1) COLORADO

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Bulletin 72. **August, 1902.**

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The Agricultural Experiment Station

OF THE

Agricultural College of Colorado.

A SOIL STUDY.

PART IV.

THE GROUND WATER.

—BY—

WILLIAM P. HEADDEN.

PUBLISHED BY THE EXPERIMENT STATION
Fort Collins, Colorado.
1902.

The Agricultural Experiment Station,

FORT COLLINS, COLORADO.

THE STATE BOARD OF AGRICULTURE.

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A SOIL STUDY:

Part IV. The Ground Water.

BY WILLIAM P. HEADDEN, A. M., PH. D.

§ 1. I have presented the results of our experiments and observations upon the effects of alkaline conditions of the soil upon crops, upon the sugar beet in particular, in Bulletins 46 and 58, forming Parts I and II of this study. In Part III, Station Bulletin 65, I have presented the subject of the soil, and the effects of cultivation upon it, from both the chemical and physical standpoint. The conclusions reached in these bulletins have been summarized in the respective publications and will not be reproduced in this place, as reference can easily be made to the statements of them in the originals, which are fuller than could be made here.

SOME OBSERVATIONS ON ALKALIZATION.

§ 2. The statement made on page 3 of Bulletin 46, relative to the general question of alkalization in Colorado is, I believe, correct. I would state the question even more explicitly, especially for the eastern slope of the Rocky Mountains, for I am convinced *that the only question of alkali that we have resolves itself into one of drainage, and beyond this, there is no alkali question for us.* I believe this to be true of the western as well as of the eastern portion of the State.

§ 3. I am aware of the fact that some sections of the State have an abundant supply of alkali salts, but their presence and whatever injurious effects they may have produced, is due principally, if not wholly, to the lack of drainage, which, in many instances, has been made more apparent and its effects greatly augmented by over-irrigation. An immoderate use of water, especially when no regard is had for drainage, the peculiarities of the soil or the requirements of the plants, can prove as disastrous to the agriculture of a section as other naturally adverse conditions. This cause of trouble will be lessened in all parts of the State as the demand for water approaches the limit of the supply and an economic and intelligent use of it is forced upon the agriculturists. As an illustration I may give the following facts which were stated to me—not for the purpose for which they are here used—by a person conversant with them: In a certain section of the State the water table was about 18 feet below the surface and the water was usable, though not good. A few years after the irrigating ditch, which furnished a super-abundance of water, had been built, the water plane had raised by 15 feet or more, with the result that the depressed portions of the country were being drowned out. The water, which had become heavily laden with the alkalies, was much less desirable than formerly, or wholly unfit for use. The people, as a matter of course, did not take it kindly when the writer insisted that there were two contributing causes to this state of affairs, over-irrigation and lack of drainage, and that the remedies were simple if feasible. The first was to apply less water, which could easily be done; the second, to drain the land, which could not easily be done.

§ 4. The character of the underlying strata, the presence or absence of a hard pan, often contributes to bringing about bad drainage conditions, but this was not the case in the above instance, and I think that it is not very generally the cause in any section of this State. I have seen no occurrence of alkalies in this State where their accumulation was not due to these causes, usually to the lack of drainage, the alkalies accumulating in depressions with no outlet which serve as collecting places for the water running off of or draining from the higher ground, or along water courses where the lowness of the land and character of the vegetation prevent proper drainage.

THE CONDITIONS OF THE PLOT EXPERIMENTED ON.

§ 5. The plot of ground chosen for our experiment was in the worst condition of any plot at our disposal. It was quite wet, had no hard pan, but a stratum of clay at a depth of about 5 feet, underlain by gravel. It was not drained, though a tile drain had been laid to the west, south and east of it, but at so great a distance that it failed to perceptibly affect the condition of this plot. An irrigating ditch flows within 50 feet of the east end of the plot, and one perhaps 150 feet from the west end of it, both being at a higher level than the plot itself, which has a slope to the eastward of six inches in a hundred feet. The ditch passing the east end of the plot was, we feared, an important factor. We will subsequently state the results of our observations made to determine to what extent this ditch influenced the water level of the plot.

§ 6. Such were the general conditions of the ground chosen to experiment on, and which was chosen as representative of much land in Colorado which is neither so wet as to be untillable nor so strongly alkalized as to be hopeless, and yet was strongly enough impregnated with salts to yield, under favorable conditions, incrustations reaching a half inch in thickness.

§ 7. Parts I and II of this study deal exclusively with the effects of these conditions on the growth and composition of sugar beets, the crop chosen to grow on this land, because we thought it probably more tolerant of the conditions than any other crop which would at the same time serve the other purposes of our study.

§ 8. Part III deals with the soil, giving an account of the mechanical and chemical effects resulting from our cultivating and manuring it. In this bulletin, Part IV of our study, we shall present the results of our observations on the ground water, the changes in the water used for the purpose of irrigating, the salts removed, etc. I shall confine myself in this bulletin to the subject of water, as in Part III I confined myself to the subject of the soil.

§ 9. I have stated the general condition of the plot at the beginning of the experiments; I have stated the reasons which induced us to choose this plot of ground as well as the crops to be grown thereon; and in Part III I have given the condition of the soil at the end of our experiments, which is summed up by stating that the store of plant food in the surface soil, taken to a depth of ten inches, was actually increased. This, however, was the lesser part of the improvement, the greater part lay in the betterment of the general conditions, whose best features cannot be shown by chemical analysis or expressed in any formula. The strongest and most interesting point in this connection is that the conditions of water supply and drainage have remained the same throughout the experiment. The ground has subsequently been drained, in part, at least.

§ 10. The amount of water in the soil was not determined for the reason that the soil was excessively wet, the water table being at times within a few inches of the surface, and in parts of the plot, seldom more than three feet six inches below it, while in the highest portion of the plot it was only six feet from the surface at its lowest stage. One would think that, under such conditions, irrigation would not be needed; that the sub-irrigation would be sufficient. We did not find this to be the case. The explanation probably lay in the fact that the root system accommodated its development to the conditions obtaining during the earlier and greater portion of the season, and when the water table fell the surface soil, owing largely to its unfavorable mechanical condition, dried out rapidly to a greater depth than a soil in good mechanical condition would have done, causing the plants to suffer. The plant, too, may have become more sensitive to a lack of water, owing to the usually large supply of it. Whether this is the explanation or not, we had to irrigate two out of three seasons, and while we irrigated the third season also, it was probably not actually necessary so far as the growing of the beets was concerned.

§ 11. The height of the water table in the plot was referred to a plane 10 feet below our bench mark. The wells were designated as A, B, C, D, E, F, G and H; their respective heights, referred to the same plane, were: A, 9.41′; B, 11.12′; C, 11.23′; D, 12.71′; E, 7.24′; G, 9.59′. The heights of F and H were not determined; these wells were dug for special purposes, which it would be out of place to explain at this time. Wells A, B, C and D were the principal ones and were dug at intervals along the central line of the plot, which had a width of 50 feet and a length of 600 feet. The distances between the wells were not equal. Well A was the most easterly one, and was 130½ feet from the center of the ditch; B was 150 feet west of A; C 175 feet west of B, and D 160 feet west of C. The surface of the plot at D is 3.3 feet higher than at A; the surface of the underground water is 1.83 feet higher. The distance from A to D is 485 feet, accordingly the surface of the water table has a fall of 1.83 feet in 485 feet, while the surface of the plot has a fall of nearly twice as much. The greater height of the water table at the west end is probably due to the friction of the flow, and is but little modified by the contour of the surface.

§ 12. I suppose that the escape of the ground water is to the eastward, though I have no direct proof of this. There is a drain running from a depression west of the plot, making a wide curve and passing again to the east of it. This drain was put in in this shape to cut off seepage from higher lying land to the westward and to drain a still lower lying portion to the east of the plot. I have elsewhere stated that it accomplished its purpose but partially.

§ 13. The daily records of the height of the water plane show that it varied quite uniformly throughout the plot—the wells as a rule rising and falling together. At times there would be a rise in the water table when no rainfall had taken place and no land had been irrigated which could affect the height of the water plane in this plot. Such rises in the water plane were probably due to meteorological conditions. A rainfall of a fraction of an inch also affected it, owing to the nearness of the plane to the surface, by modifying the capillary force within the soil. A rainfall of 0.28 of an inch at 4:30 on the 8th of July was followed on the 9th by a rise of from 0.74 to 0.90 of a foot in the water level; but a rainfall of 0.9 of an inch on the night of the 9th produced a mixed result, which was probably due to the varying character of the soil and the air contained in it. On the night of July 18th a rainfall of 0.21 of an inch occurred, and the water plane on the morning of the 19th had risen rather more than 0.40 of a foot as an average for the four wells. No further rainfall occurred, and the weather conditions remained favorable for observing how long the effect of such a rainfall would remain noticeable. On the morning of the 20th the level had fallen about 0.2 of a foot, and by the morning of the 22d it had attained the same level that it had on the 18th, prior to the rainfall. On the 23d it was a little lower, but rose again on the 24th.

§ 14. The height of the water plane oscillated throughout the season, owing to the causes already mentioned, and was also influenced directly by irrigation of higher lying land. The record for 1898 was a weekly instead of a daily one, and the minor changes due to meteorological causes were largely eliminated, and only the larger ones, such as were caused by drainage, or continued meteorological conditions, are shown.

§ 15. There was a rise of the water table throughout the plot during the month of February, 1898, of about 0.5 of a foot. The total rainfall was only .08 of an inch. During the month of March there was a fall in the water level. There was a greater rainfall than in February, though it was still insignificant. This oscillation was a longer one than is due to the usual meteorological influences or to irrigation, besides no irrigation was being practiced at this season. It may have been due to freezing and thawing and to the consequent change in the freedom of the circulation of either the water or the air within the soil.

§ 16. I supposed that the presence of the irrigation ditch near the east end of the plot exercised some influence upon the height of the water level in its immediate neighborhood. In order to observe the extent of this, the height of the water in two wells, A and G, was observed before water was turned into the ditch in the spring, and when no water had run in it for several months. We made no effort to determine whether its influence was by leakage or otherwise. The wells taken under observation were close together, A entering the gravel below the clay, while G did not reach the stratum of clay mentioned as separating the soil from the gravel, and was presumably supplied with water from the soil proper. Well G was not so deep as well A by 2 feet. The distance between the wells was 12 feet. The water in well G usually stood a little higher than in well A, whether there was water in the ditch or not. It should be added, for a better understanding of the conditions, that the ground on the east side of the ditch sloped gently to the eastward and lay between the ditch and the drain already mentioned. Water was turned into the ditch late in the afternoon of April 20th. By 6:15 p. m. of the 23d the water plane had risen 0.31 of a foot in well A, and 0.30 of a foot in well G, the former being 130½ feet and the latter 142½ feet distant from and west of the ditch. No rain had fallen during the preceding 17 days, and the effect observed was probably wholly due to the influence of the ditch, and it is doubtful whether the effect of the ditch upon the height of the water plane was ever much greater than is here indicated, 0.30 of a foot.

§ 17. The total solids and the chlorin present in the water before and after the rise showed a decrease. If the rise were due to unfiltered water passing in from the surface, or even near it, as from the bottom of the ditch, this result would stand alone and in contradiction to the results observed when the level of the water had been raised by a copious rainfall or by the application of irrigation water. In both of these cases the total solids and the chlorin were greatly increased, but not in any definite ratio—the increase in the amount of chlorin being more rapid than that of the total solids.

§ 18. The decrease in the total solids held in solution suggests the damming back of the underground water and a rising of water which was usually below the clayey stratum. The principal fact on which this interpretation rests is that the water taken from below this stratum was actually poorer in total solids than the water above it. We also attempted to study the effect of a drain run for the most part just outside of and south of the plot, but owing to a variety of causes, the principal one of which was our inability to properly attend to it, this experiment was abandoned.

§ 19. When the water table in this plot had been raised by irrigation it required from 10 to 13 days for it to fall to the level at which it stood before irrigation. The rate at which it fell was very nearly the same throughout the plot and did not reach this level at the west or higher end first and gradually proceed eastward as it would do if there were sufficient freedom of flow and the drainage was from the east end of the plot.

§ 20. It is mentioned on a preceding page that when the water level rose owing to the change in the conditions of capillarity caused by a slight rainfall, it required only about three days for it to recede to its former level, while we state that after an irrigation it required from 10 to 13 days. The two cases are quite different. In the latter case we have displaced the air and filled the soil with water, piling it up on the existing water plane; in the former we pulled it up by a force which gradually lost its power and permitted it to subside.

§ 21. The general observations on the water level in this plot shows that it is subject to small oscillations due to meteorological conditions, and that there are also oscillations extending over several weeks, the cause of which we have not attempted to suggest, and in addition to these, the accidental ones caused by rainfall or irrigation.

§ 22. The water table in the east end of the plot was seldom at a depth exceeding the height to which water would be raised by the force of capillarity, and in this section the accumulation of alkali was the greatest. This plot gave us throughout its whole extent a good opportunity to study the changes in the character and quantities of salts in the ground water.

TOTAL SOLIDS IN THE GROUND WATER.

§ 23. Samples of the ground water were taken weekly for the determination of the total solids. There seemed to be no relation between the different wells in this respect, their content being determined by the conditions obtaining in their immediate vicinity. For instance, well A, situated in the worst portion of the plot, carried on May 24th 3.6114 parts per thousand; * this quantity fell, with slight fluctuations from week to week till the end of June, when it carried 2.8714 parts. Well B, which was 150 feet west of A, carried at the beginning of this period 2.7843 parts per thousand, which rose to 3.2828 parts by June 21st, and fell to 2.9143 parts by the 28th. Well C carried, May 21st, 2.5000 parts per thousand, on June 28th 2.3286 parts. The changes in the total solids present in well D were almost identical with those observed in the case of well C. The rainfall during this time amounted to 2.08 inches. The height of the water table had varied during this period, but it was almost exactly the same at the end of it as at the beginning, the greatest variation being 0.1 of a foot higher.

§ 24. The cause of this gradual fall of the total solids held in solution by the ground water was probably not due to the influx of ground water from the west carrying a less quantity of salts in solution, for subsequent examination showed that the ground water from this direction, some of which, at least at times, found its way into this ground, was richer in this respect than the ground water usually filling this soil. The above statement that some of this water from the west found its way into the plot merely means that in extreme cases the level of the water table in the plot was affected by

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* To convert parts per thousand into grains per U. S. gallon, multiply by 58.334946, into grains per Imperial gallon by 70.0.

it, and not that I assert the actual flowing of this water to the eastward through the plot, for the total lack of agreement in the amount of the total solids in the water of the different wells, there being only an approximate agreement when the wells were only 12 feet from one another, indicates that the change of level was an actual rising and falling due to changes in pressure, mostly hydrostatic, rather than to a flowing in and mixing of other waters. If such took place above the water plane, we should expect to observe effects similar to those produced by the entrance of water from above as in the case of heavy rainfalls or irrigation.

§ 25. I have not been able to detect any pushing along of the water, indicated by the amount of total solids in solution, nor yet by their composition. I thought to test this by the addition of a quantity of a lithium salt into one of the wells, but this experiment was a failure for reasons hereafter given.

§ 26. The water soluble in the soil at various depths with high and low water plane, was not determined, but it is probable that the diminution of the total solids in solution was due to the removal of the salts from the solution and deposition of the salts in the upper portions of the soil. The organic matter held in solution fell with the total solids, judging by the loss on ignition, allowance being made for water which may have been present in gypsum.

§ 27. The irrigation applied on June 29th was not a copious one, because we had only a small quantity of water at our disposal. Its effect on the height of the water plane did not reach its maximum for several days. It was followed by an increase in the total solids in the water, but this was so irregular in its amount and in the time of its appearance that it is difficult to give an exact statement of it beyond the general one that an increase followed it. On the day previous to the application of irrigation water, the total solids in the water of well A were 2.8714 parts per thousand; five days later it carried 3.6871 parts, and twelve days after irrigation it reached 4.4443 parts. This quantity gradually decreased until just before the next irrigation it had fallen to 2.5900 parts per thousand.

§ 28. There was only a general similarity in the deportment of the wells, the individuality of the separate wells being very marked. In well B, for example, the total solids present just before irrigation amounted to 2.9143 parts per thousand, which rose to 3.1000 parts, fell to 3.0000 parts, and then rose continuously for the next eight weeks while they were falling in the other wells. The subsequent, second irrigation caused an increase in the total solids in the water of all the wells, but it was very much less in that of well B than in that of wells A and C on either side of it. This was not influenced by the height of the wells, for A was 0.70 of a foot lower, and C 0.77 of a foot higher than B. This irrigation caused an increase of 1.2286 parts per thousand in the solids in A, 2.7714 parts in that of C, and rather less than 0.0428 parts in that of B. In the case of well D there was an actual depression of the solids by 0.0714 parts per thousand, but this was probably due to the running in of water from the surface. The subsequent deportment of this well was similar to that of well B.

§ 29. The total solids in wells A and C increased suddenly after the irrigation and then fell again, reaching the point at which they stood prior to the irrigation in about three weeks. In wells D and B the total solids increased throughout this period, at the end of which the water in B showed its maximum content for the season, 4.2143 parts per thousand; in D, however, they continued to increase for three weeks longer before reaching their maximum for the season of 3.6986 parts. The maximum quantity of salts in solution in the water of well A was reached immediately after the irrigations, 3.7857 and 3.8143 parts per thousand respectively; the minimum was found in September, 2.7871 parts per thousand; in B the minimum was found in May and the maximum in September, more than three weeks after the irrigation. In C the minimum was found in June, immediately before irrigation, and the maximum, 5.1929 parts per thousand, in August, immediately after irrigation. In D the minimum was found in June and the maximum in October, over six weeks after the last irrigation. From October, 1897, till May, 1898, the total solids in the water gradually decreased, with only a few increases which were slight and immediately lost. The net result at the end of the year was a very slight decrease in the salts held in solution by the ground water. The wells showed the following quantities of salts in solution at the beginning and end of the year respectively: A, 3.6114—2.8714 parts per thousand; B, 2.7843—2.8328 parts per thousand; C, 2.5143—2.0329 parts per thousand; and D, 2.5700—2.0843 parts per thousand.

§ 30. The deportment of well B is not such as one would expect to observe in it judging from its location. Wells A and C were located in wetter and apparently more strongly alkalized sections than well B, and the sample of the soil taken near B showed the presence of less sulfuric acid and soda than those from near the other two wells, yet the water from this well is richer in dissolved salts throughout the year than the others, excepting that of well A for the month of May alone.

§ 31. When the height of the water plane is raised by irrigation water, or a continued rainfall, the percolating water carries the soluble salts with it into the ground water, and an increase in the salts dissolved in the ground water is simultaneous with the rise of the water table. It is evident that this rise is due to the piling up of water on a portion of the general water plane represented by the irrigated plot, and would not take place if the water could flow perfectly freely through the soil, which it does not do. This does not fully state the facts in regard to the increase and decrease of the salts in the ground water; for while it is true that there is an increase in the salts concurrent with the rise of the water table when it is due to the application of water to the surface, and a subsequent fall, usually quite a rapid one, we have the solids in the water of two of the wells showing a different course. The solids in that of wells B and D began to increase immediately, or very soon, after the irrigation of August 18th to 20th, and continued to increase for several weeks, though the water table was steadily falling during this time, which in the case of well D was six weeks. This is the more remarkable for in both these cases the maximum reached was the maximum for the season. In the case of the other two wells the results were in the opposite direction. In the waters of these wells the amount of the dissolved salts reached their maximum for the season immediately after the irrigation and fell within four weeks to their minimum for the remaining months of the year, and within 0.1571 parts per thousand of the minimum for the whole season. The cause of this difference is not suggested by a consideration of the rate at which the water table fell. The height of the water table above the reference plane was not the same in the different wells, and there were slight variations in the rate of fall, but neglecting these irregularities, the rate of falling was very nearly the same, so that the rapid decrease in the amount of the total solids in the water of wells A and C was not probably due to any drainage, affecting these wells to a greater extent or in a different manner than it did the wells B and D. The conditions of diffusion obtaining in the different wells probably contributed to the observed results. The composition of the solids contained in these waters will be given subsequently.

§ 32. In this irrigation, as well as in the preceding, the head of water at our disposal would not permit of our attempting to flood off any salts, and practically all the salts which were on the surface at any given place were carried back into the soil, so that there was but little, if any, transporting of salts even for a few feet in the direction of the flow of the water. It follows that any removal of salts during this season was by drainage.

§ 33. In the following season, 1898, the conditions were quite different. During April, and especially during May, there were frequent light rains. The water table was rather higher at the west end of the plot and lower at the east end than in 1897. The average height of the water table at the west end of the plot for May, 1897, was 9.80 feet, and for the same month in 1898 it was 9.98 feet for the east end; for May, 1897, it was 8.11, and for May, 1898, 7.55 feet. The rainfall in the two years differed both in its amount and distribution; there was also another changed condition, the plot had been divided into sections 100 feet long by 25 feet wide, and the alternate sections had received a heavy dressing of manure. These conditions undoubtedly had an effect upon the movement of the soluble salts in the soil and also upon the salts themselves.

§ 34. There was a remarkable change in the amount of the total solids contained in the waters of wells A and C between May 16th and 23d, each containing less by 14.3 parts per thousand on the later date. The waters of the wells contained from 3.57 to 5.71 parts per thousand more total solids on May 24, 1898, than on this date in 1897, except in the case of well D, the water of which contained 3.43 parts per thousand less.

§ 35. An examination of the results obtained in 1898 corroborate those of 1897, *i. e.*, that as a rule, the solids in the waters fell as the water table fell, and that a sufficient rainfall or an application of water to the surface was followed by an increase in the amount of salts held in solution by the ground water.

§ 36. The amount of water necessary to raise the height of the water table and at the same time produce an increase in the amount of the salts in the ground water was not observed. I have already stated that a rainfall of a few tenths of an inch was followed by a disproportionate rise in the height of the water table. In the particular instances referred to we unfortunately made no determination of the total solids immediately before and after the change of the water level.

§ 37. In May, 1898, there were nine days on which no rain fell. The aggregate rainfall for the 3d, 4th and 5th was 1.66 inches, this was followed by a rise in the height of the water table, and though there were daily light rains, except on the 10th, until the 16th the water table fell by 0.2 of a foot. In this interval 0.69 of an inch of rain had fallen, 0.22 and 0.24 of an inch being the largest amounts for any one day, an amount which under other conditions had been sufficient to cause a rise.

§ 38. The total solids present in the waters of wells A and C were very high at this date, the 16th, containing 6.1043 and 4.3414 parts per thousand respectively, while those of wells B and D were much lower, 2.9000 and 2.1000 respectively; but seven days later they had fallen in wells A and C and risen in wells

B and D. A little rain had fallen during the week, and the wells, A excepted, were lower than on the 16th.

§ 39. On June 3rd, 4th and 5th we had a rainfall aggregating 1.82 inches, which under the conditions prevailing at that time might have wet this soil to a depth of 5 inches. The water capacity of this soil, air dry, ranged from 36 to 51 per cent. The actually observed rise in the water table ranged from 0.32 to 0.95 of a foot, and the waters of the different wells showed an increase in the total solids present. The increase in the case of well B was slower than in the others. The greatest difference was shown in the case of Well C, where it amounted to 1.0630 parts per thousand. The water table and the total solids had both begun to fall by the 13th, or seven days after the last rainfall.

§ 40. The rising of the water table at times when there had been no rainfall has already been mentioned, as has also the effect of a slight moistening of the previously dry surface upon the height of the water table, but here we have the effect of 1.82 inches of rainfall upon the height of the water table reaching the considerable amount of 0.95 of a foot, or 11.4 inches, while the amount of water which fell was not sufficient to wet this soil for more than 5 inches. The amount of the rise in the different wells varied considerably, as did the increase of the total solids. The former is probably due to the capillary condition of the soil at the different places, and the latter, partly to the solution of salts out of the soil through which the water rose and partly to changes in the conditions of diffusion, for the smallest change in the amount of total solids was not in the well that rose the least, nor in one which was usually low in total solids.

§ 41. The increase in total solids present in the ground water was not always accompanied by an increase in its height. Our observations on the relation of these—increase in height of ground water and total solids contained—are not quite consonant with one another, but they agree that the effect of the addition of considerable quantities of water applied to the surface is to increase the amount of salts in solution. Sometimes the increase in the amount of the salts in solution and that in the height of the water plane fell together, but at other times they did not.

§ 42. The influence of the changes in the water level, due to very light rains or other meteorological causes, was not marked enough to be noted without special study.

§ 43. The solids in the ground water during the season 1898, from May 24th till the end of October, were a little higher during the first two-thirds of the season, but lower during the last third, than in 1897; the water level was also very low, well D going dry about September 1, and B a month later, October 1. The differences in the individual wells were the same as in 1897, except in the extent of their variation.

§ 44. No attempt was made in 1899 to continue the study of the relation of the height of the water table to the amount of total solids contained in the water.

§ 45. The question whether the height of the water in the wells corresponded with the height of the water table in the soil was repeatedly suggested. Investigation showed that, for all of our purposes, it was safe to consider them the same.

§ 46. The matter was apparently different with the total solids present in the soil and well waters, especially in newly made holes in the soil, in which the solids were higher than in water from the near-by wells. This was not due to rain water falling directly into the wells, for they were covered to prevent this, nor to its running in from the surface, for the tiles which formed the lining of the wells projected above the surface sufficiently to escape this danger. The difference in the amount of salts present in the soil and well waters varied more than I expected them to. In one case, the water table being very high, within 18 inches of the surface, the difference in the amount of the total solids in the water taken from the soil and from the well, well A, was 2 6286 parts per thousand. In another portion of the plot where the water table was not so near to the surface, and where the soil was very different, the difference in the amounts of the total solids was only 0.4714 parts per thousand.

§ 47. It was unfortunately not feasible for us to determine whether the water drained into the wells from the surrounding soil, higher than the water plane, or not. If this took place at all it would seem that it did not drain from a very wide area, the radius of the soil affected must have been very small, or we would probably not have found so great a difference in the total solids present in the soil water and that of the wells. We made an attempt to determine the distance to which an under-drain would affect the height of the water table, and also to determine its influence upon the total solids present in the ground water at different distances from it; but as already stated, the experiment, owing to a variety of causes, was abandoned. The best data that I have bearing on this point was afforded by a well situated about two-thirds of the way from the east end of my plot to an under-drain east of and lower than the plot. The conditions here were in every respect better than in the plot under observation. They had probably not been so unfavorable to begin with, but assuming that they were the results of cultivation and drainage, the drain being about 70 feet from this well, was to reduce the total solids to less than one-half the amount found in the easternmost well in my plot, 254 feet west of it. This difference held throughout the two years these wells were under observation. These data are not so good as would appear at first sight, for the plot had been under experimental cultivation for several years, five at least, and I have no means of judging to what extent, if any, the changes were due to the direct action of the drain upon this ground.

§ 48. If the water in the easternmost well was part of an eastward flow out of my plot, a large amount of the salts, 50 per cent., had been removed from solution in flowing from the eastern portion of my plot to the well, a distance of not more than 250 feet. The observations, however, upon the dissimilarity of the salt contents of the waters of the different wells justifies a serious doubt as to the existence of a flow through the soil, or if any, it is a slow one and is accompanied by an extremely slow translocation of the salts in the soil. It is certain that the soil has the power of retaining salts, but there are reasons for believing that there are marked differences in the soil in this respect, and if there were a flow, this property of the soil would tend to retard the translocation of· the salts. Some facts supporting this view will be mentioned under the subject of drainage.

§ 49. There is another consideration which should be mentioned, the difference in the amount of salts in the water actually in contact with the soil and that in the wells may indicate that the true soil water coming into the wells from the sides may have received an admixture of water coming from below, and from which those salts most readily retained by the soil had been partially removed. If this were the case it would be strongly suggestive of a flow through the gravel, and as the well referred to entered the gravel, the water may have been a mixture of waters, some entering laterally from the soil and others rising vertically from the under-flowing waters. Such might be the case, even when the height of the water in the well and that in the soil outside of the well were the same, or so nearly so that refined means of measurement would have to be used to establish the difference.

§ 50. That the water flowing through the gravel, even if it were water percolating through the overlying soil, should differ in its content of salts from the water in the soil, is in keeping with the observed fact that the total solids present fell as the water table fell. The soil through which the water table fell not having reached its point of saturation for these salts, retained them until an equilibrium between those in solution and those present in the soil had been established.

§ 51. To what extent this well A and all the others were affected by such mixing of waters has been a serious question throughout this work. The doubts entertained led me to have wells of different depths dug, and to endeavor to determine the extent to which samples of water obtained from slightly different depths taken from the same place and on the same date would differ. The results obtained prove beyond a doubt that the ordinary laws of solubility and diffusion are very radically modified and that the mixing of waters as suggested was improbable.

§ 52. I stated in Bulletin 46, page 5, that the water in the gravel stratum was different from the water in the soil proper. This appears, from the preceding statements, to be almost a matter of course; but there is a broader sense in which it might be the case, as I was at one time tempted to believe, *i. e.*, that the water in the gravel might be practically cut off from the water in the soil by the clayey stratum overlying the gravel, and that the water in the latter came from higher ground and constituted a sheet flowing eastward through it. The possibility that such might have been the case is evident, but I am satisfied that the clayey stratum did not suffice to separate the waters in the soil from that in the gravel, and I am doubtful whether the water from the higher land actually finds its way into the gravel as a distinct course for its flow. That it does not is indicated by our experience in June and July, 1899, when, because of an unusually large supply of water, the land to the west of us was excessively irrigated and the water table in our plot was raised to within eighteen inches of the surface. This water either flowed above the clayey stratum or rose through it.

§ 53. Transportation of the salts laterally through the soil did not, even in this case, seem to take place, for the individuality of the different wells was quite unaffected. Still the results of three seasons' cultivation, irrigation included, shows the removal of large quantities of soluble salts, if the amount of these held in solution by the soil waters be a reliable index. Taking the total solids in the waters of the different wells, ten days after irrigation, August 20, 1897, and August 31, 1899, we have wells A, B, C, and D showing the following total solids respectively in 1897: 30.8571, 35.2857, 3.3429 and 2.6429 parts per thousand; in 1899, 1.7857, 2.7286, 2.8857 and 3.4000 parts per thousand. In the case of Well D, in 1899, we have an increase, but after making allowance for all minor variations and a marked capriciousness in the amount of salts dissolved, there is still evidence of the removal of large amounts of the soluble salts from the soil.

§ 54. The crops, as shown in Bulletins 46 and 58, did not remove these salts, and if they did not remain more generally distributed through the mass of the soil, whereby they would be rendered more difficultly soluble in water, they must have been removed by drainage even though we were unable to detect the flow.

CHLORIN IN THE GROUND WATER.

§ 55. The amount of chlorin in the ground water was not at any time extremely high. The maximum for 1897 was 0.2400 parts per thousand, unless we include one abnormal result obtained immediately after irrigating the plot, in which case we have 0.3429 parts per thousand; this result stands alone for 1897. The same well, however, in 1898 showed two such variations reaching 0.3143 parts per thousand after an irrigation, and 0.5286 parts on May 16th. The month had been wetter than usual, 2.9 inches of rain having fallen up to this date. With these exceptions this well was not so high in chlorin as two of the other three.

§ 56. The ratio of the chlorin to the total solids in the water ranged from 1:18 to 1:25 for well A from May, 1897, till May 1, 1898; for well B it ranged from 1:15 to 1:19; for well C from 1:18 to 1:22; and for well D from 1:16 to 1:22. In other words the salt, NaCl, found in the water did not, at any time during the year, amount to quite 1-9 of the total matter held in solution by the water and fell as low, in round numbers, as 1-16 of the total solids. In 1898 the ratio of the chlorin to the total solids for the respective wells varied as follows: for A, from 1:13 to 1:21; for B, from 1:14 to 1:16; for C, from 1:11 to 1:27; and for D, from 1:18 to 1:33. The largest amount of salt, NaCl, present equalled 1-7 and the smallest 1-20, or from 14.3 per cent. down to 5.0 per cent. of the total solids present. The latter part of the season of 1898 was quite dry and the water table fell so that some of the wells went dry. The total solids fell with the water table and so did the chlorin, but not proportionately with the total solids; the latter fell from 4.1857 parts per thousand on May 23 to 2.3429 parts on November 7, and the former fell from 0.32400 parts to 0.11071 parts per thousand in the same time. The total solids fell by a little less than one-half their quantity, while the chlorin fell by two-thirds of the amount present when the water table was high, May 23.

§ 57. The chlorin in the water was no indication of the amount of total solids present except within the very wide limits given above, which were different for each individual well; furthermore its quantity varied with the falling of the water table differently from that of the total solids, and increased in a most irregular manner when it rose, especially when the rising of the water table was due to irrigation or to heavy rainfalls. Experiments made by filtering salt solutions through sandstones have shown that they have a considerable power to retain it. Something similar probably takes place in this case, but the conditions of equilibrium between the salt solution and the soil are changed, perhaps are constantly changing, and the soil retains more of the sodic chlorid as the water table falls, or gives it up as it rises, sometimes in a most irregular fashion. Evaporation from the surface and capillarity undoubtedly influence these changes continuously. This view seems so fully conformable to what we know concerning the deportment of mixed salt solutions when in contact with soil that one is tempted to assert it as a demonstrated fact.

§ 58. Two experiments were made in the hope of gaining definite data relating to it. An excavation was made and a sample taken as soon as the water table was entered, a second sample was taken one foot below this, the water from the first foot being cut off as completely as possible so that the second sample represented water from the soil one foot below the water table; a third sample was taken at a depth of an additional foot with the same precautions. The respective samples showed the presence of 0.23286, 0.1771 and 0.1171 parts per thousand. Thirteen days later we repeated this experiment, choosing another portion of the plot for our observations. The sample of water taken at the surface of the water table contained 0.2129 parts, and the second one, taken a foot below the surface, showed the presence of 0.1457 parts per thousand. Two other samples were taken at greater depths, but the inflow of water was so great that the results were not so reliable. They showed, however, essentially the same as the second sample.

§ 59. The ratios of the chlorin to the total solids in the two experiments are not concordant and permit no inference whatever to be drawn from them. These facts establish what I have elsewhere stated, that the order of solubility of the different salts and the laws of diffusion are greatly modified by the properties of the soil particles and the relative masses of the soil water and the soil.

§ 60. The effect of irrigation, particularly when sufficient to raise the height of the water table, was to increase the absolute quantity of chlorin in the water, but not proportionately with the other salts. There were differences in the wells in this respect. The ratio of the chlorin to the total solids in well D before irrigation was 1:34, and after irrigation 1:64; in wells A and B the changes were in the same direction, but much less; in the case of well C the change in the ratio, though small, was in the opposite direction. The local conditions, including variations in the soil, seem to influence the amounts of the salts taken into solution and especially the relative quantities of the same. The soil in the vicinity of well C contained, according to analysis, more than twice as much chlorin as the soils in the vicinity of the other wells. The water soluble in this soil was less than in that about well A, but greater than in that about wells B and D for both the first and second two inches. The percentages of chlorin in the water soluble portions of the soils are not very different, but it is not probable that the salts present in the soils are the same. The whole of the chlorin may be present in the form of ordinary salt in one case and in the form of magnesic or some other chlorid in the other; this seems to be the actual case for we were unable to combine the results of the analyses of these different water soluble portions in the same manner.

§ 61. It was hoped that the amount of the chlorin in the water and its variation from time to time might throw some light upon the movement of the alkali salts in the soil; but these seem so dependent upon local conditions and the character of the soil that no general deductions are justified.

TOTAL SOLIDS.

§ 62. The term total solids is here equivalent to alkali salts in solution in the ground water, and these are not the same as those which form the alkali incrustations, nor are they equal to the water soluble portion of the soil. These are three different mixtures of salts.

§ 63. It has been given as the result of three seasons' observation on this plot that the amount of the total solids varied in different portions, as shown by the fact that the wells differed from one another in this respect, and that there was no relation in the rate or extent of their variations. This is not the case with the composition of the solids held in solution, as shown by more than one hundred complete analyses of the waters of the different wells.

§ 64. I wish to emphasize the statement that the well waters represent the composition of all the water flowing into the well, between the surface of the water table and the bottom of the well, also possibly of water coming from the gravel below the well, for it is certain that however abnormally the salts may diffuse through the solution within the mass of the soil, they are entirely relieved from the influence of the soil particles in the free water accumulating in the wells. These well waters probably represent the average free solution in the soil for a depth represented by the height of the water plane above the bottom of the well, especially if there is no hydrostatic pressure forcing water upward out of a more porous stratum, as might have been the case in some of my wells where they entered the gravel.

§ 65. I have two analyses which, taken with the conditions under which the samples were collected, will fully present this view. They are of water from wells designated as B and G respectively. Well B was put down in May, 1897, and had been open for a year at the time the sample in question was taken; well G was put down the day the sample was taken. Well B reached the gravel at a depth of 6 feet, while well G was but 4 feet deep, leaving about 2 feet of a difficultly pervious soil between the bottom of the well and the gravel. The analyses of the two samples follow:

TABLE I.—ANALYSIS OF WATER FROM WELL B, MAY 30, 1898.

Analytical Results.	*Per Cent.*	*Grs. Imp. Gal.*	*Combined.*	*Per Cent.*	*Grs. Imp. Gal.*
Silicic Acid	0.541	1.176	Calcic Sulfate	39.704	86.317
Sulfuric Acid	45.871	99.724	Magnesic Sulfate	24.934	54.207
Carbonic Acid	3.318	7.214	Potassic Sulfate	0.370	0.795
Chlorin	6.239	13.563	Sodic Sulfate	10.173	22.166
Sodic Oxid	15.165	32.969	Sodic Clorid	10.292	22.376
Potassic Oxid	0.200	0.435	Sodic Carbonate	7.994	17.378
Calcic Oxid	16.361	35.568	Sodic Silicate	1.099	2.389
Magnesic Oxid	8.304	18.054	Ferric and Alu. Oxids	0.031	0.067
Ferric and Alu. Oxids	0.031	0.067	Manganic Oxid	0.021	0.045
Manganic Oxid	0.021	0.045	Ignition	5.235	11.381
Ignition	5.235	11.381			
Sum	101.286	220.196	Sum	99.853	217.073
Oxygen Eq. to Chlorin	1.406	3.057	Excess Sodic Oxid	0.223	0.050
Total	99.880	217.139	Total	99.876	217.123

Total solids 3.1057 parts per thousand, or 217.4 grains per imperial gallon.

TABLE II.—ANALYSIS OF WATER FROM WELL G, MAY 30, 1898.

Analytical Results.	*Per Cent.*	*Grs Imp. Gal.*	*Combined.*	*Per Cent.*	*Grs. Imp. Gal.*
Silicic Acid	0.665	1.350	Calcic Sulfate	38.430	78.013
Sulfuric Acid	46.504	93.997	Magnesic Sulfate	24.897	50.541
Carbonic Acid	3.580	7.267	Potassic Sulfate	0.212	0.430
Chlorin	6.226	12.639	Sodic Sulfate	12.444	25.261
Sodic Oxid	16.450	33.394	Sodic Chlorid	10.247	20.855
Potassic Oxid	0.115	0.233	Sodic Carbonate	8.632	17.523
Calcic Oxid	15.831	32.137	Sodic Silicate	0.997	2.024
Magnesic Oxid	8.297	16.843	Ferric and Alu. Oxids	0.041	0.083
Ferric and Alu. Oxids	0.041	0.083	Manganic Oxid	0.041	0.083
Manganic Oxid	0.041	0.083	Ignition	4.102	8.327
Ignition	4.102	8.327			
Sum	101.652	206.353	Sum	100.073	203.140
Oxygen Eq. to Chlorin	1.403	2.848	Excess Silicic Acid	0.174	0.353
Total	100.249	203.505	Total	100.244	203.493

Total solids 6.7285 parts per thousand, or 203 grains per imperial gallon.

§ 66. These two analyses differ slightly in the ratios of the respective salts to the total solids, but serve to justify the statement made above that the well waters may be assumed to faithfully represent the composition of the freely circulating waters within the soil to the depth of the well. This is still the case when the water level changes. The samples, of which analyses have just been given, were taken when the water plane was relatively high and the ground water contained rather more than 28.5714 parts per thousand. The following sample was taken when the water plane had been raised by irrigating the plot, and the total solids present in the water were almost 70 per cent. higher than on May 30th, when the preceding samples were taken. While there are some differences, they are comparatively small, which fact appears most clearly from the percentage composition of the total solids as given by the direct results of the analysis which follows:

TABLE III.—ANALYSIS OF WATER FROM WELL G, JULY 11, 1898.

Analytical Results.	*Per Cent.*	*Grs. Imp. Gal.*
Silicic Acid	0.337	1.149
Sulfuric Acid.	46.106	157.221
Carbonic Acid	3.456	11.785
Chlorin	6.317	21.541
Sodic Oxid	17.165	58.533
Potassic Oxid	1.002	3.417
Calcic Oxid	13.539	46.168
Magnesic Oxid	9.052	30.867
Ferric and Alu. Oxids	0.070	0.239
Manganic Oxid	0.060	0.205
Ignition	4.352	14.840
Sum	101.456	345.965
Oxygen Eq. to Chlorin	1.423	4.852
Total	100.033	341.113

Combined.	*Per Cent.*	*Grs. Imp. Gal.*
Calcic Sulfate	32.866	112.073
Magnesic Sulfate	27.162	92.622
Potassic Sulfate	1.845	6.283
Sodic Sulfate	13.897	47.389
Sodic Chlorid	10.424	35.546
Sodic Carbonate	8.333	28.416
Sodic Silicate	0.684	2.332
Ferric and Alu. Oxids	0.070	0.239
Manganic Oxid	0.060	0.205
Ignition	4.352	14.840
Sum	99.693	339.945
Excess Sodic Oxid	0.337	1.149
Total	100.030	341.094

Total solids 4.7714 parts per thousand, or 341.0 grains per imperial gallon.

§ 67. What has just been said is true of the water of all of the wells throughout the three seasons during which we had them under observation.

§ 68. The salts present, that is constituting the total solids, in the waters are calcic, magnesic, and sodic sulfates with sodic carbonate and chlorid.

§ 69. In the analyses already given, and in those to follow, I have combined the acids and basis in the order adopted in Bulletin 65, believing that this order represents as nearly as any other which might have been adopted, the salts which actually exist in the solution. It is certainly not always correct, but it gives us an easy and uniform method of statement. That it is not correct in every case is clear, for the sodic carbonate appears in the analysis as the normal salt, which when present in the quantities shown by the analyses, ought to react with phenolphthalein, but it does not, and is probably present wholly as the acid carbonate or bicarbonate. The total carbonic acid in the waters as they were taken from the wells was not determined, still there is no doubt but that the sodic carbonate existed essentially if not wholly as a bicarbonate. Again the calcic sulphate appears in the analysis without any water of crystallization, but it is in no way intended to state that calcic sulphate was actually present as anhydrite. I do not think it possible to tell just how these groups were arranged in the solution, how many of them were free and how many of them combined, but I simply present the probable combinations as an easy and convenient way of expressing our results. The statement of the analysis is so full that further explanation is unnecessary.

§ 70. I find it a common thing, almost a rule, that the analyses show a slight excess of sodic oxid, sometimes, however, the excess is silicic acid. I have also found this to be a common result in the analysis of alkali incrustations. I attributed this excess to the probable presence of organic acids. Examinations for volatile organic acids did not justify the assumption of the excess being due to their presence, for I found them present in very minute quantities. The excess of sodic oxid is usually higher when the loss on ignition is high, than it is when this loss is low. The excess is often very insignificant and within the limits of analytical errors.

§ 71. For the purpose of presenting the general composition of the well waters I will give analyses of samples taken in the month of July, 1897 and 1898, because I think that the samples of this month show less uniformity than those of any other in which regular samples were taken. The following are all of the samples taken from these wells during this month, except some taken immediately after irrigation.

TABLE IV.—ANALYSIS OF WATER FROM WELL A, JULY 5, 1897.

Analytical Results.	*Per Cent.*	*Grs. Imp. Gal.*	*Combined.*	*Per Cent.*	*Grs. Imp. Gal.*
Silicic Acid	0.474	1.223	Calcic Sulfate	36.500	94.207
Sulfuric Acid	48.853	126.090	Magnesic Sulfate	28.795	74.320
Carbonic Acid	1.997	5.154	Potassic Sulfate	0.594	1.533
Chlorin	5.598	14.448	Sodic Sulfate	13.995	36.121
Sodic Oxid	14.373	37.097	Sodic Chlorid	9.233	23.830
Potassic Oxid	0.321	0.829	Sodic Carbonate	4.815	12.428
Calcic Oxid	14.999	38.712	Sodic Silicate	0.963	2.486
Magnesic Oxid	9.596	24.767	Ferric and Alu. Oxids	0.177	0.457
Ferric and Alu. Oxids	0.177	0.457	Manganic Oxid	0.143	0.369
Manganic Oxid	0.143	0.369	Ignition	4.410	11.382
Ignition	4.410	11.382	Sum	99.625	257.133
Sum	100.941	260.528	Excess Sodic Oxid	0.054	0.139
Oxygen Eq. to Chlorin	1.261	3.255	Total	99.679	257.272
Total	99.680	257.273			

Total solids 3.6871 parts per thousand, or 258.1 grains per imperial gallon.
Sample taken six days after irrigation.

TABLE V.—ANALYSIS OF WATER FROM WELL A, JULY 25, 1898.

Analytical Results.	*Per Cent.*	*Grs. Imp. Gal.*
Silicic Acid	0.547	1.456
Sulfuric Acid	45.209	120.346
Carbonic Acid	2.140	5.696
Chlorin	6.475	17.235
Sodic Oxid	14.114	37.572
Potassic Oxid	0.057	0.152
Calcic Oxid	15.397	40.988
Magnesic Oxid	8.515	22.668
Ferric and Alu. Oxids	0.091	0.243
Manganic Oxid	0.037	0.099
Ignition	8.621	22.948
Sum	101.203	269.403
Oxygen Eq. to Chlorin	1.459	3.884
Total	99.744	265.519

Combined.	*Per Cent.*	*Grs. Imp. Gal.*
Calcic Sulfate	37.366	99.468
Magnesic Sulfate	25.568	68.061
Potassic Sulfate	0.106	0.281
Sodic Sulfate	10.903	29.025
Sodic Chlorid	10.681	28.433
Sodic Carbonate	5.155	13.721
Sodic Silicate	1.111	2.958
Ferric and Alu. Oxids	0.091	0.243
Manganic Oxid	0.037	0.099
Ignition	8.621	22.948
Sum	99 639	265.237
Excess Sodic Oxid	0.101	0.268
Total	99.740	265.505

Total solids 3.8028 parts per thousand, or 266.2 grains per imperial gallon.

TABLE VI.—ANALYSIS OF WATER FROM WELL B, JULY 5, 1897.

Analytical Results.	*Per Cent.*	*Grs. Imp. Gal.*
Silicic Acid	0.646	1.406
Sulfuric Acid	46.912	102.081
Carbonic Acid	2 166	4.713
Chlorin	5.795	12.610
Sodic Oxid	16.679	36 294
Potassic Oxid	0.531	1.155
Calcic Oxid	14.158	30.808
Magnesic Oxid	8.299	18.059
Ferric and Alu. Oxids	0.141	0.307
Manganic Oxid	0.070	0.152
Ignition	5.909	12 858
Sum	101.306	220 443
Oxygen Eq. to Chlorin	1.306	2.842
Total	100.000	217.601

Combined.	*Per Cent.*	*Grs. Imp. Gal.*
Calcic Sulfate	34 359	74.765
Magnesic Sulfate	24.903	54.189
Potassic Sulfate	0.982	2.137
Sodic Sulfate	17.149	37.316
Sodic Chlorid	9.558	20.798
Sodic Carbonate	5.223	11.365
Sodic Silicate	1.312	2.855
Ferric and Alu. Oxids	0.141	0.307
Manganic Oxid	0.070	0.152
Ignition	5.909	12.858
Sum	99 606	216.742
Excess Sodic Oxid	0.394	0.856
Total	100.000	217.598

Total solids 3.1085 parts per thousand, or 217.6 grains per imperial gallon.
Sample taken six days after irrigation.

TABLE VII.—ANALYSIS OF WATER FROM WELL B, JULY 25, 1898.

Analytical Results.	*Per Cent.*	*Grs. Imp. Gal.*
Silicic Acid	0.619	1.750
Sulfuric Acid	45 837	129.581
Carbonic Acid	2 561	7.240
Chlorin	6 413	18.129
Sodic Oxid	17.849	50.459
Potassic Oxid	0.101	0.286
Calcic Oxid	14.146	39.981
Magnesic Oxid	7.712	21.802
Ferric and Alu. Oxids	0.030	0.085
Manganic Oxid	0.030	0.085
Ignition	6.117	17.293
Sum	101.415	286.691
Oxygen Eq. to Chlorin	1.445	4.085
Total	99 970	282.606

Combined.	*Per Cent.*	*Grs. Imp. Gal.*
Calcic Sulfate	34.339	97.076
Magnesic Sulfate	23 141	65.420
Potassic Sulfate	0.186	0.526
Sodic Sulfate	17.988	50.852
Sodic Chlorid	10.583	29.918
Sodic Carbonate	6.175	17.457
Sodic Silicate	1.258	3.556
Ferric and Alu. Oxids	0.030	0.085
Manganic Oxid	0.030	0.085
Ignition	6.117	17.293
Sum	99.847	282.268
Excess Sodic Oxid	0.121	0.342
Total	99.968	282.610

Total solids 4.0385 parts per thousand, or 282.7 grains per imperial gallon.

TABLE VIII.—ANALYSIS OF WATER FROM WELL C, JULY 5, 1897.

Analytical Results.	*Per Cent.*	*Grs. Imp. Gal.*
Silicic Acid	0.408	0.816
Sulfuric Acid	50.288	100.576
Carbonic Acid	2.550	5.100
Chlorin	3.294	6.588
Sodic Oxid	15.651	31.302
Potassic Oxid	0.341	0.682
Calcic Oxid	16.854	33.708
Magnesic Oxid	7.623	15.246
Ferric and Alu. Oxids	0.260	0.520
Manganic Oxid	0.137	0.274
Ignition	3.661	7.322
Sum	101.067	202.134
Oxygen Eq. to Chlorin	0.741	1.482
Total	100.326	200.652

Combined.	*Per Cent.*	*Grs. Imp. Gal.*
Calcic Sulfate	40.901	81.802
Magnesic Sulfate	22.874	45.748
Potassic Sulfate	0.631	1.262
Sodic Sulfate	19.003	38.006
Sodic Chlorid	5.433	10.866
Sodic Carbonate	6.149	12.298
Sodic Silicate	0.829	1.658
Ferric and Alu. Oxids	0.260	0.520
Manganic Oxid	0.137	0.274
Ignition	3.661	7.322
Sum	99.878	199.756
Excess Sodic Oxid	0.447	0.894
Total	100.325	200.650

Total solids 2.5714 parts per thousand, or 200.0 grains per imperial gallon.
Sample taken six days after irrigation.

TABLE IX.—ANALYSIS OF WATER FROM WELL C, JULY 25, 1898.

Analytical Results.	*Per Cent.*	*Grs. Imp. Gal.*
Silicic Acid	0.609	1.121
Sulfuric Acid	46.151	84.965
Carbonic Acid	3.911	7.201
Chlorin	4.770	8.781
Sodic Oxid	19.651	36.177
Potassic Oxid	0.015	0.028
Calcic Oxid	12.672	23.329
Magnesic Oxid	8.200	15.097
Ferric and Alu. Oxids	0.045	0.082
Manganic Oxid	0.040	0.073
Ignition	4.938	9.090
Sum	101.002	185.944
Oxygen Eq. to Chlorin	1.075	1.979
Total	99.927	183.965

Combined.	*Per Cent.*	*Grs. Imp. Gal.*
Calcic Sulfate	30.752	56.615
Magnesic Sulfate	24.622	45.329
Potassic Sulfate	0.029	0.053
Sodic Sulfate	20.666	38.047
Sodic Chlorid	7.869	14.486
Sodic Carbonate	9.423	17.348
Sodic Silicate	1.237	2.278
Ferric and Alu. Oxids	0.045	0.082
Manganic Oxid	0.040	0.073
Ignition	4.938	9.090
Sum	99.621	183.401
Excess Sodic Oxid	0.304	0.560
Total	99.925	183.961

Total solids 2.6300 parts per thousand, or 184.1 grains per imperial gallon.

TABLE X.—ANALYSIS OF WATER FROM WELL D, JULY 5, 1897.

Analytical Results.	*Per Cent.*	*Grs. Imp. Gal.*
Silicate Acid	0.639	1.040
Sulfuric Acid	45.490	74.012
Carbonic Acid	2.351	3.825
Chlorin	5.765	9.380
Sodic Oxid	18.578	30.226
Potassic Oxid	0.191	0.311
Calcic Oxid	14.619	23.785
Magnesic Oxid	6.351	10.333
Ferric and Alu. Oxids	0.639	1.040
Manganic Oxid	0.067	0.109
Ignition	6.579	10.704
Sum	101.269	164.765
Oxygen Eq. to Chlorin	1.299	2.113
Total	99.970	162.652

Combined.	*Per Cent.*	*Grs. Imp. Gal.*
Calcic Sulfate	35.477	57.712
Magnesic Sulfate	19.057	31.006
Potassic Sulfate	0.353	0.574
Sodic Sulfate	20.893	33.993
Sodic Chlorid	9.509	15.471
Sodic Carbonate	5.669	9.223
Sodic Silicate	1.298	2.112
Ferric and Alu. Oxids	0.639	1.040
Manganic Oxid	0.067	0.109
Ignition	6.579	10.704
Sum	99.541	161.943
Excess Sodic Oxid	0.429	0.698
Total	99.970	162.651

Totol solids 2.3242 parts per thousand, or 162.7 grains per imperial gallon.
Sample taken six days after irrigation.

TABLE XI.—ANALYSIS OF WATER FROM WELL D, JULY 19, 1897.

Analytical Results.	*Per Cent.*	*Grs. Imp. Gal.*
Silicic Acid	0.539	1.103
Sulfuric Acid	45.095	92.309
Carbonic Acid	2.695	5.517
Chlorin	6.271	12.837
Sodic Oxid	17.089	34.981
Potassic Oxid	0.345	0.706
Calcic Oxid	15 185	31.084
Magnesic Oxid	6.928	14.182
Ferric and Alu. Oxids	0.207	0.424
Manganic Oxid	0.061	0.125
Ignition	6.490	13 285
Sum	100.995	206.553
Oxygen Eq. to Chlorin	1.413	2 892
Total	99.492	203.661

Combined.	*Per Cent.*	*Grs. Imp. Gal.*
Calcic Sulfate	36.851	75.435
Magnesic Sulfate	20.789	42.555
Potassic Sulfate	0.638	1 306
Sodic Sulfate	16.472	33.718
Sodic Chlorid	10.343	21.172
Sodic Carbonate	6 498	13.301
Sodic Silicate	1.095	2.241
Ferric and Alu. Oxids	0.207	0.424
Manganic Oxid	0.061	0.125
Ignition	6.490	13.285
Sum	99.444	203.562
Excess Sodic Oxid	0.047	0.096
Total	99.491	203.658

Total solids 2.9242 parts per thousand, or 204.7 grains per imperial gallon.

TABLE XII.—ANALYSIS OF WATER FROM WELL D, JULY 25, 1898.

Analytical Results.	*Per Cent.*	*Grs. Imp. Gal.*
Silicic Acid	0.520	1.203
Sulfuric Acid	46.633	107.862
Carbonic Acid	3.217	7.441
Chlorin	3.067	7.094
Sodic Oxid	15.448	35.731
Potassic Oxid	0.096	0.222
Calcic Oxid	14.610	33.793
Magnesic Oxid	7.959	18.409
Ferric and Alu. Oxids	0.087	0.201
Manganic Oxid	0.087	0.201
Ignition	8.821	20.404
Sum	100.545	232.561
Oxygen Eq. to Chlorin	0.691	1.598
Total	99.854	230.963

Combined.	*Per Cent.*	*Grs. Imp. Gal.*
Calcic Sulfate	35.466	82.033
Magnesic Sulfate	23.883	55.241
Potassic Sulfate	0.178	0.412
Sodic Sulfate	17.353	40.137
Sodic Chlorid	5.059	11.701
Sodic Carbonate	7.757	17.942
Sodic Silicate	1.056	2.443
Ferric and Alu. Oxids	0.087	0.201
Manganic Oxid	0.087	0.201
Ignition	8.821	20.404
Sum	99.747	230.715
Excess Sodic Oxid	0.107	0.248
Total	99.854	230.963

Total solids 3.30429 parts per thousand, or 231.3 grains per imperial gallon.

§ 72. These analyses present the highest limit of the sulfates not only for this month but for the whole time that the plot was under observation. The sample from well C, taken July 5, 1897, six days after irrigation, shows the presence of 50.29 per cent. sulfuric acid, SO_3, which is nearly 1.5 per cent. higher than the next highest one given and is the highest, with one exception, in the whole series representing the three seasons' work. That the average percentage of sulfuric acid for all of the analyses made of these well waters is lower than that shown by these for the month of July may be inferred from the fact that there are only 8 in the 105 analyses made showing 48 per cent. or more of this constituent.

§ 73. The analyses given show almost as great a range in the quantity of chlorids present as the whole number of samples taken. There are only a few exceptional samples which show either higher or lower figures for the chlorids than those given.

§ 74. These samples also serve to represent the general composition of the total solids present in this class of ground waters. As a matter of course it is not intended that one shall infer from this statement that the alkaline ground waters occurring in different parts of the state are so rich in total solids or that the different salts are present in the same proportions, but that the ground waters in alkalied sections are of this general type. I have not yet found any ground water materially richer in sodic chloride (common salt) or sodic carbonate. It is true that some surface well waters that have come to hand for analysis, have shown relatively much larger amounts of carbonates, while the total solids were materially less in quantity. These waters were from wells sunk for the purpose of obtaining potable water, or water for use in boilers, and I assume that the samples represented the best procurable quality of such waters.

§ 75. The following analysis of a water struck at a depth of 28 feet and occurring in a two-foot stratum of sand, will serve for comparison with the analyses of ground waters already given. This sample of water was sent to us from Rockyford, in the Arkansas Valley:

TABLE XIII.—ANALYSIS OF WATER FROM ROCKYFORD, JULY 26. 1900.

Analytical Results.	*Per Cent.*	*Grs. Imp. Gal.*	*Combined.*	*Per Cent.*	*Grs. Imp. Gal.*
Silicic Acid	0.141	0.880	Calcic Sulfate	15.206	94.870
Sulfuric Acid	45.136	281.603	Magnesic Sulfate	29.059	181.299
Carbonic Acid	3.989	24.887	Potassic Sulfate	Trace	Trace
Chlorin	3.772	23.533	Sodic Sulfate	29.865	186.328
Sodic Oxid	22.277	138.986	Sodic Chlorid	6.224	38.832
Potassic Oxid	Trace	Trace	Sodic Carbonate	9.619	60.013
Calcic Oxid	6.264	39.081	Sodic Silicate	0.286	1.784
Magnesic Oxid	9.684	60.418	Ferric and Alu. Oxids	0.010	0.062
Ferric and Alu. Oxids	0.010	0.062	Manganic Oxid	0.040	0.250
Manganic Oxid	0.040	0.250	Ignition	9.233	57.605
Ignition	9.233	57.605	Sum	99.542	621.043
Sum	100.546	627.307	Excess Sodic Oxid	0.152	0.948
Oxygen Eq. to Chlorin	0.850	5.303	Total	99.694	621.991
Total	99.696	622.004			

Total solids 8.9129 parts per thousand, or 623.9 grains per imperial gallon.

§ 76. A sample of ground water from this locality, Rockyford, taken under my own directions, but at a depth of 12 feet, differed from the above in the relative amounts of calcic and magnesic sulfates, but the quantities of sodic sulfate and chlorid were nearly the same.

§ 77. There is, as I have previously intimated, probably a difference between samples taken as soon as the water plane has been entered and after the well has been emptied several times by continued pumping or bailing; there is, besides, in shallow wells at least, a difference due to the conditions which prevailed immediately prior to the time of taking the sample.

§ 78. Outside of these general features but little is shown by the composition of the ground waters as collected in the wells. The changes observed are not so great as were looked for, and when the variations due to changes in conditions immediately before the taking of the samples have been allowed for, the uniformity throughout the period of observation, a period of nearly three years, leaves but little doubt of the correctness of the conclusion that, while the total solids may vary in their quantity and in composition, too, within narrow limits, they remain in all essential respects the same.

THE GROUND WATERS DIFFERENT FROM ALKALIES—ALSO FROM THE DRAIN WATERS.

§ 79. The total solids, obtained by evaporating the ground waters, represent a different mixture of salts than that which is obtained by continued treatment of the soil with frequently renewed portions of distilled water, until it is so thoroughly exhausted that no sulfuric acid can be found in the solution after standing in contact with the soil for not less than 12 hours. Attention was called to this fact in Bulletin 65, where some analyses of the water-soluble portions of this soil are given, together with their most characteristic features.

§ 80. In the following comparison we shall not make any attempt to assign causes for the differences which are undoubtedly to be found in the complex reactions taking place between the different salts or their ions within the mass of the soil, and also to the formation of salts de novo, due to the action of water as such, and of solutions upon the rock particles in the soil. In Bulletin 65 the suggested explanation was confined almost wholly to the latter phase of the question because it is the simplest feature of it and conveys a sufficiently extensive view of the subject without introducing any of the more difficult questions involved in the theory of solutions. For a fuller and sufficient explanation of the facts recourse must be had to this branch of the subject, but I shall content myself with as clear a statement of the facts as I may be able to make.

§ 81. The samples which I have chosen are a sample of water from well C, the water soluble portions from two samples of soil C and a representative alkali incrustation. The designation well C and soil C is equivalent to stating that the sample of soil was taken as near to well C as we deemed advisable, which in this case was within 11 feet.

§ 82. It is difficult to present this subject without reproducing all of the analyses representing the different sections of the plot, for they differ so much in character that one is not really representative of the plot. The suggested difficulties are still greater than the simple lack of representativeness, for it suggests that the chemical reactions taking place within very limited areas of soil may be but partially or not at all comparable. This difference is made strikingly evident by the difference in the salts present in the water-soluble portions of the first and second two inches of these soils. Whether I have adopted the proper order of combination or not does not matter. I have adopted the same method of interpretation in all cases, which in itself may be an error, still it brings out several important and scarcely questionable differences.

§ 83. I shall select section C for my present purpose, because it is less favorable to my presentation of this subject than B or D, and rather more favorable than section A. The reader who wishes to compare the results obtained for the other sections can find the analyses of the water-soluble portions of the soil in Bulletin 65, pages 36, 37 and 38.

§ 84. The samples of soil were taken, one in May and the other in June. The sample of water was taken in June. It would have been better for the present purpose had they been taken at the same time as well as from the same place, but I have chosen these from the samples taken, as being the nearest together in the point of time of collecting.

§ 85. The alkali which I use in this case was also collected in June, but nearer to well A than to well C. This, however, does not detract from its value for the purpose of comparison, for other samples show that the differences in the alkali incrustations of this plot do not lie in the salts of which they are composed, but in their relative quantities. I have a sample taken nearer to well C, but it was taken in January during freezing weather, which, owing to the deportment of sodic sulfate at low temperatures, might make it less comparable than the one chosen.

The arrangement of the analyses is evident.

TABLE XIV.—ANALYSIS OF ALKALI, INCRUSTATION.

Analytical Results.	*Per Cent.*
Silicic Acid	0.491
Sulfuric Acid	52.403
Carbonic Acid	0.730
Chlorin	2.004
Sodic Oxid	26.797
Potassic Oxid	0.048
Calcic Oxid	3.050
Magnesic Oxid	8.951
Ferric and Alu. Oxids	0.030
Manganic Oxid	0.129
Ignition	5.384
Sum	100.017
Oxygen Eq. to Chlorin	0.451
Total	99.566

Combined.	*Per Cent.*
Calcic Sulfate	7.404
Magnesic Sulfate	26.859
Potassic Sulfate	0.088
Sodic Sulfate	53.450
Sodic Chlorid	3.307
Sodic Carbonate	1.760
Sodic Silicate	0.997
Ferric and Alu. Oxids	0.030
Manganic Oxid	0.129
Ignition	5.384
Sum	99.408
Excess Sodic Oxid	0.157
Total	99.565

TABLE XV.—ANALYSIS WATER-SOLUBLE, SOIL C, FIRST TWO INCHES.

Analytical Results.	*Per Cent.*
Silicic Acid	1.084
Sulfuric Acid	48.826
Phosphoric Acid	None
Carbonic Acid	0.385
Chlorin	4.321
Potassic Oxid	1.338
Sodic Oxid	10.190
Calcic Oxid	17.826
Magnesic Oxid	8.080
Ferric and Alu. Oxids	——
Manganic Oxid	0.342
Ignition	8.281
Sum	100.673
Oxygen Equivalent to Chlorin	0.973
Total	99.700

Combined.	*Per Cent.*
Calcic Sulfate	43.260
Magnesic Sulfate	24.260
Potassic Sulfate	2.475
Sodic Sulfate	10.789
Sodic Chlorid	7.128
Sodic Carbonate	0.928
Sodic Silicate	2.202
Ferric and Alu. Oxids	——
Manganic Oxid	0.342
Ignition	8.281
Sum	99.665
Excess Sodic Oxid	0.031
Total	99.696

The percentage of water-soluble equalled 2.0544.

TABLE XVI.—ANALYSIS WATER-SOL., SOIL C, SECOND TWO INCHES.

Analytical Results.	*Per Cent.*
Silicic Acid	9.095
Sulfuric Acid	34.832
Phosphoric Acid	0.522
Carbonic Acid	5.558
Chlorin	2.663
Potassic Oxid	3.252
Sodic Oxid	8.778
Calcic Oxid	20.981
Magnesic Oxid	7.131
Ferric and Alu. Oxids	0.878
Manganic Oxid	0.245
Ignition	6.996
Sum	100.951
Oxygen Equivalent to Chlorin	0.600
Total	100.351

Combined	*Per Cent.*
Calcic Sulfate	50.917
Magnesic Sulfate	3.197
Potassic Sulfate	6.016
Magnesic Phosphate	0.963
Magnesic Chlorid	3.565
Magnesic Carbonate	8.646
Sodic Carbonate	2.490
Sodic Silicate	14.418
Ferric and Alu. Oxids	0.898
Manganic Oxid	0.245
Ignition	6.996
Sum	98.351
Excess of Silicic Acid	1.998
Total	100.349

The percentage of water-soluble equalled 0.813.

TABLE XVII.—ANALYSIS OF WATER FROM WELL C, JUNE 13, 1898.

Analytical Results.	*Per Cent.*	*Combined.*	*Per Cent.*
Silicic Acid	0.656	Calcic Sulfate	35.054
Sulfuric Acid	44.875	Magnesic Sulfate	21.520
Carbonic Acid	3.517	Potassic Sulfate	0.107
Chlorin	5.144	Sodic Sulfate	17.517
Sodic Oxid	18.108	Sodic Chlorid	8.487
Potassic Oxid	0.058	Sodic Carbonate	8.474
Calcic Oxid	14.445	Sodic Silicate	1.333
Magnesic Oxid	7.167	Ferric and Alu. Oxids	0.026
Ferric and Alu. Oxids	0.026	Manganic Oxid	0.041
Manganic Oxid	0.041	Ignition	6.911
Ignition	6.911	Sum	99.470
Sum	100.948	Excess Sodic Oxid	0.316
Oxygen Equivalent to Chlorin	1.159	Total	99.786
Total	99.789		

§ 86. The alkali or incrustation which collected on the surface of the soil is essentially a mixture of sodic and magnesic sulfates in the ratio of two to one. These two salts make up 80 per cent. of the whole mass. Calcic sulfate is subordinate in quantity, with sodic chlorid and carbonate still more so.

§ 87. In the first two inches of the soil we find that the soluble salts consist largely of calcic, magnesic and sodic sulfates, which together form 78.3 per cent. of them, with the calcic sulfate predominant. In the second two inches the calcic sulfate constitutes almost 51 per cent. of the water-soluble portion of the soil, with magnesic sulfate subordinate and sodic sulfate absent. On the other hand, sodic silicate, which is very subordinate in the alkali and ground water, is here next in quantity to the calcic sulfate, and the potassic sulfate, which is present in scarcely more than traces in the alkali given, makes about 1-16 of the water-soluble portion of the second two inches of the soil. The potassic salts in the alkali incrustations which I have examined and which were formed as efflorescences, are sometimes higher than in the one given, amounting in some cases to about 1 per cent. In an alkali from South Park, Colo., the potassic salts were a little over 8 per cent., but the conditions are wholly different from those prevailing in our plot.

§ 88. The variety of salts in the water-soluble portion of the soils seems to be greater and the relative quantities of the subordinate ones are much more nearly equal than in the alkali or the water. Reference to the analyses of the other water-soluble portions of the soils will show a tendency in this direction in the first two, but it is more marked in the second two inches of soil. In no case do we have an increase in the amount of the more soluble sodic and magnesic sulfates in the second two inches of soil, while that of the less soluble calcic sulfate is quite marked.

§ 89. The analyses of the waters from the wells agree with the one given in showing that the total solids in the ground water contain more calcic sulfate than the incrustations, but much less than the water-soluble portions of the soils, whether it is of the first or second two inches. The results of the analyses of other samples also agree relative to the magnesic sulfate, viz.: that there is almost as much in the water residues as there is in the incrustation or in the first two inches of the soil C, and more than in any of the other seven water-soluble portions examined.

§ 90. The most marked difference is shown in the case of the sodic sulfate, which makes up 53 per cent. of the alkali incrustation, 17 per cent. of the solids dissolved in the ground water, 10 per cent. of the water-soluble in the first two inches of the soil, and is absent in the second two inches. The analyses given above do not stand alone in indicating this difference, but many analyses, all that we have made of the ground waters and three other soil samples, indicate this to be a fact. Sodic sulfate is always a constituent of the total solids in the ground waters, varying in quantity from less than 5 per cent. to 23 per cent. I may state here, as an unlooked-for result, that this salt almost disappears from the drain water coming from this area.

§ 91. The appearance of these two salts, sodic and magnesic sulfates, in the incrustations, seems very reasonable if the suggestion made in Bulletin 65, that the incrustation is formed by an approximate separation of these efflorescent salts from the more permanent ones, especially calcic sulfate, at the contact of the water surface with the air, is correct. The suggestion of the formation of a double magnesic sodic sulfate lies near at hand in this case, but whatever the case may be, we are not justified by the ratio of the magnesic salt to the sodic salt in assuming its formation; besides there is no urgent need of it, as the deportment of these two sulfates toward the air surface is sufficiently different from that of calcic sulfate to permit of the separation as observed. The formation of these incrustations is very different from the simple evaporation of a solution of different salts to dryness, for these efflorescent salts are removed from the solution and its former status is changed.

§ 92. Why the sodic sulfate forms so small a percentage of the water-soluble portion of the soil is not easily explained. That it should sometimes be found in the upper portions of the soil in large quantities is to be expected, even if as a rule it were present in small quantities only or entirely absent, for the tendency is to a separation of it on the surface, whence it may be carried back into the soil by rain or abundant atmospheric moisture, being retained within the surface layers of the soil in which it may form a large percentage of the water-soluble portion. We have one instance in which it forms 27 per cent. of it. But, remembering that this sulfate does not pass into the drain waters, while it usually exceeds 10 per cent., often rises above 17 and sometimes reaches 23 per cent. of the salts in the ground water, it seems strange that the water-soluble portion of the soil should so frequently give good reason for supposing it to be absent. I do not know any facts nor have I seen any statement of established or probable changes which will account for these facts as observed.

§ 93. The magnesic and sodic sulfates are both present in the ground water, or their ions are, and constitute the efflorescent salts passing out of solution at the surface of the soil, or where the surface of the solution comes in contact with the air. Evaporation is proceeding at this surface and the capillary movement of the ground water is rapid and free, for when the condition of the soil is such that we can sufficiently impede the capillary rise of the water, we prevent the formation of such incrustations. The result may be roughly presented as the movement of a free solution through the interstices of particles which are themselves not free to move, but capable of being modified in regard to their composition either by exchange or by attracting to themselves and retaining other salts. These processes may be subject to the greatest variety of modifications, so that they are not exclusive or constant, and seldom perfected, but vary from point to point within the soil.

§ 94. It has been accepted for a long time that soils as a rule have a high power of retaining potassic salts and but a very feeble one of retaining soda salts. If this were wholly correct, we should expect to find the drain waters from such areas as the one forming the subject of this study loaded with soda salts, at least to the same extent, if not to a much greater one, than the ground waters. But we do not find this to be the case, and the conditions are such that it is not probable that the difference is due to the dilution of the drain waters from this area by water from other sources.

§ 95. Under the subject of the total solids in the ground water, I stated the result of experiment to be an indication that they decreased with depth, that the first foot of water after entering the water plane was richer in total solids than the second, and so on. At first I did not believe this. An instance in point was well D, which on September 20th showed the presence of 3.4071 parts total solids per thousand. A temporary well opened on this date 40 feet south of well D, the surface contour and the character of the soil being the same but the sample of water being obtained at a greater depth, probably two feet deeper, showed only 2.18713 parts total solids per thousand. The residue from the water of well D showed the presence of 16.87 per cent. of sodic sulfate, while that from the newly opened one showed 14 per cent., a difference of nearly 3 per cent. in this respect. In this case we almost certainly had an admixture of water from points above that at which we endeavored to collect the water, for with our appliances we could not prevent it. The drain waters, in which we have a better separation of the waters, show a still greater difference, both in the amount of the total solids and in the percentage of the sodic sulfate. We are justified in extending our statement that the ground water, in so far as it is a solution of salts, differs from the alkalis which effloresce, from the solution obtained by exhausting the soil with distilled water as previously described, and also from the drain water flowing from under the area.

LITHIA IN THE GROUND WATER.

§ 96. Reference has been made in a preceding bulletin to the failure of an attempt to determine the lateral movement of this salt through the soil, or the rate and direction of the flow of the ground water. The detection of lithia in the samples of water tested to ascertain with certainty that my experiment was actually a failure, led me to test a considerable number of samples of the ground water and also samples of drain water to ascertain whether its presence was accidental or whether its occurrence was general and constant. The result was that its presence was established qualitatively in every sample tested, and these represented samples taken during a period extending over more than two years. The quantity present was as a matter of course not large, but sufficient to be readily detected by the aid of the spectroscope, and in some of the samples sufficient for quantitative determination without great trouble. This element seems to be present in all of the water in this basin. Its presence was detected in the ash of beets grown upon this plot, and also in the ash of their leaves. This is peculiar for I have tested a number of ashes of alfalfa; some of it grown within this same swale and have never succeeded in detecting it.

NITRATES IN THE GROUND WATER.

§ 97. The results of the only determinations of the nitrates in the soil are given in Bulletin 65, page 45. The variation in the amount present in the different portions of the plot and also in the first and second two inches of soil is very considerable. The determinations are entirely conclusive that the conditions obtaining do not prevent the formation of nitric acid, and further, that its distribution in depth as well as from place to place throughout the plot is very uneven. The minimum quantity of nitric acid in a million parts of the air dried soil of the first two inches was 32 and the maximum 162; of the second two inches the minimum was a trace and the maximum was 9 parts. In A, the section of the plot where the conditions were most unfavorable to cultivation, there was 32 parts per million; in B, where the conditions of cultivation were good, but where we had trouble to obtain a good stand of plants and the ground water was generally the most heavily laden with total solids, the nitric acid was the highest, reaching 162 parts per million; in C, a section which is quite wet and yields incrustations, but in a less degree than A, the nitric acid falls to 55 parts per million, but it again rises to 86 parts per million in D, which section is in good condition and whose surface is always from 3.5 to 6 feet above the water table.

§ 98. We do not find nitric acid abundant in any portion of the plot in the second two inches, it being present in the sample from section A as a trace only, but it increases as the ground rises to the westward until it reaches a maximum of 9.3 parts per million in D.

§ 99. At the close of the season of 1897, 23 days before our crop was harvested, the ground water from the wells showed a range of total solids from 2561 to 3986 parts per million, while the nitric acid ranged from 4 to 7.8 parts. A sample of water taken from a newly made opening penetrating the gravel and quite near to the Town Ditch, an irrigating ditch, showed the presence of 2187 parts total solids and 11.34 parts of nitric acid per million. The water plane was low at the time these samples were taken.

§ 100. On the 16th of May, 1898, the level of the ground water was not especially high, but the total solids were exceptionally so, and the nitric acid in the waters of wells A and C was unprecedentedly high, 41 and 68 parts per million respectively, but this was not so in the case of wells B and D, which carried 5.0 and 2.7 parts respectively. From this date, May 16th, the nitric acid fell continuously till June 6th, when owing to a rainfall there was a change in the soil conditions, followed by an increase of nitric acid in wells A and D and by a decrease of it in wells B and C. From this time, June 6th, till July 14th, the water table gradually fell and so did the quantity of nitric acid present; the surface of the ground having become somewhat dry in the meantime. The plot received an irrigation on July 14th and the samples of water taken on the following day showed an increase in the amount of nitric acid present; but this increase was not uniform in the different wells. The water plane was raised according to the position of the wells, and the amount of water we were able to bring on the surrounding section, which varied, as we had only a scanty supply of water at our disposal. The effects of this irrigation upon the total solids held by the waters was as marked as any that I have had the opportunity of observing. Wells A, B and C rose from 28.0000, 29.2856 and 16.1429 parts per thousand on the 8th to 58.8571, 44.8571, and 58.1429 parts per thousand on the 11th, while well D, probably due to accidental inflow of water from the surface, fell. The nitric acid rose in the meantime by 7 parts per million in A, 13 parts in B, 18 parts in C, and 1 part in D. The largest increase, however, was observed in a well sunk in an adjoining plot which had been manured and which chanced to receive an irrigation at this time. This well showed 3.59 parts of nitric acid per million on June 27th and 475.63 parts on July 9th. The water table was raised, in this case, almost to the surface.

§ 101. The duration of the effects of this irrigation upon the amount of nitric acid in the water was quite different in the different wells. The greatest increase in my plot was shown in the case of well C, which, throughout the season, proved to be the richest in nitric acid of any of the four wells here considered, and also of all the wells on my plot of ground. The water of this well carried on the 8th of July 2.69 parts nitric acid per million; this rose to 21.18 parts just after the irrigation and fell to 2.51 parts by August 1st. The nitric acid in well B did not increase to the same extent as in well C, but it fell a little more slowly, and on this date, August 1st, showed more than either of the other three wells. The quantities for all the wells ranged from 1.8 to 6.1 parts per million.

§ 102. The rate of decrease was quite rapid at first, and while it gradually grew slower, it was quite abrupt at the end. The well alluded to as being in an adjacent plot may serve as an illustration of both the rapidity of the rise and the rate of decrease. On July 4th, before irrigation, and with a low water level, it carried only a trace; on the 9th, after irrigation, and with the water plane near the surface, it carried 475.63 parts per million. In the next two days this fell to 242.0 parts, in the succeeding seven days it fell to 89.74, in seven days more to 35.89 parts, and in seven days more to what may be expressed as within the range of its constant content. This well behaved unlike the others, for while mine showed a temporary increase in nitric acid about August 8th, this one continued to decrease until there was less than 1 part of nitric acid per million.

§ 103. As a rule the nitric acid was lower when the water plane was low, but there were variations which showed no relation to either the height of the water level or to the amount of the total solids present; for instance, the nitric acid in the water of well C on August 1st was 2.5 parts per million, on the 8th 8.4 parts, on the 22d 2.7 parts; the total solids on the 1st were 2.0143 parts per thousand, on the 8th 1.9143 parts, and on the 22d 1.8000 parts. The height of the water table on the 1st was 7.75 feet, on the 8th 7.67 feet, and on the 22d 7.15 feet above the reference plane. The increase on the 8th was probably due to a rainfall which took place on the 5th and 6th and amounted to 0.78 of an inch. There were also slighter rainfalls on the 1st, 2d, 16th and 17th, but the total of these amounted to only .12 of an inch, the heaviest one was only .07 of an inch, too small an amount to produce an observable influence. The comparatively small rainfall of .78 of an inch seems to have been the cause of the increase of the nitric acid in the ground water, for the increase in the four wells was simultaneous, though quite unequal; the greatest increase being 6 parts per million, the least 1 part per million. The effect of this rainfall was not great enough to show in well E, as the nitric acid was falling at a rapid rate and our samples were not taken often enough to show small variations in the rate of falling.

§ 104. There was a slight change of the water table between the 6th and the 8th, amounting to a few hundredths, the greatest being 0.08 of a foot. The actual distance of the water table below the surface at this time was from 3.0 to 5.2 feet. Under these conditions there can scarcely be a thought of the nitric acid, nitrates, having been added to the ground waters by its direct washing downward through the soil. The wells in which the water was the deepest below the surface showed the greatest increase. This is what we would expect if the rain water simply flowed through the soil, carrying the nitric acid or its equivalent nitrates down with it. This amount of rainfall, 0.78 of an inch, is, however, insufficient to wet this depth of soil. As the surface of this soil was in an almost air dry condition at the time of the rainfall, it was probably not wet to a depth greater than two inches, which is a liberal estimate, but if we put the depth to which the rain water penetrated at four times this estimate, it would not account for the rise in the water table, nor for the washing downward of the nitric acid to a depth of a little more than 5 feet. I think that the oscillation in the water plane and the increase in the nitric acid in the water were both due to the effect of the rainfall upon the capillary conditions of the soil; the nitric acid, more explicitly the nitrates, exhibiting a downward capillary movement.

§ 105. A sample of water taken from well A on December 7, 1898, showed only a trace of nitric acid. This determination was repeated to assure myself that no mistake had been made, but the results were the same, corroborating the first determination. This was the fourth instance that we had met with in which there was only a trace of nitric acid present in the water. These four instances were met with when the water plane was low, but not when it was at its lowest.

§ 106. Well A was located in a portion of the plot where the incrustations formed most abundantly, where the mechanical conditions of the soil were most unfavorable and where the water plane was the nearest to the surface at all times. This last fact may have effected a more regular removal of the nitric acid as it was formed than in the other cases. Whether this is the explanation or not, the water from this well showed uniformly as much nitric acid as that of any of the other wells, though the first two inches of the soil was lower in nitric acid than the corresponding samples from the other sections, but irrigation did not increase the nitric acid in the water of this well as it did in some of the others.

§ 107. Well C is located in the next most unfavorable section and the water level is in round figures 1 foot further below the surface than in well A. The nitric acid varied greatly in the water from this well, and its amount was immediately and greatly affected by irrigation or rainfall, even a light rainfall being followed by a marked increase in the amount of nitric acid.

§ 108. I have said nothing about well G, a shallow well near well A, in connection with the nitrates. This well was separated from the gravel stratum by two feet of soil and was only 12 feet from A. There was no more relation between the quantities of nitric acid in these wells, nor in its variations, than between it and wells farther removed.

§ 109. A careful consideration of the results at my disposal do not justify me in making any comparison or assuming any relation as existing between the nitric acid in the waters of these different wells. There is a general similarity in their conduct, but it is greatly modified by, if not wholly dependent upon, the soil conditions in the immediate neighborhood of the well. Well A, on July 8th, before irrigation, showed the presence of 1.79 parts per million and well G only a trace; on the 11th, after irrigation, A showed 15.2 parts and G 19.2 parts of nitric acid per million; by the 25th inst., the nitric acid in A had fallen to 6.59 parts per million, and in G to 2.69 parts. The water plane was nearly the same in the two wells, it being 0.18 of a foot higher in G than in A.

§ 110. The relation between the amount of nitric acid and the total solids is even less intimate than that of the chlorin to the total solids, which is practically equivalent to stating that there is no relation between them.

§ 111. An examination of the 300 determinations of the nitric acid in this ground water does not permit us to draw any conclusions in regard to the effect of either the physical condition of our soil or of the amount and character of our alkalies upon the formation of nitric acid in the soil. The average of the soil samples taken to a depth of two inches indicates the presence of 469 pounds of potassic nitrate or its equivalent in every acre of soil taken to this depth, *i. e.*, two inches, which is a goodly supply. Our determinations, however, show that this statement cannot be extended to the second two inches, and much less to the first foot of soil, the conventional depth on which to base such computations. Whatever the effects of our conditions may have been, they were certainly not prohibitive of the production of nitric acid.

§ 112. I can find no examinations of ground waters with which to compare my results. The nitric acid in drain waters is another question, and I shall subsequently, in another bulletin, show that drain waters and ground waters from the same territory are not comparable, so that nitric acid determinations in drain waters are not available for my present purpose. I am compelled by the lack of better data to use samples of another ground water taken by myself as the basis of my statements in regard to the effects of our conditions upon this subject.

§ 113. A sample of ground water from a field lying to the west of my plot, several feet higher, and of an entirely different aspect and character, was taken 10 days after irrigation and showed the presence of 0.718 part of nitric acid per million. This land is in good condition, is not alkalized, water logged, or subject to the adverse conditions obtaining in my plot. The field, however, was in alfalfa at the time the sample was taken, July 5th, and the sample represented the ground water in the soil at that time, for the sample was taken immediately after the hole was dug. The nitric acid in this sample is lower than was usually found in ground water from my plot, but is not so low as was sometimes found in it, but as these smaller quantities are exceptional, it is probably safe to conclude that the ground water in my plot is quite as rich, or even richer, in nitric acid than the average ground water of the neighboring soils.

I did not know, nor even suspect at the time these samples were taken, that I could not compare them with drain waters, nor did I fully appreciate the fact that a sample of water taken from the soil represented so little beyond the conditions prevailing within a very few feet of the point where it was taken.

§ 114. Judging from the amount of nitric acid found in the aqueous extract of the soil, especially in that from the first two inches and from the amount usually present in the ground water as represented by the wells, ranging up to 6 or 8 parts per million, but as a rule from 2 or a little less to 5 parts per million, the alkalized condition was not unfavorable to the formation of nitric acid, The abundance of proteids in the beet crops grown on this ground. they being slightly higher than the average in this respect, also support this view.

§ 115. The great difference in the amount of nitric acid in the first and second two inches of soil, suggested the question of a possible reduction of the nitric acid from some cause. I had no reason to suspect the formation of ferrous salts, and the amounts of ammonia and nitrous acid found in the well and drain waters examined for these constituents did not strongly support the idea of a reduction. The maximum amount of free ammonia found in the well waters before irrigation was 0.0850 part per million, and after irrigation 0.5780 part. The maximum quantity of nitrous acid found in the well waters before irrigation was 0.0837 part per million, and after irrigation 0.1000 part. The increase in the free ammonia present after irrigation is not accompanied by a corresponding increase in the nitrous acid, but is greatly exceeded by the increase in albumenoidal ammonia, so that the probabilities are in favor of another source for it rather than that of the reduction of nitric acid. The nitric acid in these samples was, moreover, quite as high as the average, being 2.692 parts per million before irrigation and 7.628 parts per million after irrigation.

§ 116. When we consider the large amount of nitric acid per acre, 293.14 pounds, existing in the uppermost two inches of this soil, and while the second two inches show less than a tenth as much, and further, that the ground waters are comparatively poor in it after as well as before irrigation, we are forced to the conclusion that there is a tendency in our soil to the concentration of this salt in the upper portions. Whether this is due to a very rapid formation of it at this point, or to the action of capillarity under our meteorological conditions, is an open question. Long continued cloudiness, with or without continued or heavy rains, which means impeded evaporation, is followed by a greater increase in the amount of nitric acid in the ground water than we have observed to be due to irrigation. In fact the increase due to irrigation has in no case been comparable to that observed after long rains. I have no explanation to offer for this fact unless we find one in the difference between the rate at which the nitrates tend to move upward, due to capillarity, whose effects are made more marked by our conditions, almost continuously favorable to a rapid evaporation from the surface and that at which they may be washed downward by the amount of water used. It is well known that the nitrates appear in alkaline crusts under favorable conditions, sometimes forming several per cent. of the mass, but I have not found it present in any incrustation collected in Colorado except in traces.

§ 117. I expected to find relatively large quantities of nitrates n the ground water, owing to the fact that the soil is not usually credited with any great power of retaining them when solutions of these salts are passed through them, and I at first assumed that there was enough downward moving water in the soil, even when the voids between the soil particles were not completely filled with water to carry the nitrates into the ground water. Such does not seem to be the case, for if it were, the ground water immediately after irrigation ought to be richer in nitrates than they were found to be, even after making liberal allowance for the fact that the irrigation might effect a dilution of the ground water. In the case of the total solids we find a very decided increase, more salts having gone into solution than was necessary to maintain the degree of saturation. This is true, too, of the nitrates, at least in a measure. In the case of the irrigation applied August 31st and September 1st, 1899, the results were not uniform in regard to the increase of the nitrates in the ground water, indeed an increase in their quantity was the exception. This result was probably due to the fact that I had a more liberal supply of water than in any previous irrigation and the results were due to dilution of the ground water, owing to the addition of a large quantity of water in a short time.

NITROUS ACID IN THE GROUND WATER.

§ 118. I have given the limits found for the nitrous acid in the ground water, especially before and after irrigation, in a preceding paragraph. Our examination of the water did not as a rule extend to the determination of this constituent except in studying the effects of irrigation upon the composition of the ground water, offflow and drainage, under which topic the results observed will be given more fully. The results of the determinations made indicate that as a rule the nitrous acid present in the ground water of this plot was low, not exceeding 0.0837 part per million, except immediately after irrigation, when it rose to 0.1090 part per million. The least quantity of nitrous acid was found in the ground water from the alfalfa field west of our plot, in which we found only a trace.

§ 119. The few samples of drain water which we examined were richer in nitrous acid than the ground waters. The ground waters were richer in nitric than in nitrous acid; while the reverse was the case with the drain waters. The cause of this might be a reduction of the nitrates in passing through the soil to the depth of the drain, which is about four feet, but the ratio of increase above that of the nitrates caused by irrigation suggests that it is rather due to the deportment of the salts of this acid toward the soil particles. For while irrigation did not always increase the nitrates in the ground waters, it always increased the nitrites, and in those cases in which it caused an increase of the nitrates from 1½ to 3 times their previous amount, the nitrites were increased from 8 to 30 or more times. It should be remembered that we always had very much smaller amounts of nitrites than of nitrates to deal with.

The presence of larger quantities of nitrites in the drain than in the ground water is more probably due to the deportment of the solution of these salts within the soil than to a reduction of the nitrates. This view is suggested by the facts stated above, and also by the fact that the off-flow water is poorer in nitrates than the ground water either before or after irrigation, while the nitrites in the off-flow water amounted to more than 200 times as much as was found in the ground water, but the amount was less than that which was found in the drain waters. I do not maintain that there is no reduction of the nitric to nitrous acid taking place in this soil, but simply that the appearance of the nitrous acid in the drain and off-flow water in excess of the nitrates does not necessarily indicate a reduction of the nitric acid, but is probably to be explained in this case by the different deportment of these salts after they have been formed, without regard to the method of their formation. I stated in a former paragraph that I had no reason to assume the formation of ferrous salts or the presence of other conditions favoring the reduction of the nitrates in any unusual degree, micro organisms not included.

AMMONIA IN THE GROUND WATER.

§ 120. The ammonia and ammonia salts in the soil were shown in Bulletin 65 to probably amount to a little more than 0.00211 per cent. of the soil. The amount of these salts in the ground water is small, ranging from 0.0230 to 0.0850 part per million. Irrigation increased this amount to from 0 0570 to 0.5780 part per million. The drain waters were found to contain from 0.0496 to 0.0944 part per million.

§ 121. The albumenoidal ammonia present ranged from 0.0674 to 0.3029 part per million in the ground water and was greatly increased by irrigation. The maximum found after irrigation was 3.1170 parts per million. This kind of ammonia does not pass into the drain very freely; it amounted to 0.2299 part per million in the drain water from this plot. The comparatively small amount of ammonia found in the drain waters strengthen the statement made relative to the reduction of the nitrates to nitrites. The reader may be tempted to think that we intend to discuss the potability of this water. Such is not the case. It is purely a matter of the soil conditions. It is for this reason that certain properties of the water are not discussed at all.

AMOUNT OF NITRATES, ETC., REMOVED BY THE IRRIGATION WATER.

§ 122. The question as to how much of the nitrates, nitrites, and ammonia of both kinds was taken from the soil by the water naturally suggests itself. This question is difficult to answer in regard to the ground water, for there are a number of considerations entering into the answer which are not known with sufficient definiteness. The same may be true of the off-flow water, but this water is the same that flowed onto the soil, and, after having been in contact with it for a certain length of time, flowing over it for a distance of 600 feet in this case, was collected for examination. The water as it flowed onto the soil contained only traces of nitrates; the first portions that flowed off contained 1.970 and 1.077 parts per million respectively; the last portions that flowed off contained 0.3590 and a trace respectively.

§ 123. The ground water in two instances showed an increase in the nitrates from 1.970 and 2.513 to 3.231 and 7.628 parts per million respectively. In two other instances a slight decrease was observed.

§ 124. The rapid diminution in the amount of the nitrates removed by the off-flowing water shows that their removal by the water flowing over the soil is very limited, probably confined to the very surface of the soil. In this connection I would recall the fact that comparatively large quantities of nitrates existed in the upper two inches of this soil. It is evident that the water upon coming in contact with the soil wets the uppermost portion before flowing over it; this takes place even when there is a good head of water. This wetting means a downward movement of the water at first, which may carry the nitrates not somewhat firmly held by the soil, down into the soil and beyond the action of the succeeding, overflowing portions of water.

§ 125. It is stated above that two instances of a decrease in the nitric acid were observed after irrigation. This decrease was in wells B and D and amounted to 0.1840 and 1.0870 parts per million respectively. In the case of D, which was near the point at which the water was brought onto the plot and where the soil was a sandy loam, it may be that the irrigation water may have found its way into the well more directly than it was intended it should, or it may be that the amount of water received at this point sufficed to produce leaching, but I am very doubtful of this.

§ 126. The water, especially the ditch water, used for irrigating, contained an unusual amount of nitrous acid. Whence it came I did not attempt to ascertain, and it was probably not true of the water after it had been running for some hours. Some of the water used was what we designate as seepage water, and contained 0.2340 parts nitrous acid per million. The off-flow was from 3 to 8 times as rich in nitrous acid as the ground water after irrigation. The amount of the off-flow was comparatively small. What relation it bore to the amount applied, I did not determine, nor have I any means of estimating how long the water collected was in contact with the soil. No account has been taken of the amount of water evaporated, which was probably a larger fraction of the water applied than we would think, possibly not less than a sixteenth of it. The rate of evaporation from a standard tank at the time this irrigation was made was 6 inches in 30 days, and as our irrigation extended over 3 days, the evaporation probably amounted to fully .6 of an inch.

It required about 34 hours for the water to flow the length of the plot, 600 feet, and produce an off-flow. The first samples of the off-flowing water were taken soon after the off-flow began, and the second samples were taken 8½ hours later. At this time the off-flow was estimated to be about half of the on-flow.

§ 127. The albumenoidal ammonia in the ground water was materially increased in two of the wells, but in the other two wells its amount was affected in a very much less degree. The off-flowing water was only slightly richer in this kind of ammonia than the on-flowing water.

§ 128. The rate at which the water flowed over the ground and also the rate at which it passed into the soil probably exerted an influence upon the amount and kinds of salts taken into solution. An attempt was made to determine the rate at which the wells filled; they were measured, pumped down, remeasured, and the time noted which was required for them to fill again. The rate varied with the soil and other conditions, but our results indicated an inflow of from 7 to 11 cubic inches per minute, the water outside of the wells standing from 24 to 36 inches above the surface at the beginning of the experiment. This does not indicate so rapid a draining out of the water from a comparatively free surface as I expected. The surface varied in the different wells, but this requires nearly 30 square inches to furnish one cubic inch of water per minute, or a square foot yielded at the rate of 4.8 cubic inches per minute. No attempt was made in this crude experiment to find out how much space about the well was affected by the lowering of the water in the well; it was very small at best. This rate of inflow would have diminished materially after a short time. I have elsewhere stated that the lateral movement of the solutions, which may be quite equivalent to water, is very small, if not zero, in this plot, for the amount and kinds of salts in the water in wells near to one another are different and maintain their individuality throughout a series of changes in the conditions of the ground water, including the effects of irrigation. The rate of the flow into the wells does not seem to be sufficiently high to disturb the relation of the well water to the ground water to such an extent as to demand special consideration. The differences between the ground waters and aqueous extracts of the soil already noted are not sensibly affected by the lateral passage of the solutions through the soil and probably not by their downward movement in the plot under discussion. If the conditions were changed, for example, by judicious and thorough drainage, then the question of alkali salts in the soil would be one of time and the amount of water applied to the surface. Our object from the beginning was not to study the effects of drainage as such, but the effects of cropping and cultivation where irrigation is necessary but drainage difficult or impossible.

SUMMARY.

1. The question of alkalization in Colorado resolves itself into a question of drainage.

2. Alkalization in this state has been made more apparent, and its effects increased, by over irrigation.

3. Crops growing on alkalized soil with the water table quite near the surface were sensitive to drouthy conditions.

4. The water plane is 1.83 feet higher at the west end of the plot than at the east end and the drainage is probably to the eastward.

5. The inclination of the water plane to the eastward is less than that of the surface.

6. The height of the water plane often changes without sensible cause, probably due to atmospheric conditions, pressure, temperature, etc.

7. Light rains during dry periods produce, as a rule, comparatively great increases in the height of the water plane, probably due to modification of the capillary conditions.

8. Light rains during an interval of abundant moisture when the soil is wet do not produce an increase in the height of the water plane.

9. Moderate rains were sometimes accompanied by temporay depression of the water plane. This was accounted for by the rate of rain fall, character of soil and the air contained therein.

10. The effect of an irrigating ditch running past the east end of the plot was to raise the height of the water plane by 0.30 of a foot at a distance of 142 feet from the center of the ditch. This raise was apparently produced by the causing of a backward pressure and not by direct infiltration of water.

11. When the water plane rose due to changes in capillary conditions caused by light rain falls it usually fell to its former level in about three days, but when it rose after an irrigation it required from 10 to 13 days for its fall.

12. The total solids, salts held in solution in the different well waters,

varied both in quantity and in the ratio of the different salts present. Their amount and character depended upon the conditions obtaining in the immediate vicinity of the well.

13. The total solids rose and fell with the water plane, passing into the water as it rose, and remaining in the soil when it fell. This is the same as saying that the total solids in solution depend upon the relative masses of the water and soil and vary with the character of the soil, including the salts retained in it. The preceding is a general statement and does not consider the irregular increase or decrease of the total solids in the same well at different times. These are unquestionably dependent in a large measure upon the unlike conditions of chemical equilibrium obtaining in the solution at different times.

14. The increase in the amount of total solids in a well water is not always the greatest in those wells which show the greatest rise in the water plane, nor in those which usually show the greatest quantities of total solids. The increase in the total solids due to the rise of the water plane seems to be partly dependent upon the rate of diffusion through the soil.

15. The height of the water in the different wells was essentially the height of the water table in the soil.

16. The total solids in the well waters were less than in the water in the soil. This difference was not due to a mixture of water entering the wells from different sources, but was seemingly due to the modification of the laws of diffusion and solubility by the soil itself.

17. The total solids in the ground water were lower in 1899 than in 1897 as indicated by samples of ground water taken 10 days after irrigation.

18. The chlorin, or its corresponding salt, sodic chlorid, was at no time very abundant in the ground water and bore no definite relation to the total solids, as the sodic chlorid ranged from 5 to a little more than 14 per cent. of their total weight. The increase or decrease of sodic chlorid, common salt, was not proportional to the increase or decrease of the total solids and did not serve as an index of either the amount of total solids present or of their variation, except within very wide limits.

19. The chlorin may not always be present in the form of sodic chlorid, which is tacitly assumed in the preceding statement. Analytical results indicate that it may sometimes be present as magnesic chlorid, and the irregular deportment of chlorin in the waters may be due to such causes, *i. e.*, differences in the manner of its combination.

20. The chlorin present in the ground waters and its variations in quantity throw but little or no light upon the movement of the alkali salts within this soil.

21. The term total solids is equivalent to the salts constituting the free solution in the soil. The term represents a different mixture of salts than is found in the incrustations forming on the surface of the soil, or obtained by evaporating an aqueous extract of the soil to dryness.

22. The total solids in the ground water varied greatly in the different wells, and also from time to time, in regard to their quantity, but only to a limited extent in their chemical composition. The difference in the latter respect was almost exclusively confined to the relative quantities of the respective salts.

23. The method of combining the analytical results has been adopted as convenient and probable, but not as infallible.

24. In combining up the analyses there is frequently a slight excess of sodic oxid, this is often within the limits of analytical errors, at others it is rather high. We have observed that this excess is usually higher when the loss on ignition is high and are inclined to attribute it to the presence of organic acids.

25. The alkali incrustations from this plot consist essentially of sodi

and magnesic sulfates in the ratio of two to one; they together constitute 80 per cent. of the mass. Calcic sulfate is subordinate in quantity with sodic chlorid and carbonate still more so.

26. The salts dissolved in the ground water, the total solids, consist much more largely of calcic sulfate than of sodic sulfate, and contain about the same amount of magnesic sulfate as the incrustation from this plot. The ratio of calcic sulfate to the magnesic and sodic sulfates in the total solids is approximately 2:1¼:1.

27. The salts extracted from the first two inches of the soil by continued treatment with water consisted of the same salts, they made up nearly 80 per cent of the total, but the ratio was approximately 4:2:1.

28. The aqueous extract of the second two inches of soil contained very little magnesic sulfate, no sodic sulfate, and almost 51 per cent. of calcic sulfate. This extract showed a large amount of soluble silicic acid, corresponding to 14.5 per cent. of sodic silicate calculated on the dried residue.

29. The upper portions of the ground water are richer in total solids than the successively deeper portions and the salts in solution differ, especially in their relative quantities.

30. There seemed to be an abundant formation of nitric acid in the upper portions of the soil, even in portions of the plot where the alkali salts were abundant.

31. Nitric acid occurred so generally in the ground waters and its variations were so dependent upon other conditions that we cannot judge of the effect of the alkalies present nor of that of the mechanical conditions.

32. There was no relation between the amount of total solids and that of the nitric acid present.

33. There was no relation between the different wells in regard to the quantity of nitric acid present or its variations.

34. Irrigating the ground increased the nitric acid in the well waters, so did even light rainfalls, probably due to increase of capillary exchange of the nitrates between the upper portions of the soil and the ground water.

35. The ground water from this plot is richer in nitrates than that from neighboring land which is in better condition.

36. The nitrites in the ground water are relatively high and are increased by irrigation. This is probably due to the biological conditions of the soil and the deportment of solutions of nitrites toward the soil, especially in regard to the readiness with which they will pass through it.

37. The free ammonia and ammonia salts were not especially abundant in the ground water, either before or after irrigation, though more abundant after than before.

38. The ground water was slightly richer in free ammonia than the drain water from this plot.

39. The albumenoidal ammonia in the ground water was not excessively high, but it was materially increased by irrigation. The albumenoidal ammonia did not appear to pass freely into the drain water.

40. The amount of nitrates removed by off-flow water is probably quite limited as their quantity in the off-flow diminished rapidly.

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12. Drainage of the plot.
13. Changes in height of water plane affected by meteorological conditions. Water plane depressed by rainfall. Duration of effects of rainfall upon height of water plane.
15. Effects of the freezing and thawing of the soil on height of water plane
16. Influence of town ditch on height of water plane.
17. The filling of the town ditch caused decrease in total solids and chlorin in ground water. Total solids and chlorin decreased by filling of town ditch.
19. Rate of fall in height of water plane. No free drainage from east end of plot.
20. Difference between rise of water plane due to capillarity and irrigation.
21. Other oscillations in height of water plane.
22. Plot favorable to the study of the character of the salts in ground water
23. Amount of total solids in different wells not the same.
24. The rise and fall in the water plane an up and down movement of the water.
25. No lateral movement of water detected.
26. Falling water plane leaves salts in soil.
27-28. Increase in total solids due to irrigation irregular.
29. Duration of the effect of irrigation on the amount of total solids. Minima and maxima for total solids in wells—1897.
30. Well B richest in total solids.
31. Increase of total solid in wells B and D with a falling water plane, while they decreased in wells A and C, attributed to conditions of diffusion.
33. Meteorological conditions and height of water plane, spring of 1898.
34. Exceptional amount of total solids in water, May 16.
36. Amount of water necessary to cause change in height of water plane not determined.
37. Light rains during wet periods do not cause rise of water plane
38. Total solids in wells A and C exceptionally high.
39-40. Effect of 1.82 inch rainfall on height of water table and total solids
45. The height of water in wells and soil the same.
46. Total solids less in the well waters than in soil water.
47. Effect of drain on amount of total solids in well waters. Radius of influence of wells upon salts in soil probably small.
48. Translocation of salts through soil improbable.
49. The water in the wells possibly a mixture.
50. Decrease of total solids with fall of water table explained.
51. The waters in the wells probably not mixtures
52. The stratum of gravel underlying the plot not necessarily course of flow.
53. Soluble salts eliminated by cultivation.
56. Ratio of salt, sodic chlorid, to total solids. Variation in quantity of salt present not same as variation of total solids.
57. Chlorin present no measure of total solids present.

Section.
58. Chlorin in ground water diminishes with depth.
60. Chlorin in ground water increased by irrigation.
61. Chlorin in ground water does not show the movement of the alkali salts in the soil.
62. Total solids defined
64. Well waters represent the average free solution in the soil.
69. Method of combining analytical results. Method of combining results of analyses not always correct.
70. Excess of sodic oxid in analyses. Excess of sodic oxid higher when organic matter is higher.
74. Surface well waters.
78. Composition of total solids throughout experiment.
82. Individual samples of water or soil not representative.
86. Composition of alkali crust.
87. Differences between alkali crusts and water soluble in soil Silicates in water and soluble of soil. Potassic salts in alkali crusts.
88. Characteristics of water-soluble portion of soil.
90. Percentage sodic sulfate in alkali crusts, ground water, etc.
91. Double sodic-magnesic sulfate probably not formed.
93. Presence of magnesic and sodic sulfates in incrustations accounted for.
94. Drain water not rich in sodic sulfate.
95. Lower portions of ground water poorer than upper. Ground water and drain water different.
96 Lithia in the ground water. Lithia in ash of beets and beet leaves
97. Nitric acid in air dry soil; first two inches
98. Nitric acid in air dry soil: second two inches.
99. Nitric acid in ground water, 1897.
100. Nitric acid in ground water, 1898. Effect of irrigation on nitric acid in ground water.
101. Duration of effects of irrigation on nitric acid.
102. Rate of decrease in quantity of nitric acid after irrigation.
103. Variation in amount of nitric acid caused by light rainfalls.
104. Variation of nitric acid in ground water due to capillary movement of nitrates.
105. Nitric acid absent in well A, Dec. 7, 1898.
106. Nitric acid in well A more constant than in the others.
108. No relation between amounts of nitric acid in adjacent wells.
112. Ground water richer in nitric acid than that from neighboring land
114. Condition of plot probably not restrictive of the formation of nitric acid.
115. Free ammonia in ground water. Nitrous acid in ground water before and after irrigation.
118. Nitrous acid in ground water.
119. Nitrites less abundant in ground than in drain water. Nitrites increased more by irrigation than nitrates.
120. Ammonia in ground and drain waters.
121. Albumenoidal ammonia before and after irrigation.
122. Nitrates in off-flowing water.
123. Increase of nitrates in ground water caused by irrigation.
124. Nitrates removed by off-flowing water limited.
125. Decrease in nitrates after irrigation explained.
128. Drainage out of soil into wells slow.
Summary.
Tables I to XVII.