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THE WATERS OF THE RIO GRANDE

A Contribution to the Hydrology of the San Luis Valley, Colorado

By

WM. P. HEADDEN

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THE WATERS OF THE RIO GRANDE

By WM. P. HEADDEN

In Bulletin No. 82 of this station, "Colorado Irrigation Waters and Their Changes", I dealt with the waters of the eastern slope, treating those of the Poudre Valley in greater detail than the rest, for four reasons, the principal one being that irrigation has been practiced on a larger scale in this valley than in any other section of the State. Irrigation was practiced on a small scale in the San Luis Valley by the Mexicans earlier than by the settlers of the Poudre Valley, but this practice was by no means so extended as it has been in the Poudre Valley, from the time of its introduction.

The second reason for confining our study largely to the waters used in the Poudre Valley was the fact that we are situated within this territory and all parts of it; the streams, ditches and reservoirs, are easily accessible at all times. These reasons were formulated in the bulletin referred to as follows: "The considerations which have led me to confine myself to the study of the Poudre River water to so great an extent as I have done, are evident. First, the water of the Poudre irrigates, at the present time, as much if not more land than that of any other stream in the State. Second, it flows through our home valley, is easy of access, and we have fuller data and more intimate knowledge of it than of any other stream in the State. Third, irrigation has been practiced in this valley as long as in any other part of the State (a few sections where irrigation was practiced by the Mexicans expected), extending over a period of 43 years. Fourth, the oldest, and at the same time an extensive system of reservoirs, whose beginning dates back to 1875, has been made to supplement the summer flow of the river.

"Under these conditions the flow of the return waters has already been established, the first exaggerated effects of irrigating this land have passed away and the rate at which the return waters are carrying the soluble salts from the soil has presumably approached, if it has not already reached, the point at which it will remain for years to come. The same may be assumed to be true in regard to the character of the salts taken into solution.

"In this section, the period of drainage has begun, land having become valuable enough and water in such demand that drainage has already been instituted for the double purpose of preventing the land from being waterlogged or seeped, and for rendering the water available for irrigating other land."

CHANGES IN WATERS OF EASTERN SLOPE

These paragraphs were written thirteen years ago and are as applicable now as then. The work done preparatory to the publication of Bulletin No. 82 made the changes which take place in the amount and character of the mineral constituents, held in solution by these waters upon their entrance into that part of their course which lies outside of the mountains very definite and showed that these changes were radical. The total solids increased from 2.9 and 2.6 grains per imperial gallon in samples taken within the mountain section of its course, to 114.5 grains in a sample taken perhaps thirty miles further down its course. The composition of the mass of salts had changed to even a greater degree than the amount of them held in solution. The reader may judge for himself how radical these changes are from the following statements of analytical results given in grains per imperial gallon:*

ANALYSES OF CACHE LA POUDRE WATER

I		II	
Taken within the mountains		Taken about thirty miles out from the mountains	
Salts	Grains per imperial gal.	Salts	Grains per imperial gal.
Calcic sulfate	0.3417	Calcic sulfate	46.013
Calcic carbonate	0.7186	Magnesic sulfate	36.406
Magnesic carbonate	0.2628	Potassic sulfate	0.719
Sodic chlorid	0.1711	Sodic sulfate	6.059
Potassic carbonate	0.1254	Sodic chlorid	4.565
Sodic carbonate	0.2652	Sodic carbonate	14.337
Sodic silicate	0.2544	Sodic silicate	2.099
Ferric and Al. oxid	0.0113	Ferric and Al. oxids	0.079
Manganic oxid	0.0018	Manganic oxid	Trace
Excess silicic acid	0.0798	Excess sodic oxid	0.096
Ignition	(0.2678)	Ignition	4.191
Total	2.8999	Total	114.504

SANITARY ANALYSES

Salts	Taken within the mountains — Parts per Million	Taken about thirty miles out from the mountains — Parts per Million
Tota solids	41.4286	1,635.710
Chlorin	1.9804	36.630
Nitrogen as nitrates	Trace	0.400
Nitrogen as nitrites	None	0.022
Saline ammonia	0.0350	0.060
Albuminoidal ammonia	0.0900	0.160
Oxygen consumed	2.550	1.160

The total solids contained in this water had been increased approximately forty times, though it had reached a point only about 30 miles beyond the mountains. The carbonates which predominated in the mountain water have disappeared, with the exception of sodic

*I retain this old form of statement because I believe it to be, all things considered, more easily apprehended by the general reader than other forms often used. The imperial gallon, being an even ten pounds, is a convenient measure and the hypothetical compounds are, for the most part, familiar, at least by name, to the general reader. The scientific man will have no difficulty in accommodating himself to this mode of statement, even though he is accustomed to the really more simple and scientific ionic statement.

carbonate, and in their place we find sulfates, with a very great increase in the amount of the bases present in this form. The total sodium present in various forms also has been increased very greatly.

The water of the Cache la Poudre is typical of all of our mountain streams in its composition and the changes in its composition due to its use in irrigating our lands are typical of those produced in the waters of other streams when used for this purpose. These changes have been studied for the Arkansas and the results justify the statement just made. The results obtained were:

ANALYSES OF ARKANSAS RIVER WATER

I
Taken at Canon City

Salts	Grains per imperial gallon
Calcic sulfate	2.037
Calcic carbonate	3.733
Magnesic carbonate...	1.856
Potassic sulfate	0.138
Sodic chlorid	0.659
Sodic carbonate	0.573
Sodic silicate	1.280
Ferric & Alum. oxids..	0.023
Manganic oxid (br)....	0.011
Excess Silicic acid.....	0.216
Ignition	0.273
Total	10.799

II
Taken about 120 miles below Canon City

Salts	Grains per imperial gallon
Calcic sulfate	64.942
Magnesic sulfate	27.994
Potassic sulfate	0.942
Sodic sulfate	32.449
Sodic chlorid	12.044
Sodic carbonate	7.007
Sodic silicate	1.358
Excess sodic oxid	3.832
Ignition	6.797
Total	157.363

SANITARY ANALYSIS

	Parts per million
Total solids	2,234.290
Chlorin	103.971
Nitrogen as nitrates	1.500
Nitrogen as nitrites	0.040
Saline ammonia	0.065
Albuminoidal ammonia	0.140
Oxygen consumed	2.000

This sample of Arkansas River water was taken at Canon City, a little way below the Royal Gorge, and while it carries more salts in solution than the Poudre water, it remains in its essential features a mountain water. This is more remarkable than the fact that it carries nearly four times as much solid matter in solution as the Poudre water, for the course of the Poudre River, up to the point where the sample was taken, is wholly within a granitic area, with but little meadow land along its borders and with an exceedingly sparse population.

The Arkansas at Canon City has already traversed a long course, some of the way through meadow lands. It received during a portion of the year the sluicings from placer workings and its drainage area includes the towns of Leadville, Buena Vista and Salida. The conditions, however, have not been such as to materially change the character of the water. The sample of water taken about 120 miles further down the stream, was wholly return water, namely, irrigating water that had been applied to the land and had found its way back into the river's course. At the time that this sample was taken, no river water was flowing past Rocky Ford, the point at which the sample was taken, for all of the river water had been diverted into the various irrigating canals or ditches. The differences shown in the two cases, those of the Poudre and Arkansas river waters, are wholly quantative; the changes shown are identical in kind.

The waters of the South Platte have been studied but to a less extent than those of the other streams. The conditions obtaining in this case are somewhat different from those obtaining in the cases of the Poudre and Arkansas. Still, the results obtained agree in showing that the changes produced in the character of the solids held in solution are the same as in the cases previously given.

These changes are thorough-going; in the mountain waters we have the carbonates of lime, magnesia and soda predominating, while in the return waters we have these changed to sulfates and the quantity of these salts very greatly increased—ten times in the case of the Arkansas and forty times in the case of the Poudre water.

These general statements evidently hold for the Laramie, for its waters are partly diverted into the Poudre without perceptible modification of the results. They will probably hold for all of the streams of our arid regions where the conditions are similar to those obtaining in these cases; but it is not safe to assert that they will hold for all of our streams.

CONDITIONS IN SAN LUIS VALLEY EXCEPTIONAL

We recognize, on examining the water conditions of the San Luis Valley, that they are exceptional. While the big features of the case may be very simple, there are others which are not, and the problem becomes, taken in its entirety, far more difficult to explain satisfactorily than those of the eastern slope, where our problems of natural drainage and return waters are quite simple, and the changes in the waters of our streams are really such as should be produced by the waters entering them after flowing through adjacent higher-lying lands whether under cultivation or not.

The Rio Grande enters the San Luis valley a little north of the middle of the west side and flows southeasterly and south to the state line. We shall consider it only as far as the State Bridge, a distance of about 60 miles.

BED OF RIVER HIGHER THAN VALLEY

The river has built up its bed till it is higher than the valley. It does not matter to us when or how this has been done; the important fact is, that the present bed is higher than the adjacent territory. Under such condtions it may seem a perfectly simple matter that a river flowing over a pervious bottom should lose a considerable portion of its water and that none could flow into it, if these conditions prevail in all sections of its course. The annual discharge of the Rio Grande at the State Bridge, is about two-thirds of its discharge at Del Norte; or, in flowing about 60 miles, it loses one-third of its annual flow. There is no other visible outlet for the waters of the valley. The discharge at Embudo in New Mexico, however, is much greater than at the State Bridge, though the river receives no considerable visible streams in the intervening section. This last statement is made to avoid the plainly legitimate inference from the preceding statement that the valley is being filled with water by the Rio Grande. While the facts to be presented may appear at times to approach very near to this problem, it remains entirely beyond our purpose to discuss it. As stated, our problem would seem very simple, if its solution depended wholly upon the Rio Grande waters, which flow over a pervious bed higher than the surrounding country. Such waters should flow, as they actually do, for about 60 miles, over such a bed with small, almost insignificant changes in their composition.

In the beginning of this work we proposed to treat it as an extension of the work presented in Bulletin 82. This included ground and return-waters and had been preceded by a presentation of the composition of the soil, its water-soluble portion and of the ground-waters. While the water-soluble portion of the soil is not necessarily identical with our alkalis, it is so closely related to them that it seems useless to insist on the difference. While I disclaim any intention to discuss the water-supply questions of the valley and its drainage, the smaller questions suggested above cannot be avoided. It is true that these questions are subordinate to the geological question of the drainage of the valley, but they involve the questions pertaining to the river and well waters used for irrigation, the ground waters and the alkalis.

The waters used for irrigation in the San Luis Valley are, as in the Poudre Valley, essentially mountain waters, and I shall take the Rio Grande waters as typical of them, but I have no proper return-waters to present, and but few ground-waters.

The Rio Grande has no tributary entering it from the north, though the valley receives the waters from a very large mountain area at this end. I am credibly informed that the water flowing into the valley north of the Rio Grande aggregates 2,000 second-feet for several months during the year and a very considerable amount at all times. There is no doubt in regard to the source of the artesian waters found throughout a large portion of the valley. It is assumed to be from the streams flowing from the mountains, mostly from the north and west, and also from the east, but in a smaller measure. This artesian water has received attention from several writers as a supply for irrigation. I have made some inquiry and have failed to learn of its application for this purpose. It furnishes an excellent water supply for stock and perhaps for irrigating some small areas but I have no definite information of such excepting lawns. The ranches depend upon the ditches for their irrigating water. The Rio Grande, Conejos, and some other streams furnish the ditch water but of these the Rio Grande is by far the most important.

ANALYSES OF RIO GRANDE WATERS

The course of the Rio Grande extends many miles into the mountains west of the San Luis Valley. We did not go up the river further than just above the mouth of Willow Creek near the town of Creede. We took samples of the water from here down to the State Bridge. We present the analytical results in the order in which the samples were taken beginning just above the mouth of Willow Creek and going down the stream. This will present such changes as we found in their natural order.

SAMPLES TAKEN ABOVE MOUTH OF WILLOW CREEK

Analytical Results	Percent
Carbon	1.685*
Silicic acid	43.395
Sulfuric acid	6.096
Carbonic acid	13.352
Phosphoric acid	0.229
Chlorin	0.907
Calcic oxid	19.845
Magnesic oxid	3.791
Potassic oxid	2.886
Sodic oxid	6.759
Ferric oxid	0.610
Manganic oxid (br)	0.657
Sum	100.212
Oxygen equivalent to Chlorin	0.212
Total	100.000

Combined	Grains per Gal.
Carbon	0.090
Calcic Sulfate	0.553
Calcic Carbonate	1.497
Magnesic Chlorid	0.066
Magnesic Carbonate	0.148
Magnesic Phosphate	0.019
Magnesic silicate	0.283
Potassic Silicate	0.255
Sodic Silicate	0.542
Ferric oxid	0.035
Manganic oxid	0.032
Excess Silicic acid	1.899
Total	5.420

The total solids in this water was 5.39 grains per imperial gallon. Loss on ignition 1.2 grains.

*The carbon was separated during the drying necessary to render the residue anhydrous and is given as such in the analysis. Of course, it was present as organic matter which could not be burned out of such a mixture without altering its composition and yet this organic matter rendered the solution very difficult to work if not destroyed.

Sanitary Analysis

	Parts per Million
Total solids	77.0000000
Chlorin	.0001400
Nitrogen as nitrates	None
Nitrogen as nitrites	.0000700
Saline ammonia	.0000014
Albuminoidal ammonia	.0000021

SAMPLE TAKEN AT DEL NORTE

Analytical Results

	Percent
Carbon	3.032
Silicic acid	32.102
Sulfuric acid	7.870
Carbonic acid	14.710
Chlorin	1.514
Calcic oxid	19.350
Magnesic oxid	3.428
Potassic oxid	2.893
Sodic oxid	8.481
Ferric oxid	0.721
Aluminic oxid	0.399
Manganic oxid (br)	0.120
Ignition	(5.722)
Sum	100.342
Oxygen equivalent to Chlorin	342
Total	100.000

Combined

	Grains per Imp. Gal.
Calcic Sulfate	0.7753
Calcic Carbonate	1.4301
Magnesic Carbonate	0.4105
Sodic Carbonate	0.0166
Sodic Chlorid	0.1447
Sodic Silicate	0.7798
Potassic Silicate	0.2749
Ferric oxid	0.0412
Aluminic oxid	0.0231
Manganic oxid	0.0069
Carbon	0.1716
Excess Silicic acid	1.3767
Total	5.4559

Total solids in the water 5.46 grains per imp. gal.; loss on ignition 1.26 grains. The loss on ignition probably includes a large part, if not all, of the carbonic acid, owing to the action of free silicic acid.

SAMPLE TAKEN AT MONTE VISTA

Analytical results	Percent
Carbon	2.227
Silicic acid	31.372
Sulfuric acid	7.570
Carbonic acid	16.120
Phosphoric acid	Trace
Chlorin	1.541
Calcic oxid	20.700
Magnesic oxid	3.484
Potassic oxid	2.876
Sodic oxid	8.783
Ferric oxid	0.574
Aluminic oxid	0.251
Manganic oxid (br)	0.088
Ignition	(4.761)
Sum	100.348
Oxygen equivalent to chlorin	0.348
Total	100.000

Combined*	Grains per Imp. Gal.
Calcic Sulfate	0.7954
Calcic Carbonate	1.6953
Magnesic Carbonate	0.4498
Sodic Carbonate	0.0366
Sodic Chlorid	0.1570
Sodic Silicate	0.8439
Potassic silicate	0.2914
Ferric oxid	0.0355
Aluminic oxid	0.0155
Manganic oxid (br)	0.0054
Carbon	0.1375
Excess Silicic acid	1.4178
Total	5.8811

Total solids 5.88 grains per imperial gallon. Loss on ignition 1.68 grains. nil.

SAMPLES TAKEN AT ALAMOSA 30 SEPT., 1908

Analytical results	Percent
Silicic acid	28.312
Sulfuric acid	8.837
Carbonic acid	16.386
Chlorin	2.053
Calcic oxid	21.797
Magnesic oxid	3.978
Potassic oxid	2.747
Sodic oxid	9.709
Ferric oxid	0.559
Aluminic oxid	0.583
Manganic oxid (br)	0.098
Ignition	(5.404)
Sum	100.463
Oxygen equivalent to Chlorin	0.463
Total	100.000

Combined	Grains per Imp. Gal.
Calcic Sulfate	1.4277
Calcic Carbonate	2.1450
Magnesic Carbonate	0.7136
Potassic Carbonate	0.2871
Potassic Chlorid	0.0635
Sodic Chlorid	0.2409
Sodic Silicate	1.3917
Ferric oxid	0.0480
Aluminic oxid	0.0500
Manganic oxid (br)	0.0084
Excess Silicic acid	1.7441
Total	8.1000

Total solids 8.12 grains per imperial gallon. Loss on ignition 1.68 grains.

SANITARY ANALYSIS

	Parts per Million
Total solids	101.71428
Loss on ignition	24.00000
Chlorin	2.00000
Nitrogen as nitrates	0.00030
Saline Ammonia	0.01200
Nitrogen as nitrites	0.03000

*In this and the preceding analysis the loss on ignition is not included in the statement of grains per gallon because all of the errors are thrown into this factor and its influence upon the statement of the analysis is practically

SAMPLES TAKEN AT STEWART'S PLACE 6 OCT., 1908

Analytical results	Percent	Combined	Grains per Imp. Gal.
Silicic acid	23.392		
Sulfuric acid	10.222	Calcic Sulfate	1.5860
Carbonic acid	16.289	Calcic Carbonate	2.8244
Phosphoric acid	Trace	Magnesic Carbonate	0.3761
Calcic oxid	24.644	Potassic Carbonate	0.1337
Magnesic oxid	1.949	Potassic Chlorid	0.2227
Potassic oxid	2.553	Sodic Chlorid	0.1815
Sodic oxid	10.239	Sodic Silicate	1.6454
Ferric oxid	0.686	Ferric oxid	0.0620
Aluminic oxid	0.475	Aluminic oxid	0.0432
Manganic oxid (br)	0.111	Manganic oxid (br)	0.0101
Ignition	(7.569)	Excess Silicic acid	1.3145
Sum	100.536	Total	8.3996
Oxygen equivalent to Chlorin	0.536		
Total	100.000		

Total solids 8.4 grains per imperial gallon. Loss on ignition 2.24 grains.

SAMPLE TAKEN AT STATE BRIDGE 10 OCT., 1908

Analytical results	Percent	Combined	Grains per Imp. Gal.
Silicic acid	22.568		
Sulfuric acid	11.674	Calcic Sulfate	1.8700
Carbonic acid	17.193	Calcic Carbonate	2.3570
Phosphoric acid	Trace	Magnesic Carbonate	0.8747
Chlorin	2.228	Potassic Carbonate	0.3840
Calcic oxid	22.204	Sodic Carbonate	0.0114
Magnesic oxid	4.444	Sodic Chlorid	0.3463
Potassic oxid	2.780	Sodic Silicate	1.6092
Sodic oxid	10.685	Ferric oxid	0.0486
Ferric oxid	0.517	Aluminic oxid	0.0520
Aluminic oxid	0.552	Manganic oxid (br)	0.0048
Manganic oxid (br)	0.049	Excess Silicic acid	1.3320
Ignition	(5.608)		
		Total	8.8900
Sum	100.502		
Oxygen equivalent to Chlorin	0.502		
Total	100.000		

Total solids 8.89 grains per imperial gallon. Loss on ignition 2.38 grains.

SANITARY ANALYSIS

	Parts per Million
Total solids	127.000000
Chlorin	0.000315
Nitrogen as nitrates	None
Nitrogen as nitrites	None
Saline Ammonia	None
Albuminoidal Ammonia	0.0000014

The distance between the points where the first and last of these Rio Grande waters were taken is not far from 100 miles, probably more than 60 of these are within the valley proper. The total solids increased only from 5.4 to 8.9 grains per imperial gallon though farms and pastured meadows border a large portion of its course and the three towns of Del Norte, Monte Vista and Alamosa are located on its banks. In addition to these factors, which usually cause radical changes in the character of our river waters, the Rio Grande may receive waters from the Alamosa, La Jara, Conejos and other streams. I cannot state from what streams the river received water at the time the sample was taken at the State Bridge. There was some water flowing into the Rio Grande from the Conejos but how much I do not know, neither do I know whether this flow was continuous or only accidental.

ANALYSES SEEM TO INDICATE THAT NO RETURN WATER FLOWS INTO RIVER

The analyses of the six samples taken at different points in the river, the extreme points being about 100 miles apart, show no differences in the character of the total solids held in solution and no differences in the quantity of solids held in solution that might not be accounted for by evaporation. These results are wholly different from those obtained in our study of the Poudre, the Arkansas and other streams. These results are, however, in harmony with the inferences to be drawn from the topography of the valley, i. e., from the fact that the bed of the river is higher than the valley and further that the volume of the flow is decidedly less as we go down the river, at least, as far as the State Bridge. At this point the flow of the river during the months of August, September and October is usually very small, in fact, is never large, except during the months of flood, which are May and June, and, exceptionally, a part of July. The range of the flow for the other months of the year, given for the eight years of which I find records, is from 17 second feet in August, 1902, to 196 second feet in September, 1904. The usual flow is considerably under 75 second feet. The flow at Del Norte for the same months and years was 152 second feet in August, 1902, and 689 second feet in September, 1904.* The irrigating canals take out, at times, nearly all of the water by the time it passes a little way beyond Monte Vista.

If any volume of return waters finds its way into the river, it would follow from our results, that these waters have the same characteristics and composition as the river water before it is used for irrigating the land or while it is still within the mountain section of its course. This is very improbable, or, judging from our knowledge of the changes which take place in the waters of other streams, impossible.

*These data are taken from U. S. Geo. Survey Water Supply Paper No. 240. C. E. Siebenthal.

The nature of the land irrigated with the water taken from the Rio Grande, as it abounds in alkali salts, practically precludes the possibility that return waters should have the composition of that applied as irrigating water. There are, it is true, two classes of water which might be considered as furnishing an increase in the flow of the river, i. e., waters previously used for irrigation, yielding what we usually understand as return waters, and artesian waters. The latter class of waters occur throughout the greater part of the cultivated portion of the valley. I am informed that, up to the present time, some 5,500 artesian wells have been sunk in the valley. The fact that some of these wells are not flowing at the surface does not necessarily preclude their discharge of water into the valley in such a way as to affect the water problems of the soil and the river. The great majority of these wells are, however, flowing freely and but few of them are cased for more than a few feet, leaving the waters entirely free to fill up any strata not already full and to affect in this way the general water problems of the valley.

While our problem clearly contains these factors, we assume that the waters, the river being for the most part actually higher than the neighboring portions of the valley, retain their character because there is actually no admixture of other waters. This assumes that the Rio Grande actually fails to drain the valley. I believe that this assumption is essentially correct and consider the results obtained in the analyses of the water as positively indicating this condition.

There are two classes of artesian waters, white and brown. If the former class should find their way into the river through strata of sand, or as springs, they would not affect the character of the river water. The flow of the river might be increased in this way and the character of the water not changed any more than we find indicated by our analyses, namely, a slight increase in the quantity of the solids held in solution without any essential change in their character. In making this statement I am not forgetful of the fact that the increase in the amount of solids contained in the water may be accounted for by evaporation. It must be remembered that the increase found is only 3.5 grains per imperial gallon in samples taken at points in the river 100 miles apart. While we shall neglect the effects of evaporation it is evident that it may be an important factor.

Prof. L. G. Carpenter gives, in a bulletin not yet issued, the results of river gaugings in August, 1898, which show a total gain between the U. S. Gauging Station above Del Norte and the State Bridge, of 15.75 ft.; in 1900, a total gain of 63.06 ft.; in 1901, a total loss of 11.01 ft.; in 1902, a total loss of 37.7 ft.; and in 1910, a total gain of 46.19 ft. Our samples of river water were taken in 1908 for which year we unfortunately have no gaugings so we do not know whether the flow would have shown a gain or loss between the U. S. Gauging Station and the State Bridge.

THE GROUND-WATER AND ALKALIS SOUTH AND WEST OF THE RIVER

The statement has been made that no return waters could be finding their way into the river, and the reason assigned was that, owing to the character of the soil and the prevalence of alkali, such waters would change the composition of the river water. We have, in fact, no return waters by whose composition we can definitely demonstrate that this is the case—the best that we can do is to present some ground- and drain-waters.

The use of these, unfortunately, needs an explanation as to why they are of limited and not of general application to the whole valley. Any samples taken to the south and west of the river would be applicable to this portion of the valley but samples taken north of the river and in the eastern part of the valley, about Hooper for instance, would not apply to that portion of the valley south and west of the river, though both sections abound in alkalis.

There are two classes of artesian wells in the valley which are commonly designated as white and brown waters. The former waters are colorless and of excellent quality, the latter are of various shades of brown. Analyses of these waters will be given subsequently, but it may be stated here that these brown waters differ in composition from the white waters in carrying considerable quantities of sodic carbonate which forms, in the deeper strata, a solution of humus, imparting the brown color to the waters. These brown waters are confined to the northern and eastern part of the valley. I may anticipate a little by stating that the color of the water is determined by the humus obtained from the strata underlying this section of the valley and in this case may be taken as definite proof of the presence of sodic carbonate, but the converse of this, that a colorless water is free from sodic carbonate, is not necessarily true.

Our statement is practically this, that no ground or return waters are finding their way into the Rio Grande during its flow through the valley, because the composition of its waters retains the characteristics which it possesses on entering the valley, those of a mountain water, i. e., such as contain carbonates as the essential salts in solution with subordinate quantities of sulfates and chlorids with an excess of silicic acid. The character of the ground and drainage waters will undoubtedly vary somewhat from place to place, but their general character will persist just as the character of mountain waters persists. In the ground waters the sulfates and chlorids become predominant, the carbonates of the alkaline earths and the silicates recede or disappear while the carbonate of soda is usually present in small quantities.

The following sample of ground-water was taken from SE.¼ sec. 23, T. 38 N., R. 8 E. and less than 400 feet from a drainage ditch which had been opened for 21 months at the time the sample was taken. The land had never been cultivated, cleared or in any way improved, The water was encountered at 3′ 11″ in stratum of sand. Beneath this was a clay mixed with large quantities of calcic sulfate and carbonate. I do not know whether the neighboring drainage ditch had lowered the level of the ground water or not. This water did not come from the irrigation of land in the immediate neighborhood. I consider it as representing the permanent ground water of this locality.

ANALYSIS OF GROUND-WATER
SE. ¼ sec. 23, T. 38 N., R. 8 E.

Analytical results	Percent	Combined	Percent
Silicic acid	6.303	Calcic sulfate	55.647
Sulfuric acid	32.720	Calcic carbonate	15.081
Carbonic acid	6.931	Magnesic carbonate	0.577
Chlorin	8.795	Magnesic chlorid	11.809
Calcic oxid	31.378	Magnesic silicate	3.233
Magnesic oxid	6.870	Potassic silicate	0.377
Potassic oxid	0.230	Sodic silicate	8.441
Sodic oxid	4.279	Ferric and Alum. oxids.	0.075
Ferric and Alum. oxids.	0.075	Excess Silicic acid	0.056
Ignition	(4.704)	Ignition	(4.704)
Sum	101.985	Total	100.000
Oxygen equivalent to Chlorin	1.985		
Total	100.000		

Total solids 98.9 grains per imperial gallon. Loss on ignition 16.9 grains.

The drainage ditch referred to in connection with the preceding ground-water was upwards of 4 miles long at this time and was being extended. The discharge was given to me as varying from 4 to 10 second feet. At this time it was carrying the smaller amount, about 4 second feet. There was probably no admixture of run-off water in the ditch at this time, so we may take the results obtained in the analyses of this drain-water as representing the ground-water in the land above the point at which the sample was taken, probably a mile and a half below the then upper end of the ditch.

ANALYSIS OF DRAINAGE-WATER
Parma Land Company Ditch

Analytical results

	Percent
Carbon	3.102
Silicic acid	8.105
Sulfuric acid	28.863
Carbonic acid	8.536
Chlorin	9.561
Calcic oxid	23.495
Magnesic oxid	3.184
Potassic oxid	0.072
Sodic oxid	14.560
Ferric and Alum. oxids.	0.098
Manganic oxid	0.089
Ignition	(2.493)
Sum	102.158
Oxygen equivalent to Chlorin	2.158
Total	100.000

Combined

Carbon	3.102
Calcic sulfate	49.087
Calcic carbonate	5.835
Magnesic carbonate	6.655
Potassic carbonate	0.106
Sodic carbonate	5.946
Sodic chlorid	15.778
Sodic silicate	5.338
Ferric and Alum. oxids.	0.089
Excess silicic acid	5.473
Ignition	(2.493)
Total	100.000

The remoteness of the relation between the alkalis or in the surface portions of the land and the salts removed by the drainage-waters is made evident by the analyses of the alkalis from the land through which this drain, or its laterals, run.

This sample of alkali was taken a few feet from a lateral open drain emptying into the main ditch a few hundred feet south of this point.

ANALYSIS OF ALKALI
Sample taken just inside Parma Land Company's Gate

	Percent
Silicic acid	0.065
Calcic sulfate	8.135
Magnesic sulfate	6.209
Sodic sulfate	61.473
Sodic chlorid	20.974
Organic matter	3.144
Sum	100.000

ALKALI NE.¼ SEC 14, T. 38 N., R. 8 E. PARMA LAND CO.

Analytical Results	Percent	Combined	Percent
Silicic acid	0.345	Calcic sulfate	10.347
Sulfuric acid	45.463	Magnesic sulfate	2.121
Carbonic acid	Trace	Potassic sulfate	10.314
Chlorin	8.352	Sodic sulfate	59.010
Calcic oxid	4.263	Sodic chlorid	13.782
Magnesic oxid	0.710	Sodic silicate	0.681
Potassic oxid	5.578	Excess Sodic oxid	0.586
Sodic oxid	34.015	Ignition	(3.159)
Ignition	(3.159)	Total	100.000
Sum	101.885		
Oxygen equivalent to Chlorin	1.885		
Total	100.000		

The crust on the soil was very thin. The soluble portion of the sample as taken was 5.88 percent.

The next sample was taken from the same section as the preceding but at a subsequent time. The sample was prepared by the manager, Mr. W. H. Sommers.

ALKALI—SAME LOCALITY AS PRECEDING

Analytical results	Percent	Combined	Percent
Silicic acid	1.232	Calcic sulfate	4.040
Sulfuric acid	43.665	Magnesic sulfate	2.242
Chlorin	9.667	Potassic sulfate	8.015
Calcic oxid	1.667	Sodic sulfate	64.143
Magnesic oxid	0.751	Sodic chlorid	15.593
Potassic oxid	4.336	Sodic silicate	2.431
Sodic oxid	39.563	Ferric and Alum. oxids.	0.176
Ferric and Alum. oxids.	0.176	Excess sodic oxid	1.875
Ignition	(1.125)	Ignition	(1.125)
Sum	102.182	Total	100.000
Oxygen equivalent to Chlorin	2.182		
Total	100.000		

The next alkali was collected from the bank of the drainage-ditch of the Parma Land Company. Incrustation as taken varied from 1 inch to 2 inches in thickness. The water-soluble portion of the sample equalled 27.7 percent.

ALKALI—DRAINAGE DITCH, PARMA

Analytical results	Percent	Combined	Percent
Silicic acid	0.922	Calcic sulfate	1.456
Sulfuric acid	52.779	Magnesic sulfate	0.326
Carbonic acid	0.540	Potassic sulfate	1.442
Chlorin	0.815	Sodic sulfate	90.639
Calcic oxid	0.600	Sodic carbonate	1.302
Magnesic oxid	0.109	Sodic chlorid	1.345
Potassic oxid	0.780	Sodic silicate	0.869
Sodic oxid	41.522	Ferric and Alum. oxids	0.160
Ferric and Alum. oxids	0.160	Manganic oxid	0.030
Manganic oxid	0.030	Excess Silicic acid	0.504
Ignition	(1.927)	Ignition	(1.927)
Sum	100.184	Total	100.000
Oxygen equivalent to Chlorin	.184		
Total	100.000		

ALKALI

(This sample was taken because we took a sample of ground-water at the same place, SE. ¼ sec. 23 T. 38 N., R. 8 E. The incrustation as gathered yielded 7.4 prcent of its weight to water.)

Analytical results	Percent	Combined	Percent
Silicic acid	1.044	Calcic sulfate	0.874
Sulfuric acid	46.816	Magnesic sulfate	0.033
Carbonic acid	1.440	Potassic sulfate	3.217
Chlorin	4.468	Sodic sulfate	79.557
Calcic oxid	0.360	Sodic carbonate	3.472
Magnesic oxid	0.011	Sodic chlorid	7.373
Potassic oxid	1.740	Sodic silicate	0.748
Sodic oxid	41.087	Ferric and Alum. oxids	0.130
Ferric and Alum. oxids	0.130	Excess Silicic acid	0.684
Ignition	(3.912)	Ignition	(3.912)
Sum	101.008	Total	100.000
Oxygen equivalent to Chlorin	1.008		
Total	100.000		

A sample of the soil and subsoil was also taken at this place. The series of analyses thus presents as complete a set of analytical data as we can present from the chemical standpoint.

ANALYSES OF THE SOIL SAMPLES DRIED AT 100° C.

	Soil 7 inches deep	Subsoil Sample 10 inches
	Percent	Percent
Insoluble (sand)	56.271	51.285
Soluble silicic acid	17.531	11.662
Sulfuric acid	0.255	0.128
Phosphoric acid	0.651	0.019
Carbonic acid	3.956	10.207
Chlorin	0.462	0.184
Calcic oxid	6.900	14.318
Magnesic oxid	1.618	1.444
Potassic oxid	1.047	1.183
Sodic oxid	1.464	0.679
Ferric oxid	4.420	3.567
Aluminic oxid	3.382	2.868
Manganic oxid	0.192	0.161
Ignition	1.867	3.085
Sum	100.017	100.790
Oxygen equivalent to chlorin	0.104	0.042
Total	99.913	100.748
Total Nitrogen	0.071	0.050

These analyses show that the soda salts were very largely in the top 7 inches of soil and that the calcium carbonate probably was concentrated below the surface soil which was, at this place, 7 inches deep. Our marls sometimes contain calcium as a silicate. This may, by giving rise to soluble double silicates, account for the high silicic acid in some of the alkalis.

The preceding samples of alkali were all taken in the latter part of the summer, mostly in the month of August. This is a season when the general prevalence of alkali is not apparent as in mid or late spring, especially after light snows or rains. At this time we sometimes find areas of several square miles in a body white with these alkalis.

The following sample was taken on 8 May, 1916, in the same general section of country in which the preceding samples were taken. This land has never been cultivated, so I doubt whether it has ever been irrigated. The principal vegetation is chico and greasewood (*Sarcobatus and Bigelovia*). The surface of the ground at this time was perfectly white over an area of many, probably 15 or 20 square miles.

ALKALI FROM UNCULTIVATED LAND

Sample taken from near Parma. The portion soluble in water equalled 27.55 percent

Analytical results

	Percent
Carbon	0.070
Silicic acid	0.165
Sulfuric acid	54.222
Carbonic acid	0.358
Phosphoric acid	0.152
Chlorin	0.632
Calcic oxid	1.431
Magnesic oxid	0.155
Potassic oxid	0.352
Sodic oxid	41.506
Ferric and Alum. oxids.	0.001
Manganic oxid	0.338
Ignition	(0.761)
Sum	100.143
Oxygen equivalent to chlorin	.143
Total	100.000

Combined

	Percent
Carbon	0.070
Calcic sulfate	3.474
Magnesic sulfate	0.462
Potassic sulfate	0.652
Sodic sulfate	91.507
Sodic carbonate	0.863
Sodic phosphate	0.352
Sodic chlorid	1.043
Sodic silicate	0.334
Ferric and Alum. oxids.	0.001
Manganic oxid (br)	0.338
Excess sodic oxid	0.143
Ignition	(0.761)
Total	100.000

It is not safe to assume that the alkali covering this large area was identical in the details of its composition, but it is safe to assume that this analysis represents the general character of all of the alkali in this area, and even further, that this is the general type of alkali occurring in this whole section of the valley. We have other analyses that support this statement, but I consider it needless to indicate how general this type of alkali is. I took a sample of alkali within the limits of the town of Alamosa which on analysis proved to consist of upwards of 96.0 percent of sodic sulfate. This alkali occurred very abundantly at the point where it was collected and the following note entered at the time the sample was collected may be of some interest:

"The lot adjoining the one from which this sample was collected. was improved and the house occupied. The lawn (blue grass) was excellent, and the garden in fine condition. Corn, beets, peas, cabbage, carrots and potatoes were growing thriftily."

Another sample of alkali collected near La Jara some 16 miles south of the Alamosa sample, contained 25.5 percent of water-soluble of which 91.0 percent was sodic sulfate. Two samples of soil were taken with this last sample. One of them represented the top 2 inches of soil of a cultivated field; the other one represented the succeeding 4 inches. The following partial statement will suffice for our purpose:

WATER-SOLUBLE IN TWO SAMPLES OF SOIL FROM LA JARA

Top 2 inches	Percent	Succeeding 4 inches	Percent
Water-soluble	3.05	Water-soluble	1.50
Calcic sulfate	12.76	Calcic sulfate	30.17
Magnesic sulfate	2.30	Magnesic sulfate	4.44
Sodic sulfate	65.21	Sodic sulfate	46.12
Potassic sulfate	0.736	Potassic sulfate	7.29

This land was occupied by a crop of peas at the time the samples were taken. The stand was irregular but the peas were, in the main, fairly thrifty.

NO RETURN WATERS FROM SOUTH AND WEST

I have presented the composition of the drainage, the ground-waters, the alkalis and the soil extracts of a section of the valley lying south and west of the Rio Grande to a sufficient extent and in sufficient detail to support the statement made, that return waters from this section cannot, in any considerable quantity, find their way into the Rio Grande. The flow of the river is so small (as low as 17 second-feet at times), while the maximum found at the State Bridge in 7 years' observation, was only 150 second-feet for the month of August, that the ground-water would change wholly the character of the river-water, which is contrary to what we found in 1908. Further, the gaugings carried out under the direction of Prof. Carpenter, show a loss about as often as they show a gain.

This last observation would seem just as applicable to the area north and east of the river as to that south and west of it. The conditions north and east of the river are not the same as those obtaining south and west of it. If the surface conditions ever were the same, which I am inclined to think was the case, at least in the main, in the early nineties, say 1894, they are no longer so.

The character and importance of the results that have followed justify a more complete presentation of the facts than I shall be able to give. Nevertheless, we can present the big features of these facts just as we have done for the section already discussed.

CONDITIONS NORTH AND EAST OF THE RIVER

I will digress to justify in a measure the acknowledgement of insufficiency contained in the last sentences which, however, will come to light again and again in the following pages. In the first place, the area of the valley mentioned here does not lie wholly within Colorado, and is credited with a total area of 900 square miles. The area which is discussed probably exceeds 3,300 square miles within which we encounter unusual conditions; for instance, practically the whole of this area constitutes an artesian basin, but this artesian water varies greatly in its character. We have already presented the fact that we have immense quantities of soluble salts in our soil which, so far as we have presented them, are almost harmless but they constitute a factor which cannot be disregarded; in fact, many evils are attributed to these same salts by the public at large and by some students of our agricultural conditions. The character of these soluble salts may change from place to place in so large a territory without our chancing to discover it and statements which are perfectly applicable to one place might be a sad misfit applied to another. But, with all this, the main features of our presentation are without doubt faithful to the facts. We shall give, as we proceed, facts which we believe justify our views. Some of these facts, both of conditions and practices, may be unusual in other places and still be very real in this area.

We shall now proceed to present the facts pertaining to the ground-waters, soil extracts and alkalis of that section of the valley designated as the Hooper Mosca section. The limits of this section are difficult to define. This does not matter much on the eastern side but the limits to the west are important. This will be appreciated when it is stated that to the eastward of the D. & R. G. Railroad, we soon encounter land that is still open to entry under the desert-land laws, while to the westward lies land that 30 years ago was under cultivation and produced excellent crops—from 30 to 50 bushels of wheat to the acre—but this is not now true of much of the land lying within 14 to 16 miles west of it. This is a part of the reason why I stated that I believe that conditions have changed since the period of this productiveness. The reason seems sufficient and the conclusion self-evident.

The first ground- and drain-waters are from the extreme western portion of this district.

GROUND-WATER SW. ¼ SEC. 24, T. 40 N., R. 8 E.

Analytical results	Percent
Carbon	1.128
Silicic acid	5.356
Sulfuric acid	26.081
Phosphoric acid	0.169
Carbonic acid	6.185
Chlorin	16.311
Calcic oxid	12.135
Magnesic oxid	3,599
Potassic oxid	3.893
Sodic oxid	25.703
Ferric and Alum oxids.	0.463
Manganic oxid (br)	0.089
Ignition	(2.569)
Sum	103.681
Oxygen equivalent to chlorin	3,681
Total	100.000

Combined	Percent
Carbon	1.128
Calcic sulfate	29.453
Magnesic sulfate	10.750
Sodic sulfate	2.863
Sodic phosphate	0.506
Sodic carbonate	14.914
Potassic chlorid	6.162
Sodic chlorid	22.081
Sodic silicate	7.232
Ferric and Alum. oxids	0.463
Manganic oxid	0.089
Excessive Silicic acid	1.790
Ignition	(2.569)
Total	100.000

Total solids 56.56 grains per imperial gallon. Loss on ignition 7.07 grains.

DRAIN-WATER SW. ¼ SEC. 24, T. 40 N., R 8 E.

Analytical Results

	Percent
Carbon	1.563
Silicic acid	14.456
Sulfuric acid	14.697
Phosphoric acid	0.142
Carbonic acid	14.813
Chlorin	6.309
Calcic oxid	17.418
Magnesic oxid	5.231
Potassic oxid	6.282
Sodic oxid	16.549
Ferric and Alum. oxids.	0.205
Manganic oxid (br)	0.210
Ignition	(3.549)
Sum	101.424
Oxygen equivalent to chlorin	1.424
Total	100.000

Combined

	Percent
Carbon	1.563
Calcic sulfate	24.995
Calcic phosphate	0.310
Calcic carbonate	12.406
Magnesic carbonate	10.934
Potassic carbonate	9.213
Sodic carbonate	1.748
Sodic chlorid	10.411
Sodic silicate	19.726
Ferric and Alum. oxids.	0.205
Manganic oxid	0.210
Excess Silicic acid	4.730
Ignition	(3.549)
Total	100.000

Total solids 21.8 grains per imperial gallon.
Loss on ignition 8.6 grains.

The above analyses are given to show the general composition of the ground- and drain-waters in this portion of the district under discussion and to show that they are widely different from the Rio Grande water proper, but they also serve very well to show the differences between a ground-water and a drain-water for they were taken within a very short distance of one another.

The next samples of water are from the center of this district. The lake-water was from a temporary lake and probably represents run-off water.

GROUND-WATER MOSCA

	Percent
Silicic acid	2.226
Sulfuric acid	37.249
Phosphoric acid	0.076
Chlorin	5.342
Carbonic acid	10.042
Calcic oxid	4.651
Magnesic oxid	2.906
Potassic oxid	3.596
Sodic oxid	34.289
Ferric and Alum. oxids.	0.035
Manganic oxid (br)	0.059
Ignition	(3.792)
Sum	102.263
Oxygen equivalent to chlorin	2.263
Total	100.000

TEMPORARY LAKE, RUN-OFF WATER
Partial Analysis

	Percent
Sodic sulfate	69.92
Sodic carbonate	13.91
Sodic chlorid	14.54
Ferric and Alum oxids.	0.56
Calcic oxid	0.61
Silicic acid	0.85
	100.39

The next sample is a ground-water from a drained, cultivated field. The draining was effected at this place by an open ditch and as the water plane had fallen below the bottom of the ditch there was no other than ground-water to be obtained. This residue was also prepared in the field and the total solids are not given.

GROUND-WATER. DIBBERS, MOSCA

Analytical Results

	Percent
Silicic acid	9.591
Sulfuric acid	22.588
Carbonic acid	11.790
Chlorin	5.018
Calcic oxid	10.429
Magnesic oxid	4.512
Potassic oxid	8.085
Sodic oxid	22.965
Ferric and Alum. oxids.	0.542
Manganic oxid (br)	0.054
Ignition	(5.548)
Sum	101.131
Oxygen equivalent to chlorin	1.131
Total	100.000

Combined

	Percent
Calcic sulfate	25.312
Magnesic sulfate	11.589
Magnesic carbonate	1.332
Potassic carbonate	11.857
Sodic carbonate	17.661
Sodic chlorid	8.281
Sodic silicate	16.240
Ferric and Alum. oxids.	0.542
Manganic oxid (br)	0.054
Excess silicic acid	1.584
Ignition	(5.548)
Total	100.000

ALKALIS

(These two samples of effloresced alkalis were collected 4 miles south and 5 miles west of Hooper.)

NW. ¼ sec. 23, T. 40 N., R. 9 E.

	Percent
Silicic acid	0.200
Sulfuric acid	51.436
Chlorin	3.463
Nitric acid	Present
Calcic oxid	3.300
Magnesic oxid	0.522
Potassic oxid	2.831
Sodic oxid	35.800
Ignition	3.228
Sum	100.780
Oxygen equivalent to chlorin	.780
Total	100.000

SE. ¼ sec. 15, T. 40 N., R 9 E.

	Percent
Silicic acid	0.427
Sulfuric acid	52.175
Carbonic acid	0.992
Chlorin	2.712
Calcic oxid	0.223
Magnesic oxid	Trace
Potassic oxid	1.164
Sodic oxid	41.282
Ferric and Alum. oxids.	0.135
Ignition	(1.530)
Sum	100.620
Oxygen quivalent to chlorin	.620
Total	100.000

ALKALI

From Uncultivated Land at Hooper, Greasewood (Sarcobatus) Abundant

Analytical Results	Percent	Combined	Percent
Silicic acid	0.355	Calcic sulfate	4.155
Sulfuric acid	46.810	Magnesic sulfate	0.459
Carbonic acid	3.451	Potassic sulfate	3.143
Chlorin	1.589	Sodic sulfate	75.688
Calcic oxid	1.712	Sodic carbonate	8.321
Magnesic oxid	0.153	Sodic chlorid	2.621
Potassic oxid	1.699	Sodic silicate	0.721
Sodic oxid	40.202	Ferric and Alum. oxids.	0.081
Ferric and Alum. oxids.	0.081	Manganic oxid	0.090
Manganic oxid (br)	0.090	Excess sodic oxid	0.505
Ignition	(4.216)	Ignition	(4.216)
Sum	100.358	Total	100.000
Oxygen equivalent to chlorin	0.358		
Total	100.000		

THE WATER-SOLUBLE PORTION OF SOIL

From the same locality from which the preceding alkali was taken. It equalled 1.935 percent of air-dried soil.

Analytical Results	Percent	Combined*	Percent
Silicic acid	3.483	Calcic sulfate	1.456
Sulfuric acid	25.744	Magnesic sulfate	0.345
Phosphoric acid	0.211	Potassic sulfate	8.256
Carbonic acid	10.533	Sodic sulfate	37.085
Chlorin	9.702	Calcic phosphate	0.461
Calcic oxid	0.850	Sodic carbonate	25.398
Magnesic oxid	0.115	Sodic chlorid	16.010
Potassic oxid	4.483	Sodic silicate	2.617
Sodic oxid	40.893	Ferric and Alum. oxids.	0.030
Ferric and Alum. oxids.	0.030	Manganic oxid (br)	0.050
Manganic oxid (br)	0.050	Excess silicic acid	2.149
Ignition	5.503	Ignition	5.503
Sum	101.552	Total	99.360
Oxygen equivalent to chlorin	2.186		
Total	99.366		

*The amount of water-soluble carbonates in this soil extract is noteworthy.

The soil dried at 100° C. was digested with hydrochloric acid for 5 days and the solution gave the following results:

SOIL, HOOPER, COLORADO. SAMPLE DRIED AT 100° C.

	Percent
Insoluble (sand)	62.241
Soluble silicic acid	15.229
Sulfuric acid	0.362
Phosphoric acid	0.320
Carbonic acid	2.629
Chlorin	0.081
Calcic oxid	4.295
Magnesic oxid	1.595
Potassic oxid	1.383
Sodic oxid	1.326
Ferric oxid	3.930
Aluminic oxid	4.259
Manganic oxid (br)	0.175
Ignition	2.260
Sum	100.085
Oxygen equivalent to chlorin	0.018
Total	100.067

These samples were collected in 1907. It is unfortunate that we cannot give the total solids present in these ground- and drain-waters but it can be stated that those from Sec. 24, T. 40, N., R. 8 E. were not remarkably rich, while those from the neighborhood of Mosca were quite rich. The drain-water from Sec. 24, T. 40 N., R. 8 E., however, is sufficiently rich in calcic sulfate to distinguish it from mountain waters though its other salts are very similar to the salts present in these. This is also a noticeable feature in the composition of the ground- and drain-waters previously given. The waters, alkalis, and soil extracts, so far given, with only one exception, are poor in chlorids. In this exception, the ground-water from Sec. 24. T. 40 N., R. 8 E., the chlorin, calculated as sodic chlorid, amounts to 22.0 percent of the total solids, which were not excessively abundant.

WATERS ON EITHER SIDE OF RIVER DIFFER GREATLY FROM RIVER-WATER

These data present the conditions existing on both sides of the Rio Grande up to 1908 and they reveal no such marked differences as one acquainted with the sections might expect. They are, however, consistent in one point, namely, they show that the waters, whether they are surface-, ground- or drain-waters, differ from the Rio Grande waters in that they carry very greatly increased quantities of sulfates. The ground- and drain-waters of these sections differ from other ground- and drain-waters that we have studied in that they, in general, seem to carry the carbonates of the alkaline earths and an excess of silicic acid. This last feature is not for the moment the specific object of our study. The main point, in this part of our discussion, is that the character of the alkalis, the soil extracts, the ground- and drain-waters is such that an admixture of them with Rio Grande waters would reveal itself in the changed composition of the latter. We shall have further use for these data, but, for the present, the main purpose is to demonstrate the absence of their influence on the composition of the river water.

RELATION OF GREASEWOOD TO SODIC CARBONATE CONTENT OF SOIL

We may observe in passing that the last alkali given was collected amid greasewood (*Sarcobatus*)* bushes with the expectation of finding large quantities of sodic carbonate present, but we find only 8.3 percent of this salt in the water-soluble portion of the effloresced mass which, as gathered, probably contained 75.0 percent of its weight of surface soil. The aqueous extract of this soil, amounting to 1.94 percent of the soil, contained 25.4 percent of this salt, or 0.49 percent calculated on the soil. We have presented no sample of ground-water from this locality, for we took none.

The theory that soil about these bushes is rich in carbonates because of the nature of these plants was advanced by Prof. Hilgard. These greasewood (*Sarcobatus*) bushes may have been the cause of the presence of this carbonate in the soil but there is also another, and perhaps a better, explanation possible in this case, but we shall refer to this subsequently. In the following case the debris of the greasewood growth may have been the source of the carbonate, I know of no other probable source of the salt. The sample is of a virgin soil taken from a rather low place, with an abundant growth of greasewood (*Sarcobatus*). The surface soil yielded 3.71 percent of soluble salts to water. Organic matter was very abundant; there was no calcium, and only a trace of magnesium present. The acid determined and calculated as sodic salts corresponds to sodic sulfate 44.8 percent, sodic carbonate 31.7 percent, sodic chlorid 8.0 percent and organic matter 15.0 percent. This sample of soil was not taken to a greater depth than 2 inches. The sodic carbonate in this sample amounts to 1.1 percent of the soil and its presence may account for the growth of the *Sarcobatus*. It is a question whether any other plant can tolerate so large an amount of this salt, owing to its toxic qualities. Another sample of alkali containing sodic carbonate was obtained two miles from the latter. It would not be at all unreasonable to attribute the occurrence of the sodic carbonate in the two preceding samples to the prevalence of the greasewood, but in this case, I know of no source to which it could reasonably be attributed, therefore, I have considered it as an isolated sample of little or no importance, an exception, a curiosity among our alkali waters. The dried salt consisted of:

*Bigelovia is locally called "Greasewood" and this is the reason for the word, "Sarcobatus" in parentheses.

Sodic sulfate	31.780
Calcic sulfate	0.928
Sodic chlorid	6.691
Sodic carbonate	39.706
Organic matter	20.896
	100.000

The last two samples were met with in the section south and west of the Rio Grande. The explanations offered are the only ones possible in this case. These are, so far as I know, of very limited occurrence, and could not in any event modify in any important manner the character of the Rio Grande waters though they might be local factors in the unproductiveness of the soil.

THE PRODUCTION OF SODIC CARBONATE FROM THE FELSPARS

While there are differences between the composition of the Rio Grande water and the drain- and ground-waters, and the extracts of the soils presented, there are also persistent resemblances which we did not find in our stuly of these subjects in the neighborhood of Fort Collins and other sections.

In an article entitled "The Significance of Silicic Acid in the Mountain Waters, etc.,"* I pointed out that the characteristic results of the action of natural waters on the felspars is the production of a solution carrying principally the carbonates of the alkaline earths and alkalis with some sulfates and chlorids. Of the carbonates of the alkalis, the carbonate of soda occurs in excessively large amounts in proportion to the amount of soda in the felspar; in other words, the amounts of lime and soda taken into solution indicate the predominant decomposition of the soda-lime felspars. This characteristic in the composition of the salts in solution persists almost wholly unmodified in the Rio Grande water in spite of the long distance that it flows through the valley, but it also persists in the drain and ground waters in a marked degree with only one pronounced modification, namely, the increase of sulfates; the ground-water, for instance, from SE. ¼, sec. 23, T. 38 N., R. 8 E., or the drain-water from the Parma Land Company's ditch, or that taken from a drain in SE. ¼, sec. 24, T. 40 N., R. 8 E., might be taken for mountain waters, except for the large amounts of calcic sulfate present, which reach a maximum of 55.6 percent. It is not easily explicable why sodic carbonate does not appear in this analysis unless it be due to the abundance of calcic and magnesic oxids, but the appearance of this salt in ground- and drain-waters, as well as in river waters, is to be expected, except under such conditions as are indicated in the case just given.

Attention is called to these facts in this place, not only because these ground- and drain-waters present these characters, but also for

*Am. Jour. of Sc., Vol. XVI. Aug., 1903, pp. 169-184.

the reason that the artesian waters, to be presented in this connection, will offer another phase of this, if not an entirely new question. It is for this reason that I call attention to the production of sodic carbonate in the decomposition of the felspars and at the same time to show that it is also possible to lay too much stress on this fact, as the sodic carbonate may be changed wholly into other forms. Still, it is a fact that sodic carbonate is almost always present in soil extracts and natural waters in larger or smaller quantities. The original source and general distribution of sodic carbonate may be easily explained, but these are not the questions to be answered in the case in hand, and do not answer the specific question presenting itself.

It is evident that neither the ground-waters nor solutions of these alkalis or soil extracts from either side of the river find their way into it, for if they did, they would both increase the amount of salts in the river-water and change their character.

THE ARTESIAN WATERS

Artesian water in the San Luis Valley was discovered by accident in 1887 and I am informed that there have been sunk, up to the present time, more than 5,500 such wells, ranging in depth from about 70 to upwards of 1,800 feet. It is indifferent, in our inquiry, whether any of these wells are used for irrigating purposes or not. Very many of these wells are now flowing at the surface, and but few of them are cased to any considerable depth and may consequently be furnishing water to the general supply of the valley by leakage, though they may not be flowing at the surface. We are, therefore, interested in the character of these waters.

There is a thoroughly justified classification of these artesian waters into white and brown, according to their color. The color, however, is probably due to an accident, the occurrence of humified matter in the strata of certain portions of the valley. It is possible that some of the white waters may contain the same mineral constituents as the brown water and that in as large quantities. This is more than a possibility, for every sample taken shows that the former statement, i. e., that the dissolved salts are the same in kind, is true, but the brown waters are usually richer in total solids. Two wells, locally designated as the gas-well and the soda-well, yielded waters which were not highly colored, but were comparatively rich in total solids. The water from the gas-well carried 37.63 grains, and that from the soda-well 103 grains of total solids per imperial gallon. In the brown water the upper flows are not strongly colored and are not excessively rich in total solids whereas the deeper flows are darker colored and are richer in total solids. The deepest flows, however, do not necessarily furnish the darkest waters.

ANALYSES OF WHITE ARTESIAN WATERS

BUCHER WELL, ALAMOSA. DEPTH FROM WHICH FLOW COMES, 923 FEET. WATER IS COLORLESS

Analytical Results

	Percent
Silicic acid	50.202
Sulfuric acid	3.345
Phosphoric acid	None
Carbonic acid	14.346
Chlorin	0.485
Calcic oxid	2.877
Magnesic oxid	None
Potassic oxid	1.903
Sodic oxid	23.267
Ferric and Alum. oxids.	0.260
Manganic oxid	None
Ignition	3.081
Sum	99.766
Oxygen equivalent to chlorin	0.110
Total	99.656

Combined

	Percent
Calcic sulfate	5.689
Calcic carbonate	0.951
Potassic carbonate	2.791
Sodic carbonate	31.443
Sodic chlorid	0.800
Sodic silicate	8.756
Ferric and Alum. oxids.	0.260
Excess Silicic acid	45.885
Ignition	3.081
Total	99.656

Total solids, 14.07 grains per imperial gallon. Loss on ignition, 2.2 grains. An older determination of the total solids in this water gave 15.9 grains.

Sanitary Analyses

	Parts per Million
Total solids	201.00000
Ignition	31.42860
Chlorin	3.00000
Nitrogen as Nitrates	0.00002
Nitrogen as Nitrites	0.01000
Saline Ammonia	0.00100
Albuminoidal ammonia	0.00400

WELL AT ELECTRIC LIGHT PLANT, ALAMOSA. DEPTH, 820 FEET. WATER IS COLORLESS

Analytical Results

	Percent
Silicic acid	50.592
Sulfuric acid	2.926
Phosphoric acid	None
Carbonic acid	14.610
Chlorin	0.468
Calcic oxid	3.229
Magnesic oxid	None
Potassic oxid	1.976
Sodic oxid	24.087
Ferric and Alum. oxids.	0.236
Manganic oxid	0.100
Ignition	(1.882)
Sum	100.106
Oxygen equivalent to chlorin	0.106
Total	100.000

Combined

	Percent
Calcic sulfate	4.976
Calcic carbonate	2.104
Potassic carbonate	2.898
Sodic carbonate	30.775
Sodic chlorid	0.772
Sodic silicate	11.175
Ferric and Alum. oxids.	0.236
Manganic oxid	0.100
Excess of Silicic acid	45.082
Ignition	(1.882)
Total	100.000

Total solids 14.63 grains per imperial gallon. Loss on ignition 2.59.

Sanitary Analyses

	Parts per Million
Total solids	209.00000
Loss on ignition	37.00000
Nitrogen as nitrates	0.00270
Nitrogen as nitrites	0.07000
Chlorin	2.97060

The waters of the two wells just given represent the composition of the white artesian waters of this basin. I have an older analysis of the water from the Bucher well, we have also analyzed the water of the Spriesterbach and McNeiland wells, but the statement of these analyses in full would show only minor variations in analytical results and nothing more. The big features of the analyses are absolutely identical with the two already given. These wells are all comparatively deep ones. While there are very many shallow wells in the valley, from 70 to 250 feet deep, I have only one representative of these which is entered in my notes as "Widow Smith's place, depth of well uncertain, less than 300 feet, temperature 53° F., flow very strong". The only new point of interest in the analytical data of this well is the small amount of total solids that it contained, 6.6 grains per imperial gallon; otherwise we have essentially the same facts in regard to composition—very high silicic acid, abundance of sodic carbonate and some calcic sulfate. This sulfate is more abundant than usual, due, possibly, to the fact that the well was probably not cased for more than a few feet.

Some of these samples, together with others made by different analysts, may be found on p. 112 of Water Supply Paper No. 240, by Dr. C. E. Siebenthal of the U. S. Geological Survey.

Spring-Waters

In connection with white artesian waters, at least some of the spring waters deserve presentation. I regret, however, that I have studied these only in an incidental way. Some of these springs occur in the eastern part of the valley, under conditions which suggest that they may be directly connected with the artesian waters of the basin rather than with the surface waters as is usually the case. Some of these springs have a very considerable flow and are constant without any easily discernible source of supply. Other springs are not of this nature and evidently owe their supply to melting snows or surface waters; such springs should scarcely be considered in this connection.

Washington Springs may be taken as a type of some springs occurring in the eastern part of the valley. The artesian well mentioned as Widow Smith's was not far from these springs. There is one and may be more artesian wells at or near the springs at this time but these have been put down more recently and I know nothing about the composition of the water discharged by these. My impression is that the

Widow Smith well closed up some years ago. The analyses of one of these spring-waters (there were five of them at the time the sample was taken) and of the water from the Widow Smith well, were made at the same time, some years ago. These two waters are identical in character and very similar in the details of composition. The spring-waters carry 5.8 grains total solids per gallon, the well-water 6.6; the spring-water 1.74 grains silicic acid, the well-water 1.89; the spring 2.98 grains carbonates, the well 1.64; the spring .98 grains of sulfates, the well 1.02 grains. These waters are so similar that the suggestion that they are both really artesian waters is reasonable. Against this may be offered the fact that the ground- and drain-waters so far given have not lost all of the characteristics of mountain-waters; for instance, they show the presence of carbonates and some silicic acid which may be at least partly free, for there are more acids than is sufficient to satisfy the bases present. Such a statement is correct, but does not consider the decided increase in the sulfates, nor does it consider the fact that the artesian waters differ from the mountain-waters in containing very subordinate quantities of the alkaline earths and always notably high percentages of sodic carbonate. The springs in the southern part of the valley, with which I am acquainted, are either within or at the edge of igneous rocks which form the San Luis Hills. This sheet of rocks might simply serve to divert the artesian waters upward, or the waters may come from beneath, finding their way through fissures. I have examined the Dexter and the McIntyre springs. These waters differ from the artesian waters that I have examined in that they are richer in lime than the artesian waters; this is especially true of the McIntyre springs, also, in that they are richer in sulfates, which is equally true of the two springs. In regard to the silicic acid, they retain the richness of artesian waters.

In this connection it may be asked why I have made no mention of bicarbonates but have expressed the facts as though there were no bicarbonates. We have worked almost entirely with water residues obtained by evaporation to dryness in which we would have only carbonates. These residues in many instances were prepared in the locality where the waters occurred, as this was the only practical plan of procedure. The samples that we sent to the laboratory were several days old before they were examined so we have not deemed the omission of the half bound or even free carbonic acid of much importanc, especially as the primary object had in view concerned itself very largely with the question of the mineral constituents present in the water.

WHITE ARTESIAN AND SPRING WATERS WOULD NOT AFFECT RIVER-WATER

It is evident that neither white artesian waters nor spring-waters such as those of the Washington Springs, nor even such as those of the McIntyre and Decker Springs, would greatly modify the Rio Grande waters even if a fairly large quantity of them should find their way into the river. They might change the volume of the river but they would not radically change the character of the water as we find the waters of the Poudre and other streams changed within very short reaches of their courses. If the volume of flow were the principal change effected, it would be purely a matter for mechanical measurement. The results of gaugings vary; some years they showed an increase and in other years they showed almost as decided a decrease. At this time it appears to be a matter for regret that the chemical examinations and the gaugings were not made at the same time. This, however, is the first time that the peculiar problems presenting themselves in connection with these waters have been made the subject of inquiry.

FACTS INDICATE THAT RIVER LOSES IN VOLUME AND MAINTAINS CHARACTER OF MOUNTAIN STREAM

It would appear from the results obtained that the Rio Grande, in flowing through the San Luis valley, loses in volume and maintains the character of its water as a mountain stream to such an extent that it is difficult to believe that it is receiving any significant amount of return waters, even though the ground- and drain-waters given differ in material respects from those found in or issuing from irrigated lands under cultivation in other sections.

These facts seem almost incredible and yet they are concordant with one another. First, there is a loss of water between Del Norte and the State Bridge during some months. Second, there appears to be a mean gain between Del Norte, Colorado, and Embudo, N. M.* The discharge of the river at Del Norte, is given as 711,186 acre feet, the result of 17 years' observation; at Embudo, 769,098 acre feet, observation of 14 years, a gain of approximately 58,000 acre feet. Dr. Siebenthal gives the comparative discharge of the Rio Grande at Del Norte, State Bridge and Embudo for 1900, 1901, 1902 and 1903. At Del Norte, he gives 641,017, 583,271, 315,790 and 921,561 acre feet for the respective years, and at Embudo 537,381, 572,153, 282,-032 and 1,006,600 acre feet. It will be noticed that there is a loss in three of the four years. Dr. Siebenthal gives these data in discussing the interstate aspect of the Rio Grande and shows that while the flow at the State Bridge is smaller than at Del Norte the loss is largely made up in the course of the Embudo canyon. His data show that this is the case in one year in four. This point made by Dr. Siebenthal and the geologists whom he quotes is undoubtedly well taken but this point of view is an entirely different one from that from which

*Gaugings given by Dr. Siebenthal, Water Supply Paper No. 240, U. S. Geo. Surv. pp. 13-14.

we approach the question. The question between the states pertains to the waters collected within the water-shed by the Rio Grande—whether the impounding of these waters will militate against the interests of Mexico—and their comparisons of the flow of the Rio Grande at Embudo and at Del Norte are greatly to the advantage of the citizens of Colorado and show that the discharge of the river at Embudo is largely dependent upon water which cannot be affected by the impounding of the head waters of the Rio Grande.

RIVER ONLY DISCHARGE BUT NOT ONLY SOURCE

It is not our purpose to discuss this question but to consider the discharge of the Rio Grande from another point of view. This discharge is the only one from the valley. We have seen that the discharge at the State Bridge shows a loss, two years out of five,* and at Embudo a loss three years out of four. The discharge during the year of maximum flow was over three and a half times that for the year of minimum flow, but this was also true of the discharge at Del Norte. The Rio Grande is the only visible discharge from the valley but it is not the only discharge into the valley. While it is perfectly legitimate to consider it in this light in discussing the interstate relations of the Rio Grande waters it is misleading, as it appears to me, in discussing the water relations of the San Luis Valley. It confines our consideration to the fate of the water gathered within the water-shed of the Rio Grande as though there were no other water-shed around the valley, which is, as a fact, practically surrounded by high mountains from which waters descend into the valley.

WHAT BECOMES OF EXCESS WATER?

The discharge from the valley is, at best, probably no more than equal to the discharge of the Rio Grande into the valley. There are but two conclusions to be drawn in regard to what becomes of the excess of the discharge into the valley. It must flow out by unknown channels, or evaporate, or it is accumulating in the valley. The artesian waters do not constitute an addition to the waters of the valley, and all the irrigating water taken from the Rio Grande is already taken into consideration.

The facts that the Rio Grande loses water instead of gaining, and that the composition remains practically unchanged through a course of 60 miles through an irrigated country are entirely compatible, and the latter fact excludes the accession of any return waters, for these, even in this valley, where they seem to be of exceptional composition, would increase the amount of total solids in a materially greater degree than we find to be actually the case, and would increase the ratio of the sulfates. This is not true of the white, artesian waters, which differ mainly from the waters of mountain streams in their low content of carbonates of the alkaline earths. This difference between

* See page 13.

the water of a mountain stream and that of these artesian wells is shown quite clearly by the analysis of the Rio Grande water taken at Del Norte and that of the Bucher or Electric Light Plant well. The Rio Grande water contained 5.46 grains of total solids per gallon, the artesian water 14.63 grains, the solids from the river water contained lime and magnesia, 22.77 percent, sodic oxid 8.48 percent; the solids from the artesian water contained, of lime and magnesia 3.23 percent, of sodic oxid, 24.09 percent. These changes are interesting for there is no question expressed by those who have investigated the artesian waters of this basin but that they are furnished by the mountain streams as they flow over or into the edges of the sand strata.

THE BROWN ARTESIAN WATERS

We have given the brown waters no consideration as yet, because we accept it as evident that, if the white waters affect the composition of Rio Grande waters in no appreciable manner, it is not probable that the brown waters, peculiar to an area more remote from the river, would exercise a perceptible influence upon its waters, especially, as there is an area in which the white artesian water occurs between the brown water area and the river

The area of brown artesian waters is designated as the Mosca-Hooper section, because these are the two important towns lying within the area.

The following analyses will show the uniformity in the composition of these waters and their marked differences in this respect from the white artesian waters, analyses of two of which have been given with the explanation that these are thoroughly typical of all the samples analyzed.

ANALYSES OF THE RESIDUES FROM BROWN ARTESIAN WATERS, HOOPER, COLO.

	Railroad Well 450 feet deep Percent	Mill Well 750 feet deep Percent
Silicic acid	9.576	5.167
Sulfuric acid	0.389	0.196
Carbonic acid	34.387	36.923
Chlorin	.766	0.434
Calcic oxid	0.371	0.563
Magnesic oxid	0.118	0.179
Potassic oxid	0.107	0.456
Sodic oxid	49.688	51.766
Ferric and Alum. oxids.	0.208	0.170
Manganic oxid (br)	0.239	0.146
Ignition	(4.324)	4.267
Sum	100.173	100.276
Oxygen equivalent to chlorin	0.173	0.098
Total	100.000	100.178
Total solids, gains imperial gallon	3.92	6.7
Loss in ignition	70.56	104.3

ANALYSES OF THE RESIDUES FROM BROWN ARTESIAN WATERS CONTD.

	Mosca Town Well	Mosca Mill Well	Hooper Mill Well*
	Percent	Percent	Percent
Silicic acid	5.537	4.821	4.160
Sulfuric acid	0.342	0.046	0.063
Phosphoric acid	0.247	0.148	0.168
Carbonic acid	37.603	37.104	37.365
Chlorin	0.425	0.148	0.470
Potassic oxid	0.982	1.148	1.433
Sodic oxid	53.077	53.665	54.045
Calcic oxid	0.413	0.651	0.282
Magnesic oxid	0.153	0.391	0.219
Ferric oxid	0.086 }	0.031	0.039
Aluminic oxid	0.121 }		
Manganic oxid (br)	0.086	0.054	0.048
Lithium, Iodin, Bromin, Titanic acid and Boric acid	Traces	Traces	Traces
Carbon or Organic matter	0.365	(1.721)	(1.814)
Sum	99.437	100.064	100.106
Oxygen equivalent to chlorin	.096	0.064	0.106
Total	99.341	100.000	100.000
Total solids, grains per imp. gal.	78.7	108.9	104.3

The sanitary analyses of the Mosca town well gave us a great deal of trouble. The results were as follows:

Total solids	1124.2857
Chlorin	6.9310
Nitrogen as nitrates	0.2000
Nitrogen as nitrites	0.0010
Saline ammonia	2.1300
Albuminoidal Ammonia	0.1750
Oxygen consumed	28.1000

The oxygen consumed was reduced from 28 to 10 parts per million by treating the water with calcic hydrate. The first two samples were taken in 1897 and the last three in 1907 and the analytical work was done by two different analysts, and yet the analyses are very nearly alike. The waters are essentially solutions of sodic carbonate colored by humus. The taste and odor of hydrogen sulfide is more or less strongly perceptible in many of the artesian waters, both white and brown. Some of the wells emit a comubstible gas; such wells do not furnish the most strongly colored waters. The waters from the deeper flows are richer in sodic carbonate, but not so strongly colored as those from a depth of about 500 feet. A comparison of the white and brown waters shows some marked differences. The white waters carry small amounts of total solids, 20.7 grains per imperial gallon being the maximum that I have found in the white waters, and there was some danger of pollution in this case, as it was from an uncased well in Alamosa. The well is now closed. The minimum that I have found in any tinted water is 25 grains per gallon in water from the

*These analyses appeared in the American Journal Sc. Vol. XXVII, p. 315.

first flow, while the maximum is 108 grains, in water from a depth of 880 feet. The two great differences in these classes of artesian waters are, the very marked disappearance of the silicic acid from the brown waters, and the very marked increase in the total solids. The minor changes consist of an acquired color and the lessened amounts of calcium and magnesium. The color is accounted for by the presence of humus dissolved from peaty matter in the strata traversed by the water. We accept the fragments of wood appearing in refuse washed out in sinking the wells as indicating the source of the brown matter held in solution.

ORIGIN OF THE CARBONATES

I shall later attempt to explain the concentration of the sodic carbonate. Its original source may be given correctly by tracing it back to a mineral origin, but this does not account for the concentration in these waters. The "Soda Well", now closed, carried 97 grains of this salt per gallon. One can scarcely appeal successfully to the masses of organic matter that may be indicated by the humus as the source, for our most alkali-tolerant plants would scarcely yield such pure solutions of soda, unless we assume that the plants of that time were different from those of the present, which is not probable.

The source of the soda and its predominance in the area north of the Rio Grande may far more reasonably be explained by the action of water on the igneous rocks, fragments of which constitute a very large percentage of the sand occurring in the strata. The remnants of trees (wood) which are met with in making these wells, and the peaty or brown color of the water, indicate that lake or marshy conditions existed for probably long periods in this section. At the present time the lowest portion of the valley lies within this area of artesian water rich in sodic carbonate. This area has probably been the lowest portion of the valley in former times, and for the same or similar reasons as now, i. e., because the bed of what we call the Rio Grande was higher than this portion of the valley, perhaps enough higher to prevent drainage southward, and what was then lake or swamp waters were removed by evaporation.

The action of water on the plagioclase felspars present in the sand, formed largely of small, more or less worn fragments of igneous rocks, would give rise in the first instance to carbonates of soda and calcium with the liberation of silicic acid. That the carbonate of calcium was formed and separated is evidenced by the presence of very numerous kidney-shaped concretions of this substance in the sand as it was washed up in sinking the artesian wells. Sample available was from a depth of 550 feet.

The character of the white, artesian and spring waters, at the present time, is exactly such as is produced by the action of water on plagioclase as is also that of river water flowing over sands and boulders of granitic origin. This character is very marked in the two artesian waters given as typical of the white artesian waters of the valley.

Here we find that, approximately, one-third of the total solids consist of sodic carbonate, with relatively large quantities of silicic acid and calcium salts. The latter substances are practically removed from the brown waters. The river waters show the same fact, only to a less marked degree, and the elimination of the silicic acid and alkaline earths has not taken place. In the spring waters we find the same fact. In the water from the Washington Springs, for instance, we find a total of 5.7 grains of solids in an imperial gallon, of which, 1.74 grain is silica, 2.85 grains are alkaline carbonates and 0.98 grain is sulfates of the alkaline earths.

This process of taking sodic carbonate into solution from the plagioclase felspars is going on at this time and the only adverse question attaching itself to this view of the origin of the sodic carbonate is in regard to its sufficiency, of which I think there can be no reasonable doubt. The carbonate of calcium has been deposited in the form of small concretions and the silica may have been used in a variety of ways, perhaps to enlarge sand grains or to form new silicates. I have no knowledge of any direct proof that this latter process is going on. In the case of the Cache la Poudre water we find the whole of the silica removed on its first contact with the conditions that obtain in its plains section. It seems probable that this disappears in the formation of new silicates.

The origin of the carbonates here suggested is in harmony with the facts that we find obtaining in regard to the action of water on these plagioclase felspars, also with the composition of the artesian waters themselves. It is immediate and simple, and is suggested by the facts in the case.

LARGE AMOUNTS OF SODIC CARBONATE POURED ONTO LANDS BY WELLS

In order that the general reader may form some appreciation of the amount of sodic carbonate involved in this question, let us suppose that the "Soda Well" discharged 200 gallons a minute and that it carried 97 grains to the gallon. Such a well would deliver 5¾ tons of anhydrous sodic carbonate a month, or more than 12 tons of washing soda. Some of these wells have been flowing for 20 years, others even longer. It is true that many of these wells are only 2, 3 and 4 inches in diameter, but there are many of them, and the amount of soda yielded during the past 25 years must have been considerable.

I offered, 20 years ago, to furnish a complete analysis of any sample of black alkali found in this State without charge. I excepted this section, for it has long been known that there are occurrences of pure sodic carbonate within its limits. I do not know who first discovered it. Attempts have been made to prepare and market it. It matters but little to the facts in the case whether we have any explanation to offer for them or not, the facts remain just the same, i. e., that the artesian waters in this section are rich in sodic carbonate, and the people who live in this section have observed that these waters are not good for irrigation.

Concerning the use of these waters for irrigating crops, Dr. Siebenthal says: "It seems to be pretty generally agreed, however, as the result of experience, that the dark water is nowhere as good as ditch water and that in many places it is positively harmful and should always, if posible, be used in conjunction with ditch water. Its moderate use is likely to cause a "case-hardening", or the formation of a hard crust on the soil surface. In any event, even if one application is not injurious, its continued use in subirrigation will surely impregnate the soil with alkali."*

We shall have occasion to return to this subject for a fuller consideration of the conditions and facts as they have developed during the past 20 years.

THE SAN LUIS LAKE WATER

There still remains a small body of water which is entitled to consideration. This is the San Luis Lake which presents a surface of a little more than one square mile and has an average depth of 15 feet under ordinary conditions. This is the statement usually made. I have no other knowldge as to the depth, which varies with the season and is greater some years than others. There are several lakes, but only one of them has any considerable size, which is the San Luis Lake. This lake is peculiar in that it has no outlet, though the last time that I was there I was told that it was overflowing on the west side. There was a condition of affairs at this time that I had never seen before though I have been there often. The land to the west of the lake for a distance of quite two miles I would judge, was, for the most part, under water. This water, I was informed, was from the tailings of the irrigating and drainage ditches and water flowing out of the lake. I can not well verify these statements. This lake not only has no outlet, it also has no visible inlet except at rare intervals, when the waters of the Saguache and San Luis creeks flow overland into it. I have been informed that this happened but once in 40 years prior to 1909 and I was also informed that it had happened once in 21 years prior to that time. These two statements are of course not contradictory. The persons giving the information may have referred to the same occasion. Be that as it may, it is evident that this is a rare occurrence. The Sagauche and San Luis creeks, especially the Saguache, would be classed as mountain streams and undoubtedly carry

*C. E. Siebenthal. Water Supply Paper No. 240, U. S. Geo. Survey, p. 115.

water similar in composition to that of our other mountain streams, fairly represented by the waters of the Rio Grande which we will use for comparison.

ANALYSES OF RESIDUES FROM SAN LUIS LAKE WATER

	Sample taken 15 Oct. 1902	Sample taken 8 May, 1916
	Percent	Percent
Silicic acid	9.118	13.401
Sulfuric acid	5.801	10.255
Phosphoric acid	——	0.116
Carbonic acid	22.096	16.813
Chlorin	4.209	5.146
Calcic oxid*	2.673	4.178
Magnesic oxid	5.613	4.632
Potassic oxid	13.832	8.559
Sodic oxid	35.590	28.210
Aluminic oxid } Ferric oxid }	0.629	0.856
		0.301
Manganic oxid	0.216	0.465
Ignition	1.574	(6.350)
Sum	101.351	101.162
Oxygen equivalent to chlorin	.948	1.162
Total	100.413	100.000
Total solids in grains per imp. gal.	62.2	55.9
Loss on ignition in grains per imp. gal	8.2	

Sanitary Analyses of the Waters

	Parts per Million	Parts per Million
Total solids	888.5900	798.0000
Chlorin	36.1420	39.0000
Nitrogen as nitrates	Trace	0.1500
Nitrogen as nitrites	1.4000	0.0100
Saline ammonia	0.6250	0.3300
Aluminoidal ammonia	0.7130	1.0700
Oxygen consumed	31.5000*	14.1000

*The oxygen consumed was reduced to 10 p.p.m. by treament with calcic hydrate.

These samples were taken at different seasons of the year and nearly 14 years apart. I personally took both samples and remember distinctly that the lake was very low when the first of these was taken and, though I have seen this lake very often, I do not remember ever to have seen it so high as when the last sample was taken; therefore, it is probable, that these results represent the extreme differences to be met with in samples of this water. The results are remarkable, for, as I understand it, the drain ditches have been tailing their water into the trough of the valley for three or four years, and, as stated, the country for about two miles to the west of the lake was, at the time of taking the last sample, covered with water. This was the case to such an extent that, had I not been accompanied by a person thoroughly acquainted with the ground, I would not have ventured to try to approach the lake.

An examination of these analyses makes evident the fact that the solids held in solution differ materially from those of any water so far presented. They differ from the river waters in containing less silicic acid, less lime and magnesia, more chlorin, as much or more carbonic acid, about the same amount of sulfuric acid and very much more potassic and sodic oxids. This is particularly noticeable in the case of the potassic oxid. The differences are not such as we find in the drain- or ground-waters, nor do they correspond to the changes that we might expect as due to evaporation of the river waters. Evaporation is without doubt an important factor in the case. The evaporation from the lake surface is probably not less than 60 inches annually and must effect some changes, but we find the sulfuric acid at the time of low water less than in the river waters. The concentration of these waters is very far from the point at which any sulfates would separate due to this cause. The total solids in the lake water amount to, approximately, 8 or 12 times as much as we find in the river water. The potassic oxid is from 4 to 6 times as high in the residue from the lake-water as in that from the river-water.

There is, further, no relation between the lake and artesian waters. The differences mentioned above are even more strongly pronouncd in this case than in that of the river waters. This would be a natural inference as the source of the lake- and river-waters is evidently the waters supplied directly by the mountain streams, and still it is altogether possible that the lake-water may be directly supplied from the artesian basin, as I believe some of the springs in this section of the valley to be, the Washington Springs for instance. There are artesian wells on the east side of the lake and very close to it. The water is white, tastes distinctly of hydrogen sulfide but is an agreeable, potable water. The water furnished by the nearest well that I know of on the west side of the lake, furnishes a tinted water. These wells may, indeed almost certainly do, tap different flows. The soda lakes are close to the San Luis lake on the east and south. I hold that these soda deposits owe their origin to the brown artesian waters which come to the surface at these points and are evaporated. Such an explanation is clearly not applicable to the water of the San Luis lake. These relations are pointed out because the statement of our work on the waters of the valley would not be complete without reference to it, and also for the better reason that the water presents interesting questions.

There are some very important questions which have not yet been touched upon, or if they have been suggested, they can be put much more plainly. We have given analyses of artesian waters from the town of Alamosa, others from the town of Mosca. The difference in altitude between these two towns is 15 feet. The intervening country is without known folds or faults, the distance is less than 14 miles, and yet the artesian water at Mosca is wholly different from that at Alamosa. This is true for all the different flows encountered at the respective places, which may be illustrated by the Electric Light well at Alamosa and the Mill well at Mosca. The former has a depth of 820 feet, the latter a depth of 780; the former is a white water carrying 14.6 grains of total solids per imperial gallon, 50 percent of which is silicic acid; the latter is a brown water carrying 104.3 grains of total solids, of which only 4.2 percent is silicic acid and approximately 90.0 percent is sodic carbonate. In 1896 I examined the water of a well 8 miles north of Alamosa, on what is given as the probable limit of the brown waters, and found that it carried 103.6 grains of total solids, almost 90.0 percent of which was sodic carbonate, with only about 0.33 percent of silicic acid. It is a question how waters of such different characteristics can occur in the same aquifers without any barriers caused by foldings or faults. These differences are found in all of the flows within these respective areas. The limits of the brown waters are not necessarily the limits of the alkaline water for the last water mentioned was scarcely colored at all. The limits of the alkaline waters have not been determined, neither has there ever been any attempt, so far as I know, to trace the alkalinity of the waters between the two sections to determine whether there is a comparatively sharp line of separation or no line at all. The amounts of solids held in solution might be used as a criterion but this has not been attempted to my knowledge. In other words, the line between the acid and alkaline waters has not been determined. It is difficult to conceive how such lines can continue to exist, for even within the aquifers themselves there must be some diffusion, especially when so many openings have been made, which must establish some movement of these waters. A single 2- or 6-inch vent might not be of much significance, but when thousands of vents—upwards of 5,000—even if they are not greater than 2 inches in diameter are furnished, one would expect a considerable aggregate movement within these aquifers which might tend to bring about a mingling of these waters and to eliminate any sharp boundary. No observations at all have been established on these points so far as I know and it is wholly unknown whether the limits of the alkali water may have changed during the past 20 or more years. This period of time is not too long, for there were as many as 2,000 wells estimated to have been put down by 1891.

AGRICULTURAL FEATURES OF THE QUESTION

The strictly agricultural features of this problem are interesting and also involve a large territory. The facts in the case are simple but most conclusive in their character. The Hooper-Mosca section was, in 1893 to 1896, probably the greatest wheat producing section of the State. In 1916 this section was very largely non-productive, between 300,000 and 500,000 acres of land having long since been allowed to go back into greasewood and chico. The flouring mill at Mosca was torn down some years ago and the one at Hooper has been dismantled recently as a flouring mill after running many years on an inadequate supply of grain. This mill, I am told, may be continued as a feed mill. These are a few of the bald facts.

I do not know that anyone has ever formulated a statement of causes to account for this condition. It has generally been assumed that it is due to a high water-table. On this basis, drainage has been advocated strongly and with much confidence by a number of persons. In fact, much capital has already been invested in drainage projects and a number of proposed projects have not been carried out because of the difficulties encountered in financing them.

SUBIRRIGATION HAS CAUSED WATER-LOGGING

The system of irrigation practiced almost exclusively in the valley, i. e., subirrigation, has hastened the water-logging of the lower lands; of this there can be no question. In this system it is the practice to keep the water-table within a few inches of the surface during the whole, or most, of the season. I have not personally investigated the height of the water-table usually maintained, so I cannot make definite assertions in regard to this point, but inquiry has elicited the information that this depth varies from 12 to 24 inches. The latter is the greatest depth assigned to it. I recently made inquiry of a prosperous ranchman in regard to this point. He stated that he kept the water within 12 inches of the surface. The crops grown with this high water-plane were alfalfa, peas, oats, potatoes and wheat. This man asserted that his teams would mire on his land most of the time. I made inquiry in regard to this man's standing in the community and the results obtained on his lands. I learned that he was a man of influence and that he had probably told me the truth about his crops, both in regard to growing conditions and yields. I inquired further in regard to the depth to which this water-table fell during the winter when irrigation was not being practiced. The answer was prompt, that it varied, but that in none of the land did it fall to more than 3½ or 4 feet. I have bored, or dug with a spade, holes in other wholly unproductive sections of the valley during the irrigating season, and found no such high water-plane assigned to the lowest plane for subirrigated land, 24 inches. In July of 1916, I dug a hole in unproductive land near Mosca and found the water-table 36 inches from the surface. Later a sample of water was obtained from this place and a more careful measurement made of the depth of the water-plane, 37 inches. Southwest of Alamosa, I made a boring and did not find free water at 4 feet. It is difficult to reconcile the success generally had with subirrigation in which the water-plane is intentionally held within a short distance of the surface and the failures on land with a lower water-plane, if excessive water be the cause of unproductiveness as is claimed. Facts such as those just cited lead naturally to a doubt in regard to the correctness of the assertions made in this connection.

Other facts lead to a similar conclusion regarding the insufficiency of the high-water plane to explain the cause of the unproductiveness of these lands. One of these facts is the results being obtained by flooding without other than the natural drainage of the land. In some instances a fair degree of success has been obtained with alfalfa by this method, just as marked as by drainage, perhaps more so. The trouble is not to maintain the plantation of alfalfa but to get the seed to come up and to establish the young plants. When once established the alfalfa does fairly well, some of it very well. These facts indicate a trouble at the surface of the soil and not an excess of water that drowns the plants. Some ranchmen are seriously considering these facts. I do not know to what extent such views prevail among the people but some of them do not accept the seepage theory as the principal cause of the trouble which prevails throughout many thousands of acres—from 400,000 to 500,000

I do not wish to leave the impression that I have not found any cases in which the water-plane in unproductive land was not higher than 36 inches. I have found it very near the surface, but nowhere within 12 inches, that I can recall. I have found the water-plane high, within 18 inches of the surface, in very unexpected places and under conditions which we would judge to be favorable for drainage, i. e., in sandy soil with a good fall in one direction. This instance is interesting for several reasons. It was a desert claim. Irrigation was effected on a small scale by artesian wells. The person who had taken up these claims had made an honest effort to comply with the government's conditions to obtain a patent to the land. He had failed according to the authorities and the patent was withheld. The party had sunk 17 wells on this tract of land. He had diked several pieces of it and turned in his artesian water. The first year or two he had good results, the next 4 or 5 years everything failed and the land was entirely barren during the past summer. I cannot state that these diked sections were seeped. I think that they were not, but other areas, some occupied by alkali grass, others by clumps of greasewood, were seeped. The water-table in some land near the house was within 18 inches of the surface. This party stated his case as becoming worse the more water he used. He could not grow anything without irrigation and to irrigate with this water for one or two years, was to make it impossible to grow anything. Fortunately, the government representatives sent to examine into the facts of the case, realized that this party had made an honest effort to meet the requirements of the law and that his failure was due to some cause for which he was not responsible. We have the following facts: The land had produced good crops for one or two years on the application of water; it then became unproductive, and a comparatively small well sufficed to seep a considerable area of this desert claim.

The water furnished by the wells that I saw was of good quality, it was a white water carrying 5.5 grains of total solids to the imperial gallon, 37.27 percent of which was silicic acid and the rest was essentially sodic carbonate. This is very similar to the water furnished by the Washington Springs and the Widow Smith's Well. The sample of water taken was from the second flow.

Two samples of alkali were gathered from different parts of the tract, but neither one very far from a well. These wells have been flowing 5 or 6 years. The composition of these alkalis is unusual for our state and for the San Luis Valley as well. Analyses of alkalis which appear as efflorescences from localities pretty well distributed, and I believe representative of the general conditions in the Valley, have been given in the preceding pages. These consist chiefly of sulfate of soda. The soil extracts which are given are from various sections and indicate that it is usual to find the same salts in these as in the efflorescences which occur on the surface. The exception to this statement is found in the water-soluble from a soil sample, taken amid greasewood bushes in which we find sodic carbonate making up 25.4 percent of the 1.935 percent of water-soluble. The efforescent alkali, corresponding to this sample, carried 8.3 percent of sodic carbonate. This land was once under cultivation, but how long it had been occupied by greasewood at the time this sample was taken, I do not know.

GREASEWOOD INDICATES PRESENCE OF SODIC CARBONATE

While I am not prepared to reject wholly Prof. Hilgard's theory that the debris from these plants enrich the soil in sodic carbonate, I am strongly inclined to think that in this valley the growth of greasewood is indicative of a soil condition favoring their development and that their presence is a result of the prevalence of this salt in the soil, perhaps in such quantities as to render the soil already an inhospitable one to most cultivated plants, and for this reason the *sarcobatus* becomes the predominant vegetation, for it can endure the sodic carbonate. This in no wise asserts that this plant cannot or does not flourish in other soils. The most vigorous samples of *sarcobatus* plants that I remember having seen were growing at the edge of a kitchen garden with which no one could possibly find any fault on account of any lack of luxuriant growth. But, I think, that it is true in the section of the San Luis Valley land had in mind, that the presence of this greasewood indicates a strongly alkaline soil in which sodic carbonate forms a relatively large proportion. On a preceding page we have given an analysis of the water-soluble portion of such a soil and find that sodic carbonate makes up a little better than ½ of the total, while in the alkali that effloresced from this soil, about 1/12 of the salts soluble in water was sodic carbonate.

WHITE ALKALIS NOT INJURIOUS TO CROPS

My judgment relative to the injurious nature of our white alkalis, the efflorescences of which are designated by this name in this State, is that they are so good as harmless in any quantities in which they actually occur. It is a matter for regret that there has been so much said about the injurious effects of these alkalis that there has grown up a general belief in their injurious properties. These alkalis in Colorado consist usually, of the sulfates of soda, lime and magnesia, usually with small quantities of chlorids and carbonates. I have grown beets carrying from 14 to 19 percent sugar and yielding from 9 to 19 tons per acre on land the top 2 inches of which carried 3.5 percent of water-soluble salts. I measured incrustations formed on this land which attained a maximum of more than ½ inch. I have seen so many other instances of extremely alkaline land, in so many different sections of the State, on which excellent crops were produced, that I am convinced after 23 years of observation of this particular subject, that our ordinary white alkali is not sufficiently abundant in any of our ordinary soils to deserve any serious consideration. I have elsewhere stated, apropos to this subject, that on one occasion I measured alkali incrustations 3/16 inch thick under the leaves of beet plants and on digging found the ground water within 18 inches of the surface. This crop of beets was irrigated with seepage water, carrying 259 grains of total solids to the gallon. I was interested to learn what the harvest of this crop revealed, and wrote to the officers of the factory which handled the crop. They kindly gave me their record—9 tons per acre one year and 10 tons the next, with 16 and 16.5 percent sugar in the respective years. There was more of this alkali land which yielded much larger crops and slightly better beets. I saw a crop of wheat grown on land that I, at first, thought wholly unfit for wheat-growing, but the yield was 60 bushels per acre. Such facts as these can be duplicated in many sections of the State and are so patent that one cannot justly make the unqualified assertion so often met with, that the alkalis are injurious and have rendered the land worthless. I undertook some 15 years ago to ascertain the maximum amount of alkalis that might be present in an irrigating water without becoming injurious to the crop. I found the maximum so high that its ascertainment might have been interesting, but was of no practical value. The 60-bushel crop of wheat referred to in this paragraph was irrigated with seepage water that carried nearly 500 grains of ordinary alkalis to the imperial gallon, and the land was already rich in these salts. I took a sample of this soil during the summer of the preceding year, selecting a spot in which corn had almost failed and obtained 4.67 percent soluble in water, of which 69.0 percent was sulfates and 19.0 percent chlorids. This of course was the surface soil, but this is the portion invariably considered when this subject is spoken of. It is true that sometimes the alkali in a certain depth of soil is mentioned, but this is not usually the case.

UNPRODUCTIVENESS DUE TO SOME CAUSE OTHER THAN ALKALIS

When an ordinary alkali land is unproductive, or practically barren, as some of the San Luis Valley land is, there is some other condition contributing to the unproductiveness rather than the ordinary alkalis. Too much water is sometimes an efficient cause, but my observations in the field, as well as my experience with beets in thoroughly seeped land, make me rather more cautious in making assertions in regard to this as a cause of unproductiveness than many persons are. The practice of subirrigating may be unreasonable, but if the statements of those practicing it be in any reasonable measure reliable, the results obtained throw doubt on the correctness of much that is said regarding the subject of a high water-plane. Their practice may amount to water-culture on a large scale, be it so—*they raise the crops.* The fact is probably this; that parties expected to give an explanation, knowing, as every other person knows, that something is wrong when large areas formerly productive become unproductive, and feeling impelled to assign a cause, practically adopt the irresponsible view that they might as well assign it to alkali or to a high water-table as to anything else, because these are visible, and it is difficult to prove that they may not be the cause. The assertion, especially concerning the common white alkali, is of little value by whomsoever it may be made, while the evils due to seepage have been well ridden in our country for some years. There is no question, but that seepage is a real, and a serious problem, and one that is likely to become more so, but it is possible to attribute results to seepage for which it may be only indirectly, if at all, responsible. There may be troubles in a seeped country due to other causes than the seepage and which drainage may or may not alleviate.

It is well in this connection to state the preceding facts, that there may be no doubt about the value that I believe attaches to the assertions very generally made, particularly in reference to the alkalis, as the term is commonly used among us, where it means the ordinary white efflorescences on our soils.

I stated that the samples of alkali gathered on the desert claim were of an unusual type. The analyses of these samples show the presence of 14.75 and 40.368 percent of sodic carbonate respectively. The full statement of these analyses follows:

ALKALIS FROM A DESERT CLAIM

	I	II
Calcic sulfate	1.489	3.781
Magnesic sulfate	0.367	1.065
Potassic sulfate	2.874	4.978
Sodic sulfate	26.162	30.807
Sodic carbonate	40.368	14.750
Sodic chlorid	20.938	40.161
Sodic phosphate	0.959	0.391
Sodic silicate	4.271	2.866
Ferric and Alum. oxids.	0.082	0.340
Manganic oxid	0.202	0.265
Excess of sodic oxid...	2.288	0.596
	100.000	100.000

The soil where sample II was taken was not very badly encrusted and contained only 9.2 percent soluble in water, but the sodic carbonate present amounted to 1.35 percent of this surface portion.

The presence of such large quantities of sodic carbonate and the known toxicity of this salt to ordinary vegetation, were suggestive of the cause of the failure of the grain or the unproductiveness of the plots after the second year's irrigations. I have already stated that we have examined the water from the second flow and found it excellent water from the ordinary standpoint. This water carried 5.5 grains of total solids per imperial gallon, of which essentially 37.0 percent was silicic acid and the rest sodic carbonate. Such a water is apparently a good water, but the experience of this settler was that the more water he applied, the worse the conditions became.

The evaporation from a free water surface at this place is, according to the best information that I have, 60 inches or rather more per annum; taking the evaporation from a soil surface at 36 inches and neglecting the loss by percolation which, judging by the readiness with which local water-logging may be effected, seems at most very small, even such water might be an efficient, contributing factor in bringing about unproductiveness in the soil and justify the hard fact stated by the settler, "the more water I apply the worse I'm off". Even this water will deposit 354 pounds of sodic carbonate per acre per annum under the assumed conditions. It is not at all improbable that the sodic carbonate found in these alkalis came, principally at least, directly from the evaporation of this artesian water, for these wells had been flowing for more than four years. This water belongs to the white artesian waters. A short distance from this, about ¾ of a mile, a well sunk to irrigate some meadow land yields a strong flow of brown water. Concerning the effects of this water there is no room for argument, for it had killed the grass wherever it flowed over it. The water from this particular well was not analyzed, but we assume it to be similar in composition to other brown water from the same flow.

It is a very generally admitted fact that even the white artesian waters are not good for irrigating purposes. The almost universal testimony is that ditch or river water is preferable. Further, it is a common observation that the brown waters are not at all good for this purpose but that they are bad, for they kill some plants and cause the ground to become hard and it is then impossible to get alfalfa or other crops to come up and grow.

SEVERAL DISTINCT QUESTIONS INVOLVED

The agricultural problems present several distinct questions, each one of which may be of greater or less importance. The first question is in regard to the effects of our ordinary alkali salts.

That this question should be the first one suggested by the ordinary inquirer is natural, for the occurrence of these salts is abundant and sufficient to coat large sections of the valley with a covering, quite literally, as white as snow.

I have already stated my personal conviction, that this of itself is not a very serious matter. This conviction is based upon cultural facts and not on a theory to explain something.

The second one is the question of seepage. This is *per se* a more important question, perhaps, than that of the alkalis. Unfortunately this condition seldom occurs with us without being accompanied by the first question. The results of practicing subirrigation for many years raises serious questions in connection with the problems directly involved, to which general principles scarcely apply. In order to indicate more fully, but not to argue the question, it may be stated that in one section of the valley excellent crops, alfalfa, peas, oats, potatoes, etc., are grown with a water-plane intentionally kept nearer than 24 inches of the surface, sometimes as near as 12 inches, while other sections are only partially productive or wholly unproductive, with a water-plane 36 or more inches below the surface. The productive, subirrigated land is very far from being free from alkalis. How abundant they may be I do not know.

A third question, one presenting itself in the case of the desert claim, applies to a very large section, but not to all of the valley; this question is: Has the carbonate of soda, or black alkali, become so abundant as to be the determining factor in the unproductive condition of the area had in mind—in this case, the Hooper-Mosca section, an area coincident with the brown, artesian waters?

A fourth question pertains to this and to other sections of the valley as well: This is the question of the development of nitrates in injurious quantities. I have seen at least one tract of 640 acres on which the pea crop was wholly destroyed due to the presence of excessive nitrates. I heard of a second tract of 80 acres which was destroyed by the same agent. The people attributed these failures of the crop to the grasshoppers, though the peas that I saw either had not come up at all or had turned yellow and died without having been touched by the hoppers, if indeed there had ever been any hoppers there.

This general statement of the case by no means presents all of the problems of the valley, but these are the big, patent ones.

The United States Land Office sent a party out to investigate claims on which patents had been withheld for one cause or another. Some of these investigators recognized that there was something radically wrong in many of the cases. These settlers are not all dishonest men, trying to get patents to land for unworthy purposes, and yet they have been unable to satisfactorily comply with the government's requirements, as in the case of the desert claim mentioned in preceding paragraphs, or have abandoned the claims after having spent several years and perhaps all of the money that they have been able to get in order to make a success of them. In conversation with a member of this party, I found that he was seriously considering these questions. The trend of his argument was that men would not spend two or three thousand dollars and four years of their lives, perhaps with their families, on these claims, and then fail to comply with the government's reasonable demands or abandon the claims altogether, unless there was something wrong, for which an adequate explanation had not yet been found. I believe that his conviction was an honest one, that the government ought to protect such parties against the possibility of undertaking to prove up on such lands without full knowledge of the difficulties, or of giving them a full chance to try if they wished to knowingly undertake it.

It was not our intention to take up these agricultural features in this bulletin, but the growing conviction of their unusual character, their seriousness, and, as I believe, their intimate relation to the character of the artesian waters of the section justify me in giving the outlines of the salient problems presenting themselves. Up to the present time these questions have been dealt with only as they were incidental to the chief work presented, i. e., a study of the hydrology of the valley.

A REVIEW OF THE HYDROLOGICAL FACTS

In this work we find that the river water is characterized by a composition peculiar to mountain waters which is the result of the action of pure water on the rocks of the mountains, or the gathering grounds of the rivers. There are but comparatively few minerals concerned in the reactions which it is necessary to consider in this connection, in fact, we can confine our consideration to the plagioclase felspars, because these are the minerals that play the predominant part in these reactions. It is scarcely necessary to state that it does not matter whether the felspar constitutes a part of a metamorphic or an igneous rock, though its association and physical condition may affect the rate of alteration. Our white artesian water, especially from the shallower flows, differs but little from the mountain water, in fact, the water from a depth of 923 feet from the Bucher Well at Alamosa, carries only about three times as much mineral matter in solution as the Rio Grande water taken just above Willow Creek, but otherwise it is similar, exchanging lime for soda.

The residue from the water of this deep well contains 50 percent silicic acid, 14 percent carbonic acid (CO_2) and 23 percent sodic oxid, with some lime. The river water contains 43 percent silicic acid, 13 percent carbonic acid and 20 percent lime with 6.8 percent soda. The great change here is the exchange of lime for soda. When we pass from the area of white waters to that of the brown waters we find a further change in the elimination of the silicic acid and an increase in the amount of soda present with an almost complete elimination of the lime. The brown color is accidental for we have almost colorless water from this same area very rich in sodic carbonate. These peculiarities of composition are maintained by the different flows. The shallower flows may not be so deeply colored nor so heavily charged with mineral matter, but the composition of the mineral matter has the same peculiarities—absence of silicic acid and lime with sodic carbonate very strongly predominant. This is true of shallower wells, 15 feet in depth, which yield a white water carrying about 20 grains of total solids to the imperial gallon. Fifty percent of this was found to be sodic carbonate. The sulfates were not determined in this sample. This is an agreeable, cool water used for domestic purposes. The excellent quality of this water seems remarkable, for the whole country in this section is quite alkaline, in fact, there is a piece of land within a short distance of this well that is in very bad condition and white alkali is very abundant. The prevalent unproductive condition of the land and the area of sodic carbonate-bearing artesian water, usually brown in color, are nearly if not altogether coincident.

It is true in both areas, that of the white acid artesian waters and that of the brown alkaline waters, that the deeper flows are richer in total solids than the shallower, but the increase in the brown water area is much more marked than in the white water area. In the latter area this increase is from about 5 grains to 15.9 grains per imperial gallon; in the former, the brown-water area, the first flow carries about 22 grains which increases to 108 grains per imperial gallon in the deepest flow examined. For the present, we may consider the source of the carbonate to be the country itself, i. e., we may consider it as existing throughout this whole section as ready formed sodic carbonate without any regard to the original source from which it was derived or the agencies contributing to its formation. I have previously indicated my belief in its formation by the action of water on the sands consisting very predominately of grains of igneous rocks and possibly in a large measure to the evaporation of such water within this area due to a lack of drainage throughout a long period. It is, however, much more convenient for our present purpose to adopt the preceding statement—that it occurs, already formed, in the strata of this section of the valley. This agrees with the fact that if you start at Alamosa and go northward, the water increases both in alkalinity and the amount of total solids contained, until you get a little north of McGinty; from here to Hooper it remains about the same. It is understood that these statements are, in a sense, general in character, for, at the present time, it is practically impossible to obtain reliable information relative to the depth from which a well may be delivering water and general statements are the only ones that can be made, as the flows taken may not be the same.

If we start at Center near the western rim of the artesian basin and sample the waters eastward to Hooper, we find a very similar series of results—an increase in both the alkalinity and total solids.

While the foregoing statements are, in a sense, general ones, they are based upon two series of samples taken, as suggested, from Alamosa northward and from Center eastward to Hooper. In a few instances we can ascertain the depth from which the water rises, but in the majority of cases we cannot get satisfactory information. Another difficulty is that but few of the wells are so cased that we get the water from a definite flow. In the instances in which the depth of the well is known, I shall give it, in other cases I can only designate the wells as shallow or deep.

ALKALINITY OF ARTESIAN WATERS

Locality	Depth of Well	Sodic Carbonate in parts per Million
Alamosa	923 feet	68.0
Alamosa	820 feet	68.0
½ mile south McGinty	Deep	795.0
North of McGinty	Deep	1070.9
2 miles north McGinty	Deep	1171.3
2 miles north McGinty	Deep	1229.6
4 miles north McGinty	Shallow	371.0
Mosca	780 feet	1388.6
Mosca	500-600	1003.0
2 miles north Mosca	Shallow	318.0
3 miles south Hooper	Deep (780?)	1446.9
2 miles so'east Hooper	Shallow (2d flow or deeper)	593.6
1 mile north Hooper	Shallow (1st flow)	371.0
Hooper	750 feet	1356.0
Center	200 feet	74.2
3 miles east Center	Shallow	74.2
4 miles west Hooper	375 feet	79.2
4 miles west Hooper	739 feet	477.0
2 miles west Hooper	Shallow	212.0
1 mile west Hooper	Shallow	291.5
Hooper	450 feet	840.0

The samples from Alamosa to Hooper represent water taken in an almost straight line beginning south of and outside of the alkaline area and running due north to approximately the center of the area. The samples from Center to Hooper represent a line beginning west of and running due east to the central portion of the area.

In addition to the above data the results obtained on examining the water carried by the Sylvester drainage ditch will give an idea of the character of the ground-water in the line of the latter samples, Center to Hooper. A sample of this water was taken two miles west of Hooper and carried 159.0 p.p.m. of sodic carbonate; another sample was taken as tailing water one mile east of Hooper, and this carried 227.9 p.p.m. A shallow well, 15 feet deep, used for domestic purposes, carried 159.0 p.p.m. of sodic carbonate. The depth of the Sylvester drainage ditch where the sample was taken, west of Hooper, was probably 8 feet.

The data herewith presented to exhibit the alkalinity of the artesian and even surface waters of the section under discussion are sufficient to show that we are justified in presenting them for serious consideration in connection with the unfavorable agricultural conditions that prevail throughout this section of country, which, as I have previously stated, is co-extensive with the area of alkaline water. I do not know the exact outline of this area, but there are probably at least 400,000 acres of land affected by these conditions.

The quantities of sodic carbonate given in the above statements may not convey any definite idea to some readers, therefore it may be advisable to state how much they may mean. The annual evaporation from a free water surface in the San Luis Valley may be taken as 60 inches, and from a soil surface as 30 inches. The drainage water carries 159 p.p.m., or each million pounds of water carries 159 pounds of sodic carbonate. If 3 acre-feet of such water were evaporated to dryness on an acre of land, and the whole of the carbonate were left on the surface, it would mean the deposition of 1,300 pounds of sodic carbonate, which would add, if thoroughly mixed through the top foot of soil, 0.03 percent of sodic carbonate. In experimenting with beet seedlings years ago, I ascertained that the presence of 0.05 percent of this salt in the soil was injurious and could not be exceeded without killing the seedlings. This is the importance of the preceding figures, i. e., the ground- and drainage-waters, and all of the artesian wells in this area contain sodic carbonate. The brown artesian waters are, for all purposes proper to consider at this time, simply weaker or stronger solutions of this salt. This is true to such an extent that we illustrate it by the following statement: If a gallon of brown water contains 70 grains of salts in solution, 63 grains of these 70 grains are sodic carbonate or black alkali. The presence of this salt is a fully adequate and satisfactory explanation of the fact observed by many ranchmen that artesian water is not so good for irrigating purposes as ditch, or river-water, which is a conservative statement, for many of them have observed that the brown waters are fatal to vegetation. The water from one of the wells mentioned in the preceding table flowed over some land for a few months and the owner told me that it was several years, four years I think, before he succeeded in overcoming its effects.

I have previously stated that, for our view of agricultural conditions, we can consider this black alkali, sodic carbonate, as existing in strata of this country to a depth of at least 900 feet, for we find the water of cased, artesian wells becoming richer in this salt till we gain this, approximately our greatest depth. We certainly do not need to concern ourselves about the more remote origin of the salt so far as it pertains to the agricultural questions of the section.

UNFAVORABLE CONDITIONS PREVAIL WHEREVER WATER IS ALKALINE

An important consideration in this connection is the actual soil conditions that obtain. If these contradicted the views set forth, we would certainly conclude that their presentation was worse than unwise. *It is, however, a fact that the unfavorable agricultural conditions and the alkaline character of the water are coincident in their occurrence, which is of itself very suggestive.*

SOIL SAMPLES TAKEN TO PROVE RESULT

In order to prove this question further, two series of soil samples were taken along the same lines that the water samples were taken. It is readily foreseen that soil samples taken to represent so long a stretch of land, the lines aggregating more than 30 miles, will vary greatly and it would be no matter for surprise if some of them seemed to contradict the statements made. This, fortunately, is not the case, for we find that our results agree very well with the facts as seen in the field.

In the following statement of results, I shall give the conditions of the land as of more interest than the locality and state the results in parts per million of air-dried soil.

Sodic carbonate present to the extent of 400 p.p.m. is injurious to most crops and I doubt whether any cultivated crop can endure as much as 500 p.p.m. I think that it is perfectly safe for the general reader to use these figures as guides in judging the results given in the following table:

ALKALINITY OF SOIL EXTRACTS

Condition of land or crop	Sodic Carbonate (Black Alkali) in parts per million
An old "gone-back" ranch	865.0
Land in bad condition, crops failed	375.0
Land barren for some years	722.0
Land barren	925.0
Barren, sandy soil	5103.0
Alfalfa field, stand good	144.0
Old alfalfa, stand medium	200.0
Alfalfa field, stand good	259.0
Sandy soil, alkali grass, some sweet clover	121.0
Diked and flooded soil	109.0
Sandy loam, uncultivated	253.0
Oats, a failure in 1916	609.0
Deserted land	200.0
Wholly unproductive, though under good treatment	510.0
Wholly unproductive and has been for many years	3222.0
Land just surfaced	200.0
Flooded 1916, planted to rye, poor stand	398.0
Flooded 1916, planted to rye, not much living	410.0
Planted to peas 1916, died	633.0

The preceding samples represent both good and bad conditions as they are found throughout this area.

Unfortunately, the problem, like most of our agricultural problems, is not a simple one, for there are several factors playing their respective parts. The one here pointed out, sodic carbonate, is, without doubt, the principal one affecting the conditions in this area, though it has not previously been pointed out, or even given serious recognition. Excessive water alone has been charged with the ruin of the land and drainage urged as its greatest need. I am among those who do not believe this.

DRAINAGE NOT THE MAIN PROBLEM

That our ordinary crops, oats, wheat, alfalfa or potatoes, cannot be successfully grown with the water-plane an inch above the surface, no one doubts, and lands that become filled with water to such an extent as this should be provided with an outlet for the excess water. This can be effected by surface drains. The practice of sub-irrigation, under which crops are grown with a water-plane maintained within 18, or even 12 inches of the surface, gave my ideas on aeration, etc., a decided shock at first. While some drainage is necessary, this is not the main problem to be solved in this section. In a great big sense, the problem has been, for a period extending back to the draining of the old lake and the building of the bed of the Rio Grande, a drainage question.

HEIGHT OF BED OF RIO GRANDE CAUSE OF EXCESS SODIC CARBONATE

I believe that the sodic carbonate owes its origin to the fact that the drainage south has been no better since the valley itself was formed than it is now and for the same reason as now. The bed of the Rio Grande has never been cut down so as to let the water north of it drain southward out of the valley. The efficiency of this simple cause to account for the concentration of sodic carbonate in this area to the extent that we find it, is impressive on a little consideration. Under this condition, the water-plane has always been high in this section of the valley. Evaporation has gone on rapidly from the surface of the land at all times. Assuming that this evaporation has been 3 feet per annum over an area of 500,000 acres, we have 1,500,000 acre-feet of water. Taking 720 acre-feet as equivalent to a flow of 1 second-foot for a year, we account for a discharge of 2,000 second-feet of water into the territory. The evaporation of 1,500,000 acre-feet of mountain water, carrying only 2½ grains of sodic carbonate in each imperial gallon, will deposit 145,500,000 pounds of sodic carbonate, or 291 pounds on each acre which must remain within the area if there be no drainage to remove it, so there would be an accumulation of this salt just in proportion as this drainage was inadequate. In this sense the whole situation resolves itself into a drainage problem, but no one has heretofore suggested this question.

There are intelligent men in the valley who appreciate that the water, *per se,* is not the most important question that they have to deal with. Many of them have become convinced that the liberal application of water to the surface, so long as there is space enough between the water-plane and the surface of the land to let the water applied pass a few inches below the surface, ameliorates conditions materially though the water-plane has not been lowered. They know that this is only a palliative, but it enables them in some cases to establish a crop, alfalfa for instance, which when once established may tolerate the conditions.

APPLICATION OF GYPSUM WOULD BE HELPFUL

The important question is, Can the ranchmen ameliorate these conditions? They are proving that they can by diking and washing, which, to the present time, has proven the most effective means of reclamation. A still more effective measure would be the application of land plaster, ground gypsum, which occurs very abundantly within the State. The amount of sodic carbonate in most of the surface soil, is not so abundant that the cost of the land plaster necessary to correct the alkalinity would be prohibitive; in fact, the cost ought to be very moderate. The most serious item would probably be haulage or freight owing to the location of the valley between high mountains. If, however, the use of this material should prove to be sufficiently beneficial, as I firmly believe it will, proper organization of the users can undoubtedly bring about the production and transportation of this material to the valley at a very reasonable cost. It would be greatly to the advantage of the railroad, the Denver & Rio Grande for instance, to encourage this development. I believe that the production of the land plaster ought to be a community undertaking, and also all transportation arrangements, if the most extended and beneficial results are to be obtained, for private production will look principally to private profit, whereas the amelioration of conditions in this section, to such an extent as to restore from 300,000 to 500,000 acres of land to a condition of productiveness which it formerly possessed, but which it has almost entirely lost, is a consideration worthy of the united effort of all the parties concerned.

The facts given at the beginning of this discussion, to-wit, that one large flouring mill has been torn down, that a second one has recently been dismantled, that an elevator still standing, has not been used for its legitimate purpose for years, that the towns have dwindled instead of grown, that homes have been deserted, to which remnants of fallen houses still bear witness, and the lands have been permitted to go back to the native vegetation, chico and greasewood, ought to constitute a sufficient appeal for the united and beneficial effort of the whole community. Further, the State or the Government, for the latter is still largely interested, ought to devise some effective measures for the protection of the interests of both the individual and the public against those of selfish private enterprise. Such effort and protective regulations ought to be capable of accomplishment, but it is, perhaps, useless to hope for such a consummation.

SUMMARY

The Rio Grande flows for about 60 miles through the San Luis Valley without any considerable change in the character of its waters.

The flow of the river diminishes rather than increases in its passage through the valley.

There are only a few streams having a visible discharge into the Rio Grande.

The drainage is practically out of the Rio Grande into the valley, instead of out of the valley into the Rio Grande.

The ground-waters of the valley retain the characters of the mountain waters in a noteworthy degree.

The ground-waters, though retaining some of the features of mountain waters, have their own characteristics which are pronounced enough to affect those of the Rio Grande water if any significant volume of them is mingled with it.

The alkalis, i. e., salts that collect in the surface portions of the soil or appear as efflorescences, are of three types which are not further discussed.

These types are:

Plain sulfates, soda and lime being the predominant bases. This type is the predominant one.

Sulfates and chlorids. This type is not abundant though it is well distributed.

A type in which sulfates and carbonates occur. The occurrence of this type is for the most part confined to the area north of the Rio Grande.

Solutions of these alkalis do not find their way into the Rio Grande in sufficient quantities to noticeably modify the composition of its water.

The valley is an exceedingly large artesian basin, but the waters are of two characters. Those of the southern portion and the rim of the basin are white and carry an excess of acids. Silicic is especially high, while those of the northern interior portion of the basin are alkaline and usually brownish or brown in color.

The white artesian waters, especially those flowing from shallow wells, from 75 to 300 or even more feet, are very similar to river or mountain water and would simply increase the volume and would not change the character of the river-water if they mingled with it.

The brown water is free from silicic acid and contains so good as no salts except sodic carbonate.

This character of the brown waters is the same for all flows from the shallowest to the deepest examined, 880 feet.

The deeper flows increase in the amount of salts held in solution without any change in their character.

This increase was from 22 grains to 108 grains in each imperial gallon.

These waters would change the character of the river water if they mingled with it, which they appear not to do.

The brown color is accidental and is due to peaty material dissolved out of the aquifers themselves. The presence of fragments of wood obtained in sinking the wells and the deportment of these waters when submitted to sanitary analysis is taken as proof of the peaty nature of the color.

The presence of peaty substances and wood in this area is interpreted as indicating that this portion of the valley was, in former times, low land and probably marshy, i. e., poorly drained.

The sodic carbonate is considered as originally coming from the mineral constituents of the rocks furnishing the sands and clays that form the strata now composing the floor of the valley.

The changes necessary to remove the silicic acid and lime from the mountain waters are simple. The small concretions of calcic carbonate met with in the sand from the strata passed through at 550 feet indicate simple precipitation as the method of removing the lime.

As the drainage of this portion of the valley has probably been just what it is now for the whole period of the existence of the valley with but little or no change in its water supply, evaporation alone is considered adequate to account for the concentration of the sodic carbonate that we find in this section.

Evaporation at the present time is sufficient to add 145,500,000 pounds of sodic carbonate to this section of the valley yearly. This is on the supposition that the mountain water carries 2½ grains of sodic carbonate in each imperial gallon, or 10 pounds of water evaporated.

The present agricultural condition of this section of the valley is due to the accumulation of this salt, black alkali, rather than to an excess of water.

Local surface drainage is necessary in many small localities.

The evaporation from the area involved is equivalent to an inflow of 2,000 second-feet throughout the year. This is probably a larger amount than this section of the valley actually receives, except for a very short period in the spring of the year when the direct overland inflow may equal or possibly exceed this amount.

The San Luis Lake water is peculiar in its composition and unlike either the river- ground- or artesian-waters.

The deposit of sodic carbonate east of the San Luis Lake is probably derived from the evaporation of the brown artesian water, and has no connection with the lake.

The conditions which have determined the character of the brown artesian waters are still active in determining the agricultural features and questions of this section of the valley.

The question of black alkali in this section is in places further involved by the occurrence of nitrates.

The conditions which obtain and are inimical to vegetation can be ameliorated by rational irrigation, chemical treatment of the soil and surface drainage where needed.

INDEX

INDEX TO TABLES GIVING ANALYSES