Big and Little Cottonwood waters is considerably higher during the fall months than during the summer. But during none of the seasons is the quantity and composition of the salts occurring in these streams such as would produce injury when judiciously used on normal soils.

In Table IX is given the average composition of the waters of American Fork, Hobble Creek, Maple Creek, Provo River, Salt Creek, Spanish Fork, and the Strawberry U. S. Reclamation Service Canal.

Table IX. Average Composition of the Waters of the American Fork, Hobble Creek, Maple Creek, Provo River, Salt Creek, Summit Creek, Spanish Fork and the U. S. Reclamation Service. (Stated as parts per million).

Stream.....	Where Sampled.....	No. of Analyses.....	Total Salts.....	Calcium Bicarbonate.....	Magnesium Bicarbonate.....	Magnesium Chloride.....	Magnesium Sulphate.....	Sodium Bicarbonate.....	Sodium Nitrate.....	Sodium Sulphate.....	Sodium Chloride.....
American Fork.....	American Fork	3	252.2	148.9	63.2	0.0	49.8	0.0	0.4	29.9	2.9
Hobble Creek.....	Above Springville	2	155.0	162.1	29.4	4.7	33.0	0.0	1.7	0.0	0.0
Maple Creek.....	Near Springville	2	160.5	139.8	72.1	4.8	3.8	2.5	1.2	7.3	0.0
Provo River	Olmstead	6	243.4	135.8	74.9	4.8	36.1	2.6	0.3	7.3	3.2
Salt Creek..	Nephi	7	455.0	204.4	61.3	4.0	27.3	5.1	0.2	21.4	126.4
Summit Creek.....	Santaquin	4	192.0	156.3	80.0	14.1	10.1	0.0	1.3	0.0	0.0
Spanish Fork.....	Mouth of Canyon	4	347.0	214.0	128.3	7.9	48.7	0.0	0.0	23.3	22.0
U.S. Reclamation Service	Spanish Fork	3	324.7	188.7	106.6	0.0	31.3	5.5	0.1	33.9	15.3

With the exception of Salt Creek, Spanish Fork, and the U. S. Reclamation Service Canal, these waters are all low in salt and the greater portion of the salt is in the form of the calcium and magnesium bicarbonate, making it certain that no damage can result from the salt carried to the soil by these streams. Although the total salts in the water of Spanish Fork River and the U. S. Reclamation Service Canal is high, 98 per cent and 91 per cent, respectively, of the total is in the form of the non-

injurious calcium and magnesium bicarbonates, making it quite certain that no damage should result from their use. In the case of Salt Creek the condition is quite different. Here about 42 per cent of the total salt is in the form of the injurious "alkalies." Since one acre-foot of this water would carry to the soil 1237.7 pounds of soluble salts, 344.0 pounds of this being common salt, so that its excessive use may lead to injured land. The quantity of salts in this water shows a wide monthly variation; in June it carries 347.0 parts per million, whereas in September there are 484.0 parts per million.

In Table X is given the composition of the waters of Utah Lake and Jordan River.

Table X. Average Composition of the Waters of Utah Lake and Jordan River.

Stream.....	Where Sampled.....	No. of Analyses.....	Total Salts.....	Calcium Bicarbonate.....	Magnesium Bicarbonate.....	Magnesium Chloride.....	Magnesium Sulphate.....	Sodium Nitrate.....	Sodium Sulphate.....	Sodium Chloride.....
Utah Lake.....	Pumping Plant	2	915.5	190.5	95.2	0.0	214.1	2.5	70.9	261.6
Jordan River..	At Narrows	4	905.4	214.9	65.0	5.1	245.3	.4	45.0	283.2

There is a marked difference in the composition of Utah Lake and the waters flowing into it. The waters entering are low in salts and from 70 to 98 per cent of the total salt carried by the stream is in the form of the bicarbonates of calcium and magnesium, and in the Lake only 31 per cent of the total salt is bicarbonate. Both waters contain large quantities of sulphates and chlorides, the Jordan River being slightly higher in both constituents than is the water in the Lake. The monthly variation in the composition of the waters is great. During June, 1916, the water contained 880 parts per million of total salts, and in September of the same year it contained 951.0 parts per million. Both of these waters would carry large quantities of injurious salts to the soil as may be seen from Table XI.

Table XI. Pounds of Salts per Acre-foot of Water in Utah Lake and Jordan River.

Stream.....	Total Salts.....	Calcium Bicarbonate.....	Magnesium Bicarbonate.....	Magnesium Chloride.....	Magnesium Sulphate.....	Sodium Bicarbonate.....	Sodium Nitrate.....	Sodium Sulphate.....	Sodium Chloride.....
Utah Lake.....	2440.0	518.0	258.9	0.0	582.0	0.0	6.8	192.9	711.5
Jordan River.....	2463.0	584.6	176.8	13.9	667.3	0.0	1.0	122.4	770.2

It is evident from these figures that the application of one-acre-foot of these waters to the soil carries with it over three-fourths of a ton of injurious "alkalies." When we remember that many farmers use even three or four times this quantity of water on their soils yearly we readily recognize that the quantity of saline constituents carried to the soil is going to make itself felt in ruined soil sooner or later. Where the soil is light and fairly free from soluble salts with a good under-drainage, the water may be used without severe injury for a considerable or even indefinite time if judiciously used. But when the soil is tight with poor underdrainage or already heavily charged with saline material, the use of the water presents more serious problems. Moreover, it is quite possible that the salts reaching the soil with an acre-foot of these waters in the future will increase and not decrease.

STREAMS OF THE SEVIER SYSTEM

Monthly samples were taken from Clear Creek at its junction with the Sevier River, at Sigurd Bridge, and the Sevier water from the Delta Land and Water Company's Canal (Canal A) at Melville. The average results are given in Table XII.

We have here a typical example of a stream which near its head is nearly free from saline material. In short, it is a stream containing only a small amount of soluble salts, and over 76 per cent of this is in the form of the non-toxic bicarbonate. But after flowing about 50 miles through a district rich in soluble salts, receiving seepage and being concentrated by evaporation, its nature has been so changed that by the time it reaches Sigurd Bridge at Sigurd it is a strongly saline water. In flowing from be

Table XII Composition of Sevier River Water. (Stated as parts per million.)

Stream.....	Where Sampled.....	No. of Analyses.....	Total Salts.....	Calcium Bicarbonate.....	Magnesium Bicarbonate.....	Magnesium Chloride.....	Magnesium Sulphate.....	Sodium Nitrate.....	Sodium Sulphate.....	Sodium Chloride.....
Clear Creek	Junction with Sevier	5	205.8	102.0	55.9	1.7	14.7	.3	.4	4.8
Sevier River	Sigurd Bridge	6	831.3	214.8	72.9	5.7	194.6	2.8	32.9	653.3
Sevier River	Near Delta	5	1316.4	280.4	34.6	9.7	382.2	3.8	18.8	531.1

Sigurd to the in-take of the Delta Land and Water Company's Canal there is a decrease in common salt, but an increase of over 100 per cent in the equally noxious sulphates. In flowing from Clear Creek to Sigurd Bridge this stream has gained over 400 per cent in soluble salts and the percentage of non-toxic carbonates in the water had decreased from 76 per cent to less than 35 per cent of the total. By the time the water reaches the Delta Land and Water Company's Canal the salts have increased over 600 per cent with only 25 percent of it in the form of calcium and magnesium bicarbonate. We, therefore, have the transformation from a good carbonate water to a strongly saline sulphate water which presents a tremendous problem to the water users.

The magnitude of the problem which is confronting the users of this water is clearly seen from a study of Table XIII in which is given the pounds of the various salt in one acre-foot of these waters.

The application of one acre-foot of the Sevier water at Delta to land would carry with it 3581 pounds of soluble salt, 75 per cent of which is the toxic chlorides and sulphates. This would mean that in twenty years if one acre-foot of water is applied to the soil yearly the salts carried to the soil would be 35.8 tons. This, if it were all collected in the surface foot of soil, would be sufficient to increase the salt content of the soil over 2 per cent, which in itself is sufficient alkali to destroy many plants. True, it would not all concentrate in the surface foot, but would be distributed throughout a number of feet and probably much of

Table XIII. Pounds of Soluble Salts per Acre-foot of water from Sevier River.

Stream.....	Where Sampled.....	Total Salts.....	Calcium Bicarbonate.....	Magnesium Bicarbonate.....	Magnesium Chloride.....	Magnesium Sulphate.....	Sodium Nitrate.....	Sodium Sulphate.....	Sodium Chloride.....
Clear Creek	Junction with Sevier	559.8	227.4	152.0	4.6	40.0	0.9	1.1	13.1
Sevier River.....	Sigurd Bridge	2261.3	584.1	198.3	15.5	529.3	7.6	89.5	653.3
Sevier River.....	At Delta	3581.0	762.6	94.1	26.4	1039.6	10.3	51.1	1445.0

it may be removed in drain water. It must be remembered that many of these soils are already heavily impregnated with alkali and the farmer seldom uses as little as one acre-foot a year; hence, the accumulation will be even more rapid than calculated above. This being the condition, methods for combating the threatened difficulty must be carefully studied and judiciously applied.

The remedy will vary considerably with the nature of the soil. At times it may be averted by systematic drainage; at others, by practising cultural methods which will conserve the water and thus decrease the quantity of water applied. Although the composition of the water does not vary greatly from year to year, there is a great variation within one season. That is, the salt content of the water increases with the lateness of the season, there being only two-thirds of the salts in the water during June that there is during September.

THE BEAVER VALLEY WATERS

Samples of the Beaver Valley waters were taken from North Creek below the stamp mill and north of William Twitchell's, of Indian Creek at Upper Manderfield, and of the Beaver at Beaver, Minersville, and Milford. The average results are given in Table XIV.

The waters of North Creek, Indian Creek and Beaver at the City Power Plant are exceptionally free from salt and can be

Table XIV. Composition of the Waters of the Beaver Valley. (Stated as parts per million).

Stream.....	Where Sampled.....	No. of Analyses.....	Total Salts.....	Calcium Bicarbonate.....	Magnesium Bicarbonate.....	Magnesium Chloride.....	Magnesium Sulphate.....	Sodium Nitrate.....	Sodium Sulphate.....	Sodium Chloride.....	Calcium Sulphate.....
North Creek	Below Stamp Mill	3	86.0	63.6	3.3	0.0	11.1	1.7	.2	0.0	5.3
North Creek	N. of Wm. Twitchell	4	80.0	61.3	11.6	2.4	21.6	0.1	.5	0.0	2.3
Indian Creek	Upper Manderfield	5	99.0	50.3	19.0	0.9	15.7	1.4	.7	2.3	0.0
Beaver..	City Power Plant	6	91.8	50.5	27.1	0.5	11.2	0.2	4.3	0.0	0.0
Beaver..	Minersville	5	404.8	194.6	73.5	0.0	50.9	0.2	44.9	80.4	0.0
Beaver..	Milford Bridge	4	730.2	151.3	86.5	0.0	36.8	0.2	183.6	203.3	15.9
Beaver..	West of Milford	1	990.0	113.4	43.8	0.0	54.8	0.5	307.6	389.2	0.0

used for irrigation purposes without fear of injury from alkali. But in flowing from the City Power Plant to Minersville, the Beaver River increases over 400 per cent in salt content, but only 37 per cent of the salts in the water at Minersville are injurious chlorides and sulphates; hence little or no damage will result from its use. By the time it reaches Milford the soluble salts have increased nearly 800 per cent, and just west of Milford it has increased over 1000 percent, and in this latter case over 83 percent of it is the injurious salts. The water of the Beaver at

Table XV. Pounds of Salt in One Acre-foot of Beaver River Water.

Where Sampled.....	Total Salts.....	Calcium Bicarbonate.....	Magnesium Bicarbonate.....	Magnesium Sulphate.....	Sodium Nitrate.....	Sodium Sulphate.....	Sodium Chloride.....	Calcium Sulphate.....
Milford	1986.0	411.5	235.3	100.1	.6	499.4	533.0	43.2
Bridge west of Milford.....	2694.0	308.5	119.1	149.0	1.4	836.6	1058.5	0.0

Milford and below should be used with the understanding that they are carrying appreciable quantities of soluble salts to the soil, as may be seen from Table XV. Moreover, the greater part of its salt contents are the toxic chloride.

There is over twice as much soluble salts in these waters during September as during June; moreover, during the month of June 67 percent of the total is in the form of the non-toxic bicarbonate, whereas during September there is only 25 percent in the form of the bicarbonate. Hence, these waters may be used with much greater safety during the early part of the season than during the latter part.

OTHER STREAMS OF THE GREAT BASIN

The following small streams, which may be grouped together, were sampled and analyzed: Paragonah Creek at Paragonah, Red Creek at Parowan, Parowan Creek at Diversion Dam north-east of Parowan, Cedar Creek at Diversion, and Summit Creek north of Summit. The average results are given in Table XVI.

Table XVI. Composition of the Waters of Paragonah, Red, Parowan, Cedar, and Summit Creeks. (Stated as parts per million.)

Streams.....	Where Sampled.....	No. of Analyses.....	Total Salts.....	Calcium Bicarbonate.....	Magnesium Bicarbonate.....	Magnesium Chloride.....	Magnesium Sulphate.....	Sodium Nitrate.....	Sodium Sulphate.....	Sodium Chloride.....	Sodium Bicarbonate.....
Paragonah Creek.....	Paragonah	1	208.0	77.0	105.2	0.0	0.0	1.0	0.0	87.6	11.6
Red Creek..	Parowan	3	162.3	120.3	85.9	3.2	11.7	0.0	0.0	0.0	0.0
Parowan Creek.....	Diversion Dam N.E. of Parowan	4	205.3	127.6	98.0	1.5	10.5	0.0	13.3	1.1	1.0
Cedar Creek*....	Diversion Dam	4	341.5	190.3	41.2	4.7	106.6	0.0	1.4	7.2	0.0
Summit Creek	Summit	4	265.2	167.0	140.6	14.4	16.0	0.0	4.4	4.7	.33

*Contains 20.2 parts per million of Calcium Sulphate.

The waters of these streams are all excellent for irrigation purposes. Their soluble salt contents are well under the danger limit for toxic salts. No harm will be caused by their rational

with Duchesne, Rock Creek at junction with Duchesne, Strawberry at Duchesne, Duchesne Creek at Randlett, and Duchesne at Duchesne and at Tabby. The average results are given in Table XVII.

The waters of this series present an interesting study. The waters of Rock Creek and the Duchesne at Tabby are both exceptionally free from salt for waters of these districts. Those of Ashley and Duchesne at Duchesne contain considerably more, but they are composed mainly of the non-toxic carbonates, and hence would not be injurious. The Duchesne at Randlett, the White River, and the Uinta all are exceptionally high in magnesium sulphate. The first two are nearly devoid of other toxic salts and carry fairly large quantities of calcium which will greatly reduce the toxic action of the magnesium sulphate. They can, therefore, be safely used on land which is not already highly charged with soluble salt. But in the use of the latter it must be borne in mind that it carries not only sulphates but the more toxic chlorides in large quantities.

The Strawberry not only carries large quantities of sulphates but is much higher in the caustic sodium bicarbonate than any other water we have examined.

The waters of Rock Creek, Duchesne at Tabby, Duchesne, and Randlett all increase in soluble salts from spring to fall, whereas both Uinta River and Ashley Creek have a higher salt content in July than in August. Lake Fork has a concentration

Table XVIII. Pounds of Salt Contained in an Acre-foot of the Waters of White River, Uinta River, Lake Fork, and the Strawberry.

Stream.....	Total Salts.....	Calcium Bicarbonate.....	Magnesium Bicarbonate.....	Magnesium Chloride.....	Magnesium Sulphate.....	Sodium Nitrate.....	Sodium Sulphate.....	Sodium Chloride.....	Calcium Sulphate.....
White River.....	1501.5	848.8	213.0	0.0	445.1	1.0	159.4	13.1	0.0
Uinta River.....	1871.0	434.2	0.0	0.0	497.0	1.3	154.3	294.4	195.3
Lake Fork.....	2148.0	412.7	4.1	3.3	283.5	1.1	139.3	644.6	303.8
Strawberry*.....	1257.3	483.4	503.2	0.0	53.9	1.9	323.4	20.9	0.0

*One acre-foot of the Strawberry would also carry 95.8 pounds of sodium bicarbonate.

three times as high in July as at any other time sampled. Were it not for this abnormally high salt content during this month the water would be classed with the water of the Duchesne at Randlett. Moreover, the large quantity of sodium bicarbonate reported in the water of the Strawberry River nearly all occurred in the July sample. The waters of this group have a much greater seasonal fluctuation in salt content than most of the waters examined.

The quantity of salts, which would be carried to the soil by an acre-foot of the waters of the four streams which must be used with exceptional care, especially on tight soil or soil containing large quantities of soluble salts, is given in Table XVIII.

STREAMS OF THE EMERY DISTRICT

The following streams from the Emery District were sampled: Price River at Price, Huntington Creek at Huntington, Cottonwood above Orangeville, Ferron River at mouth of canyon, Emery Canal at Petty's Ranch, Green River at Green River north of the town. One sample was also taken from Emery Creek at Emery. The average results are given in Table XIX.

Table XIX. Composition of the Streams of the Emery District. (Stated as parts per million).

Stream.....	Where Sampled.....	No. of Analyses.....	Total Salts.....	Calcium Bicarbonate.....	Magnesium Bicarbonate.....	Magnesium Chloride.....	Magnesium Sulphate.....	Sodium Nitrate.....	Sodium Sulphate.....	Sodium Chloride.....	Sodium Bicarbonate.....	Calcium Sulphate.....
Price River..	Price	6	1312.3	334.8	45.7	0.0	487.7	.9	315.6	25.6	0.0	44.2
Huntington Creek	Huntington	5	794.4	234.2	39.8	1.0	263.6	.6	194.0	7.9	0.0	53.8
Cottonwood..	Above Orangeville	6	451.1	191.9	112.4	0.0	84.6	.6	102.4	10.4	2.7	0.0
Ferron River..	Mouth of Canyon	6	1668.0	426.8	103.4	0.0	116.2	1.4	177.7	4.5	12.5	15.7
Emery Canal..	Petty's Ranch	3	345.3	101.1	157.6	9.6	13.7	.1	104.0	21.3	0.0	0.0
Emery Creek..	Emery	1	1616.0	399.8	0.0	0.0	212.0	0.0	806.4	35.0	0.0	45.4
Green River..	Green River	3	482.3	216.6	22.5	0.0	118.8	.3	126.9	14.2	0.0	0.0

All the waters of this district are similar in that they contain considerable sulphate and comparatively small quantities of chlorides. Only three streams—Cottonwood, Emery and Green River—contain less than 500 parts per million of total salts, and of this over 50 per cent in every case is in the form of the toxic salts. Emery Creek at Emery contains very large quantities of salts, the greater portion of which is injurious, while the Emery Canal contains only one-fifth as much. Price River, Huntington Creek, Ferron and Emery Creeks all contain large quantities of noxious salts, which if used as irrigation water would greatly increase the alkali content of the soil, as may be seen from a study of Table XX.

Table XX. Pounds of Salts contained in one Acre-foot of Water from some Emery District Streams.

Stream.....	Total Salts.....	Calcium Bicarbonate.....	Magnesium Bicarbonate.....	Magnesium Chloride.....	Magnesium Sulphate.....	Sodium Nitrate.....	Sodium Chloride.....	Calcium Sulphate.....	Sodium Sulphate.....
Price River.....	3561.0	910.8	124.3	0.0	1326.6	2.6	69.6	120.2	858.6
Huntington Creek..	2160.8	637.1	108.3	2.7	715.4	1.6	21.5	146.4	527.7
Ferron Creek.....	1668.0	426.8	281.3	0.0	316.1	3.8	12.3	42.7	48.4
Emery Creek.....	4395.0	1087.5	0.0	0.0	576.6	0.0	95.2	123.5	2193.0

The large quantities of calcium bicarbonate and calcium sulphate would tend to offset the toxic action of the other salts present. The injury resulting from the use of the water will depend upon the quantity used and the nature of the soil. It is also important that there are much larger quantities of the salts in each of these streams during the latter part of the season than earlier, thus making their excessive use during the fall much more dangerous than the use of the same quantity of water early in the season.

The April samples taken from the Ferron River were extremely high in soluble salts, which may be due to high water, local rains, or other disturbing factors. During June it reached its lowest salt content; from then on throughout the remainder of the season there was a gradual increase. During June 74.8

parts per million of sodium bicarbonate occurred in the Ferron but during the rest of the year it was practically free from this compound. Moreover, the calcium sulphate reported all occurred in the April sample, thus showing a far greater seasonal variation in the composition of this water than has been noted in any of the others.

SANTA CLARA CREEK

Three samples were taken of the Santa Clara Creek during May, July, and September, at Santa Clara and west of the town. The average results are given in Table XXI.

Table XXI. Composition of the Water of the Santa Clara Creek. (Stated as parts per million).

Where Sampled.....	Total Salts.....	Calcium Bicarbonate.....	Magnesium Bicarbonate.....	Magnesium Chloride.....	Magnesium Sulphate.....	Sodium Nitrate.....	Sodium Sulphate.....	Sodium Chloride.....
Santa Clara.....	326.3	206.7	30.7	3.1	95.1	.2	0.0	16.6
West of Town.....	307.6	181.1	50.3	4.7	32.8	.2	43.3	3.9

Both of these waters are well within the limits of safety. Moreover, of the total salts 72 and 75 percent, respectively, are in the form of the non-toxic bicarbonates.

GENERAL CONSIDERATIONS

The quantity of alkali which a water may contain and yet be used without damage varies greatly with a number of factors, the chief of which are: the kind of salts in the waters, the crops to be grown on the soil, the form and quantity of alkali in the soil, the method of irrigation, the quantity of water applied, and the physical nature of the soil as to whether sandy or clayey, and as to whether well drained or water-logged.

It is generally conceded that sodium carbonate is more injurious than the chlorides or sulphates. Practically all of the waters examined are very low in this compound, but we must not lose sight of the fact that sodium sulphate or sodium chloride in the presence of large quantities of decaying organic matter which

liberates carbon dioxide may be readily transformed in the soil into the more harmful carbonate. Moreover, water which contains sodium carbonate if used on soils containing large quantities of gypsum would be no more detrimental than if it contained equivalent amount of sulphate. For the gypsum would readily convert the carbonate into the less toxic sulphate.

Moreover, as we have seen from the given results, a stream may be comparatively free from alkali during part of the year, but at other times it may be heavily charged with alkali. The melting of snow in the mountainous regions usually has the effect of freshening the water, but local rains often have the opposite effect, and drainage water, especially from alkali soils, greatly increases the alkali content of a stream. Many of the cases in which large increases of alkali salts are noted in the water during the later irrigation season must be attributed to this factor.

With good natural drainage a more highly concentrated water may be used than where drainage is poor. For instance, in the Algerian Oases, where Arabs use alkaline waters, the conditions are as follows: "The Arabs' gardens are divided into small plots about twenty feet square, between which run drainage ditches dug to a depth of about three feet. The soil being very light and sandy, this ditching at short intervals insures the most rapid and thorough drainage. Irrigation is made by the check method and application is made at least once a week, though two wettings are often deemed necessary. A large quantity of water is used at each irrigation. Thus a continuous movement of water downward is maintained. There is little opportunity for the soil water to become more concentrated than the water as applied, and the interval between irrigations being so short but little accumulations of salt from evaporation at the surface takes place."*

The difficulty here is increased by the fact that the soil is heavily charged with alkali. Under these conditions such plants as melons, tomatoes, cabbage, pepper, figs, and pomegranates do well. In this work reported by Means the water used was all artesian water.

Wherever the soil is a clay loam, heavy adobe has a hardpan or poor sub-drainage entirely different methods must be employed for the salt would tend to accumulate near the surface and soon become injurious to plants. In such soils every effort must be used to conserve the soil moisture and in this way to cut down

*U. S. Dept. Agr. Bur. of Soils, Cir. 10, p. 3.

on the quantity of water added to the soil, especially if the water carries much soluble salts. It is always well to remember that such soils often produce better crops with 15 inches of irrigation water than with more.

Furthermore, there may be cases in which, due to the physical and chemical composition of the soil together with the alkali content of the water, the crop must be selected with this fact in view. For instance, Sweet or Egyptian clover may be irrigated with water of such a high saline content as to be fatal to other crops. Old alfalfa is much more resistant to alkali than is young alfalfa.

A soil which is heavily charged with soluble salts may often be tilled if care be used in the use of irrigation water, but when we have such a soil on which is to be used a highly saline water the problem becomes complex.

Although the use of a saline water on any soil is a problem which must be determined independently in each locality after taking into consideration the saline content of the water, the quantity and nature of alkali in the soil, and the physical conditions of the soil, yet there are certain standards which have been laid down which are valuable guides. Hilgard* considers that the extreme limits of mineral contents usually assigned for potable waters, viz., forty grains per gallon (571.2 parts per million), also applies to irrigation waters. Should it happen that all or most all of this is gypsum and epsom salts, only a large excess of the latter would constitute a bar to irrigation, while on the other hand if a large proportion of the solids consist of sodium carbonate or common salt, even a much smaller proportion of salts might preclude its regular use, depending upon the nature of the soil to be irrigated.

Forbes† feels that 0.25 percent 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 waters should be carefully controlled. He states further that water containing 1000 to 1500 parts per million of salts, as sulphates and chlorides, have often embarrassed the agriculture of the farmer, and in some cases it has led to the abandonment of farms. Forbes therefore considers in the salt river waters "that under the condition of water supply, drainage, and climate found in the principal irrigated districts of Arizona and with prevailing

*Calif. Exp. Sta. Bul. 128, p. 34.

†Ariz. Exp. Sta. Bul. 44, p. 166.

agricultural practice, waters containing 1000 parts per million of salts of average composition are liable to cause in a few years harmful accumulations of alkali."

The Bureau of Soils* states that 5000 parts per million of soluble salts when added to the Pecos Valley soils may be taken as the extreme limit of endurance by plants, while 2500 to 3000 marks the danger zone. However, in this case only about 50 per cent of these salts are harmful. At Carlsbad about 3000 parts per million marks the limit of safety.

Means,† however, maintains that the amount of alkali salts permissible in irrigation water has been underestimated by American writers and calls attention to the fact that the Arabs in Sahara, Africa, use irrigation water containing over 8000 parts per million, more than one-half of which is sodium chloride. He also quotes from an earlier publication: "The limit of endurance for most cultivated plants in a water solution is about 1 percent, or one thousand parts of the readily soluble salts in one hundred thousand parts of water."

There is some truth in Means' contentions, for many of the early works on soil alkali have taken into consideration the quantity of salt present within the water, but not the relative proportion of the various constituents which is a determining factor as to whether or not a water will be toxic. For instance, marine forms of life transferred from sea water to a pure salt solution containing no more salt than there is in the sea water soon die. Seventy parts of magnesium sulphate in 1,000,000 parts of water represents the highest concentration in which plant roots can survive, but in the presence of a concentrated solution of calcium sulphate 33,600 parts of magnesium sulphate in 1,000,000 parts of water can be tolerated. Gypsum and common salt are both antidotes for magnesium sulphate; magnesium carbonate is an antidote for sodium carbonate and sodium chloride; lime counteracts the action of magnesium and sodium in the form of sulphates, carbonates or chlorides.

But the fact which must be borne in mind is that even though plants may tolerate large quantities of alkalies in solution, if they be in the right proportion the great danger comes from the accumulation of the salt in the soil from their continued application. Many saline waters when first applied to a soil may

*U. S. Dept. Agr. Bur. of Soils Rpt. 64, p. 19.

†Bureau of Soils, U. S. D. A., Circular 10, p. 2.

furnish nutrients to the plant and actually stimulate plant growth, but later due to their accumulation within the soil, have an opposite effect.

For the purpose of direct comparison of the total salts, both non-toxic carbonates and the more toxic chlorides and sulphates, the average results from all of the streams tested are presented in Figures 2, 3, 4, and 5. In this grouping we do not wish to convey the idea that all in the first group may prove injurious or that all in the second group may be used with impunity. It has been used merely as a convenient method of handling them. So in interpreting the results it is well to keep in mind the factors outlined in the foregoing pages.

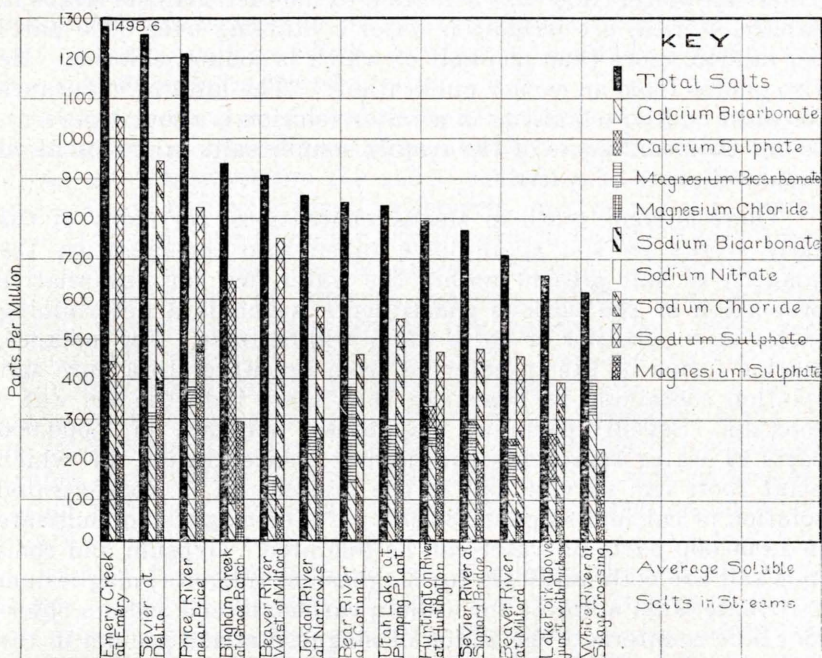


Fig. 2. Average soluble salts in streams.

All of the waters, the analysis of which are listed in Figure 2, are high in soluble salts. It is, however, questionable whether any of them are high enough in saline constituent to destroy plants at the present concentration. But the magnitude of the problem which confronts the users of these waters is made clear by the following: One acre-foot of the Sevier water ap-

plied to soil would carry with it 3581.0 pounds of soluble salts which in twenty such irrigations would reach the enormous sum of 71,620 pounds, or sufficient, if it be allowed to accumulate, to render the soil sterile. White River, which is lower than any of the others in this group in soluble salts, would carry to the soil in every acre-foot 1502.0 pounds of salts, or in twenty such applications it would carry over 15 tons of soluble salts to the soil. It is therefore evident that the all-important principle to guide the users of these waters is to prevent as far as possible the accumulative action of these waters. The methods by which this end may be gained will vary with the specific soil, as has been pointed out in the preceding discussion.

The waters of the Sevier River contains comparatively small quantities of calcium and magnesium carbonates and enormous quantities of the chlorides and sulphates. The unbalanced condition of the salts within the Beaver River makes it even more dangerous than is either the Sevier River of the Price River. It is highly important to note that in all of these streams, except

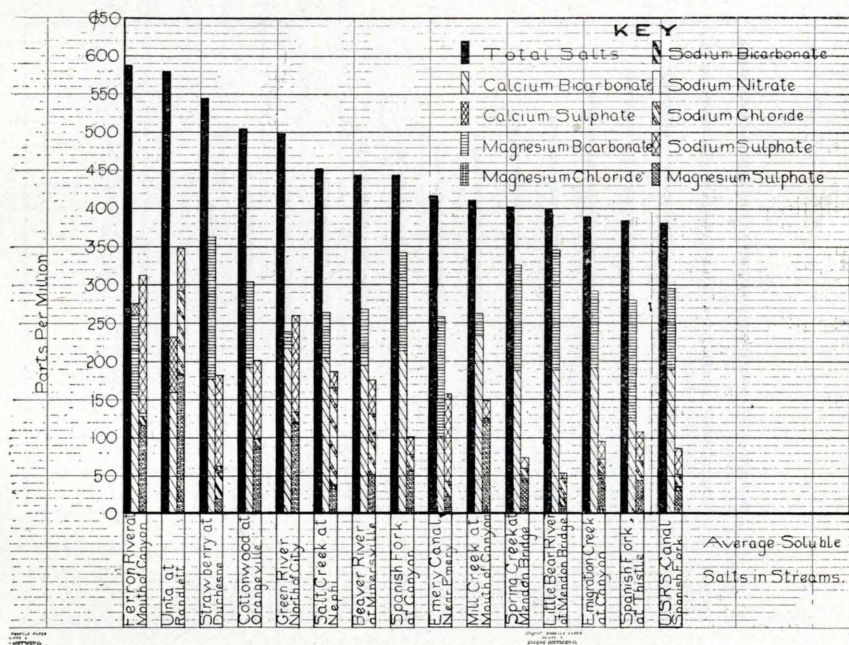


Fig. 3. Average soluble salts in streams.

the White River, the toxic sulphates and chlorides greatly predominate over the carbonates.

The composition of the fourteen streams listed in Figure 3 are quite different from those listed in Figure 2. With the exceptions of Ferron, Uinta, and Green River the non-toxic carbonate predominate in these waters. Even in the three in which the toxic salts are in excess there are large quantities of calcium and magnesium bicarbonates which would tend to neutralize the toxicity of the other salts.

Although the problem confronting the users of these waters are not nearly as complex as the problems confronting the users of the waters listed in Figure 2, yet it must always be remembered that they are using waters high in soluble salts, and if conditions be right there may be at any time an accumulation of salts which may cause trouble. This is especially true with regard to the first two in which there are large quantities of the toxic chlorides and sulphates. The others, if used correctly on soils not already heavily charged with soluble salts, should do no damage.

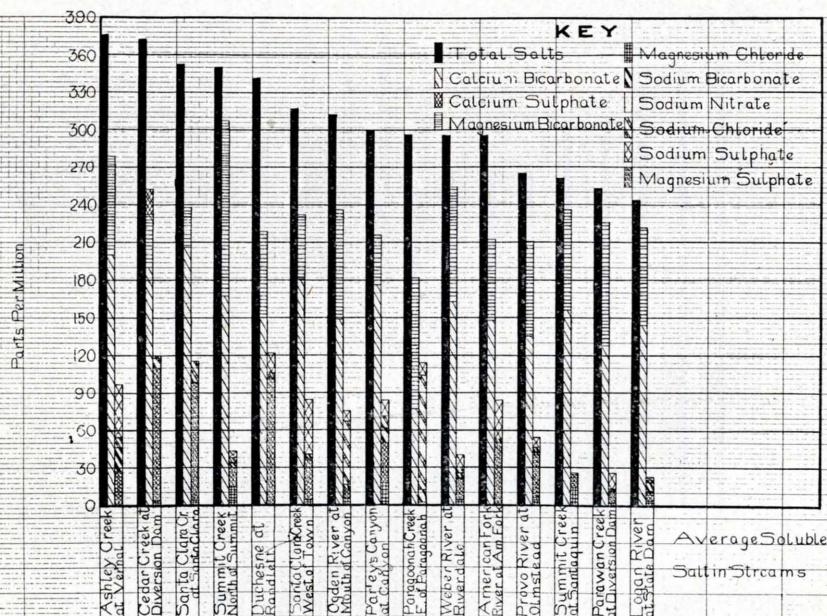


Fig. 4. Average soluble salts in streams.

The streams which are listed in Figure 4 contain between 340 and 380 parts per million of soluble salts, and in every case the non-toxic bicarbonates greatly predominate. In no case does the toxic salts reach 150 parts per million, and in most cases the quantity present is far below this amount.

These waters, if intelligently used on land with even fair drainage and not already filled with alkali, should cause no trouble. But, on the other hand, the quantity of soluble constituents in the water should act as plant stimulants, thus increasing plant growth and not retarding as in the case with larger quantities of alkalies.

All of the waters which are listed in Figure 5 contain less than 180 parts per million of soluble salts and in every case the toxic salts make up only a small part of the total.

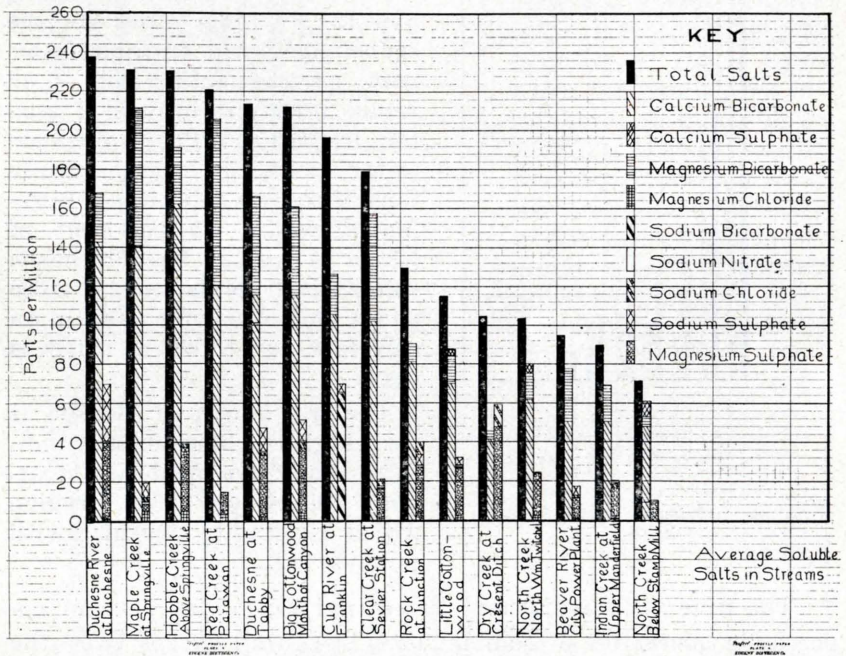


Fig. 5. Average soluble salts in streams.

Where injury results from these waters, it will be due either to injudicious use of the water or else to its use on soil already heavily impregnated with alkali which the water may cause to accumulate at the surface.

FLOWING WELLS

During the summer of 1917 samples were taken from thirty-two wells and analyzed. The majority of these are flowing and in some cases yield a large volume of water which is or could be

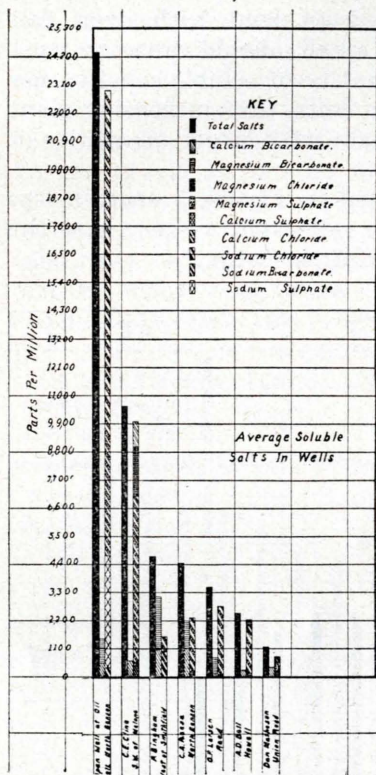


Fig. 6. Average soluble salts in wells.

used for irrigation purposes. The analyses of the seven which are highest in soluble salts are given in Figure 6. They range from 1105, in the case of the Dan Matheson's well, to 24,218, in the case of the well west of Smithfield. In all, except the Bingham well, the toxic chlorides and sulphates predominate, and in only one other do the carbonates form an appreciable part of the total salts. All would quickly injure soil if used for irrigation. The Smithfield water contains nearly thirty tons of soluble salts in one acre-foot of water, 91 per cent of which is toxic. The Matheson water would contain nearly a ton and a half of soluble salts in an acre-foot, two-thirds of which is toxic.

The well north of Benson is very high in chlorides and indicates that there must be a stratum underlying that region which is heavily charged with common salt.

The nine wells which are listed in Figure 7 all contain appreciable quantities of soluble salts, but in all except two—the one at Enoch and the Calhoon well at Erda—the bicarbonates predominate. It is rather likely that plants would be injured with the water from the Calhoon well at Erda sooner than they would with water from any of the other wells even though some of the others are much higher in soluble salts.

Wherever these waters are used for irrigation purposes, care must be taken to prevent the accumulative effect, for it is this alone which injures the soil.

The remaining sixteen samples of well water, the analyses of which are given in Figure 8, all contain less than 460 parts per million of soluble salts. Furthermore, in all except the ones at Erda, Grantsville, and Robinson's well at Fillmore, the non-toxic bicarbonates are greatly in excess. Even in these, the quantity is fairly large when compared with the total salt present. It is not likely that any of the waters placed in this group will cause injury when used judiciously unless it be by bringing up alkali from lower soil.

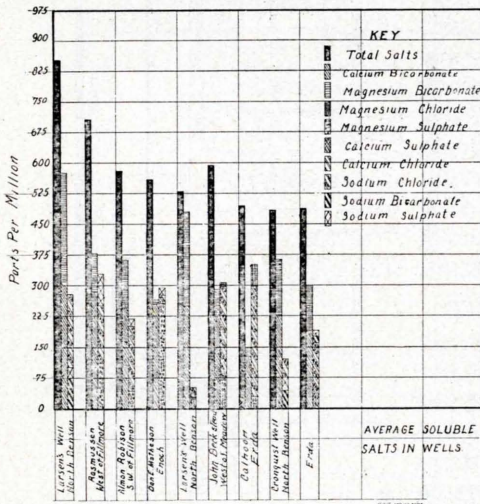


Fig. 7. Average soluble salts in wells.

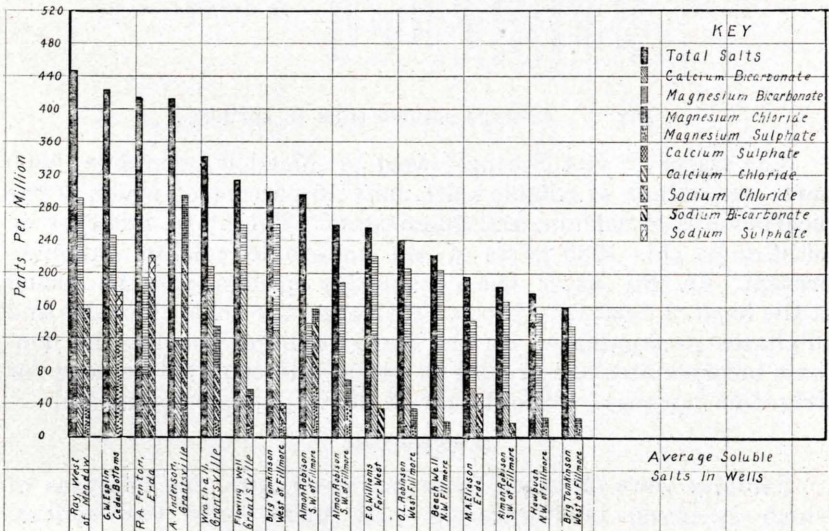


Fig. 8. Average soluble salts in wells.

SPRINGS

Analyses were made of eight spring waters. These are listed in Figure 9.

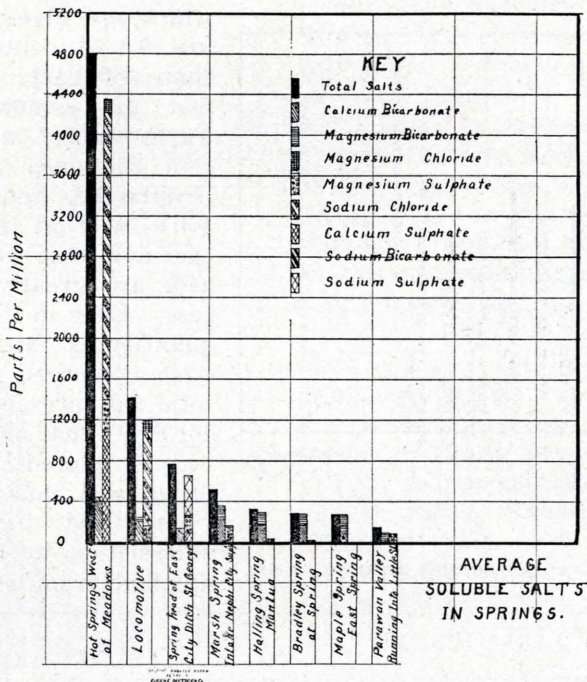


Fig. 9. Average soluble salts in springs.

The water of Hot Springs, west of Meadow, contains 4800 parts per million of soluble salts, only 10 percent of which is the bicarbonates of calcium and magnesium. There are, however, in addition to this 1080 parts of the non-toxic calcium sulphate present. In this water, the Locomotive springs, and the spring at the head of East City Ditch, St. George, the toxic chlorides and sulphates predominate. In the five remaining springs the non-toxic bicarbonates are greatly in excess and could all be used for irrigation purposes without fear of doing damage to the soil.

RESERVOIRS

Samples were obtained from five reservoirs, the analyses of which is given in Figure 10. Of these, only two contain excessive quantities of soluble salts,—the Blue Creek Reservoir

and the Sevier River Reservoir. In these toxic salts greatly predominate and the quantity present is sufficient to injure land

if it be allowed to accumulate. This, however, raises the question as to whether there are certain seasons of the year in which the waters which are used to fill these reservoirs contain larger quantities of soluble salts than at others. If so, would it not be possible to fill the reservoirs with the better waters and thus avoid the excessive quantities found in these waters?

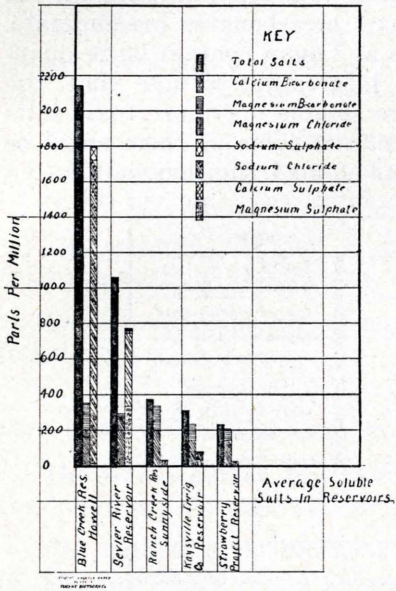


Fig. 10. Average soluble salts in reservoirs.

The Range Creek Reservoir at Sunnyside, the Kaysville Company Reservoir, and the Strawberry Project Reservoir are all low in total soluble salts and the quantity of toxic salt is also low. There is no question but that the water can be used without injury to the land.

DRAINS

The analyses of eight drain waters is given in Figure 11. In only three of these do the non-toxic bicarbonates predominate. The one at St. George and the one at Logan contain large quantities of the toxic salts, but it is interesting to note that the remaining six contain neither more soluble nor more toxic salts than some of the irrigation waters, and some of them could be used with less danger than can some of the irrigation waters.

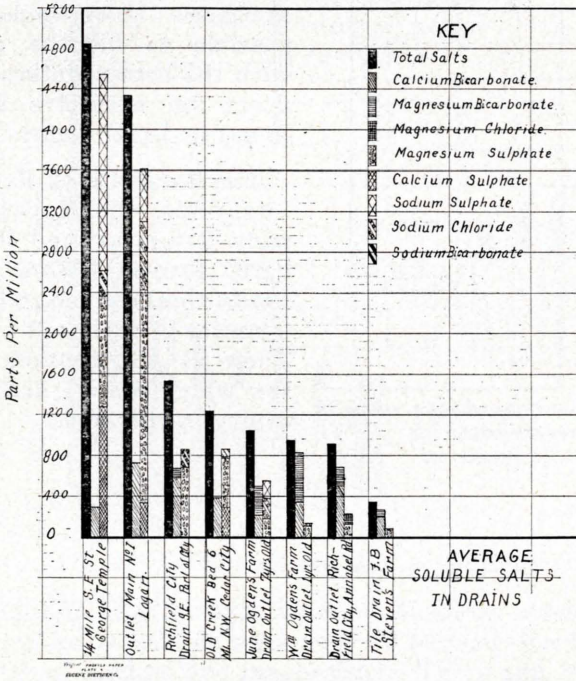


Fig. 11. Average soluble salts in drains.

SUMMARY

The results herein reported represent 254 analyses of water distributed as to kind as follows: Fifty-eight rivers or creeks, the majority of which are used extensively for irrigation purposes; thirty-two wells, most of which are flowing; eight springs; five reservoirs; and eight drains.

The composition of these streams varies from 84 to 1250 parts per million of soluble salts. Thirteen of these contain more than 40 grains per gallon as suggested as the limit by Hilgard.

The amount and kind of salt varies with the nature of the drainage basin of the stream.

The waters of nearly all streams at their source are ideal for irrigation purposes.

The salts in the head waters of most streams studied consist very largely of calcium and magnesium bicarbonate.

The total amount and kind of salt is greatly augmented by the influx of drainage waters as the stream proceeds downward.

The nature of the water is frequently changed by the influx of drainage water from a non-injurious carbonated water to a highly saline noxious water.

Some soils are already heavily charged with alkali salts. The waters high in soluble salts must be used with extreme care on such soils.

Waters, such as the Sevier, Price, Emery, etc., must be used with care on all soils to prevent the accumulation within the soil of the alkali salts.

Artificial drainage should be applied to tight soils already charged with alkali before highly saline waters are applied.

Where possible use should be made of the high waters to flush out the soils as these waters are usually fresher than the same stream later in the season. Moreover, some streams may be used with impunity during the early part of the season, while later they become so heavily charged with soluble salts that they are very likely to do damage.

Cultural methods and surface tillage should be practised wherever possible to prevent the concentration of soluble salts

at the surface.

The composition of the well waters range from 24,400 to 120 parts per million. Eleven of these contain more than 40 grains per gallon.

The composition of the springs range from 4800 parts per million with only 10 per cent of the total non-toxic bicarbonates to 150 parts per million with 66 percent of it non-toxic carbonates.

In only two of the reservoirs examined were there excessive quantities of soluble salts. Reservoirs should be filled with the fresher high waters and the drainage and seep waters should be avoided where possible.

Two of the drains examined contained large quantities of soluble salts, but the others did not contain greater quantities than are found in a number of the irrigation waters.

ACKNOWLEDGMENT

The writers wish to express their appreciation to the following for their kind assistance in this work: Prof. L. M. Winsor for valuable information concerning many of the irrigation streams of the state; Prof. William Peterson for the collecting of the samples of well waters; Jacob Free who collected the samples of Santa Clara; Alma Esplin who collected the samples from Parowan, Red Creek, Cedar Creek, and Summit Creek; Prof. L. A. Merrill and William W. Owen for the samples of Sevier River and Clear Creek; H. A. Christensen for the samples of Beaver River and Indian Creek; J. P. Welch for the sample of Sevier River at Delta; Warren S. Tew for the samples of Hobble Creek and Maple Creek; M. L. Harris for Strawberry, Duchcesne, Rock Creek, Lake Fork, Uintah, Ashley, and White River; the Provo Reservoir Company for the sample of Provo River; Preston Thomas for the Weber and Ogden Rivers; Clyde W. Lindsay for samples from Spanish Fork, U. S. Reclamation Service and American Fork; A. R. Hudson for samples of Summit Creek; J. E. Lunt for samples from Salt Creek; H. J. Webb for samples of Little and Big Cottonwood, Parley's Creek, Emigration Creek, Jordan Pumping Station, and Mill Creek; Wallace Sullivan and R. Stewart for samples from Green River, Price River, Huntington Creek, Cottonwood, Ferron and Emery; also to Yeppa Lund, H. P. Anderson, and H. C. Goldthorpe for assistance in the analytical work.