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THE FIXATION OF NITROGEN IN COLORADO SOILS

A Study of the Wellington District, Larimer County, Colorado

By

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THE FIXATION OF NITROGEN IN COLORADO SOILS

By WM. P. HEADDEN

It is now 8 years since our last publication under this title, "The Fixation of Nitrogen in Colorado Soils", appeared and the content of our previous publications on this subject may be unknown to some reader of this. It is therefore proper to give a concise statement of the principal points already presented in order that the relation of this bulletin to the general question may be evident.

Bulletins 155 and 178 present the facts relative to the occurrence of nitrates in our soils, often in very excessive quantities. This fact is established by many instances in which the amount of nitrates, usually given, as a matter of convenience, as sodic nitrate, but sometimes as mixtures of calcic, magnesic, potassic and sodic nitrates in the statement of the analyses, ranged from a few hundredths of one percent up to more than six percent of the air-dried soil. Twenty-seven separate occurrences in soils and two in well waters were discussed in order to establish the fact that such occurrences are not simply scientific curiosities and to show that their distribution is general throughout a very large territory.

In these bulletins is also presented an explanation of their formation. It was first shown by a process of elimination that these nitrates are not derived from the waters used for irrigation nor from ground-waters. Further, that the very prevalent, popular view, that these salts are brought up from beneath, is not tenable. Further, that the facts in regard to the occurrence of nitrates in the rock strata do not permit us to assume these as the source of these nitrates. Further, that the manner of these occurrences, often being confined to very limited areas, and in such positions that we cannot explain them on the assumption that the nitrates have been concentrated in these places by being washed out of other lands, indicate a local origin. Such explanations having been eliminated, we concluded that the occurrence of these excessive quantities of nitrates were exaggerated instances of a process going on in our soils, to wit, that these nitrates are being formed in the soil. It was evident that these areas, at first designated as "spots" because of their small size,—and this term, nitre-spots, was retained throughout, even when an area of 8, 10 or more acres was indicated,—were very much richer in nitrogen than ordinary soil and it was suggested that this nitrogen was derived from the air by the micro-flora of the soil. Later the power of these soils to fix nitrogen, i.e., to take it from the air, was shown by direct experiment. The amounts fixed under laboratory conditions were very considerable. The results actually obtained showed that, had the rate of fixation continued for one year, the top two inches of soil would have appropriated as much nitrogen as is contained in 2.8 tons of sodic nitrate. The only new feature in this suggestion was that this fixation may be accomplished on so large a scale and with such an intensity.

We also showed that nitrification, as well as fixation, goes on very rapidly in these soils. The maximum increase obtained by laboratory experiments in the amount of nitrogen in the form of nitrates was 138 percent in 48 days. Observations were made on the increase of this form of nitrogen in the field for several months—from the beginning of August till the latter part of November. Our results are given in pounds per acre of sodic nitrate equivalent to the nitric nitrogen found in the top 4 feet of the soil. This land had been cropped to wheat. We found for four sections taken 1 August, 91.9, 51.7, 51.4 and 38.9 pounds of sodic nitrate; on 22 November, the same plots yielded 179.0, 136.3, 154.3, and 191.6 pounds. The August samples were taken just at the time the crop ripened and the November ones almost 4 months later. The crop was harvested 10 August. These results show that nitrification goes on rapidly in the soil as soon as the crop is removed. We see that we have, in practically 3½ months, an increase of from two to fivefold in this form of nitrogen.

The distribution of this nitric nitrogen was also determined both in cropped land and in the nitre-spots. It is the latter only that interests us at this time. Bulletin 186 presents a study of this phase of the subject. The question of general distribution and the possibility of subsequent concentration to account for the nitrates found in these spots is considered at length and the conclusion arrived at, that we have no grounds for assuming that such concentrations have taken place, on the contrary, we showed that in the case of some areas, very rich in nitrates, such concentrations could not have taken place. Further, that these nitrates and our ordinary alkalis do not have a common origin. Further that it is only the surface portions of these nitre-spots that are excessively rich in nitrates. It is, however, recognized that they may be washed down into the deeper portions of the soil or into the underground waters by irrigation or by rain-water. The lateral distribution is often very sharply defined, a variation from 7,077.0 to 16.0 p.p.m. of nitric nitrogen was found within 16 feet; again from 6,444.5 to 2.0 p.p.m. within 20 feet. These sharp limits can generally be recognized by the color and other physical properties of the soil.

In this connection, the ground- and drain-waters were investigated. When these underlie or come from beneath nitre-areas, they may contain nitrates, otherwise this is not the case. In no instance have we found the least justification for believing or assuming that the nitre-spots have been produced by these agencies.

It is claimed that Colorado soils very generally possess both high fixing and nitrifying efficiencies, so high that the quality of crops may be affected even to an injurious extent. Bulletin 183 presents a study of this feature of the problem as it affects sugar beets.

In prosecuting a "Study of Colorado Wheats" we again came in contact with this question which proves as important in connection with the wheat as with the beet crop.

Of course, there has never been any question of the importance of nitrates in the growing of crops and this is in no manner at issue in this study. The question is wholly one of the quantity of nitrates present and the source of the nitrogen that they contain.

OBJECT OF THIS BULLETIN

The object of this bulletin is to present the facts as existing in a new district, that of Wellington, about 14 miles north and east of Fort Collins. This district lies in the valley of Box Elder creek, a small tributary of the Poudre river.

Our attention was directed to this occurrence by the fact that well-waters brought to the station laboratory from this section were sometimes found to be relatively rich in nitrates. In one instance a ranchman brought in a sample of water and a portion of a residue that he had obtained by evaporating some of the water to dryness. This water was very rich in total solids and especially in nitrates. He had lost 17 head of cattle by allowing them to drink this water. While the water was heavily charged with ordinary "alkali" salts, it was not richer in these than other waters that are used without injury to stock. The unusual feature in the water was the presence of nitrates. The water was evidently unfit for any farm use. Inquiry elicited the fact that other wells in that section had also caused the death of stock, especially when they were first brought in from the range.

This section has been brought under irrigation within comparatively recent years. It is certainly not yet 25 years since this happened. The death of the cattle, due to the drinking of this well-water, occured 6 or 7 years ago and a well-water, in what is known to me as the Boon place, had caused the death of some cattle each year for some years before this, so these conditions had established themselves in less than 15 years after the section had been brought under irrigation. It must not be inferred from this statement that there is any proof at all that irrigation has any proven, direct, and necessary connection with the formation of these nitrates. A certain amount of moisture is necessary. Irrigation plays no other part than to supply this moisture. Previous to the incident of the killing of the cattle by this water, the occurrence of nitrates in this particular section was unknown to me, though I knew of their occurrence in other sections of our immediate neighborhood. A superficial examination of this land sufficed to convince me that it presented another instance of a remarkable amount of nitrates in the surface soil.

A few years later other samples of well-waters carrying nitrates were brought in to us. This occurred so frequently that it seemed to be worth the while to study the section to ascertain the relation existing between the occurrences in well-waters and in the surface soils. This attempt has led to the preparation of this bulletin, whose object it is to give the general facts of this, heretofore, undescribed occurrence of nitrates; to present the relation between the occurrence of these salts in the soil and the well-waters; and also to present in so far as possible the composition of waters obtained from deep wells.

PLAN OF STUDY

The plan of study was in the first place to gather samples of surface soil and of waters from shallow wells, on an east and west line across the district, 16 miles, and also on a north and south line through it, 13 miles. In the first line we have the section of one valley and the western portion of one and the eastern portion of a third one. The north and south line gave us a section of the central valley. This preliminary work revealed the fact that we had to do with only one principal area on the east and west line which was rather more than 2 miles wide, but on the north and south line it was broken into subordinate areas for the greater portion of the line. We afterwards sampled the soil and water in a section on this line 2 miles wide and 8 miles long.

To give the data of this preliminary work would show nothing that cannot be stated in a few words. Starting at our eastern limit we found no nitrates in either the soil or water samples, till we got within about 3½ miles of Wellington, for the next 2 or 2½ miles the nitrates were abundant, but there were none in either the waters or soils westward till we reached the region of Dry Creek, just west of Waverly, where they occurred again, but irregularly and much less abundantly than east of Wellington. The Waverly district did not present sufficient interest to justify further study at the time. While we found some nitrates in this section, the more striking occurrence was that of small areas rich in calcic chlorid. These were neither large nor numerous enough to be of much interest to us as we know of another section, a district in the San Luis Valley, in which such areas are larger, more abundant, as rich or richer and apparently more difficult to account for than these. In the case of these occurrences near Waverly, Larimer County, it might be contended that a possible or even probable explanation can be found in the history of the section, i.e., as there is still a small cattle industry in the section which formerly was predominant throughout the country—these spots where the calcic chlorid is now found might be places where salt had been put out for the cattle. A successful refutation of such an assertion would be difficult even if the assertion is not true. While it is easy to show that the reaction between calcic sulfate or carbonate and salt may form calcic chlorid, I scarcely believe that these areas represent old salting spots. This is not the question which concerns us now and we have said, perhaps unwisely, more about this than its importance justifies.

The history of our acquaintance with the occurrences of nitrates in the Wellington district, though imperfectly given, establishes the fact that the matter is of some importance, and that the conditions have persisted long enough to show that they are established and are not temporary as I have known them to be in a few cases. The preliminary work or survey of the district showed that a single area of 16 square miles is involved and that there are smaller areas lying outside of this.

WATER-SOLUBLE SALTS IN SOILS

We shall give only a few analyses of the water-soluble portion of these soils as we have published a great many such in connection with this general subject, but it is advisable, perhaps, necessary, to give a few to give the reader an idea of the richness of some of these soils in nitrates and to present the peculiarities in the composition of the mass of soluble salts present in the soils.

DIFFICULTIES IN ANALYZING EXRTACTS

The difficulties met with in making these analyses are serious enough to justify mention of the fact in the text and not relegate it to a foot-note. We have found it necessary in other publications to state that the analyses had been calculated to one hundred. This has never meant that the determination of any constituent had been omitted but usually that owing to the organic matter and the nature of the salts present the errors were distributed. The determination of the organic matter was considered the least reliable and of the least importance and was, therefore, bracketed or rejected.

The analysis of an ordinary alkali may not be either an important or a high grade piece of work, still it may prove to be a difficult matter, not to make it add up to 100 with only an allowable deviation, but to make the acids and bases balance. It is a very common experience to find that the bases are in excess of the amount required by the acids present, and a repetition of the whole analysis will probably fail to change this result. If there are chlorids of calcium and magnesium or nitrates of these elements present, it is possible that basic salts may be formed on evaporation, and drying at a higher temperature is out of the question. In manipulating these soil extracts I have frequently found it impossible to obtain a solid residue without easily perceptible decomposition of the nitrates. This difficulty has proven so great that in some cases we have used the aqueous extract of the soil without concentration which presents other difficulties. Evaporation under reduced pressure was not feasible.

It is fortunate that in this work a slight misstatement in regard to the absolute quantities of the respective salts present or their relative proportions does not conceal, or seriously distort the main facts. If the question had to be decided by any narrow margin in the quantity or so nice an adjustment of the relations that the errors introduced by this manner of treating the results became important, the question itself would disappear. The facts themselves are so big and evident that even great big inaccuracies cannot conceal nor in any serious degree affect them.

The first sample of soil presented represents a piece of ground that had been planted to beets the preceding year, but the crop was for the most part a failure. The surface of the ground was black and shining. This field was separated from a tract of virgin prairie-land by the public road. We did not attempt to ascertain the height of the water plane, because there was a well at the end of the tract, probably 300 feet to the east of the point where the sample was taken and only a very little, if any, higher. This well is 25 feet deep and had at the time apparently about 5 feet of water in it. While this may indicate the water level for this land in a general way, it cannot be taken as indicating that the water plane in the land where we took the soil sample may not have been materially higher. My judgment is that it was because I have found at other points that there may be small basin shaped areas of varying size with impervious bottoms which may be almost filled with water, but if one passes through this bottom in digging a hole, little or no water will come in below it.

I make mention of this fact because the water plane in the well may be, for the reason here stated, misleading in regard to the height of the water plane where the sample was taken and I did not make this an object of study at this point. This sample was collected about 4 years ago and this land has continued to grow worse during the intervening period. I do not know the history of this land nor how long it had been under irrigation at the time the sample was taken. There is very little land under the irrigating ditch to the east or north of this, so that the amount of seepage that may flow into or through this land cannot under any circumstances be very great. It is true that there may be leakage from the irrigating ditch, which carries water at times. I do not know how long it carries water each season nor the amount of leakage. The ditch is located a little to the east of this point and I believe that there is no irrigated land beyond this ditch to the east. The east flank of the valley rises rather abruptly only a little way, from ½ to 2 miles, to the east of this and beyond it lies a dry-land country.

ANALYSIS OF WATER-SOLUBLE, SOIL LABORATORY NO. 2369
The water-soluble equalled 11.03 percent.

	Percent
Calcic sulfate	11.345
Calcic chlorid	40.444
Magnesic chlorid	18.736
Magnesic nitrate	14.946
Potassic nitrate	4.816
Sodic nitrate	9.057
Sodic silicate	0.284
Ferric and Aluminic oxids	0.149
Manganic oxid (br)	0.223
	100.000

The next soil given was collected along the edge and from a corner of a field that was still in fair condition. The surface of the soil showed all the characteristics of land affected by nitre-trouble. The water-soluble was not quite so high as in the preceding case, and the condition of the land at the time the sample was taken was not very bad.

ANALYSIS OF WATER-SOLUBLE, SOIL Laboratory No. 2368
Water soluble equaled 7.46 percent of air-dried soil.

	Percent
Calcic sulfate	10.222
Calcic chlorid	32.711
Magnesic nitrate	41.766
Calcic nitrate	6.428
Potassic nitrate	8.111
Potassic silicate	0.493
Ferric & Aluminic oxid	0.094
Manganic oxid (br)	0.175
	100.000

The third sample of soil was taken in a beet field and from the spaces between the rows. The beet tops were very large and very green. The stand was somewhat irregular, but it was a surprise to find so good a one under the conditions. One would scarcely think that the seed would germinate in such soil. The soil was black but not so wet as it appeared. We dug a hole at the edge of this field to get a sample of the ground-water. The water came in at a depth of 4 feet and below this it did not seem to come in at all. The hole was in all a little more than 5 feet deep. We had to wait an hour for the water to run in before we could get a five gallon sample.

The analysis of this soil extract gave us an unusual amount of trouble. The analysis was repeated three times with fair agreement and yet we have an excess of bases. The analyses were made on the aqueous extract without concentration.

ANALYSIS OF WATER-SOLUBLE, Soil Laboratory No. 2454

Water-soluble equaled 7.81 percent of air-dried soil.

	Percent
Calcic sulfate	7.823
Calcic chlorid	22.716
Calcic nitrate	21.551
Magnesic nitrate	38.102
Potassic nitrate	6.784
Excess as sodic oxid	3.024
	100.000

These soil samples were taken relatively close together, the most distant pair being about a mile from one another. This land shows no efflorescent salts, it is simply black and more or less shiny; in some places it is a little mealy.

SALTS IN SOIL—EXTRACTS DIFFERENT FROM ORDINARY ALKALIS

The analyses show that the salts present in these soils are wholly different from those in our ordinary alkalis. The small amount of sodic salts present is as remarkable as the very large percentage of nitrates and chlorids which are present as calcic and magnesic salts. The analytical results are such that there can be no question in regard to the order of combining the elements to form salts, there is no choice. The salts present are essentially the chlorids and nitrates of calcium and magnesium, with more potassium than we usually find in such extracts and only very small amounts of sodic salts, whereas, it is generally the case that the sodic salts are very strongly predominant. That there should be no soluble carbonates in the presence of such excessive quantities of calcic chlorid is what we should expect, but there is no reason why the sulfates of calcium and sodium should not be present. These sulfates are abundantly present throughout the Poudre Valley and in almost every other portion of the State. In fact, the sulfates are the characteristic salts of our alkalis. There is no property of the chlorids that would militate against the presence of the sulfates of either calcium or magnesium. We have one section of country not as yet discussed in any of our publications where we have calcic chlorid present as an important, and in some samples the predominant constituent of the soluble salts.

How these quantities of calcic and magnesic chlorids have been formed or can be present is by no means clear. The alkalis in the Poudre Valley carry magnesic sulfate to a larger extent than those from other sections of the State. The presence of this salt is shown by all of the analyses of alkalis and also ground-waters that we have published. Why these sulfates should be absent and the chlorids so plentiful in this section is not in any measure apparent. I do not even see how the usual explanation offered for the formation of calcic chlorid, namely, the interaction of calcic sulfate or carbonate and sodic chlorid, can apply in the present case. There is no local abundance of sodic chlorid in this district that has come to our knowledge to account for the prevalence of the calcic and magnesic chlorids.

In the other occurrences of calcic chlorid referred to, there is an abundance of these salts, sodic chlorid, calcic sulfate, calcic carbonate, sodic sulfate, with nitrates and sodic carbonate. In the Wellington District, we find comparatively little sulfate or other sodic salts associated with the calcic and magnesic chlorids, though we should expect them if these latter were formed by the action of sodic chlorid on the respective carbonates or sulfates.

GENERAL CHARACTER OF COUNTRY

The country with which we are particularly concerned is drained by the Box Elder Creek. The country does not present an even valley-floor but rather a series of depressions surrounded by ridges which serve as water sheds, cutting off the depressions from one another and rendering the drainage question a special one for each individual depression. These basins are sometimes quite small. The one in which the first sample of soil, No. 2368, was collected, is scarcely one mile in diameter. There is no drainage that I have noticed into this basin and very little out of it. I think that it could be drained but with considerable difficulty. The contour of the country and the recent date at which this section was brought under irrigation render the question of accumulation of these salts by transportation and concentration almost irrelevant.

How such easily soluble salts as the chlorids and nitrates of calcium and magnesium can be accumulated or concentrated to the extent that we here find them without the concentration of sodic salts, especially the sulfate which is so generally distributed, is difficult to understand. The universal presence of our ordinary alkalis, which are mixtures of calcic, magnesic and sodic sulfates, with chlorids and carbonates very subordinate, shows that our whole country is one big example of the concentration of the sulfates.

COMPOSITION OF ALKALIS IN THIS SECTION

It may serve a purpose if we give analyses to present these variations and to show that the peculiar composition of these extracts is not an accident confined to the two localities given, but is characteristic of this whole section. They will at least serve for comparison.

These analyses have not been published heretofore. The alkali chosen was gathered from the low lands along the Poudre River, nearly opposite the point where the Box Elder Creek joins the river.

WHITE ALKALI, POUDRE RIVER BOTTOM LAND

	Percent
Calcic sulfate	7.935
Magnesic sulfate	46.353
Sodic sulfate	41.926
Sodic chlorid	1.894
Sodic carbonate	0.756
Potassic carbonate	0.565
Sodic silicate	0.364
Ferric & Aluminic oxids	0.098
Manganic oxid (br)	0.109
	100.000

This white alkali represents an efflorescence that at times appears very abundantly on some of these bottom lands. The soils, analyses of whose water-soluble portion are given above, usually show no efflorescences, which is a marked difference. The process of efflorescing is one whereby the less soluble, easily crystallizable, salts are separated from the more soluble and less easily crystallizing ones. This accounts in a large degree for the differences in the analyses given. But the ordinary alkalis do not appear on these soils as efflorescenses nor in the analyses of the water-soluble. If the white alkalis were present in these soils they would form efflorescenses under favorable conditions. This is a fact that can be observed at some places.

The following is an effloresced, ordinary white alkali, collected from the margin of a very bad piece of ground in the Wellington District. The sample was scraped off the surface of the soil which was very wet at the time the sample was taken. The surface was very uneven and I gathered a great deal of soil with the alkali. The water-soluble portion was 13.36 percent of the air-dried sample. Under these circumstances the separation of the salts by efflorescence was probably very much better than my separation of alkali and soil. The character of the effloresced salts, however, is not in the least obscured and they are clearly the usual mixture of sulfates constituting our ordinary alkalis, with a little nitrate from the soil. The composition was as follows:

ANALYSIS OF EFFLORESCED SALTS, Laboratory No. 2602
Water soluble equaled 13.36 percent of the air-dried soil.

	Percent
Calcic sulfate	26.445
Magnesic sulfate	25.770
Sodic sulfate	42.040
Potassic chlorid	2.263
Sodic nitrate	3.482
	100.000

This analysis shows that the efflorescence on this soil at the time we collected the sample, 12 February, 1920, was essentially our ordinary alkali, a mixture of sulfates in which sodic sulfate predominated, while calcic and magnesic sulfates were present in about equal quantities; they made up one-half of the total. The small amount of nitrates probably belonged to the soil which constituted 86.0 percent of the sample as it was gathered. This and also the following sample was collected on the flank of a little knoll in a field that is rapidly becoming very bad. A portion of the field, only a little lower than that where we collected these samples, has become as good as unproductive within the past three years.

The soil of the field where the following sample was taken did not show very much efflorescence and beets had grown there in 1919, but the crop appeared to have been almost a complete failure. The soil was slightly mealy.

ANALYSIS OF WATER-SOLUBLE, SOIL Laboratory No. 2603
Water-soluble equaled 6.733 percent of soil.

	Percent
Calcic sulfate	22.720
Magnesic sulfate	37.467
Potassic sulfate	1.556
Sodic sulfate	17.518
Sodic chlorid	9.849
Sodic nitrate	10.835
Excess sodic oxid	0.046
	100.000

The last two samples were taken close together, the alkali formed a white covering on the ground when it was collected, but the ground where the soil sample was taken showed no efflorescence—only a little mealiness on the surface. The distance between the two lines on which the respective samples were taken was 25 feet. The differences in the analyses are very marked. Sodic sulfate makes up 42.0 percent of the effloresced alkali and only 17.5 percent of the soil extract. While magnesic sulfate makes up 37.5 percent of the soil extract and 25.8 percent of the alkali. The alkakli as it was gathered consisted of 86.0 percent of soil, still it carried only 3.5 percent of nitrates against 10.8 percent in the soil extract. It is true that the conditions where these samples were taken were patently different though they were taken so close together; this is the reason that the samples were taken and our object was to ascertain what differences exist between the alkali, effloresced salts, and the soil extracts under the conditions obtaining in such places. The differences are greater and more radical than we expected to find them. The differences in general, but particularly in regard to the nitrates, are very suggestive.

LARGER AREA NECESSARY TO ESTABLISH CHARACTER OF SOIL-EXTRACTS

The soils, heretofore given, are from two neighboring little valleys. The mixture of soluble salts is so unusual for our soils that it raised the question whether two or three samples which were taken from two places and these close together, represent the facts as they exist in the district. Whatever these facts may be it becomes incumbent upon us to ascertain and set them forth. For this purpose we have chosen a series of samples representing a continuous section about 4 miles long and one sample 4 or 5 miles further south but in the same line. The choice of these samples was determined by the results obtained on our general samples taken in this section.

The line of samples was interrupted because a reservoir and a group of small lakes intervened and the road was not opened. It was for this latter reason that the next sample was taken 6 miles further south.

ANALYSIS OF WATER-SOLUBLE, SOIL Laboratory No. 2604

Water-soluble equaled 9.779 percent.

	Percent
Calcic sulfate	15.434
Calcic chlorid	21.325
Calcic nitrate	0.241
Magnesic nitrate	51.159
Potassic nitrate	4.294
Sodic nitrate	3.809
Ferric and Aluminic oxids	0.178
Excess sodic oxide	3.560
	100.000

The next sample No. 2605, was taken as a sample of alkali from a piece of drained land which is also affected by the nitre-trouble. We did not wish to obtain a sample to exhibit the nitre-problem but on the contrary, one to represent the alkali as it occurs in this section. It would have been an easy matter for us to have taken a sample of soil which would have shown only a little, perhaps no alkali.

ANALYSIS OF WHITE ALKALI, Laboratory No. 2605.
Water-soluble 11.403 percent.

	Percent
Calcic sulfate	11.563
Magnesic sulfate	46.958
Potassic sulfate	4.389
Sodic sulfate	13.320
Sodic chlorid	4.065
Sodic nitrate	18.671
Excess sodic oxid	1.034
	100.000

The following sample was collected only a little way south of the preceding and on higher ground which, nevertheless, is wet. Why this place should be wet, I do not clearly see. I could write out an explanation which would be plausible and apparently be consonant with all the facts that we know about the place, but I do not believe that it would be a correct explanation. The fact is that I do not know where the moisture in this spot comes from. I do not know the history of this spot, whether it has been there always or has appeared within the past few years. It is not so bad that the owner has been prevented from trying to crop it. During 1919, it was planted to corn and previous to that to beets. The corn did not grow but weeds had grown to a height of 6 or 7 feet on a great deal of the ground.

ANALYSIS WATER-SOLUBLE, SOIL Laboratory No. 2606
Water-soluble 12.254 percent.

	Percent
Calcic sulfate	41.462
Magnesic sulfate	11.731
Magnesic chlorid	9.182
Magnesic nitrate	10.412
Potassic nitrate	5.239
Sodic nitrate	18.786
Excess sodic oxid	3.188
	100.000

It would seem that this land should be easy to drain, located on the flank of a hill. In fact, land only a few hundred feet from and lower than it is drained. How bad the nitre-problem might be in this land if it were not drained, of course I cannot guess, but it is so bad that a part of this land is now unproductive.

The next sample will give an idea of how bad drained land may be. There was a drain running through this land. The sample of soil was taken partly on one side and partly on the other side of the partly filled drain trench, and is intended to represent the very bad portion of the land. The distance between the last sample given and this is not more than 1200 feet. A portion of the field from which this sample was taken was planted to pop corn in 1919. Some of it grew well and some of it did not. It had no water.

ANALYSIS OF WATER-SOLUBLE, SOIL Laboratory No. 2607

Water-soluble equaled 9.704 percent air-dried soil.

	Percent
Calcic sulfate	28.245
Magnesic sulfate	0.853
Magnesic nitrate	44.930
Sodic nitrate	4.525
Potassic chlorid	3.186
Sodic chlorid	17.799
Excess sodic oxid	0.462
	100.000

The samples were washed till all sulfate disappeared from the wash-water. This means that we washed out any gypsum that may have been present in the soil.

The next sample was virgin soil which was very wet at the time the sample was taken. The location was so unfavorable that I hesitated about taking any sample, but it was either this place or none. The analysis was a troublesome one owing to the presence of much organic matter. The excess of bases, expressed as sodic oxid, is high, still I think that the determinations are correct and that the analysis shows very nearly the actual mixture of salts present in the soil.

ANALYSIS WATER-SOLUBLE, SOIL Laboratory No. 2609

Water soluble equaled 8.71 percent air-dried soil.

	Percent
Calcic sulfate	22.454
Magnesic sulfate	13.225
Magnesic chlorid	18.219
Magnesic nitrate	18.617
Sodic nitrate	19.520
Potassic nitrate	4.056
Excess sodic nitrate	3.909
	100.000

The next sample was taken about 6 miles further south where the conditions were much better, but still not good. The reason for this long jump in this series of samples has been stated in a previous paragraph. The drainage at this point was fairly good and the land under ordinary conditions should be good, productive land, at least much better than it is. The sample of soil was taken to represent the field. Had we wished to gather a sample rich in nitrates this could have been done as it was evident that there were spots where these salts were abundant. The sample represents a strongly alkalized soil rather than a nitre-spot. The land was planted to sugar beets in 1919 but was abandoned because there was a shortage of water.

ANALYSIS WATER-SOLUBLE, SOIL Laboratory No. 2608

Water soluble equaled 6.414 percent of air-dried soil.

	Percent
Calcic sulfate	17.414
Magnesic sulfate	44.688
Potassic sulfate	1.508
Sodic sulfate	21.842
Sodic chlorid	9.622
Sodic nitrate	4.258
Excess sodic oxid	0.578
	100.000

Though this sample represents an alkalized soil rather than a nitre-one we see that there is a little over one-quarter of one percent of nitrates in the soil as the sample was taken. The striking feature of this analysis is the predominance of magnesic sulfate and the relatively small amount of sodic sulfate.

The location where we gathered this sample is nearer to the Poudre river than any other here given and it is almost as rich in magnesic sulfate as the alkali gathered from the bottom lands along the river but is poorer in sodic salts.

These analyses agree in showing the great difference in the composition of these soil extracts from that of ordinary alkalis. These extracts are characterized by subordinate quantities of the sodic salts, particularly of the sulfate, by the presence of large quantities of calcic and magnesic chlorids and nitrates and by notable quantities of potassic oxid.

We have given these analyses of soil extracts, in greater number than was our original intention, to show that the presence of calcic and magnesic chlorids and nitrates was not a peculiarity of the first two samples given, but is characteristic of the whole section here considered.

Two of the samples given are of effloresced alkalis, one of them from drained land and while these samples show that they represent ordinary alkalis, the mixture of salts is not the usual one found, but is rich in magnesic sulfate and also contains some nitrates. The chlorids in these alkalis are low. The drained land from which one of the alkalis was gathered had been tilled in 1919 but the crop was a failure.

CALCIC AND MAGNESIC CHLORIDS

Reference has been made several times to the occurrence of calcic and magnesic chlorids. But the analyses of these soil extracts and alkalis may not impress the reader as justifying the emphasis laid on the subject. In fact, the question may seem to him to have been raised gratuitously, for this reason the following analysis of a sample of surface soil taken southwest of Waverly and about four and a half miles west of Wellington, is given and it will also serve to show the diversity met with in these extracts of soil samples taken within the same neighborhood. The locality at which this sample was taken was higher than the surrounding land and dark, in this case moist, the spot was of considerable size. Other such spots were observed and one other from this neighborhood was submitted to analysis with results similar to those presented in this case.

ANALYSIS WATER-SOLUBLE, SOIL 1 M. W. and ½ M. S. of Waverly, Larimer County, Colorado.

Water soluble equaled 1.96 percent of dried-soil

	Percent
Calcic sulfate	13.264
Calcic chlorid	52.137
Magnesic chlorid	17.687
Potassic chlorid	2.773
Sodic chlorid	11.585
Sodic nitrate	1.045
Sodic silicate	1.507
	100.000

There are large areas in the San Luis Valley where these chlorids, especially calcic chlorid, occur abundantly. The most striking examples of this that I have met with are in a district southwest of Alamosa. The two districts are not to be confounded for they are unlike in every other respect.

The prevalence of magnesic salts in these soil extracts suggests a question regarding their source, i.e., whether there is any unusual amount of them present in the soil itself and not soluble in water. To answer this a soil that had been washed free from chlorids and sulfates was submitted to an ordinary agricultural analysis. The results showed nothing unusual. The carbon dioxid, lime and magnesia were low for our soils. The lime CaO was 1.42 percent and the magnesia 0.336 percent. The alkalis were also relatively low, potassic oxid 0.654 and sodic oxid 0.103 percent.

The origin of this soil is principally the friable sandstone lying above the shale. There is undoubtedly an admixture from other sources but the local rocks are the principal source.

CERTAIN WELL-WATERS

We have previously stated that our attention was first seriously directed to the conditions in this section by the occurrence of nitrates in certain well-waters. This proved to be common enough to make it seem probable that an attempt to find out definitely whether this nitrate in the well-water correlated closely with the occurrences on the surface or not would give positive results. The method adopted was to visit every well in the district and take a sample of the water. It proved to be a somewhat difficult matter to obtain satisfactory data concerning these wells. The present occupants of these ranches often know but little about the places as they may have occupied them but a short time. Many of these places have changed hands or the occupants have changed since we began this work. In locating the wells we have used the names, given in our field notes as the simplest system. We have given the wells along the public roads which gives us definite lines through the section. I do not see that giving the names of the occupants of the ranches can do any harm in this case. Some of them to my certain knowledge have left the places and the names serve no other purpose than to designate where the sample was taken

We have given analyses of some of the soil extracts and we will now give the analyses of a few waters. Two of the waters correspond to soil extracts already given. The third one is an analysis of a water from a drilled well 280 feet deep, sunken in one of the worst places. This analysis follows:

ANALYSIS OF WATER-RESIDUE, Laboratory No. 2370
Total Solids 5328.0 p. p. m.

	Percent
Calcic sulfate	14.584
Magnesic sulfate	5.269
Potassic sulfate	1.271
Sodic sulfate	73.431
Sodic chlorid	4.671
Sodic silicate	0.126
Manganic oxid (br)	0.460
Silicic acid in excess	0.188
	100.000

The following water was obtained from the edge of a beet field. The stand of beets was not perfect but was most remarkably good considering the conditions. The water began to flow into the hole dug to obtain it at a depth of 4 feet and, though the hole was made a little over 5 feet deep. all of the water came in at the 4 foot point. The water-soluble in the surface soil of this field, sample taken between the rows of beets, not in vacant ground, yielded 7.81 percent of its air-dried weight to water. How the seed had germinated and the beets had grown are questions to be answered, but the seed had germinated and the beets were growing well.

ANALYSIS OF RESIDUE FROM GROUND-WATER, Laboratory No. 2372

Total solids in this water were 9808.0 p. p. m.

	Percent
Calcic sulfate	16.139
Magnesic sulfate	41.647
Magnesic chlorid	7.973
Magnesic nitrate	4.519
Potassic nitrate	1.488
Sodic nitrate	24.544
Sodic silicate	0.914
Manganic oxid (br)	0.148
Excess sodic oxid	2.618
	100.000

The 280-foot well was driven a few feet east of the well first dug to furnish water for the owners' cattle and which caused the death of 17 head in a few days. This water was not analyzed. The well was so filled up with dirt and drainage from the corral that it was unfit for analytical purposes. The water from this 280-foot well is used for watering the stock without any bad effects. The people sometimes drink it but state that it physics them. This well is sunk in a Cretaceous shale and is free from nitrates.

The laboratory sample 2372 was taken less than 300 feet south of the corral as a substitute for the first well that was dug. This was the best that we could do in the case though we were at the time satisfied that it was not a dependable sample for this purpose, but it can be considered as an independent sample, which it really is. In the 280-foot well we have no nitrates but an abundance of sulfates, while in the ground-water the total solids carry better than 35 percent of nitrates.

The organic matter in this residue was rather abundant, but can scarcely be appealed to to account for the unusual excess of bases. We must appeal to the possible presence of basic salts or organic matter to account for this excess. We have in many such cases repeated the whole analysis only to obtain the same figures. It is rather common to have a slight excess of bases in analyses of alkalis.

The water represented by our laboratory number 2,371 is locally known as a poisonous water because it frequently causes the death of cattle allowed to drink it, especially if they have been just brought in off the range. This water is very rich in total solids, 9,025.0 p.p.m., of which 36 percent or 3,247 p.p.m. are nitrates. The number of cattle that have died each year has been less than one would expect, judging from the amount and character of the salts held in solution.

ANALYSIS OF WATER-RESIDUE,
Laboratory No. 2371
Well 25 feet deep—Total solids 9025.0 p. p. m.

	Percent
Calcic sulfate	25.410
Magnesic sulfate	26.937
Magnesic carbonate	1.678
Magnesic chlorid	4.496
Magnesic nitrate	21.978
Potassic nitrate	0.558
Sodic nitrate	13.525
Sodic silicate	0.444
Manganic oxid (br)	0.289
Excess sodic oxid	4.865
	100.000

DRINKABILITY OF THESE WATERS

This class of data is really foreign to our present purpose, but the question which is brought up, is one so frequently presented and the results of our observations are so disconcerting that a digression may be tolerated, especially as we have nowhere found any more remarkable instances of the use of water for stock and occasionally for domestic purposes, that judging by all ordinary criteria we would unhesitatingly condemn as wholly unfit for either purpose, than these, and yet neither men nor stock, as a rule, die from their effects. I have a well-water that was used for both purposes, i.e., for both stock and domestic purposes, that carried 3815 p.p.m. of total solids with 51.95 p.p.m. of nitrogen in the form of nitrates. I saw a man take a very large draught of this water; he stated that to him it was an agreeable water; that he drank no other water when on the place. I do not think that there was any bravado in his drinking it. I have seen others drink very bad waters.

In the following instances the animals, horses, were accustomed to the waters used, still I was surprised at the facts and the condition of the animals. I will cite but four instances of the many that I have met. In one case the water carries 12,577.0 p.p.m. total solids with 336.0 p.p.m. of nitrogen as nitrates. Another 10,541.0 p.p.m. total solids with 142.0 p.p.m. of nitrogen as nitrates. On this ranch there is another well which is considered a very good one. Its water carries 3,634.0 p.p.m. total solids and 171.0 p.p.m. of nitrogen as nitrates. Another water carries 10,170.0 p.p.m. total solids and 140.0 p.p.m. of nitrogen as nitrates. This water is pumped from a shallow well into a large tank. The owner is a man of intelligence, and there is an atmosphere of orderliness and thrift about his place. I inquired particularly about the use of this water and its effects. He asserted that his animals after drinking it for a few days learned to prefer it to other water. The animals themselves were sleek, fat, and showed every sign of well-being. In another case a family, man, wife and eight children all rugged, apparently healthy, and happy, was using a well-water that carried 2,244.0 p.p.m. of total solids and 28.0 p.p.m. of nitrogen as nitrates. The sanitary chemist will think that this nitrogen as nitrates does not indicate ordinary pollution. Our thesis is that these nitrates are formed in the surface soil and do not necessarily indicate pollution. Still this last well referred to would shake his confidence in his inference. I believe the inference to be correct, but in this case it is certainly open to serious doubt.

We have a great many inquiries concerning the fitness of water for the use of stock and frequently for domestic uses. Of late years I have practically had no opinion to give, for the tolerance of both man and beast for the salts held in solution and their power to adapt themselves to these waters is so great that assertions based on chemical considerations relative to their fitness or unfitness for either use are of relatively little value. Perhaps they ought to be unfit for use but people who use them suffer no inconvenience and animals become accustomed to waters surprisingly rich in salts, some of which we would usually consider dangerous.

GENERAL SURVEY OF WELL-WATERS

To return to our presentation of the waters of this section. The order in which we shall present these has the object of showing how remarkably rich in nitrates some of these waters are and then to show that these are confined to areas where the surface soil is also rich. We shall endeavor in another place to answer the question whether the nitrates in the surface soil came from the water or whether those in the water came from the soil. This is the crux of the question.

WELLS ON NORTH AND SOUTH ROAD EAST OF WELLINGTON

Our next table gives all accessible wells along a line two miles east of Wellington. We begin at the north end and go south for a little over six miles. This is through the worst portion of the district. It may help the reader a little in visualizing the condition to state that the eastern flank of the valley rises sharply to a height of from 80 to 100 feet only a short distance, from ¾ to perhaps 3 miles, to the east of this road, which is itself almost the eastern limit of the irrigated section.

Beyond this valley to the east there is a large dry-land section. The dip of the rock strata is to the east or away from this valley, so that we would be justified in expecting a leakage out of and not into the valley if there were any in either direction. Reference has already been made to two irrigating ditches located not far to the east of this road and higher than the land.

WELL-WATERS NORTH AND SOUTH ROAD, 2 MILES EAST OF WELLINGTON

Eight miles from north to south.

		Total Solids	Igni- tion	Chlo- rin	Nitric Nitro- gen
		(parts per million)			
V. R. Kent	16 ft. to water	2,160.0	354.0	30.0	0.8
V. R. Kent	20 ft. to water	4,744.0	660.0	64.0	4.0
Carl Kent	12 ft. to water	4,248.0	686.0	76.0	3.5
O. W. Shields	Well 60' deep, 30' to water	6,266.0	1,000.0	76.0	5.0
Chas. Savel	40 ft. to water	5724.0	1,332.0	92.0	147.0
G. R. Hamilton	160' deep, 100' to water	2,292.0	148.0	140.0	None
Greenwald	Upper well 19 ft. to water	8,998.0	1,934.0	235.0	61.8
Greenwald	Lower well 4 ft. to water	9,786.0	2,056.0	320.0	0.8
C. V. Parker	4 ft. to water	9,212.0	1,700.0	640.0	161.0
C. V. Parker		10,170.0	2,512.0	664.0	140.0
C. V. Parker	Second sample	10,054.0	2,300.0	700.0	134.0
McCandless	Old cistern	7,264.0	1,288.0	428.0	253.0
McCandless	25 ft. deep	12,577.0	3,147.0	——	336.0
McCandless	Second sample	8,413.0	2,512.0	292.0	302.4
Fred Schreiner's	280 ft. deep	4,732.0	144.0	152.0	None
Christ Anst	Old cistern	7,870.0	2,251.0	——	309.0
Christ Anst	Hole near stable	8,725.0	2,517.0	——	296.8
Irrigating Plant		8,992.0	3,404.0	140.0	515.2
Roy Nelson	10 ft. to water	6,702.0	1,265.0	238.0	75.6
G. K. Ruff	400 ft. deep	4,174.0	136.0	90.0	None
G. K. Ruff	Second sample	4,044.0	162.0	81.0	None
G. K. Ruff	Shallow well	7,462.0	1,454.0	76.0	131.6
Fitzpatrick	Shallow well	11,154.0	2,780.0	232.0	610.0
Fitzpatrick	Second sample	11,282.0	3,782.0	228.0	599.2
Victor Akin	S. of Cobb Lake	1,176.0	174.0	68.0	1.0

This road has been chosen as practically the longer axis of the worst part of the whole district. We have given those features in the composition of these waters that may be of interest. The loss on ignition of the dried residue gives a little idea of how much organic matter is present. Of course, in all cases where nitrates are present these are partially or wholly destroyed. The ignition is given for whatever it may be worth. The maximum amount of chlorin found is 700 p.p.m. This was present in a well, 4 feet deep, located in a swale. If this is present as sodic chlorid, ordinary salt, the amount present in a gallon of water would be, in round numbers, 11 grains, which is a very moderate amount for ground waters. The maximum here given is over twice as much as was present in the next water richest in chlorin.

At the northern end of this section we have even in surface wells only small amounts of nitrates. The first 4 wells given show a maximum of 5 p.p.m. of nitric nitrogen which is less than may be present in deep wells that are certainly free from pollution. Water from a depth of 100 feet is free from this form of nitrogen. This well must penetrate the shales for the greater part of its depth, and in the adjoining ranch we find a surface water at 4 feet carrying less than one part per million. The water from a little swale through which an irrigating ditch runs carries 161.0 p.p.m. of nitric nitrogen. The next one to the south is differently situated. Here the surrounding land is black on the surface and has ceased to be productive. The soil is extremely rich in soluble salts, consisting of chlorids and nitrates. The nitrates in these shallow wells are very abundant 336.0 p.p.m. of nitric nitrogen. The next ground-water south is also rich, 309 and 297 p.p.m. of nitric nitrogen. A well 280 feet deep in an exceedingly bad place yields water of an entirely different character, carrying no nitric nitrogen and the salts present, while abundant, are sulfates instead of chlorids and nitrates. The next water obtained south of this was from a large well dug to furnish water for a small pumping plant to irrigate a piece of land; this was extremely rich, 515 p.p.m. This was followed by one with 75.6 p.p.m. and a surface well with 131.6 p.p.m. This one is close to a very bad nitre-spot. At this place there is also a well 400 feet deep, but in this well-water there is no nitric nitrogen. The next well south of this is a shallow one on the side of a hill and its water is very bad, for which, at this time, we have no explanation. Two or three miles south of this and beyond some small lakes, our series of samples ends and the water of this southernmost well carries only 1.0 p.p.m. of nitric nitrogen.

WELL-WATERS THREE MILES EAST OF WELLINGTON

The country south of this is not well opened up and it was necessary for us to go one mile east to carry our line of wells further south. This statement is made to show the relation between the foregoing and succeeding tables. They together form a continuous line southward.

WELL-WATERS ON NORTH AND SOUTH ROAD, THREE MILES EAST OF WELLINGTON AND EXTENDING FIVE MILES FURTHER SOUTH THAN THE PRECEDING.

		Total Solids (Parts	Igni- tion per Mill	Chlo- rin ion)	Nitric Nitro- gen
J. H. Martin	6 ft. to water	7,416.0	1,090.0	132.0	None
Robert Green	20 ft. to water	2,358.0	454.0	27.0	1.5
J. H. Nebergall		3,224.0	652.0	233.0	56.5
Chet Giddings	30' to water	652.0	186.0	34.0	18.2
Mrs. Norman		500.0	100.0	11.0	1.2
Arthur Tuttle	700 ft. deep	518.0	29.0	113.0	None
Alex Nelson	180 ft. deep	582.0	139.0	80.0	8.0
H. O. Boller		1,374.0	552.0	147.0	63.0
Geo. Cummings		8,630.0	1,790.0	160.0	57.0
Geo. Cummings	18 ft. to water	1,124.0	214.0	260.0	3.5
John Griffith	30 ft. to water	1,080.0	258.0	64.0	3.0
A. W. Morrish	18' deep Co. Ditch	496.0	132.0	20.0	0.6
Jacob Deering	2 mi. so. Cactus school	1,412.0	114.0	100.0	0.1
A. W. Morrish	Spring W. Cactus school	1,508.0	384.0	36.0	4.0
Mrs. Lewis	14 ft. deep	1,324.0	238.0	22.0	1.5
Seth Lewis	10 ft. to water	1,784.0	326.0	24.0	0.6

This continuation of the line of wells passes into a much better section of country and the waters show it in the less amount of total solids and nitric nitrogen. We were at first surprised to find so much nitric nitrogen in the Nebergall well-water, but a subsequent visit and examination of the soil conditions revealed the fact that the soil carried fairly large amounts of nitric nitrogen, sufficient, in spots, to interfere with vegetation. The same is the case with those marked H. O. Boller and Geo. Cummings. The soil for instance at the Boller place showed in a general sample representing 40 acres, 52.8 p.p.m. nitric nitrogen, whereas the 40 acres immediately north of it showed only 6.1 p.p.m. The Cumming's 40 showed 59.7 p.p.m. and the 40 immediately south showed 9.8. These are as clear instances of the intimate relation between the character of the well-waters and the surface conditions as our data reveal. Others show larger amounts in both soil and ground-waters and involve larger areas but none are clearer than these. These remarks, however, are really in anticipation of data to be presented.

WELL-WATERS ALONG ROAD JUST EAST OF WELLINGTON

The next line of wells runs just east of Wellington and for nearly the same distance between 11 and 12 miles from north to south.

WELL-WATERS, CHEYENNE ROAD,
North to South just East of Wellington

		Total Solids (Parts	Igni-tion per Mil	Chlo-rin lion)	Nitric Nitro-gen
Bally Bunion Ranch	3' ft. deep	1,734.0	506.0	39.0	1.0
R. F. Alcorn	65 ft. deep	10,541.0	2,085.0	....	142.0
R. F. Alcorn	18 ft. deep	3,634.0	1,156.0	....	171.0
R. A. Taylor		858.0	227.0	....	4.5
J. Rue	30 ft. deep	2,442.0	586.0	60.0	37.8
J. Rue	Second sample	2,652.0	585.0	....	32.4
Lincoln Highway Garage		1,378.0	326.0	28.0	14.0
Caillet Bros.	25 ft. deep	3,576.0	886.0	....	4.9
G. F. Strelow	16 ft. to water	2,244.0	460.0	36.0	28.0
J. W. Iddings	12 ft. to water	2,210.0	422.0	49.0	25.2
Jacob Rosenberg		2,428.0	460.0	61.0	54.6
A. Demmel	12 ft. to water	1,910.0	266.0	24.0	0.6
Joe Farrar	15 ft. deep	4,388.0	668.0	40.0	9.8
G. E. Garrett	Spring	2,212.0	318.0	31.0	6.0
G. E. Garrett	8 ft. to water	1,818.0	246.0	32.0	2.5
G. Greenwald	12 ft. to water	2,112.0	244.0	24.0	1.5
G. Greenwald	10 ft. to water	1,982.0	238.0	23.0	1.0
A. L. Seaman	6 ft. to water	2,280.0	262.0	23.0	1.5
Frank Earl	4 ft. to water	2,288.0	192.0	26.0	2.0
Wm. O'Brien	A shallow well	2,558.0	66.0	31.0	3.0

This line of wells is 2 miles west of those previously given at its northern end and 3 miles west of those for 3 or 4 miles at its southern end. We have again a great variation but for the most part it is only moderate compared with the former line.

Nothing has heretofore been given in regard to what uses these well-waters are put. The greater part of them by far is used for watering stock, though a few of them are used for domestic purposes. This applies to all of the wells that have been or shall be given.

On the next road west of Wellington only a few samples were taken because it was clearly evident from our preliminary work, as well as from the results obtained subsequently, that at this time at least nothing would be gained by doing so.

A few samples given below are from the section near Wellington for a distance of about 6 miles. The road itself runs immediately west of the town.

WELL-WATERS, NORTH AND SOUTH ROAD
West of Wellington

		Total Solids (Parts	Igni-tion per Mil	Chlo-rin lion)	Nitric Nitro-gen
Jacob Lesser	26 ft. deep	1,286.0	246.0	18.4	2.0
O. M. Porter	36 ft. deep	2,036.0	408.0	24.0	1.6
A. V. Sinnard	27 ft. deep	2,324.0	446.0	52.0	1.2
L. K. Young		1,886.0	362.0	21.6	0.8
——— Chandler	18 ft. deep	1,707.0	347.0	....	10.4
Pumping Plant	11 ft. to water	1,656.0	281.0	....	6.7

This completes our statements relative to the wells taken on north and south lines. The greatest distance between any portion of these lines from east to west is, I believe, 5 miles and the greatest distance from north to south, rather more than 11 miles.

WELL-WATERS ON EAST AND WEST SECTIONS

We made, in addition to these, one full section and some partial sections from east to west. This gives us a number of wells between the north and south series already given and extends our information relative to the distribution of the nitrates in an east and west direction beyond the territory so far described.

WELL-WATERS, EAST AND WEST SECTION,
Beginning 7 miles east of Wellington and Extending to Waverly, 4 miles West of Wellington

	Total Solids	Ignition	Chlorin	Nitric Nitrogen
	(Parts per Million)			
S. L. Davis, 7 mi. east of W. Dry-land section, 240 ft. deep	520.0	44.0	10.0	None
G. Relke, 3½ mi. east of Wellington	8,764.0	2,142.0	92.0	191.8
C. V. Parker, 2¼ mi. east of Wellington	10,170.0	2,512.0	664.0	140.0
C. B. Orcutt, 1½ mi. E. of Wellington	2,284.0	482.0	60.0	1.6
J. C. Edwards, 1 mi. E. of Wellington	942.0	218.0	32.0	4.4
.... Stock well in field 3-4 mi. E. of W.	3,052.0	574.0	28.0	19.6
S. K. Young, ½ mi. W. of Wellington	1,886.0	362.0	21.0	0.8
Fred Schneiders, 1½ mi. W. of Wellington	1,230.0	158.0	27.0	1.4
B. H. Bailey, 2 mi. W. of Wellington	9,152.0	2,180.0	34.0	2.0
W. L. Birdsill, 2 mi. W. of Wellington	1,256.0	200.0	26.5	1.6
J. H. Reichert, 4 mi. N. W. of Wellington and ½ mi. S. of Waverly, 40' deep	4,360.0	754.0	57.0	2.0
J. H. Reichert, 24 feet deep	6,328.0	1,378.0	90.0	1.2

We aimed to get these wells in as nearly a straight line as possible. It was necessary, however, to follow the roads and we had to deviate to the south or north according to where the roads were opened. It is very seldom that a ranch house or corral is located away from a public road. The maximum deviation of this line of wells from a straight line across the country is possibly 2 miles to the south.

It will be observed that there is an interval of 3½ miles between the first and second wells given in the preceding table. This is because there are no wells there. The dry-land area comes down into the eastern part of this Wellington district. The table shows that the nitric nitrogen in these waters drops to a normal quantity at a point 1½ miles east of Wellington and that there is but one case in the next 5½ miles in which the nitric nitrogen can be considered as high and that is in a well dug in a field for watering stock and in this it is not very high, 19.6 p.p.m.

Owing to the fact that the roads are not opened in the east and west direction straight through as they are from north to south, we have been compelled to be satisfied with partial sections of the country. The first series of this sort that I shall give is one on a line north of the preceding and the furthest north of any taken. The road is not opened either to the north or east from the Kent place.

WELL-WATERS, ROAD WESTWARD FROM KENT'S PLACE TO NEAR WAVERLY

	Total Solids	Igni- tion	Chlo- rin	Nitric Nitro- gen
	(Parts per Million)			
V. R. Kent, 16 ft. to water	2,160.0	354.0	30.0	0.8
V. R. Kent, 20 ft. to water	4,744.0	660.0	64.0	4.0
Carl Kent, 12 ft. to water	4,248.0	686.0	76.0	3.5
Well in Sec. 15	....	....	....	56.0
Piatt Place 18 ft. deep *	....	....	....	191.8
B. C. Andrews	2,912.0	474.0	82.0	7.0
J. L. Harms, 50 ft. deep, 34' to W.	2,202.0	330.0	30.0	2.0
J. S. Elder, 85 ft. deep, 9' to W.	518.0	94.0	10.0	0.8
Carl Smith, 12 ft. deep	3,116.0	424.0	63.0	2.4
W. H. Webster	1,428.0	280.0	69.0	5.4

*This well is one mile south of this east and west line and is in lower ground. It is included here because there is no well on our line in this section of land.

If we reject the well on the Piatt place, we see that this line shows in Sec. 15 a decidedly unusual amount of nitric nitrogen, whereas no other well in this line does so. In this work we have at no time attempted to consider, either in water or soils, such amounts of nitric nitrogen as it is usual to find. We have attempted to account only for what may be considered unusual quantities, and that within such wide limits that there can be no question about the amount present being very high. The first 3 wells given in this table are in Sec. 14 and show 0.8, 4.0 and 3.5 p.p.m. of nitric nitrogen. These normally small amounts are, I think, universally considered to be derived from the oxidation of soil nitrogen without consideration of the agency. My thesis is that this applies to the larger quantities as well as to the smaller. There is only one well in Sec. 15 with 56 p.p.m. of nitric nitrogen. In a well just across the line in Sec. 22 we find 191.0 p.p.m. of nitric nitrogen.

The next east and west line of wells that I shall give is a short one, 3½ miles south of our first line and 2 miles south of Wellington. This line begins at the first north and south line given, and extends westward 3½ miles. The ground-waters at the beginning of this line are extremely bad. The land traversed by this line is undulating, but it is not higher, if as high, as the land on the north and south line to the east of it.

WELL-WATERS, EAST AND WEST ROAD 2½ MILES SOUTH OF WELLINGTON

Beginning 2 miles East of Wellington.

	Total Solids (Parts	Igni-tion per Million)	Chlo-rin	Nitric Nitro-gen
Christ Anst, Old cistern on 1st north and south line	7,870.0	2,251.0	....	309.0
Pumping plant, on 1st N & S line	8,992.0	3,404.0	140.0	515.2
Well near pond	5,012.0	893.0	....	1.4
Second sample	5,238.0	929.0	164.0	1.3
Pond	5,878.0	1,122.0	130.0	None
P. Dalys, 2 miles south and 1 mile east of Wellington	8,265.0	1,358.0	....	9.0
E. Cavins, 2 miles so. of Wellington	3,659.0	680.0	....	7.0

The first two waters given are on the north and south road and near the beginning of this east and west line at the east end. The well at the pond would appear to be pond-water, as the well is only a few feet deep and was full to the top. This well-water was very rich in magnesium salts and we were informed that it physiced the cattle, but both it and the pond-water are poor in nitric nitrogen. The few wells that we found on this road are also low in nitric nitrogen.

WELL-WATER ALONG THE AULT ROAD

The next wells that we have taken on an east and west line are about 8 miles south of the last and are given from west to east, while the preceding ones have been given from east to west. This line of wells begins 6 miles east of Fort Collins on the Ault road and ends north and west of Windsor.

WELL-WATER TAKEN WEST AND EAST ON AULT ROAD

	Total Solids (Parts	Igni-tion per Million)	Chlo-rin	Nitric Nitro-gen
E. D. Pitcher, 6 mi. east on Ault road	7134.0	1402.0	276.0	23.8
Dr. Atkinson's, 12 ft. to water	8380.0	238.0	22.0	14.0
M. J. Kerr, 12' deep, 4' to water	4340.0	498.0	92.0	28.0
Fred Weiss, Alkali on surface of ground	5874.0	1064.0	240.0	0.3
Frank Wells, 215 feet deep	690.0	100.0	31.0	None
C. C. McElravy	1384.0	38.0	72.0	None
W. E. Poor	978.0	242.0	26.0	6.0

I believe that the well-waters previously given, faithfully represent the distribution of the nitrates in the soil and the underlying rocks of the section. I do not assert that we have sampled every well in this large section of country represented, but none within the limits given have been intentionally omitted.

WELL-WATER IN WAVERLY SECTION

The Waverly section, so far as our work is concerned, is simply a western and northern extension of the Wellington district and some work has been done in this section, because there is a small area in the vicinity of Waverly in which nitrates occur, also because we wanted to know definitely the character of the well-waters in this section, so we have not only carried our east and west lines across to Waverly but have examined a considerable section about Waverly, especially north and west of it.

WELL-WATERS, WAVERLY DISTRICT

	Total Solids	Igni- tion	Chlo- rin	Nitric Nitro- gen
	(Parts per Million)			
D. C. Harned, 50 ft. deep	5934.0	1542.0	72.0	4.0
Geo. Specht, 9 ft. deep	3316.0	754.0	72.0	1.5
R. F. D. No. 3, Flowing from pipe	2868.0	712.0	110.0	0.8
Ripple Bros, 30 ft. deep on Dry Creek	832.0	196.0	14.0	2.0
P. Aragon, 22 ft. deep	10722.0	2062.0	160.0	0.15
P. Aragon, 90 ft. deep	4496.0	786.0	52.0	None
J. A. Harris, 45 ft. deep	546.0	156.0	34.0	3.0
Roy Randleman, 30 ft. deep	1136.0	274.0	81.0	5.0
Low Christman	4454.0	666.0	44.0	1.5
DRY CREEK, WEST AND SOUTH OF WAVERLY				
Dry Creek at Douglass Dam	4123.0	677.0	....	13.2
W. Dry Creek at road crossing	5771.0	950.0	....	Lost
Dry Creek before entering Douglass Reservoir	3992.0	632.0	....	38.0

This completes the statement of our data on the local waters investigated in connection with this subject.

We have endeavored to so arrange these that the series are easily located in their relative positions and the wells follow consecutively in the direction given for the series. There are a few instances in which the wells may be one-half mile to one side or the other of the line given but there are only four or five of which this is true and to attempt to give these separately would have no object.

It is evident that the rule is, that however rich these waters may be in total solids, the normal water is not rich in nitrates. The presence of these salts is due to local conditions. A second thing which is also clearly and strikingly evident is that none of the deep wells contain any nitric nitrogen and the underlying rocks cannot contain nitrates.

It is entirely out of the question for me to attempt to state the conditions obtaining at these different wells though in some instances a description of the location and surroundings would add somewhat to the value of the data. In the last table for instance, the 22-foot well of P. Aragon is in a depression in otherwise high ground and is remote from his building, in fact it is in a field. The total solids are very high, 10,722.0 p.p.m., with only 0.5 p.p.m. of nitric nitrogen, whereas the shallow well on the Ruff place is similarly located, i.e., on the edge of a depression in high land, really on a hillside, carries 7,462.0 p.p.m. of total solids and 131.6 p.p.m. of nitric nitrogen. These wells may be 7 miles apart on a straight line. Again the well on M. J. Kerr's place was given as 12 feet deep, but when the sample of water was taken, the well was full to the top. This water was being used for irrigating other land. It was evidently seepage water from the immediate vicinity of the well and contained 4,340.0 p.p.m. total solids and 28.0 p.p.m. nitric nitrogen. On the Seth Lewis place a pumping plant had been established for using the seepage water in irrigating adjacent land. The plant raised the water from a depth of 10 feet. The water carried 1,784.0 p.p.m. of total solids and only 0.6 p.p.m. nitric nitrogen. It is evident that there is no general subsurface source from which these nitrates are obtained.

NITRIC NITROGEN IN THE SURFACE SOILS

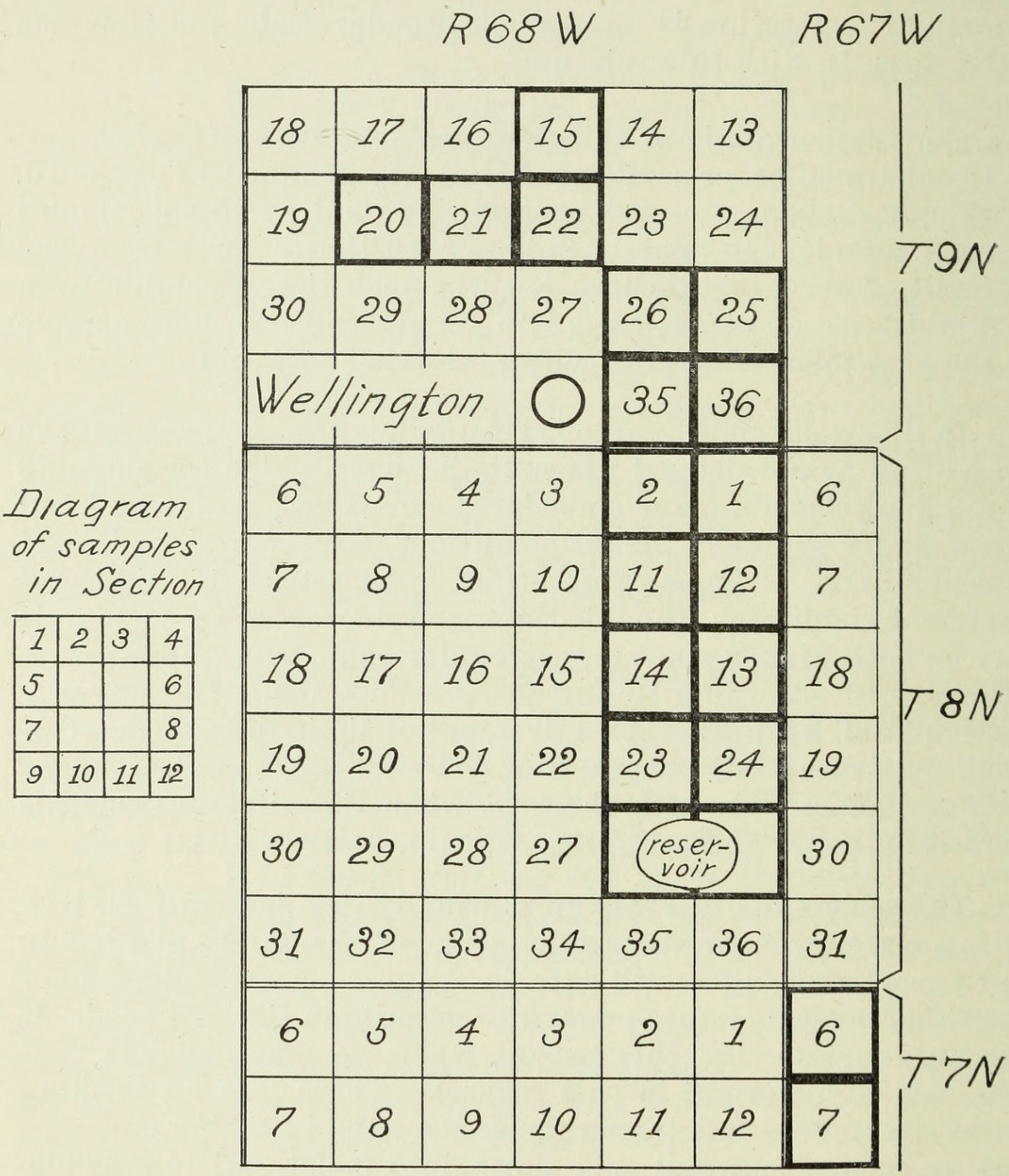
One of our principal objects in this work was to find out whether there was any relation between the quantities of nitric nitrogen in the soils and in the well-waters. This subject has been suggested but not dwelt upon in other bulletins. In Bulletin 186, p. 38, it is stated that the soil there discussed carried in the top 3 inches, 42.3 p.p.m. nitric nitrogen, which decreased rapidly till at 4 feet 9 inches it contained less than 1.0 p.p.m.; the ground-water at this point carried 9788.0 p.p.m., total solids and 4.0 p.p.m. nitric nitrogen. On the page just cited, we find another instance given in which the surface 3 inches of soil carried 52.9 p.p.m. nitric nitrogen and the last section of soil taken above the water-plane carried 57.0 p.p.m. of nitric nitrogen. The ground-water out of this hole carried 18,557.0 p.p.m. total solids and 318.8 p.p.m. nitric nitrogen. The question is put, Why this difference in the distribution of the nitrates, and the answer given is that in one case the nitrates had been washed down into the ground-waters by a previous irrigation, and in the other case they were not washed down, because of the uneven distribution of the water. Again, one of the conclusions formulated in Bulletin 178, p. 95, is, "The ground-waters, unless derived from nitre-areas, are free from nitrates and these nitrates (in the soil) cannot be accounted for by the evaporation of such water from the surface of these areas." These statements referred to small areas, nitre-spots, and the question of immediate association of the nitrates in the soil and the ground-waters was incidental to the object had in view. Our present investigation is on a much broader scale and concerns itself directly with this relation.

For further study of this point we sampled the surface soil of 18 square miles, or sections of land. We sampled 12 of the 16, forty-acre divisions in each section. We united 15 subsamples in each sample. It sometimes happened that a forty was very difficult of access or its location was such that a sample from it would have no object except to simply add one more sample to the statement of results which we tried to avoid.

In this work on the soil nitrates we have at all times felt the need of an acknowledged upper limit above which all amounts of nitric nitrogen may be considered excessive. So far as I can learn, under ordinary humid conditions, 8.0 p.p.m. is a liberal superior limit. I know of no effort to ascertain this limit for semi-arid conditions, though the amount present in such soils may be both higher and more irregular than under humid conditions; still according to our observations, made on very productive land, 8.0 p.p.m. is a fair superior limit to assume. Our good, cultivated soil ranges from 5 to 8.0 p.p.m. unless under crop or immediately after harvest when the nitric nitrogen is materially below these figures, 1 p.p.m. or even less.,

The season of 1919 was an unusually dry one with us. Irrigating water was so short that some of the fields planted to beets remained fallow till late in August or even September when there was moisture enough to germinate the beet seed. It was unfortunate that this season, when we took our soil samples, was so abnormal in this respect. There was no washing out of the surface soil during the season, and in taking our samples we pushed our soil tube down into moist soil if possible. What the effects of such a lack of moisture may have been upon the biological activities going on in the soil, I do not know but I hoped to offset this doubt, at least in part, by taking the sample deep enough to obtain moist soil whenever feasible.

In taking our samples, we began at the northwest corner of the section and numbered our samples as in the accompanying diagram, which also gives the sections sampled and their relative positions.



The sections sampled are shown in heavy lines in the illustration. The numbers in each section give the location of the 40 acres sampled. If one or more numbers are omitted, it means that the corresponding 40 was not sampled.

NITRIC NITROGEN PARTS PER MILLION, SURFACE SOILS,
Wellington District
Samples taken to Maximum Depth of Six Inches, Range 68 W.

T.	9 N.	Sec. 15	T.	9 N.	Sec. 22	T.	9 N.	Sec. 21
(1)	1	28.5	(2)	1	15.8	(3)	1	7.5
	2	21.6		2	14.0		2	10.8
	3	20.2		3	13.1		3	14.9
	4	28.5		5	13.1		4	4.6
	5	29.4		7	1.9		5	21.5
	7	9.8		8	9.3		6	14.5
	9	8.9		9	25.7		7	52.7
	10	11.0		10	8.6		8	11.7
				11	21.5		9	23.3
							10	36.4
							11	28.9
							12	5.1

T.	9 N.	Sec. 20	T.	9 N.	Sec. 25	T.	9 N.	Sec. 26
	4	7.5		1	1.4		3	41.1
(4)	6	4.2	(5)	2	4.6	(6)	4	17.7
	8	4.6		3	25.2		5	26.6
	12	2.8		4	7.5		6	8.4
				5	56.3		7	44.8
				6	7.9		8	7.9
				7	10.8		9	78.3
				8	9.8		10	9.8
				9	19.6		11	17.3
				10	12.1		12	85.4
				11	22.9			
				12	9.8			

T.	9 N.	Sec. 36	T.	9 N.	Sec. 35	T.	8 N.	Sec. 2
	1	23.3		1	5.6		1	18.2
	2	7.0		2	30.3		2	12.6
	3	9.3		3	7.5		3	7.9
(7)	4	11.2	(8)	4	13.1	(9)	4	1092.0
	5	5.6		5	11.7		5	23.8
	6	19.7		6	36.9		6	15.9
	7	8.9		7	6.5		7	61.6
	8	9.8		8	81.2		8	21.0
	9	877.3		9	12.1		9	26.6
	10	10.3		10	14.0		10	53.7
	11	12.6		11	7.0		11	26.6
	12	10.3		12	298.7		12	1941.3

T.	8 N.	Sec. 1	T.	8 N.	Sec. 12	T.	8 N.	Sec. 11
	1	746.6		1	141.4		1	44.0
	2	72.3		2	16.5		2	24.3
(10)	3	29.4	(11)	4	25.2	(12)	3	10.7
	4	17.3		5	16.3		4	1040.7
	5	25.2		6	17.7		5	40.1
	6	11.7		7	28.5		6	15.4
	7	42.5		8	12.6		7	28.9
	9	690.7		9	33.8		8	53.7
	10	10.3		10	29.4		9	14.5
				11	19.6		10	21.0
				12	12.6		11	29.4
							12	43.4

T.	S N.	Sec. 13	T.	S N.	Sec. 14	T.	S N.	Sec. 24
	1	31.6		1	22.4		1	20.1
	2	18.7		2	19.6	(15)	2	34.1
	3	28.0		3	20.1		5	462.0
(13)	4	14.5	(14)	4	52.3		7	639.3
	5	466.6		5	21.0		9	14.5
	6	12.6		6	858.7			
	7	73.3		7	16.5			
	9	17.7		8	21.5			
	10	27.1		9	9.8			
				10	19.6			
				11	19.6			
				12	28.9			

T.	S N.	Sec. 23	R. 67	W. T	7 N. Sec. 6	R. 67	W. T.	7 N. Sec. 7
	1	9.3		1	8.9		1	59.7
	2	9.8		2	7.9		2	60.7
(16)	3	18.6		3	10.8		3	21.0
	4	9.3	(17)	4	12.6	(18)	4	15.9
	6	830.7		5	15.9		5	9.8
	8	134.9		6	9.8		6	32.7
	10	14.0		7	6.1		7	30.5
	11	5.1		8	8.9		8	27.1
	12	387.3		9	52.8		9	191.3
				10	29.1		10	25.2
				11	14.1		11	17.7
				12	30 8		12	40.6

The land given in this table as having been sampled was supposed to be within the area of high fixation. Our preliminary work referred to had for its object the approximate determination of this question. It will be noticed that in Sec. 20, T. 9 N., R. 68 W., only the eastern side of the section, our numbers 4, 6, 8 and 12 were sampled, and the nitric nitrogen present was found to be 7.5, 4.2, 4.6 and 2.8 p.p.m. This ground is neither high nor low, but a fair representative of average land.

POWER OF THESE SOILS TO FIX NITROGEN

It may appear to the reader, unfamiliar with the data, that we have given in other publications to show that our soils have a very decided capacity for fixing nitrogen under both laboratory and field conditions, and perhaps to the critical reader who is familiar with these data, that in the preceding paragraph we are assuming fixation without proofs, whereas we should produce them. The fact is that we have studied this subject in considerable detail for our Colorado soils. Dr. Sackett, of this Station, has published three bulletins pertaining to the fixing, ammonifying and nitrifying efficiency of our soils. I assume that the presence of nitrates in a soil is proof that the last two processes have been sufficiently vigorous for their production, and that the question of prime importance in my work is the source of the nitrogen contained in them. The main purpose of this bulletin is to ascertain how the nitrates in the well-waters are related to the nitrates in the surface soil; or, put otherwise, to ascertain whether the nitrates in the water have been formed in the soil and have gone into solution in the water, or whether they were first present in the water and were subsequently brought to the surface with it and left when the water was evaporated. In other bulletins the question of the source of the nitrogen, now present as nitrates, has been constantly held in view and repeatedly stated.

Dr. Sackett used 38 different samples of soil, some taken from the surface of nitre-spots, others taken at different depths in the nitre-spots, others taken from the edges of these spots and others taken from unaffected ground outside of these spots. The results of his investigation show that often the surface portion of the nitre areas do not fix nitrogen, while at a depth of 6 inches it still has some fixing power; but at the edges and slightly beyond, the fixing power is much higher than usual. Dr. Sackett's experiments were made by introducing soil extracts into a culture medium, and were strictly controlled laboratory experiments. The results showed conclusively that these soils actually possess the power to take nitrogen from the air, whereas the samples of raw adobe soil tested did not possess this power.

I was not entirely satisfied with the general method of investigation and made some experiments with soils that presented the indications observed in these nitre-areas adding nothing. In one case I kept the moist soil as it was taken from the field at ordinary temperatures, and in other cases I added enough ammonia-free water to make the moisture content of the soil from 15 to 18 percent., and keeping them at a temperature of 27° to 30°C. These experiments gave positive results—quite as pronounced as those obtained by Dr. Sackett in his cultural solutions. Dr. Sackett made a parallel experiment and he also obtained positive results. This procedure removed all questions of manipulation and artificial conditions except the fact that these experiments were made in the laboratory. Some of my experiments were made in the light and some in darkness. This did not appear to make any difference.

FIXATION AND NITRIFICATION UNDER FIELD CONDITIONS

In order to eliminate the questions attaching to the fact that all of these experiments were made in our laboratories and with comparatively small quantities of earth—1200 grains in my experiments—I prepared a sample of 3000 pounds and incubated it out of doors, protecting it from animals, rain and from other accidents. The moisture content was maintained at about 15 percent by addition of ammonia-free water to replace that lost by evaporation. The result at the end of 40 days was a gain of 36 p.p.m. in total nitrogen, and of 15.79 p.p.m. in nitric nitrogen. At the end of this period we applied a dilute solution of calcic nitrate to one portion of the surface; to another portion a dilute solution of sodic nitrate to see if these salts would bring about pigmentation. Both of these salts brought about a decided change from the ordinary light color of the soil to a dark brown, almost black, in a few days. The change was distinct in three days. Later in the season the soil itself showed this change in spots. This change has been observed on irrigating furrows in some portions of this land.

I have expressed elsewhere my conviction that these spots are only exceptional manifestations of a general process that goes on in our soils with unwonted vigor.

It may be urged that all this may be true but it does not show that these spots actually possess an excessive power of fixation in the fields where they are found. In answer to such I present the facts shown by the samples collected by Dr. Sackett, the most of them in my presence and examined by him. It is true that these experiments were strictly laboratory experiments, but the results of laboratory experiments in these lines have yielded results similar to those observed in the field and obtained under field or natural conditions. While the experiments and observations given in the preceding appear to us fully adequate for the establishment of all that we have claimed, we have endeavored to further ascertain the fixing power of samples of soil representing cross-sections of such a nitre-area by simply incubating them, adding only enough ammonia-free distilled water to bring the moisture present up to 15 percent. The area that we have chosen is in the section of country considered in this bulletin. We have had this spot under observation for about three years, during which time it has increased greatly, I would say to at least fifteen times the area that we first observed; and the rate at which it is extending its limits is much more rapid this season than at any time heretofore. Three years ago there was a very small area that was wholly unproductive and none of it was so bad that the owner or lessee did not plant the whole of it. At the present time no attempt is made to plant several acres of it. Four, perhaps five acres of it are now abandoned to such weeds as can tolerate the present conditions. There is no question but that a still larger portion will be abandoned in the spring of 1921, for some of this land which was cultivated last spring, 1920, is at this time entirely devoid of any vegetation. This affected area is on the side of a low hill and is rapidly extending up the hill. This ground is wet, seeped, but where this water comes from is not evident, and the question becomes more perplexing the longer we observe it. There is no apparent source from which this water may come. It is an easy matter to suggest irrigation and leakage from irrigating ditches, (there are two of these perhaps a mile to the east of this place) as the cause of this excessive moisture. This would seem plausible, but the more familiar one becomes with the facts in this section, considering at the same time the contour of the land, the more uncertain one becomes in regard to the validity of such an explanation. The water can scarcely come from any depth, for on the crest of this low hill—perhaps 200 feet from the western margin of this nitre-area—there is a deep well, 400 feet to water, which carries 4,170 p.p.m. total solids but no nitric nitrogen. Whereas, the worst portion of this area carries nitric nitrogen equivalent to sodic nitrate equal to 2.5 percent or rather more of the air-dried soil. Some of the land at the foot of this hill and west of the road is drained, but its condition is very bad.

FIXATION IN A NITRE AREA

In order to ascertain how vigorous a fixation the aforementioned area might manifest, five samples were taken and incubated for 30 days at 27°C. Twelve hundred grams of air-dried soil were taken and enough ammonia-free distilled water added to bring the moisture content up to about 15.0 percent. The five samples represent a section from north to south across the shorter diameter of the area. Sample 1, apparently normal soil, was taken in the field 60 feet north of the area; sample 2 was taken 30 feet north of what we considered the northern margin of the area; sample 3 at the northern margin of the area; sample 4 at the southern margin, and sample 5 still further south in an alfalfa field on the flank of a portion of this same hill.

	Before Incubation		After 30 Days		After 40 Days	
Sample	Total Nitrogen	Nitric Nitrogen	Total Nitrogen	Nitric Nitrogen	Total Nitrogen	Nitric Nitrogen
1	0.1054	0.00175	0.1163	0.00458	0.1045	0.00459
2	0.1018	0.00197	0.1031	0.00432	0.1029	0.00420
3	0.2570	0.13615	0.2574	0.1477	0.2590	0.1402
4	0.3395	0.2068	0.3620	0.2261	0.3620	0.2023
5	0.1315	0.0034	0.1282	0.0070	0.1284	0.0135

The worst portion of this area is not included in these samples. It was very rich in nitric nitrogen, carrying 4,500 p. p. m.

These determinations were made in triplicate and some of them checked by repeated determinations. One of these samples shows a decided increase in the total nitrogen, 229 p.p.m.; three of them show small increases, 4.13 and 20 p.p.m. respectively, and one of them shows an actual regression in the amount of total nitrogen present. Sample 1 shows an increase of 105 p.p.m. in the total nitrogen in 30 days, but in the next ten days it seems to have lost rapidly. Sample 4 shows a gain of 225 p.p.m. in 30 days and maintains it during the next 10 days. All of the samples show a decided increase in the amount of nitric nitrogen present for the 30-day period, but some of them show a falling off for the subsequent 10-day period. The amounts of total and nitric nitrogen in the land just outside of, and at the edge of the area, differ very markedly, and the ratio of the nitric nitrogen to the total increases from about 20 percent., which is very high, to more than 50 percent., and in only one instance has this ratio decreased during the incubation.

We were not satisfied with these samples, and besides we encountered unexpected difficulties in these determinations; therefore, we took a second series of samples. The two series of samples differ in important respects. The first series was taken in March and the second in September. It was impossible to sample the same section of the area for the second series; besides the area had increased very materially during this interval. It was practically a new part of the area that we had to sample for the second series, and we increased the number of samples to 10 instead of 5.

We first took 6 samples as nearly in a straight line as we could, from north to south as was previously done, but a preliminary test of these samples showed that there was an excessive quantity of nitric nitrogen in our northern-most sample, a condition that we suspected from the appearance of the soil in the field. In order to get beyond the affected area, we subsequently took two samples in an east and west line, beginning next to the bad area; but a quantitative test showed that our western-most sample, taken well up on the hill, contained more nitric nitrogen than an ordinary soil contains, the determination showing 129.0 p.p.m. It, therefore, became necessary to take further samples to avoid, if possible, initial, excessive quantities of nitric nitrogen. We accordingly took two other samples on a northward extension of our north and south line. This land had been in crops, oats and corn, during the season, but these had been cut before our samples were taken. The appearance of the soil, the stubble and the statement of the lessee agreed in indicating that these crops had been satisfactory. The object of these tests was to ascertain the fixing power of this soil outside of, at the edges of, and within the nitre area. That it has a sufficient nitrifying power is assumed, and its determination and statement are incidental. The samples were taken to a depth of three inches. The results obtained were as follows:

RESULTS OBTAINED BY INCUBATING SAMPLES OF SOIL FROM A CROSS-SECTION OF A NITRE-SPOT.

	Before Incubation		After 30 days' Incubation		After 40 days' Incubation	
	Percent Total Nitrogen	Percent Nitric Nitrogen	Percent Total Nitrogen	Percent Nitric Nitrogen	Percent Total Nitrogen	Percent Nitric Nitrogen
1	0.1320	0.0031	0.1435	0.0075	0.1770	0.0069
2	0.1345	0.0036	0.1508	0.0065	0.1870	0.0063
3	0.1340	0.0050	0.1300	0.0111	0.1860	0.0135
4	0.1320	0.0061	0.1560	0.0149	0.1950	0.0135
5	0.3040	0.1950	0.3020	0.1970	0.3530	0.1840
6	0.3970	0.2930	0.3940	0.2770	0.4130	0.2340
7	0.1335	0.0258	0.1580	0.0270	0.1920	0.0258
8	0.1035	0.0145	0.1295	0.0096	0.1605	0.0059
9	0.1340	0.0193	0.1520	0.0159	0.1840	0.0145
10	0.1245	0.0129	0.1525	0.0230	0.1750	0.0196

These samples, from 1 to 8 inclusive, are numbered regularly from north to south across the nitre-area. The area represented by Nos. 5 and 6 was entirely devoid of any vegetation. Nos. 1, 2, 3 and 4 were all supposed to be outside of the nitre-area. No. 1 was 150 feet, No. 2, 100 feet, No. 3, 60 feet north and outside of the nitre-area, while No. 4 extended up to within a few feet of the edge of the area. No. 7 was from a beet field at the south edge of the area. The presence of nitrates was strongly indicated by the color and the condition of the soil, also by the color and growth of the beets. No. 8 was also from this beet field, but neither the soil nor the beets indicated any excessive supply of nitrogen. Nos. 9 and 10 represent 60 feet or more in a westwardly direction, almost to the top of the hill at this point. The land outside of the area shows, in round numbers, a fixation of 500 p.p.m. in 40 days; at the edges, 610 p.p.m. and within the area the minimum of 160 p.p.m. Expressed in a different way, this soil has a high power to fix nitrogen, one sufficient to form 1,350 pounds of proteids in the surface three inches of the soil each 30 days, but near the edge of the nitre-area this amount rises to 2,745 pounds in the same period; while in the interior of the area, where the nitrates and other salts are very abundant, the amount of proteids formed falls to 720 pounds in 30 days, and may fall to zero, as we have elsewhere stated. The nitrifying power is also high. The deportment of these samples, which can be taken as representative of all of these areas in this section, shows independently of the results obtained in our general survey, that the nitrates present in them are actually formed in the soil of these areas. The amount of nitrogen fixed in our experiment is sufficient to furnish a great deal of nitrate if it were all nitrified, and we observe an increase of from 100 to 170 percent in the amount of nitric nitrogen during the period of incubation.

CORRELATION OF NITRIC NITROGEN IN WATERS AND SOIL

We have attempted to give the correlation of the nitric nitrogen in the soil and water in a specific case in the following table. While it is not wholly satisfactory, it shows that in this detailed way there is a close relation between the nitrates in the soil and in the water. Here the area is not large, but it meets the objection that the nitrates have been brought into the area by the water, and hence they should correlate in a general way, and the richness of the surface soil would have to be accounted for by concentration at the surface, due to evaporation. These suggestions involve questions that would have to be proven by the objectors before much importance can be attached to them. Our aim is to prove in a bigger way that such suggestions have no force. We are aware that the amount of nitric nitrogen found in different sets of samples, taken from any given 40 acres of land, will vary and may vary greatly according as the land is occupied by growing plants or is fallow. Further, these samples will vary with the amount of moisture in the soil, a slight depression in the surface, only enough to cause a difference in the moisture, will have a decided influence upon the amount of nitric nitrogen present. Still it is a fact that the territory surrounding the land which we have sampled is average land, containing an average amount of nitric nitrogen and a large territory to the west and south of Wellington is cultivated and exceedingly fine, productive land.

NITRIC NITROGEN IN SOIL IN EACH 40 ACRES ON EITHER SIDE OF NORTH AND SOUTH ROAD, 2 MILES EAST OF WELLINGTON, BEGINNING 1½ MILE NORTH OF AND EXTENDING 4½ MILES SOUTH OF WELLINGTON, TOGETHER WITH THE WELLS ON THE SAME ROAD.

Nitric Nitrogen, p. p. m. SOIL			Nitric Nitrogen, p. p. m. WELLS		
West	East		West	East	
7.9	10.8		0.8		
8.4	56.3			134.	
7.7	1.4				
85.4	19.6			101	
				50	
13.1	23.3				
36.9	5.6				
81.2	8.9				
298.7	877.3)	(336.0			
	)	(302.0			
1092.0	746.6	253.0			
15.9	25.2				
21.0	42.5				
1941.3	690.7				
1040.7	141.4			(309.4)	
	)			(286.8)	Well 280 ft. deep, none
15.4	16.3				
53.7	28.5				
43.4	23.8	515.2			
52.3	31.7				
858.7	466.6			131.6	Well 400 ft. deep, none
21.5	73.3	610.0			
28.9	17.7	599.0			
9.3	20.1				
830.7	462.0				
134.9	639.0				
387.3	14.5				

The bigger features of this case present these facts. The higher lands surrounding the area in question are not unusually rich in nitric nitrogen, that is, they carry less than 8.0 p.p.m., which is not sufficient to account for any accumulation of it. The rainfall is less than 15 inches and cannot effect much washing. Even with irrigation, this amount of nitric nitrogen is not sufficient to show any effect upon the nitric nitrogen contained in the ground-waters. This is shown in all of the tables giving the nitric nitrogen in well-waters, especially in those from the Waverly district or on the Cheyenne Road south of Jacob Rosenberg's. The drainage into the bad area is not great and if there were a sufficient amount of it to justify consideration, the content of neither the soil nor the ground-waters of the surrounding lands in nitric nitrogen would account for the amounts found, nor could any possible accumulation be effected in the places where we find them.

NITRATES ARE NOT DERIVED FROM ANY DEEP SEATED SOURCE

Another conceivable source of these nitrates is the waters below the surface. While water is found at various depths at different places the country is not blessed with an abundance of springs which might bring the nitrates to the surface from a subterranean source either deep seated or shallow. Our survey of the well-waters answers this question fully. The waters from deep wells are free from nitric nitrogen. The greatest depths at which water carrying nitric nitrogen has been obtained is 65 feet and this is very unusual. On the other hand I have given instances in preceding publications to show that the nitric nitrogen in ground-waters was derived from the surface and not from below—in one case, water at a depth of 6 feet was heavily charged with nitric nitrogen, while water from the same land, but obtained at a depth of 16 feet, carried none. This was not only in the same land but in the same part of that land, in fact from the same hole at different depths. In this case the water from a depth of 6 feet carried 14,230 p.p.m. of total solids of which 3.0 percent or 426.9 p.p.m. was sodic nitrate. The water from the depth of 16 feet and out of the underlying shale carried 22,100.00 p.p.m. total solids and no nitric nitrogen. (Bulletin 178, p. 64.) The table just given shows a sample of ground-water and one from a 280-foot well. This well was started in this bad ground and enters the shale a short way from the surface. The ground water (2 samples) carries 7,870 and 8,725 p.p.m. total solids with 309.0 and 296.8 p.p.m. nitric nitrogen. The well-water carries 4,732 p.p.m. total solids and no nitric nitrogen. In another case shown by the same table we have in the ground-water 7,462. p.p.m. total solids with 131.6 p.p.m. of nitric nitrogen and in the well-water 4,044.0 p.p.m. total solids with no nitric nitrogen. This well is 400 feet deep and about 500 feet from the surface well. The deepest well that we found in this section was 700 feet deep; the water carried 518 p.p.m. total solids and no nitric nitrogen. Another well carried 10,541.0 p.p.m. total solids and 142.0 p.p.m. nitric nitrogen. A well just west of this and at a lower level carries 2,036 p.p.m. total solids and 1.6 p.p.m. nitric nitrogen. In this case again there is not a general deep seated source of this nitrate and it must be an accumulation from the surface though an unusual one.

We find then that no water from any deep well carries nitric nitrogen and a deep seated source of these nitrates is disproven by this evidence. To the best of my knowledge this is in harmony with the results obtained by others in the examination of deep well-waters. I think that the depth of 65 feet previously given is an unusual depth from which to obtain nitrates. In this case it is not a question of a few parts per million but of many.

NITRATES HIGH IN WELL-WATERS ONLY WHEN NITRATES ARE HIGH IN SURFACE SOIL

If we consider the various smaller areas within this section we will find the same facts obtaining. I have brought together in the preceding table the nitric nitrogen in the soils and well-waters in such a manner that the results stand opposite to each other.

Where the nitrates are high in the surface soil the well-waters are also high. I have previously made mention of the fact that one may ask,—does the nitric nitrogen in the water come from the soil or contrariwise; does the nitric nitrogen in the soil come from the water? We have elsewhere shown that our ground-waters carry no nitric nitrogen except they come from beneath a nitre-area and have given one instance in which a ground-water was very rich in nitric nitrogen, whereas water obtained at a depth only 10 feet below this ground-water contained no nitric nitrogen. The latter water evidently could not be the source of the nitrates in the ground-water.

There is another possible explanation, to-wit: that this ground-water represents the leaching out of a large surrounding territory. This phase of the question was considered at length and in detail for a case in which the nitrates occurred in large quantities and we could find no basis whatever to support this suggestion.

Another source has been suggested, i.e., the waters used for irrigating the land. These waters have been examined very many times in the past and we have uniformly found only small amounts of nitric nitrogen usually less than 0.5 p.p.m. The maximum that I have record of is 1.5 p.p.m. for Arkansas River water taken at Rocky Ford which was a return water. If the waters used for irrigating these lands were the source of the nitrates, their occurrence should be more general and in all lands irrigated with this water, this is not the case.

In describing the part of the Wellington district that is particularly discussed in this bulletin, I stated that the depressions were small, some of them not more than a mile wide, and separated from the neighboring depression by a ridge so that drainage either into or out of them is difficult. The collecting area for such a basin is very limited and each such basin is a case by itself but is similar to the others. In such basins the shallow wells yield bad water. It was such a well that caused the death of the 17 head of cattle. At this place a deep well, 280 feet deep, yields water free from nitrates. It is not every depression within this area that yields nitrates. A little to the south, half a mile, and about 1 mile west, we find a place with water on the surface of the ground (I do not know that this is true the year round) with a well at the edge of this pond. Neither the well nor pond-water shows the presence of nitrates. The well-water was said to be bad for stock.

Perhaps 3 wells in Secs. 6 and 7, T. 7 N. R. 67 W. show the relation of the characters of the water and the surface soil better than these in which the nitrates are so abundant. In these cases the soil is richer in nitric nitrogen than normal, 52.0, 59.0, 60.0 and 191.0 p.p.m. and the well waters at these places carry 56.5, 63.0 and 57.4 p.p.m. of nitric nitrogen, whereas the neighboring wells carry 1.5, 1.2, 3.5, 3.0, 0.6 p.p.m. and two deep wells in the next section carry none and 8.0 p.p.m., respectively.

I know that objection may be made to the adequacy of this proof but it appears to me that no successful denial can be made of the conclusion that the surface soil is the source from which these nitrates are derived, as the wells are from 18 to 25 feet deep.

FOUR EXCEPTIONAL WELLS

I have met with but 4 cases in which I had any doubt at all about the nitrates having been derived from the surface soil, above and surrounding them. These four were widely separated from one another; two of them were in the Arkansas Valley and two in the area discussed in this bulletin.

The two instances in the Arkansas Valley were called to my attention by the correspondence of the owners. I went to see these wells but one of them had been filled up. The other well was 27 feet deep. The water carrying zone was one foot thick and began at a depth of 23 feet. No water came in below the 24th foot. This was in a dry-land section and there was no canal or other water very near to it. The last time that I visited this well it was dry. There was no other water found on this ranch, though one well was dug to a depth of 28 feet and another to a depth of 50 feet, which developed a pocket of good water that was soon exhausted. The nitrates present in this water, calculated as sodic nitrate, amounted to 5,440.0 p.p.m. I find that in writing of this in 1911, (Bulletin 178, p. 75.) I said "The source of the nitrates contained in this water is unquestionably, I think, the higher lying surface soil to the north of this place. Why the water should be confined, as it apparently is, to this particular area is not evident". I have quite recently endeavored to find other instances like this in that section but have failed. Deeper wells were sunk at this place without obtaining water and wells on neighboring ranches yielded good water.

These four cases that have come under my own observation are mentioned as possible exceptions to the claim that the nitrates in the waters of shallow wells come from the surface soil.

CONCERNING THE SOURCE OF THE NITROGEN IN THESE NITRATES

For my views as to the source of the nitrogen and the process by which it is converted into nitrates, reference may be had to Bulletins 155 and 178 under the title "The Fixation of Nitrogen in Colorado Soils", also Bulletin 217, p. 5 **et seq.** and Bulletin 183, p. 116.

Briefly stated, the salient features of this question are as follows: These spots or nitre-areas are richer in nitrogen than ordinary soil; they are also very much richer in nitric nitrogen or corresponding nitrates than ordinary soil. Further, the ratio of nitric nitrogen to the total nitrogen is always high. It is always assumed that the conversion of proteid nitrogen into nitric nitrogen is a process so well established, so universal and so generally accepted that it is unnecessary to so much as make mention of it. The question to be answered is, where does the nitrogen, be it in the form of proteid or of nitric nitrogen, come from.

My view is that it is derived from the atmosphere through the agency of living organisms that are capable of appropriating the atmospheric nitrogen to build up their nitrogenous components. As the azotobacter are capable of an independent existence and of accomplishing this, they were the first organisms to suggest themselves as the agency.

It does not follow that other organisms may not take part in this process; in fact, it seems very certain that there are other organisms, either alone or in association, which may effect this fixation as well as the recognized azotobacter. I have previously explained this process as one carried out by bacterial agencies. It is much better and probably more accurate to use the term biological activities which I use to include mixed floras, as well as those which are at the same time capable of fixing nitrogen and of an independent existence.

SUMMARY

The study of this setion leads us to the recognition of a rather large area south and east of Wellington throughout which nitrates occur abundantly in the surface soil.

That there is another smaller, and, at the present time a less important occurrence, in the Dry Creek section south and west of Waverly.

That the waters of shallow wells and the surface soils are closely related in regard to the nitric nitrogen present in them.

That there is not any abnormally large amount of nitric nitrogen in the soil of the district outside of the nitre-area.

That shallow wells outside of these areas do not contain any abnormal quantities of nitric nitrogen.

That the waters from deep wells, even when either sunk through or adjacent to areas very rich in nitric nitrogen, are free from it and would not, even if they should find egress at this or any other point, bring nitric nitrogen to the surface.

That the composition of the salts held in solution in the deep well-waters differs from that of those held in the ground-waters; the former holds essentially sulfates of soda and lime, while the latter carry nitrates and sulfates of magnesia and soda, with some calcic sulfate.

That the extracts of soil samples taken from these areas are characterized by the presence of much magnesia, high nitric acid, low sulfuric acid, low lime and low soda.

That the amount of potash in these extracts is uniformly high, from 0.7 to upwards of 2.0 percent of the total soluble portion.

That the ground-waters and the soluble portion of the soil, even when associated with effloresced "white alkali" are very rich in magnesic salts.

That the ground-waters derive their nitrates from the soil and the amount is determined by local conditions.

That calcic and magnesic chlorids occur in considerable abundance in some of the soil extracts, but the explanation of this fact is not apparent.

That the surface soil, especially at the edges of these nitre-areas, has a very high capacity for fixing nitrogen.

That the facts that we have been able to ascertain support the view that the nitrates occurring in this area have no source outside of the area and on the surface. Further, that there is no source beneath the area from which they are derived. Within this area the nitrates are formed **in situ**, a view that I have elsewhere maintained for other sections.