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THE DRAINAGE OF IRRIGATED SHALE LAND.[1]

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CONTENTS.

INTRODUCTION.

Drainage is now recognized as one of the most important problems confronting the farmers of irrigated lands. Drainage methods in the arid regions differ from those in the humid sections, and even with respect to arid land different methods must be used for different types of land. One of the frequently occurring types that require special treatment is the so-called shale land, by which term is meant those lands that are immediately underlain by shale which may or may not outcrop and in which the soil is made up largely of disintegrated shale. Areas of this type occur in all of the Rocky Mountain States and in some of those immediately adjoining.

In spite of the fact that shale is classed among the less pervious formations, it becomes an important factor in the movement of underground water in those areas where uplifts and displacements have occurred. Investigations by this department have shown that in those sections which have underlying shale near the surface there is a close relation between the shale and the areas of seepage. This relation depends more or less on the topography of the underlying shale,

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[1] This bulletin contains information on the drainage of those irrigated lands of the Rocky Mountain States that are underlain by shale.

ACKNOWLEDGMENTS.—The soil analyses presented in this bulletin were made in the laboratory of the Bureau of Soils, U. S. Department of Agriculture. The analyses of the water samples were made in the water laboratory of the Bureau of Chemistry, U. S. Department of Agriculture.

wet ground usually occurring near an underlying shale ridge, point, or knoll which discharges water into the soil immediately surrounding it.

The possibility of reclaiming the water-logged and alkaline shale lands has been demonstrated in numerous instances; the purpose of this bulletin is to explain how and why the shale enters into the problem and to present the principles and methods upon which the reclamation of this type of land depends.

GEOLOGICAL FEATURES.

In the drainage of shale lands some knowledge of the underground formations is essential, as the seepage water often is under pressure and the problem is similar in some respects to one of developing an artesian supply. The water may move for considerable distances at depths that can not be reached by drains and may appear on the surface at some lower point. Ordinary methods of drainage fail because of the pressure and the resulting upward movement of the water. A proper solution of the problem requires a careful study of the source and direction of ground-water movement. Obviously, this necessitates a knowledge of the strata carrying the water.

The area to which this bulletin pertains is situated in the Rocky Mountains and on the high plateau areas immediately adjacent. The land usually is at a high elevation, the slopes steep, and the topography very rough. The rivers usually are hemmed in by high rock bluffs where they emerge from the mountains into valleys that are more open and gentle in slope. These valleys often are characterized by a sharp ascent to a gravelly mesa on one side and by a long gradual slope on the other side. Some distance back from the stream the ascent is broken by terraces of gravel or sand, or by tracts of clayey "bad lands," and here and there by rocky cliffs and mesas.

Shale is a finely stratified or laminated rock, formed from the stratification of clay, silt, or mud. In some of the so-called paper shales (Plate III, fig. 2) there are as many as 30 or 40 laminæ to the inch, each representing a separate stage of stratification.

Numerous varieties of shale structures are encountered which influence the movement of the underground water; however, this discussion is limited to the following three distinct types that have a wide range: Type No. 1, hard, calcareous shales that have suffered little or no displacement; type No. 2, shales, the layers of which dip very steeply; and type No. 3, shales in which the layers are horizontal or nearly so, but which have been subjected to great pressure.

Shales of the first type need little description. Being hard, poorly laminated, and lacking fissility, they more nearly represent the popular conception of shales which classes them among the less pervious geological strata. They probably are not capable of containing more than 4 per cent of water.[1] Their value as a water-carrying medium may be considered negligible.

The second type is to be found along the sharp-crested and well-defined "hogbacks." These usually are steep ridges which affect all of the formations immediately adjacent to them, the general uplift having tilted the layers of shale until they dip sharply and, in fact, in some places are nearly vertical (see Plate I). The pitch of these layers, however, decreases with depth and the distance from the hogback. In the uplifting process they have slipped, broken and shattered in a very complex manner.

The third type usually is found in folds of great extent, where the displacement has not been so intense and the layers or strata do not vary far from the horizontal. The layers, however, are by no means continuous and unbroken. If in the elevation of land areas the only forces are those acting in vertical lines so that the strata remain horizontal, cleavage may not be introduced, but if there are great forces acting horizontally, cleavage may be developed. "Whole mountains of strata may be cleft from top to bottom in thin slabs along planes parallel to each other."[2] This is well illustrated along the sides of a deep cut in an irrigation ditch shown in Plate II, figure 1, which cuts across a number of these cleavage planes. Plate II, figure 2, also is a good example of this. "The planes of cleavage seem to have no relation to the strata, but cut through them, maintaining their parallelism, however the strata may vary in dip. Usually the cleavage planes are highly inclined and often nearly perpendicular.[2]

Owing to the fissile nature of the shale, the compression also has caused shearing planes along the bedding planes. These, in turn, have become broken and in excavation the shale comes out in large flakelike pieces (Plate III, fig. 1). In some instances where the pressure has been intense, fault planes have developed. Plate III, figure 2, illustrates one of these, showing the shale layers to have slipped about 18 inches. The extremely broken and shattered conditions along this fault plane show clearly that it would carry water quite freely.

SURFACE TOPOGRAPHY.

During remote times the shale formations were subject to erosion and formed a topography of their own, similar to that of the exposed shale which can be seen at the present time. Erosion has produced "bad land" topography differing in character according to the local conditions. On the higher slopes, where erosion was especially vigorous, the shale is cut by deep, V-shaped ravines, the sides of which are very steep or nearly vertical (Pl. IV). Sometimes knolls or domes occur, as illustrated by Plate V. The bottoms of the

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[1] U. S. Geol. Survey, Water Supply and Irrigation Paper No. 160, p. 72.

[2] Elements of Geology, Le Conte, p. 189.

ravines usually are hard and solid, for the small streams have carried away the loose shale; but the ridges are covered to some depth with loose, broken, flakelike shale which has been formed by weathering.

With the exception of some of the higher ridges and knolls, the shale in the river valleys has been overlain with a covering of soil which varies greatly in depth. In general, the surface of these valleys has a configuration corresponding somewhat to the underlying shale surface, the minor irregularities of which are masked by the overlying soil. In the design of a drainage system the locations of these minor and abrupt irregularities must be determined by a large number of subsoil borings. This is made difficult by the flakelike covering over the solid shale, for this flakelike shale is found in other places at various depths in the soil, where it has been washed, and is not underlain by the solid formation.

UNDERGROUND WATER.

The collective medium for the underground water is the soil, especially those higher and more porous portions where irrigation is heavy, and also those higher exposed portions of broken shale in which canals and reservoirs have been constructed.

PRESSURE CONDITIONS.

The underground water usually exists under pressure. This fact, together with the moisture retentiveness of the soil, renders drainage difficult. After having stated that the mantle of soil in the higher land acts as a collective medium, it may seem inconsistent to say that it serves as the confining agency in the artesian conditions that exist at lower levels. However, the existence of artesian conditions does not necessarily require that the confining strata be wholly impervious, but only that they be less pervious than the water-bearing stratum. The top formation may be penetrated by considerable quantities of water, so that the leakage is large, and yet be available as a confining agent. This loss merely causes a reduction in pressure and volume. If it were not for the leakage, the head which the water derives from the highest zone of intake would continue under the entire region, but owing to this leakage there is a gradual diminution as the distance from the source increases.

The fact that the soil is less porous and offers greater resistance to the movement of underground water than does the shale causes the soil to act as a confining agent, the efficiency of which increases with its thickness. There is little need that cover beds of highest impervious character be very thick, but when the degree of imperviousness is inferior the element of thickness, in itself, is not without consequence. This is true especially where low pressures exist. The thicker covering offers more frictional resistance as the degree of consolidation increases with depth.

The water pressure usually is low because of the frictional resistance of the shale, and because of the leakage through the cover bed which causes seepage areas where the shale ridges or points lie near the surface.

RELATION OF UNDERGROUND WATER TO SHALE.

Water moves through the pores and laminæ of shale so slowly that solid shale is of negligible value as a water-carrying medium. The displacements and uplifts, however, which caused these strata or layers to be traversed by faults, cleavage planes and joints, or which caused them to assume sharp dips, have left this shale in a comparatively permeable condition.

Those hard, calcareous shales mentioned earlier (type 1, p. 2), which have not been disturbed and which are poorly laminated, do not carry water to any great extent and for all purposes of this discussion may be considered as impervious strata, the principal movement of the underground water being laterally over the shale surface.

In the second type of shale, as mentioned on page 3, the water is carried principally between the nearly vertical shale layers, as illustrated by Plate I, and the principal direction of its movement is of course parallel with the strike, especially in the deeper and less fractured zones. These water carriers have no regularity in spacing, which may vary from a small fraction of an inch to several inches. They are partly surface phenomena and diminish in number rapidly with depth and probably are better developed in the hills than in the valleys. Since the pitch of the strata usually decreases with depth, the surface of a valley cuts across a less number than does the surface of a hill.

In the third type of shale referred to on page 3 the important water carriers are the nearly vertical planes of cleavage (Pl. II) which cut at close intervals across the more or less horizontal strata. The distance between these planes may be only a few inches, but usually the larger and more important ones are a much greater distance apart. They vary in length from a few feet to hundreds of feet. While they influence the general trend of the direction of movement of the underground water, they may not be the immediate cause of seepage areas, for these planes are connected with each other and with the sloping surface of the shale by zones and widespread areas of shale that has been shattered and broken by shearing along its bedding planes.

All shales that have been subjected to intense pressure and displacements are traversed by numerous fissures or joint cracks, and these openings carry a large portion of the water. The prominent joints may extend several hundred feet, but even though the continuity of the individual joints be short, the minor intersecting fissures may cause long continuous openings. A knowledge of this condition is very important in determining the nature of the circulation of the underground water. Naturally the circulation is greatest where the vertical joints and horizontal fractures are most open and numerous.

MOVEMENT OF WATER.

The joints and cleavage planes serve as the principal channels for the free circulation of the water, and it is apparent that a well must strike one or more open fissures in order to obtain water. The evidence for this statement consists (1) of observations on the correspondence of the direction of the major joints observable in the rock at the surface with the appearance of seepage in the lower areas; (2) of the fact that many wells have been drilled within a few feet of each other without encountering water at the same depth; (3) of the dissimilar pressures in adjacent wells of the same depth.

Often when water is struck in a relief well the rise is very sudden. Such a rise means that the water is under pressure and that enough of it is in the larger openings that extend back up the slope to cause the initial rise. Small sustained flows come probably from areas of close jointing which are more or less continuous. While the movement of water in the close joints is slow, yet the aggregate capacity for storage is many times that of the larger fissures. These areas of close jointing collect water during the irrigation season and gradually feed it out to such larger and freer channels as may cut across them.

While the greatest movement of the water is along the direction of the systems of joints, yet mechanical and other agencies have left the ridges and knolls of the shale so badly broken and shattered that often they carry water quite freely in other directions and may discharge water at their points regardless of whether they run parallel with or perpendicular to the system of jointing. This condition, together with the closing of joints and the rapid decrease in number and greater spacing with depth, makes it evident that there will be a much freer circulation of water in the upper portions of the shale, or rather, in the remainder of the upper portions which now form the ridges. This accounts partly for the phenomenon of water following the shale ridges and leaking from them rather than from the other portions.

This condition is illustrated on the contour maps in figures 4 (p. 28) and 7 (p. 33), where the surface of the ground, the ground water, and the shale have been represented by distinctive lines. The most interesting feature of the maps is the general resemblance of the water contours to those of the shale, showing the influence of the shale topography on the movement of the underground water. In figure 4 a rather broad shale ridge is shown to come in from the northwest corner, becoming more sharply defined toward the south. In the southwest quarter is a portion of a draw or embayment in the shale formation, the slope of which is quite steep. Here the surface of the water follows very closely that of the shale. In the northwest corner the water conforms in a general way with the shale surface, but this is a very wet seepage area and a point where the shale discharges considerable water into the soil above it. It is not to be expected that at such points the shale and water contours will agree closely. Farther down on the sharp-crested portion of the ridge there is a closer resemblance.

Profile A of figure 5 (p. 29) is taken along the shale with highest grade and shows a marked agreement in slope between the water and shale. Profile B of figure 5 is taken across the better defined shale ridge and illustrates very clearly the conformity between the surfaces of the shale and water. Figure 7 (p. 33) shows the point of a well-defined shale ridge. The similarity between the shale and water contours should be noted. Profile C of figure 8 (p. 34), taken across this well-defined shale ridge, represents very much the same condition as does profile B of figure 5. Profile D of figure 8 is taken along a shale ridge and its point, and shows the water closely following the ridge up to the sudden dip or change in grade and then passing out into the soil, causing seepage conditions.

ALKALI.

Aside from the problem presented in the drainage of shale lands, complete reclamation for agricultural purposes is further complicated by the fact that lands of this type are often strongly alkaline, so that where they have become water-logged and have been allowed to lie idle for several seasons they have developed a decided alkali problem in addition to the one of drainage.

As providing a criterion for determining the severity of the alkali problem of different tracts where drainage is a factor, it is believed that analyses of a limited number of samples of the soil water more nearly represent average conditions and consequently are of greater value than are analyses of the same number of samples of the soil. This view is held because the alkali in any tract of land always is more or less unequally distributed, and a wide range of results will be obtained from analyses of the soil, depending not only upon just what parts of the tract the samples are taken from, but also upon whether they represent the surface inch or surface foot or some other depth of soil. It is true, there will be also a variation in the quality of the soil-water from a tract, but in general the range is not so great as in the soil, and a few analyses will show whether it is high or low in salt content and will indicate the kinds of salts. Under ordinary conditions this is about all that is necessary to know in order to forecast the probable difficulty that will be encountered in bringing the land to a condition for cultivation subsequent to drainage.

Surface accumulations of the alkali salts should not be taken as conclusive evidence of a case of extreme alkali trouble, for when the soil water rises to such a height that the surface of the ground is kept moist by the capillary water, high evaporation results, and as only relatively pure water passes off in this manner, it follows that the salts are left at the surface. If this process continue for sufficient time, heavy incrustations of salt may form on the ground surface irrespective of whether the soil water is highly or slightly alkaline, though the higher the percentage of alkali in the soil water the more rapid the accumulation of the salts by evaporation. Consequently, the more alkaline the soil water the greater the necessity for immediate relief by drainage. The necessity of the drainage of those shale lands that have become water-logged is shown from a study of the following tables. Table I contains the results of analyses of soil water as discharged from 10 newly installed drainage systems on tracts at one time under cultivation. Samples A and B in Table II are two samples of seepage water through shale from a canal the first season after construction. Sample C in Table II is seepage water in a valley in the bad-land topography shown in Plate IV.

TABLE I.—*Analyses of drainage waters from systems in shales.*

(Tracts at some time under cultivation.)

Substance.	Milligrams per liter (parts per 1,000,000).									
	1915, Feb. 1. A.	1914, May 26. B.	1914, Apr. 27. C.	1914, Apr. 27. D.	1914, June 11. E.	1914, May 8. F.	1915, Mar. 30. G.	1915, Mar. 14. H.	1916, Feb. 15. I.	1916, Feb. 15. J.
Ions.										
Sulphuric acid (SO_4)	2,542	8,566	24,932	25,382	3,132	13,320	10,508	5,500	6,372	20,470
Carbonic acid (CO_3)	....	....	12	15.2	....	....	....	....	....	50
Bicarbonic acid (HCO_3)	467	556	583	728	348	632	513	427	861	688
Nitric acid (NO_3)	14.2	398	1,253	982	200	832	286	443	4,861	7,614
Chlorine (Cl)	41	172	294	305	156	490	262	378	232	428
Calcium (Ca)	517	428.5	427	452	505.5	425	405	453	602	492
Magnesium (Mg)	381	1,016	2,754	3,333	362.5	878	600	570	1,315	2,746
Sodium (Na)	111	2,156.7	7,123	6,178	540	5,094	3,901	1,606	2,151	7,442
Total	4,073.2	13,293.2	37,378	37,375.2	5,244	21,671	16,475	9,377	16,394	39,930
Hypothetical combinations.										
Sodium carbonate (Na_2CO_3)	....	....	....	....	....	....	....	....	....	88
Magnesium sulphate ($MgSO_4$)	1,886	5,030	13,633	16,499	1,795	4,346	2,970	2,822	6,510	13,593
Sodium nitrate ($NaNO_3$)	19.2	545.6	1,718	1,346	274	1,140	392	607	6,664	10,438
Sodium chlorid (NaCl)	68	283.5	485	503	257	809	432	623	382	706
Sodium sulphate (Na_2SO_4)	244	5,860.5	19,975	17,346	1,127	13,798	11,196	3,695	609	13,287
Calcium sulphate ($CaSO_4$)	1,236	835.5	773	689	1,329	739	803	1,063	1,085	904
Calcium bicarbonate ($Ca(HCO_3)_2$)	620	738.1	774	967	462	839	682	567	1,144	914
Calcium carbonate ($CaCO_3$)	....	....	20	25.2	....	....	....	....	....	....
Total	4,073.2	13,293.2	37,378	37,375.2	5,244	21,671	16,475	9,377	16,394	39,930

TABLE II.—*Analyses of seepage waters through virgin shales.*

(No land lying above ever under cultivation.)

Substance.	Milligrams per liter (parts per 1,000,000).		
	1915, Nov. 18. A.	1915, Nov. 12. B.	1916, Apr. 29. C.
Ions.			
Sulphuric acid (SO_4)	4,236	21,800	37,612
Carbonic acid (CO_3)		96	77
Bicarbonic acid (HCO_3)	434	849	710
Nitric acid (NO_3)	4,004	577	1,687
Chlorine (Cl)	480	1,038	2,783
Calcium (Ca)	1,110	567	535
Magnesium (Mg)	523	2,481	2,556
Sodium (Na)	1,725	6,376	15,318
Total	12,512	33,784	61,278
Hypothetical combinations.			
Sodium carbonate (Na_2CO_3)		170	136
Magnesium chloride (MgCl)	148		
Magnesium sulphate ($MgSO_4$)	2,402	12,282	12,653
Sodium nitrate ($NaNO_3$)	5,489	791	2,313
Sodium chloride (NaCl)	609	1,711	4,588
Sodium sulphate (Na_2SO_4)		16,723	39,620
Calcium sulphate ($CaSO_4$)	3,287	979	1,025
Calcium bicarbonate ($Ca(HCO_3)_2$)	577	1,128	943
Calcium carbonate ($CaCO_3$)			
Total	12,512	33,784	61,278

These are all bad waters, as only three of the 13 samples show less than 10,000 parts per million, or 1 per cent, of the soluble salts, and one of these is but slightly below this figure. The average for the 13 samples is slightly in excess of 23,700 parts per million, or 2.37 per cent.

An acre-foot of water weighs 2,722,500 pounds and with a salt content of 23,700 parts per million will contain 64,523 pounds of salt. Assuming the weight of an acre-foot of soil at 4,000,000 pounds, the salt that would be left in the soil by evaporation from it of but a single acre-foot of this water would be equivalent by weight to 1.6 per cent for the top foot of the soil. If this quantity were distributed throughout a depth of 4 feet, it would mean an average of four-tenths of 1 per cent. It is conservative to assume an annual evaporation of 36 inches under such climatic conditions as exist in those sections of the United States to which this bulletin refers, so that it would require but one season to deposit enough salts, by evaporating the average of the waters represented by Tables I and II, to make the situation three times as bad as the above. Allow surface evaporation, resulting from poor drainage, to continue for a number of years and the situation with respect to alkali is rendered extremely serious.

Many investigators, working independently, have attempted to establish a comparative standard relative to the tolerance of plants for the different alkali salts present in a soil. Owing to the variety of combinations and soil and moisture conditions under which these injurious salts may occur, it is not possible to state definitely the highest percentage a soil can contain and still support ordinary vegetation. However, in order to convey a general idea of what is meant by an alkali problem, the results of recent and very extended experiments by Frank S. Harris, professor of agronomy, Utah Experiment Station, are summarized in part as follows:

> [1] In this paper results of over 18,000 determinations of the effect of alkali salts on plant growth are reported. * * * Only about half as much alkali is required to prohibit the growth of crops in sand as in loam. * * * The toxicity of soluble salts in the soil was found to be in the following order: Sodium chlorid, calcium chlorid, potassium chlorid, sodium nitrate, magnesium chlorid, potassium nitrate, magnesium nitrate, sodium carbonate, potassium carbonate, sodium sulphate, potassium sulphate, and magnesium sulphate. Land containing more than about the following percentages of soluble salt are probably not suited without reclamation to produce ordinary crops. In loam, chlorids, 0.3 per cent; nitrates, 0.4 per cent; carbonates, 0.5 per cent; sulphates, above 1 per cent. In coarse sand, chlorids, 0.2 per cent; nitrates, 0.3 per cent; carbonates, 0.3 per cent; and sulphates, 0.6 per cent.

Using the figures as given by Prof. Harris as a basis for comparison, it is apparent that great danger to crops from alkali exists in those lands represented by the foregoing samples of drainage water, provided the water be allowed to rise above the root zone of any cultivated plant. If the rise be such as will permit of evaporation from the ground surface, it also is obvious that the trouble will be aggravated rapidly.

Illustrating this latter point, there follow the results of the soil analysis of a composite of two samples at each depth taken from near the center of about 4 acres that produced thrifty alfalfa previous to the season of 1913, but which became so wet the summer of 1913 that water rose to the surface of the ground and ran off through the waste ditches. Needless to say the land became wholly unproductive.

TABLE III.—*Salt content of shale-land soil.*

Substance.	Parts per 100,000 of soil by weight.						
	First foot.	Second foot.	Third foot.	Fourth foot.	Fifth foot.	Sixth foot.	Average.
Sodium chloride ($NaCl$)	178	92	132	337	132	46	153
Sodium sulphate (Na_2SO_4)	44	231	141	1,166	53	620	376
Magnesium sulphate ($MgSO_4$)	278	535	377	615	615	436	476
Sodium bicarbonate ($NaHCO_3$)	116	116	149	116	132	116	124
Calcium sulphate ($CaSO_4$)	680	1,373	720	3,425	8,837	4,337	3,229
	1,296	2,347	1,519	5,659	9,769	5,555	4,358
Nitric acid (NO_3)	89	600	500	556	353	188	381

Attention is called to the fact that these soil samples, as well as the water samples in Tables I and II, are unusually high in the nitrates and carry also considerable sodium chloride. As noted

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[1] Journal of Agricultural Research, U. S. Department of Agriculture, vol. 5, no. 1, Oct. 5, 1915.

earlier, Harris found that these two salts are extremely injurious to plant life, both ranking ahead of sodium carbonate in this respect.

The different alkalies, including the nitrates, present in large quantities in the shales and in the soils formed from the shales, had their origin in the brackish waters of the old inland seas.[1] That the nitrates present in the water samples of Table I are an inherent part of the virgin shales and not dependent upon conditions following cultivation is shown clearly by the analyses of the seepage waters in Table II, as all three of these samples came from tracts of desert lands that never were cultivated, nor was any land lying above them ever cultivated. The water represented by samples A and B in Table II was the direct result of losses from a new canal through which water had been run only for about six weeks during the latter part of the same season the samples were taken. Sample C represents seepage water just beneath Mount Garfield in the Bookcliff Range in western Colorado. The quantities of nitrates in these samples are remarkable, especially in samples A and C.

DRAINAGE METHODS.

Among the owners of shale lands many conflicting opinions are expressed as to the cause of seepage, and almost as many remedies suggested. Many drainage systems have been installed by landowners, with but little success. The ineffectiveness of ordinary drainage methods has been demonstrated repeatedly by the many failures in the arid West of methods which commonly are successfully practiced in the Middle West and in the East. Furthermore, even the methods that have been employed successfully in the drainage of the ordinary type of affected land in the arid West have failed when applied to shale lands. Shallow drainage is of absolutely no avail, and deep drainage with a small interval between drains fails also when the seepage water is supplied under pressure by outcropping or immediately underlying shale formations. Soil which is largely made up of shale belongs to the "adobe" type and does not respond readily, under ordinary conditions, to any type of drainage; and where shale furnishes the water under pressure, drainage systems must be designed which will take the water from the shale before it reaches the soil.

EFFECTIVE DRAINAGE.

PRELIMINARY EXAMINATIONS.

Effective drainage of shale lands depends upon the location and depth of the drains and upon the proper installation of relief wells. To locate the drains properly is a slow and laborious process, for it

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[1] Stewart, Robert, and Peterson, William. The Nitric Nitrogen Content in the Country Rock. Utah Experiment Station, Bulletin 134, 1914.

requires the mapping—or at least the gaining of a correct idea of the surface topography—of the underlying shale. This necessitates a large number of borings and very careful subsoil examinations, owing to the sudden changes and extreme irregularity in the shale topography. On some tracts the surface of the underlying shale is fairly regular and not a great many subsurface examinations are required, but in many instances the shale has been eroded into bad-land topography (Pls. IV, V, and VI, fig. 1). The auger at one point may strike the top of a shale knoll, dome, or point immediately underlying the covering of soil, while 20 feet away in any direction it will not encounter shale at a depth of 10 to 20 feet. (See profiles C and D, fig. 8, p. 34). Very narrow ridges often are found, the tops of which are near the ground surface, but a short distance on either side the shale is too deep to be reached by tile drains. A common occurrence in the shale formation is a very deep and quite wide arroyo running through a rather smooth area of shale, but with no indication of this deep depression, owing to the covering of soil.

Where only small areas are affected the shale knoll, or point, contributing the seepage water may be located sometimes by ascertaining from the landowner the spot where seepage first made its appearance. The damaging features of the underlying shale topography often can be quickly ascertained by a line of borings closely spaced along the upper edge of the affected area. Where large areas are affected, and where an idea must be gained of the topography of the shale underlying the entire district, perhaps the most rapid method is to begin with a boring at each of the extreme corners of the tract, then to subdivide the distances between these holes, continuing the process until a sufficient number of borings have been made to determine the general features, after which those spots or localities which seem to overlie points or ridges can be more carefully examined. In cases where the conditions are very complex, and it is desired to map the underlying shale, it is best to space the majority of the holes regularly over the area in question.

The topography of the underlying shale usually resembles the present surface topography in a very general way. In the bottom or older portions of a valley that are more or less even and uniform, the underlying shale usually is also fairly smooth. On the slopes the more pronounced ridges are often underlain by shale ridges which represent the general trend of the system of shale topography. Frequently outcroppings of shale will give an idea of the underlying features. In some cases large underlying shale draws can be located by noting the gaps and openings in hills forming the rim of the valley. A knowledge of the kind of shale being dealt with and its characteristic topographic features is of value in gaining a general idea of its surface.

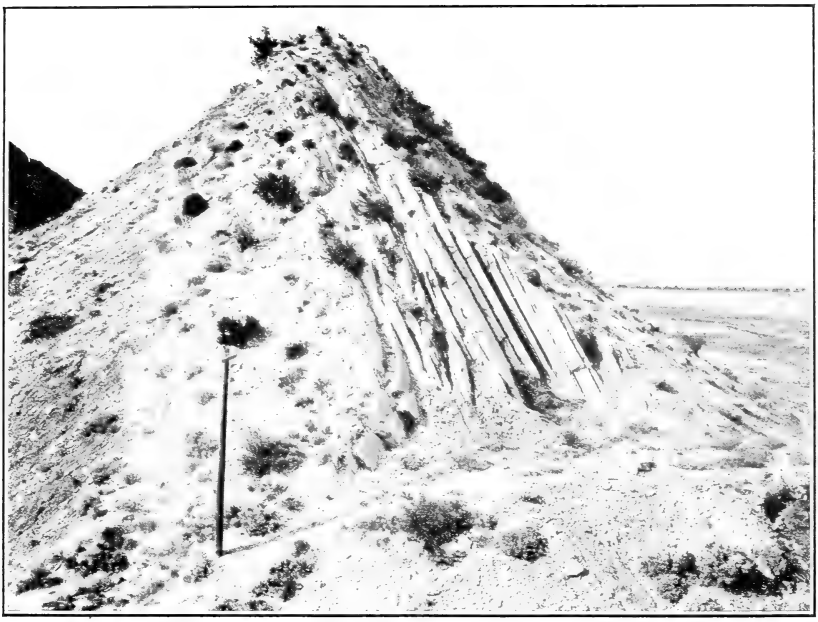

FIG. 1.

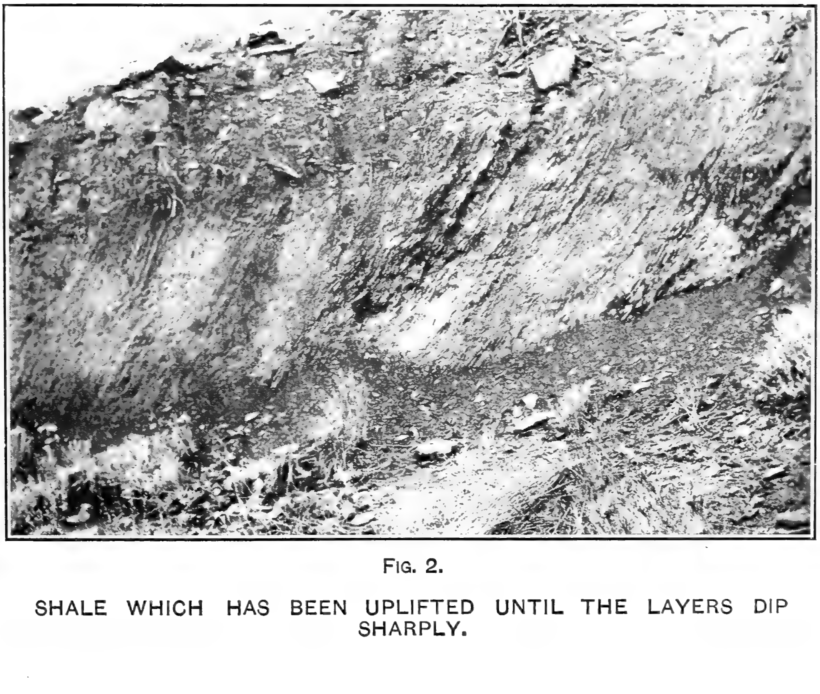

FIG. 2.

SHALE WHICH HAS BEEN UPLIFTED UNTIL THE LAYERS DIP SHARPLY.

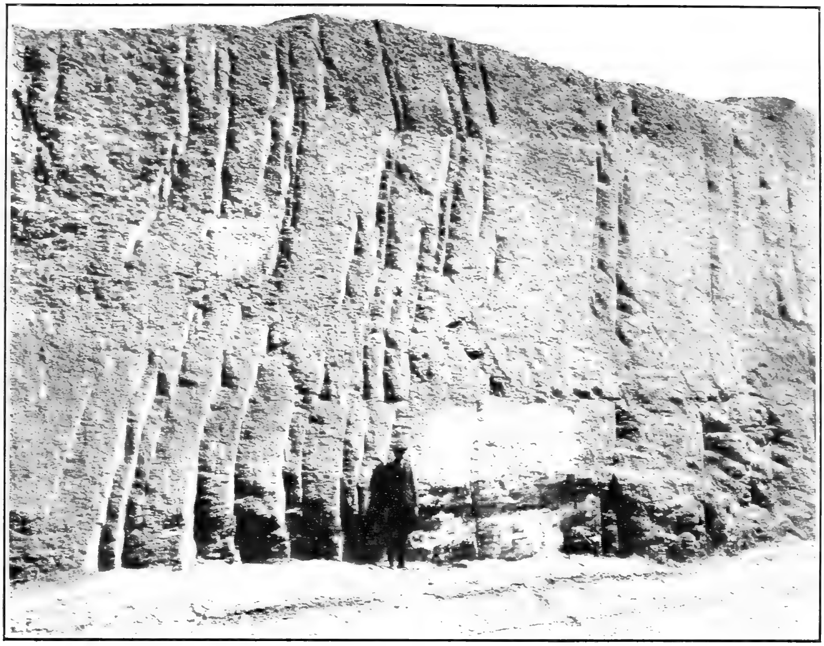

FIG. 1.—SIDE OF AN IRRIGATION DITCH, SHOWING NEARLY VERTICAL CLEAVAGE PLANES.

FIG. 2.—SHALES HAVING NEARLY HORIZONTAL LAYERS WHICH HAVE BEEN CUT BY CLEAVAGE PLANES CAUSED BY GREAT PRESSURE.

Cleavage planes continuous through shale layers and intervening rock strata.

FIG. 1.—PRESSURE HAS CAUSED SHEARING ALONG BEDDING PLANES; WHEN EXCAVATED THE SHALE COMES OUT IN LARGE FLAKELIKE PIECES.

FIG. 2.—WHERE PRESSURE HAS BEEN EXTREME, FAULT PLANES HAVE DEVELOPED.

EFFECTS OF INTENSE PRESSURE ON SHALE.

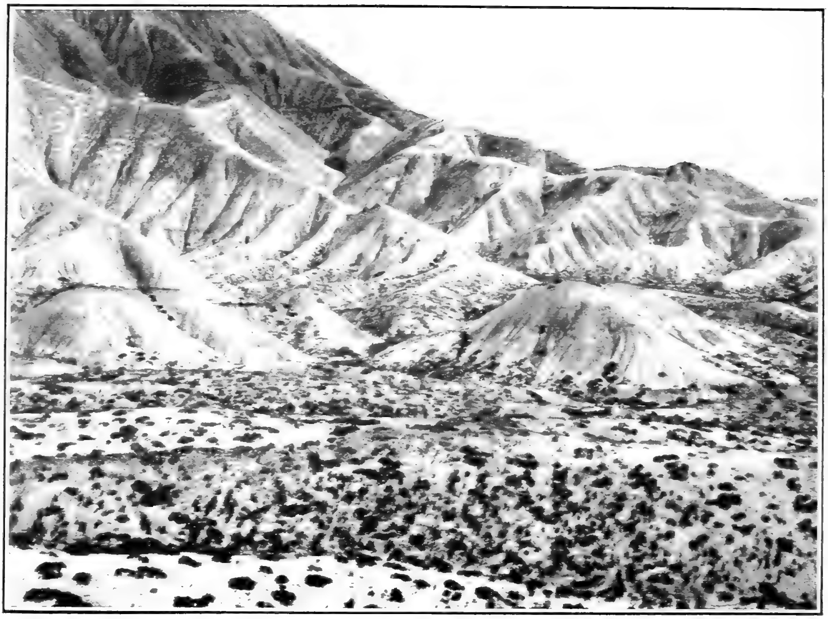

FIG. 1.

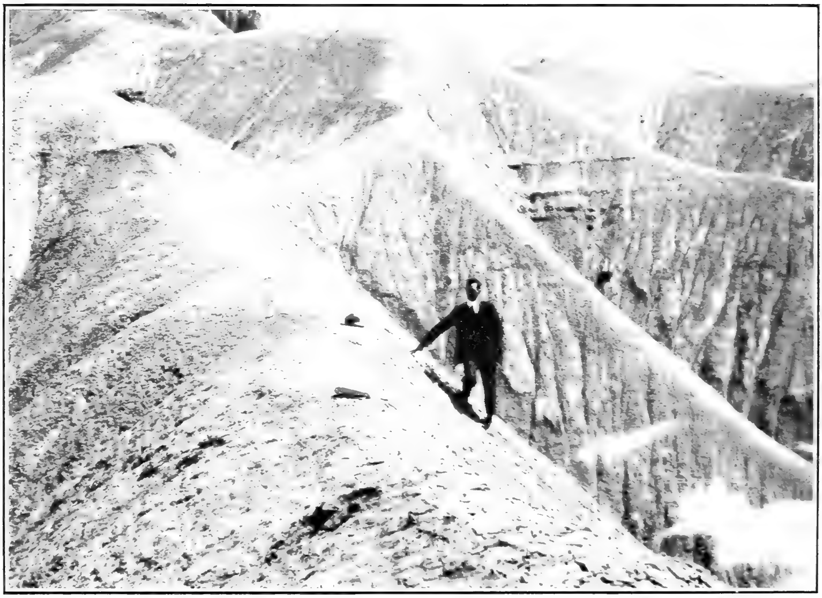

FIG. 2.

"BAD-LAND" TOPOGRAPHY, PRODUCED BY VIGOROUS EROSION OF THE HIGHER SLOPES.

FIG. 1.

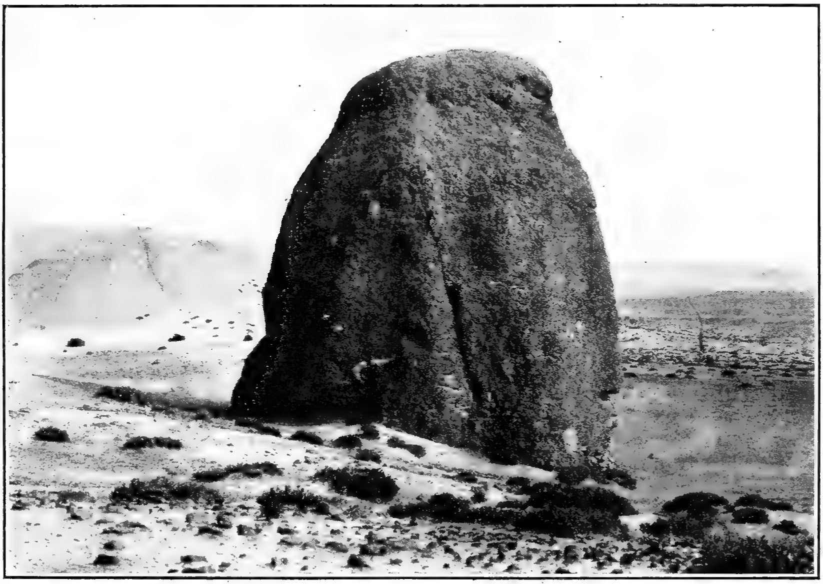

FIG. 2.

"BAD-LAND" TOPOGRAPHY. A SHALE KNOLL (FIG. 1) AND A SHALE DOME (FIG. 2).

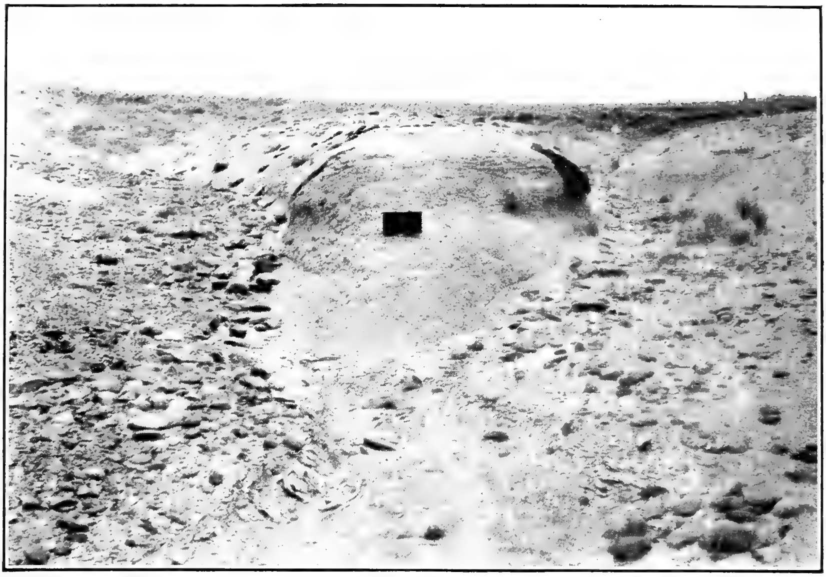

FIG. 1.—"BAD-LAND" TOPOGRAPHY. A SHALE POINT.

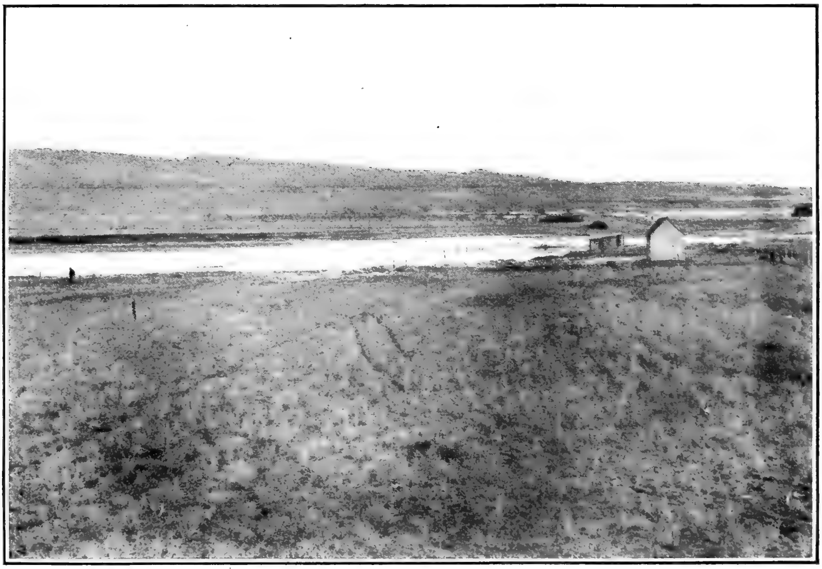

FIG. 2.—WET AND ALKALIED LAND.

At one time this tract produced alfalfa. (See Example VI, p. 32.)

In making the examinations a small stake should be driven at each hole and the stakes numbered consecutively. If a map is to be made, the depth to shale should be kept in a notebook. Otherwise the depth to shale should be marked on each stake in order to facilitate locating the drains along the ridges and other higher portions of shale.

The weathered, flakelike covering of the shale ridges, mixed with soil, frequently makes it difficult to determine the true depth to the solid shale formation, as pockets of coarse shalelike material occur in the soil and may be far from any shale formation; consequently examinations of borings from small auger holes frequently are misleading. Where there is any doubt, holes should be continued for some depth after encountering the shale to make sure that it is the solid formation. Occasionally, where the exact depth to shale seems uncertain, it can be ascertained best by excavating a pit.

LOCATION OF DRAINS.

Attempts to accomplish drainage by running tile lines across and along the upper edge of the affected area (see lateral A, fig. 9, p. 35), thereby cutting into a number of shale ridges and points contributing water, have proved unsatisfactory; (1) because of the absence of an impervious stratum that can be reached by the tile, the lack of which permits some of the water to pass freely below the tile to a point farther down the slope; (2) these ridges do not discharge water at their points alone, but frequently along the sides also. This is due to the fact that pressure exists and the water is supplied at various points from the continuous shale formation beneath the shale ridge.

These complex conditions existing in the shale make it imperative that the drainage lines should follow as nearly as possible along the backbone of the shale ridges or cut through the knolls and other high portions. Usually the lines should extend for some distance up the ridge or other formation above the affected area. Not only is it necessary to run the tile lines along the shale ridges to secure the best results, but trenching in the shale is far easier than in wet adobe soils. Where quite broad shale ridges are encountered, one line will be insufficient; on such ridges a tile line should extend along each side (lateral C, fig. 9, p. 35).

Where a number of shale ridges that are supplying the seepage water are encountered the main line should, if possible, run along the points of these ridges, with a branch following up each ridge (lateral B, fig. 9, p. 35). As not all shale ridges, or points, furnish seepage water, a number of deep holes should be put down into the shale, noting the degree of hardness, whether or not soft layers are encountered, the amount of water found, and whether or not pressure conditions exist. It is very important that none of these shale points that contribute water be missed, for, although the system may develop a considerable quantity of water from the points tapped, any remaining one will furnish enough water to these retentive adobe soils to prevent complete reclamation.

In the drainage of those lands underlain by shale that has no distinctive topographic features, but which is smooth and at a fairly uniform depth below the surface of the soil, a system should be employed which has branches spaced at regular intervals and extending up the slope. However, the determination of the interval required for the branch lines necessitates a careful examination of the shale. Experience in drilling often will enable one to determine whether or not the shale is traversed by systems of small crevices; the drill takes hold with more difficulty in shale that does not contain them than in shale that does. The nature of the borings brought out on the auger is indicative also of the presence or absence of such crevices. If the borings are fine-grained and more or less compact, few or no crevices are probable; but flaky, mealy borings indicate the contrary. By those unfamiliar with the mode of occurrence of water in shale those zones containing water often will be overlooked, for the small lumps and layers of shale between the cracks are impervious in themselves, and the auger, passing through these, will bring up fragments of perfectly dry shale, while the free water frequently found between these dry borings will be thought to have collected there in pulling the auger out through the upper wet portions of soil.

The existence of pressure often can be detected after having struck cracks in the shale containing water, by placing the ear near the hole; a hissing sound caused by the escape of the water from the small crevice into the larger opening is an almost certain indication of pressure conditions. The intensity of the pressure can be estimated by the rapidity and height of rise of the water in the well. Often the water will rise several feet within a few minutes, and again it may require a day or two for it to attain its maximum height. Where the water rises only a few inches, and that very slowly, the pressure is slight or negligible. High pressure is indicated by a rapid and high rise of the water. Of course, the height and rapidity of rise depend somewhat on the season, there being generally a seasonal fluctuation of the water table. In seasons of high water table, pressure strong enough to cause these wells to flow on the surface is encountered frequently.

The borings will indicate certain spots and streaks where the pressure seems high and the water free; drainage lines should be located to tap these areas. Figure 1 is an example of the application of the information obtained from the borings. It becomes apparent at once where the two most important lines should be located—one 120 feet from and parallel with the east fence line, and the other 45 feet from and parallel with the south fence line.

In the location of drains in those lands underlain by hard and practically impervious shale interception methods can be used, provided the shale surface is even and sufficiently near the ground surface to be reached by a tile drain throughout the entire length of the line; otherwise this method can not be used, and the overlying soil must be drained by a relief system. However, even where the interception system can be used, it often is the case that in large tracts supplementary drains will be needed to remove the water from the already saturated soil and to provide outlet for the large quantities of water that must be applied to wash out the heavy accumulations of alkali.

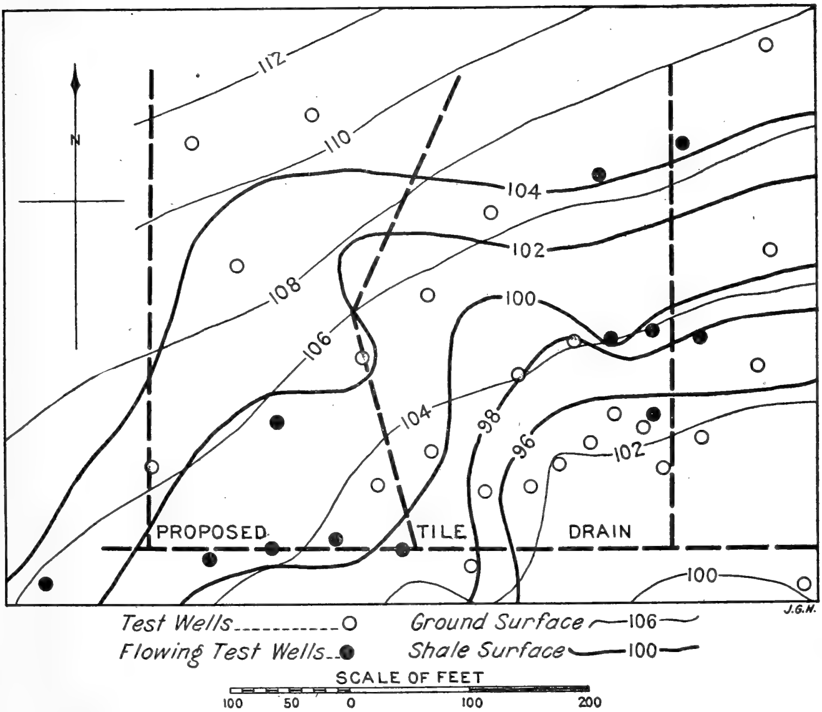

FIG. 1.—Map of an eight-acre tract, showing borings made and data obtained therefrom.

DEPTH OF DRAINS.

The tendency in the arid West has been toward increasing the depth of drainage; this has been true especially with regard to shale lands. The distance through which capillarity takes place is one of the important factors regulating the minimum. Water passing upward through the soil by capillary action carries salts in solution and by evaporation deposits them on the surface of the ground. The height to which capillary water will rise depends on the type of soil, its wetness and temperature, and, to some extent, on the kind of salts. High temperatures and certain salts increase the range of capillarity. In loose, sandy soils the rise is not great; in average soils of the arid West it probably ranges from 2 to 4 feet, and in clayey soils more than this. Of all the types of soils, the adobes encountered in the drainage of shale lands are perhaps most conducive to a high range of capillarity; thus the necessity for deep drainage.

One of the greatest advantages of deep drainage in this type of land is the increase of flow of the relief wells thus obtained. However, there is a practical limit to the maximum depth, and it is believed that in the design of a drainage system the depth should be fixed with reference to that limit rather than by setting a minimum limit determined by capillarity, depth of root zone, etc. The practical limit of depth, of course, would vary somewhat as between hand work and machine work. It would depend also upon the nature of the ground encountered. In the presence of these variable factors it becomes impossible to fix a maximum depth, but the minimum should be not less than 6 feet and in many cases should be 7 or 8 feet.

PURPOSE OF RELIEF WELLS.

In the drainage of many types of shale land the installation of relief wells is absolutely necessary for the success of the drainage system. A relief well is nothing more nor less than an artesian well. This does not mean necessarily that the water rises to the surface and overflows, since any well may be considered as artesian where the water rises to some extent after having been drilled through a comparatively impervious stratum into one carrying water; in other words, where the water enters the well under pressure.

As mentioned before, the seepage areas in shale lands occur almost invariably where pressure conditions exist and the movement of the water is upward. In cases of extreme pressure this can be detected at the surface by the appearance of drops of water that have been forced up through the small pores of the soil. In but few cases, however, is it possible to place the drains deep enough to reach the supply of water that causes the saturation. Often the water-carrying zones of shale have been found at depths approximating 30 feet. The cost of the installation of drainage lines becomes prohibitive long before this depth is attained, but unless the water-carrying medium is reached in some manner drains will be of little service, no matter how carefully they are located and constructed or how closely spaced. Cases are known where drainage systems had been constructed in shale to a depth of 7 feet and had developed considerable quantities of water, yet seepage water rose to the top of the soil within a few feet of the line and ran off the edge of the bank into the trench. Flowing springs have been found within 10 feet of a 7-foot trench. Such results indicate clearly that ordinary methods of drainage will not relieve seepage conditions where the water is supplied under pressure.

The purpose, then, of the relief well is to connect the tile line with the deeper strata which are the sources of the seepage water and thus, by permitting the water to pass out freely, to relieve the pressure.

ACTION OF RELIEF WELLS.

The pressure of water in a well depends upon the height of the source, the quantity of water supplied, and the extent of leakage and amount of friction encountered between the source and the well. In speaking of this pressure the term "static head" is used to designate the pressure at the point where the flow is measured, when the well is closed. The static head is expressed in terms of the height above the point of measurement to which the water will rise in the well. The discharge of a well is directly proportional to the static head. The flow of a relief well is measured at the point where it discharges into the tile line. If the point of measurement were at the surface of the ground, many relief wells would have no static head and consequently would not flow. A well in which the water rose to within 1 foot of the surface would have a static head of 6 feet if measured at its connection with a tile line 7 feet deep. Thus the advantage of deep drainage can be seen readily, as increasing the depth increases the flow from the relief wells. A well that has a static head of 3 feet in a ditch 4 feet deep would discharge twice as much in a ditch 7 feet deep. A better appreciation of this advantage of depth will be gained when it is realized that in this class of drainage work the wells supply the major portion of the drainage water.

As explained in the description of the shale formations, the water-carrying zones are not continuous or regular, and several different crevices and zones of close jointing probably furnish the flow to one small seepage area. These water-carrying zones may not be freely connected—at least in the immediate vicinity of the seepage area—and each one may have a pressure slightly different from those of the others. The area affected by each of these small contributing features probably is quite small. The pressure of the water, although it may have a high source, usually is very low, owing to friction encountered in the small fissures of the shale. When these crevices or closely jointed zones disappear or pinch out, the water has a tendency to move upward because of the more or less vertical nature of the crevices. Often where the overlying soil is thick, dense, and compact, the resistance offered overcomes the low pressure, and the water penetrates up into it but a little distance; but where the depth of soil is not great the water penetrates up through it and runs off the surface. More frequently, however, the friction of the soil overcomes the low pressure of the water before it quite reaches the surface, and a stationary condition would result but for a slight lateral movement of the water in the soil which causes it to spread over a more or less circular area larger than the outlet of the contributing feature in the shale.

The condition just described is relieved by wells reaching into and tapping the water-bearing zone; for the water, seeking the path of least resistance, enters the larger openings formed by the wells and passes freely upward and outward. One well, or a number of wells, will not remove all of the water from the water-bearing stratum or area, but they tend to relieve the pressure and thus prevent the further rise of water to the small area of soil above. The relief of pressure by this method is based on a well-known principle of hydraulics, viz, that the pressure of flowing water in a confined medium decreases with the increase of velocity.

It is well known that in any artesian area wells too closely spaced will interfere; that is, the discharge from each well will be reduced as the number of wells in the area is increased. In the drainage of shale lands the relief wells should be spaced so closely that this interference practically overcomes the pressure between the confining strata. Otherwise, since these confining strata always are more or less imperfect, water will continue to rise into the subsoil and the land will remain water-logged, even where immediately adjacent to drains, whether open or covered.

The relation between the tile drains and the relief wells in a drainage system can be summed up in the statement that the relief wells provide the desired drainage, while the tile drains merely provide outlets for the water developed by the wells.

AREA OF INFLUENCE OF RELIEF WELLS.

The area of influence of an ordinary relief well in shale is not large. A well may strike but one small crevice or water-carrying zone which is responsible for only a very small spot in the seepage area and which is only one among many that are contributing water. While no rigid rule can be given for the spacing and location of wells, experience has shown that from two to six for each 100-foot length of trench will be necessary ordinarily. This does not mean, however, that a certain number of wells should be decided upon for a unit length of trench and then spaced evenly throughout that length. While the location of a well that will develop the maximum flow, or any flow at all, is a very uncertain matter, the amount of water developed in the bottom of the trench as it progresses is a very good indicator. Those points that develop the most water show that they are probably underlain by water-bearing zones and that the pressures are higher there than elsewhere. Evidently a well located at such a point will develop a larger flow and will be more beneficial than one placed elsewhere. Where the greater amounts of water are found in the trench and the higher pressures seem to prevail, wells should be located quite close together. They should be spaced further apart in the drier portions of the trench. Where the conditions in the trench are uniform, the wells should be spaced regularly if the resulting flows are uniform; but if, after putting down a hole or two, very little or no flow results, it is advisable to space them farther apart until an area is encountered where more water is developed.

DEPTH OF WELLS.

The proper depth for relief wells is a matter for experiment in different localities. The maximum depth, however, usually is about 20 feet below the bottom of the drains. It becomes difficult to drill wells deeper than this by hand, and as a rule their effectiveness is not increased by the additional depth. In any event, water encountered at this depth probably is not contributing to the seepage area in the immediate vicinity. In beginning work on a new project it always is advisable to drill the first two or three wells deep to determine where the flow is most apt to be encountered. While water will not be encountered at uniform depths, yet certain limits within which it is likely to occur will be determined. In most of the work forming the basis for the conclusions in this bulletin the approximate depth at which the flows have occurred has been about 15 feet below the surface of the ground.

AMOUNT OF WATER DEVELOPED.

It will be found that some of the relief wells do not flow at all and that the discharge is small from many of those that do. In nearly all cases observed 2-inch wells have been of sufficient size to care for the water developed. Among other things, the amount of water developed depends upon whether it is the season of low or high water table. Many wells that do not flow when they are installed in the season of low water table discharge when the water rises again. Figure 11 (p. 37) illustrates the variation in discharge from a 1,600-foot system of drainage, where 1,000 feet of the tile were in shale and a total of 35 wells were installed, ranging from 12 to 20 feet in depth.

While there is no doubt that the relief wells furnish the larger part of the discharge from these systems, very few accurate data on this point are available. Information of this character has been difficult to collect because it is almost impossible to measure the discharge of the well except by noting the increase of flow at the outlet of the tile as the wells are installed. This could be done readily if the wells were installed after the line was completed, but construction in bad ground often necessitates the drilling of the wells as the work progresses, and this makes it impossible to determine how much water is developed by the tile line and how much by the wells. The following data were collected on a line of tile 350 feet long and 7 feet deep: When completed, the drain without relief wells discharged 3.2 gallons per minute. Six wells were installed in one day, immediately after which a measurement was made, which showed a discharge of 21.4 gallons per minute. Two of the six wells installed did not flow at all. Another line in this same system, and with the same length and depth, discharged 37.5 gallons per minute after completion. Twelve wells were installed in one day, after which the discharge was 85.7 gallons per minute. This latter example probably is more nearly representative of average results. About 300 feet of each of the above two lines were in shale.

CONSTRUCTION.

Construction of drainage systems in shale lands has varied greatly in respect to difficulty of installation and cost. Much of the shale is quite hard, or contains hard concretions, which makes necessary the use of picks. Trenches where the greater depths are in solid shale stand well and need little or no bracing if the work is handled properly. Shale makes a very good foundation for laying tile, and the coarse, broken shale is good material for blinding the tile.

Generally speaking, the work in shale is not difficult, but trenching in the saturated adobe soil is a real problem. Outlet lines usually have to pass for considerable distances through soil not immediately underlain by shale, and in many lines the upper several feet of the trench must be excavated through the soil before the shale is reached. With the exception of saturated fine sand or quicksand, no class of material is more difficult to handle than adobe. When partly saturated it becomes sticky and adheres to the materials and tools with a tenacity that makes progress difficult and tedious. The skeleton spade is the only tool that will handle it with any degree of success. The ordinary shovel will not scour. When this soil becomes completely saturated it often assumes a semifluid state that makes the use of tight sheeting necessary; frequently, not only must the sides of the trench be sheeted, but also the face.

The most successful cribbing in such material consists of two heavy timbers, held apart by trench jacks, behind which is driven the vertical lumber sheeting. The boards should fit tightly; they may be driven with a heavy maul and removed with a light derrick or grabhook. Where the sheeting is driven and pulled by hand, planed 2 by 6 inch planks have been found the most satisfactory. Sizes larger than this are driven and pulled with difficulty. The bottom end of each of these planks should have a long bevel on one side, so that it will drive readily and straight. The tops of the planks should be beveled slightly, or a cap used to prevent "brooming" while being driven, and the planks should be long enough to extend below the grade line. As the material is excavated, two more heavy planks should be placed near the bottom and held apart by trench jacks to prevent the weight of the material from displacing the bottom of the sheeting. These can be used also for the workmen to stand on when the bottom of the trench becomes too soft. In the latter event it becomes necessary to place boards under the tile in order to hold them on the grade and prevent them from sinking. When large-sized tile are used a cradle must be placed under them. This cradle resembles a ladder, the strips running lengthwise being of 2-inch material and spaced so that the sides of the tile will rest against them as well as on the crosspieces of broad 1-inch lumber. The tile should be covered by some material such as cinders, gravel, or broken shale. Hay and straw have been used with success. The tile should be well blinded and weighted down before removing the sheeting, which should be pulled slowly and carefully to prevent the soft material that sloughs in from the sides from pushing the tile off grade. Trenching machines especially built with shields for soft material would handle some of these soils satisfactorily.

The excavation of ditches should begin at their outlets or at their junctions with other drains and proceed toward the upper end. Trenching should be done as neatly as possible and should follow closely the line of stakes; where the drain changes direction the turn should be made by a neat curve. If possible, the top soil should be thrown out on one side of the ditch and the shale on the other, and in back-filling the shale should be put in first.

No attempt should be made to grade the tile by the water in the ditch. Grades for the drains always should be established by surveys, and the ditch should be dug accurately to the depths specified; these depths should be measured from the grade stakes set for that purpose, and the ditch graded evenly on the bottom by means of the "line and gage" method or by any other equally accurate device for obtaining an even and true bottom upon which to lay the tile.

The tile should be laid as close as possible, beginning at the lower end and proceeding upstream. They should be turned about until their upper edges close. If there is silt or other fine material that is likely to run into the tile, the lower edges must be laid close and the joint surrounded by cinders, gravel, or other suitable material. If, in making turns or by reason of an irregularly shaped tile, a crack one-fourth inch or more is left, it must be covered securely by broken tile. All junctions at manholes and branches should be made securely. Care must be exercised to prevent sediment from washing into the tile, and when each drain is complete it should be free from sand, mud, or other obstructions.

The tile should be hauled and distributed along the line of trench all in one operation. They should be hard-burned clay tile of good quality, preferably in 2-foot lengths. They should have smooth interior surfaces and should be hard burned entirely through, of uniform texture, and free from lime or other impurities. No piece should vary from a straight line more than one-half inch for a 2-foot length. No tile should be used that has a piece broken from either end deeper than 1½ inches. After the tile are laid they should be covered carefully to a depth of at least 6 inches with broken shale, gravel, or coarse cinders.

Relief wells can be installed with a 2-inch auger, or where hard strata are encountered a churn drill can be used. Each well should be located so that it will come near the end of a tile; it is then connected with the line by chipping out one end of the tile with a wrench, so as to leave a hole about 2 inches in diameter over the well. All wells must be connected, regardless of whether they flow or not, for they may flow later.

Where the banks of the trench stand up well, the tile where wells are desired should be left with but little blinding over them; after the line is completed a tile can be taken up at each of these places and the well installed. In this case the wells can be placed directly beneath the tile. In trenches where the banks will not stand, it becomes necessary to drill the wells as the tile laying progresses, and they should be placed a few inches to one side and connected with the opening in the tile by placing a half tile over the well. They should not be placed directly beneath the tile, for the sediment washing down from the construction work above is apt to fill up the weak or nonflowing wells.

COST DATA.

Where drainage systems have been installed wholly or in part by the individual landowners, itemized records of expenses incurred generally are not obtainable. However, it is believed that the tracts from which the following data were obtained are fairly representative of conditions as ordinarily encountered in this type of drainage; consequently the unit costs may be assumed to indicate fairly what may be expected in excavating in this sort of material by hand labor.

With labor at $0.25 per hour, actual unit costs for excavating, laying tile and back-filling trenches in shale ranging from 6 to 7 feet in depth averaged $0.12 per linear foot on four small projects aggregating a total of 4,430 feet of trench. A contract job of 2,768 feet of 7-foot trench was let for $0.20 per linear foot, while another job of 5,600 feet, running 6 feet in depth, was let so as to average about $0.11½ per linear foot. These figures do not include the cost of boring relief wells in the bottoms of the trenches. However, taking the work as a whole, this need not increase the cost by more than an average of $0.02 per foot, as there are nearly always some portions of trench on any job in which the relief wells are not essential. The cost of boring the relief wells probably averages about $0.05 per linear foot of well where the depth below the bottom of the trench runs from 8 to 16 feet. Where the depths vary from 16 to 25 feet the cost per foot of well may run as high as $0.10, especially if much sand rock, lime rock, or other hard material be encountered that renders necessary the use of a drill.

The acreage costs of drainage of the affected portions of those projects referred to in this bulletin have been high. This is due in part to the relatively high cost of trenching, but the chief reason is the frequency of drains required, as will be noted by referring to the maps of the several tracts. Based on the actual affected areas, the costs have ranged from $13 to $100 per acre. Almost invariably, however, at the time of drainage the trouble was spreading rapidly, so that the cost in most instances should in all fairness be distributed over the area afforded protection as well as over that directly benefited. As a matter of fact much of the real value of the drainage of shale lands is the benefit that accrues from arresting the development of the trouble. This is especially true because of the very serious alkali problem that results when the lands are allowed to remain in a water-logged condition for any considerable length of time. Once the alkali salts have accumulated in the soil to an extent that renders the land wholly unproductive, it becomes very difficult to bring the land under satisfactory cultivation again. Essentially, then, the most practical way to make this type of drainage both economical and satisfactory is to install the drains at the very first indication of trouble.

EXAMPLES OF METHODS.

EXAMPLE I.

The area of very wet land as indicated on the map in figure 2 aggregates about 22½ acres. Much of this was actually covered with water, and in but few places was it more than two feet from the ground surface to water. These 22½ acres by no means represent

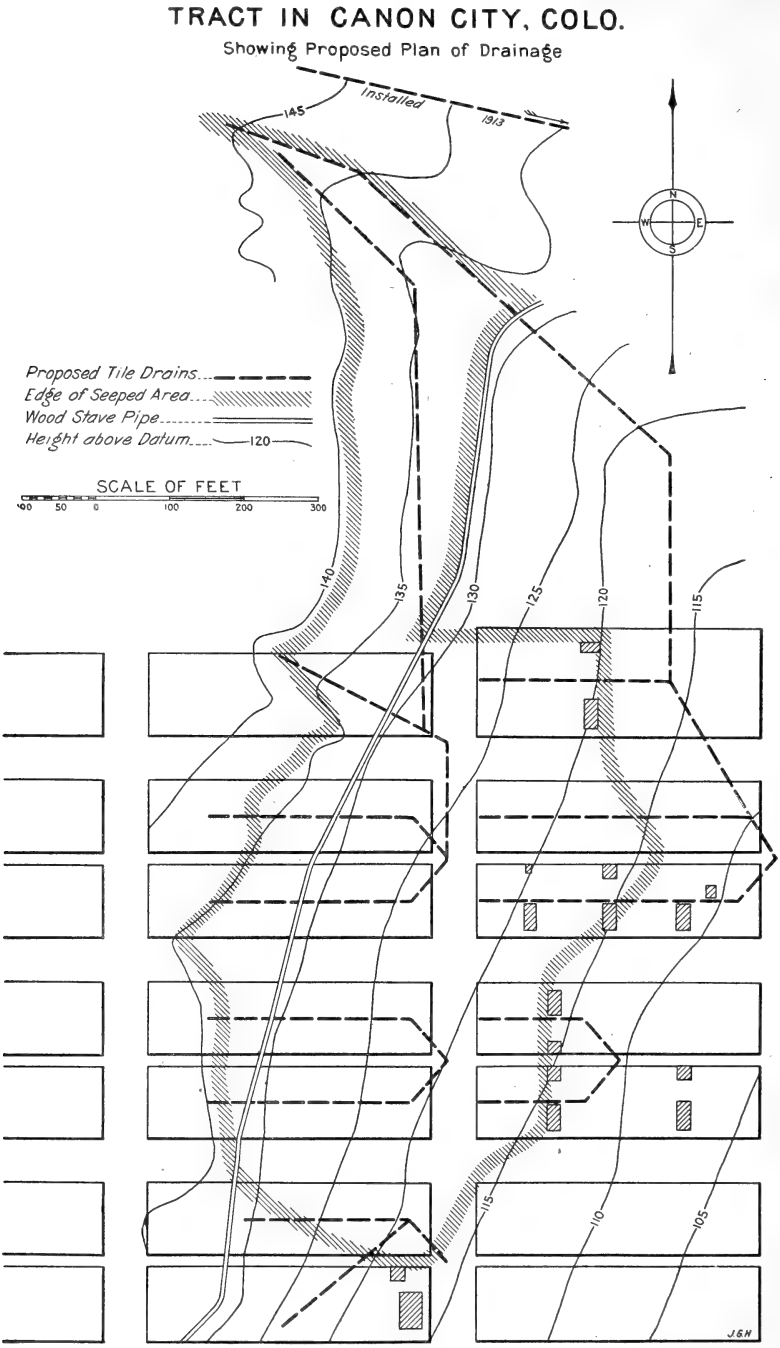

FIG. 2.—Tract near Canon City, Colo., showing proposed plan of drainage.

the total acreage affected by seepage water, as all of the lands immediately adjoining were becoming affected. The surface soil is mostly a dense blue adobe and the subsoil shale which in some cases approaches the surface, although generally it is at a fairly uniform depth of from 3 to 5 feet below. Much of the shale is a flakelike material that has been washed in. This shale formation comes under type No. 2 (p. 3), and constitutes a part of the pressure fold which is west of the tract.

The source of the seepage water was thought by the residents to be the irrigation canal which ran through the wet area and, accordingly, a wood-stave pipe was installed, as indicated in figure 2, to prevent seepage from this canal, but conditions became worse soon after its installation. This indicated that the open canal had been an actual benefit in this particular case in that it had carried away part of the surface water. In any event, the canal could not have been the source of all the water, since the seepage area was well defined for a considerable distance above the canal. The land to the south and east of this tract is lower, and the hogback on the west is a very steep, sharp-crested ridge which does not carry water, as a large irrigation tunnel through it near the base proves. The only other possible source is from the north, and in this direction a mile of unirrigated virgin land intervenes. From all indications the water follows the joints formed between the nearly vertical layers of shale which were formed by the uplift to the west. The movement of the water must take place at considerable depth, for there are no seepage areas in this intervening mile.

Since the underlying shale is rather uniform and not characterized by any distinct features of topography, a uniform drainage system was laid out as indicated on the map. Insufficient funds and other reasons have prevented the installation of all of the drains, but 2,768 feet were constructed. They were effective immediately, and the results on that portion of the tract are very gratifying. Some 8-inch tile were used, but most of it was 6-inch. They were placed 7 feet deep, and relief wells were installed where the solid shale formation was encountered. The work was done by contract and a considerable portion of it was difficult, as it was necessary to use cribbing.

EXAMPLE II.

This is a 10-acre tract of which not over one acre was affected (fig. 3). The source of the damage was the large amount of irrigation water applied on the lands to the northwest near the rim of the valley, in which the soils are comparatively porous. The soil on the tract is very dense adobe. At the time of drainage the land was in fruit trees and a few of the trees were dead on the affected area.

The wet spot became noticeable in the summer of 1913 and by the following summer had increased considerably. There was not much alkali present, but the ground was very wet.

A prominent shale ridge outcrops across the north and east sides of this tract. A deep arroyo at one time extended across the tract in the bottom of the shallow draw in which the affected area is located. This was filled in when the land was leveled. It is believed that this had much to do with the development of the seepage, for not only was the natural drainage afforded by the arroyo thus shut off, but the earth filled in became more dense than the natural soil and offered greater resistance to the movement of the ground water. A careful subsoil examination indicated that the seepage

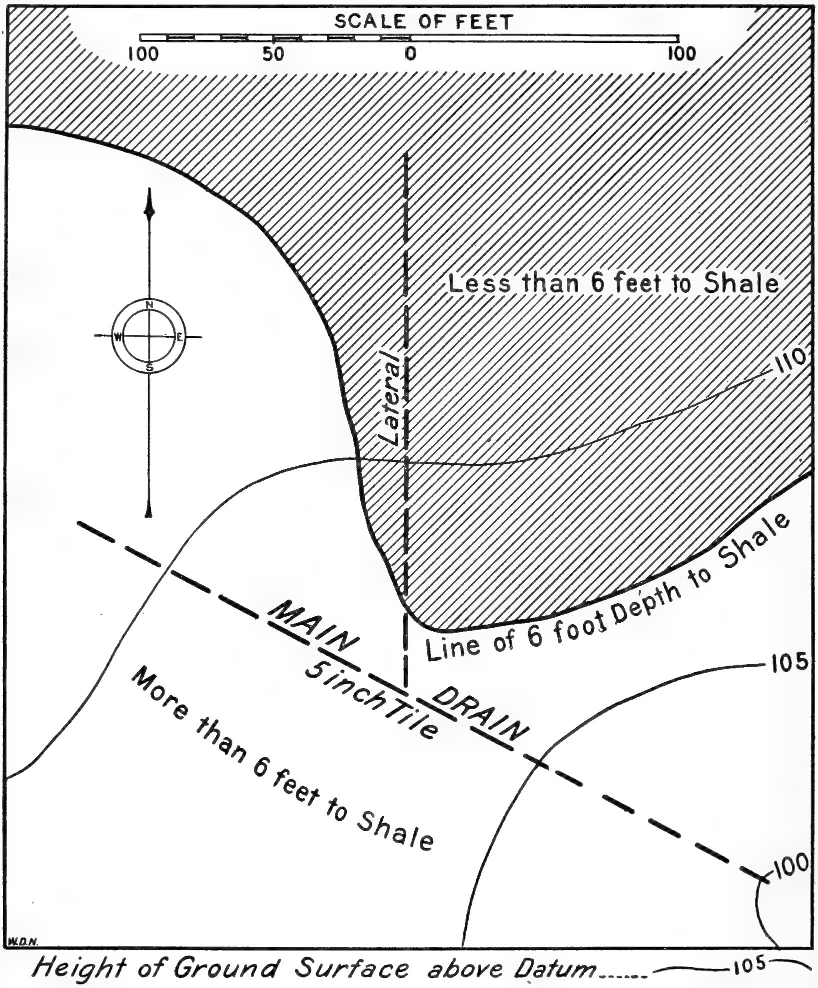

FIG. 3.—One-acre tract near Canon City, Colo., showing plan of drainage.

water had two sources of supply, the main one being an underlying shale ridge coming in from the north. This ridge is not sharply defined, but is broad and flat, being a part of the larger and exposed shale ridge mentioned above. The other source of supply seemed to be the shallow draw.

The system was laid out as shown in figure 3. The main line runs up the draw, following as closely as possible the edge of the fill next to the seepage area. The most important part of the system is the lateral, 200 feet long, which follows up the shale ridge. Considerable difficulty was encountered in constructing the main line, but in the shale construction was less difficult. In this line about 12 holes were bored with a 2-inch auger. The initial flow in them was strong, and they spouted above the bottom of the trench. This discharge gradually decreased, but the wells still furnish nearly all of the flow obtained in the small system. After a few months the surface of the affected area became so dry and hard that it was difficult to plow.

This tract is a good example of drainage for prevention. The drains were installed before the affected area had spread and before the land had become highly impregnated with salt, and as a result the land was easy to reclaim. If the condition on this tract had not been attended to at once there is little doubt that it would have spread over most of the tract, and the soil would have become so filled with alkali that it would have required two or three years of washing and careful farming, with little or no returns, to reclaim the land. Furthermore, it would have been necessary to install many more drains. That this is a logical conclusion can be deduced from the quality of the drainage water developed by this system as indicated by analysis J in Table I.

EXAMPLE III.

This tract slopes to the southeast as indicated in figure 4. The soil is a dense adobe. Small spots of alkali appeared about four years ago. The steady rise of the water table and the consequent accumulation of an excess of alkali at and near the surface was gradually killing out the alfalfa. With the exception of the southwest corner, all of the alfalfa was in poor condition. At the time of the preliminary examination there were large spots that produced no alfalfa at all, and the water table was practically at the surface which was covered with a thick crust of alkali in which sodium sulphate predominated. There were no indications of black alkali. There were two main alkali spots. One strip extended north and south through the middle of the tract and was broader at the south end, where a bunch of tulles were growing. The other spot, which was very wet, was at the northwest corner and extended across the road to the west. The road was impassable and a large portion of the tract on the west was affected.

From a large number of borings the topography of the underlying shale was determined as indicated in figures 4 and 5. Shale was found near the surface on three-fourths of the tract, but no shale nor water could be found at a depth of 12 feet at the southwest corner, and the alfalfa there was in good condition. The strata of the shale underlying the tract are nearly vertical and badly broken.

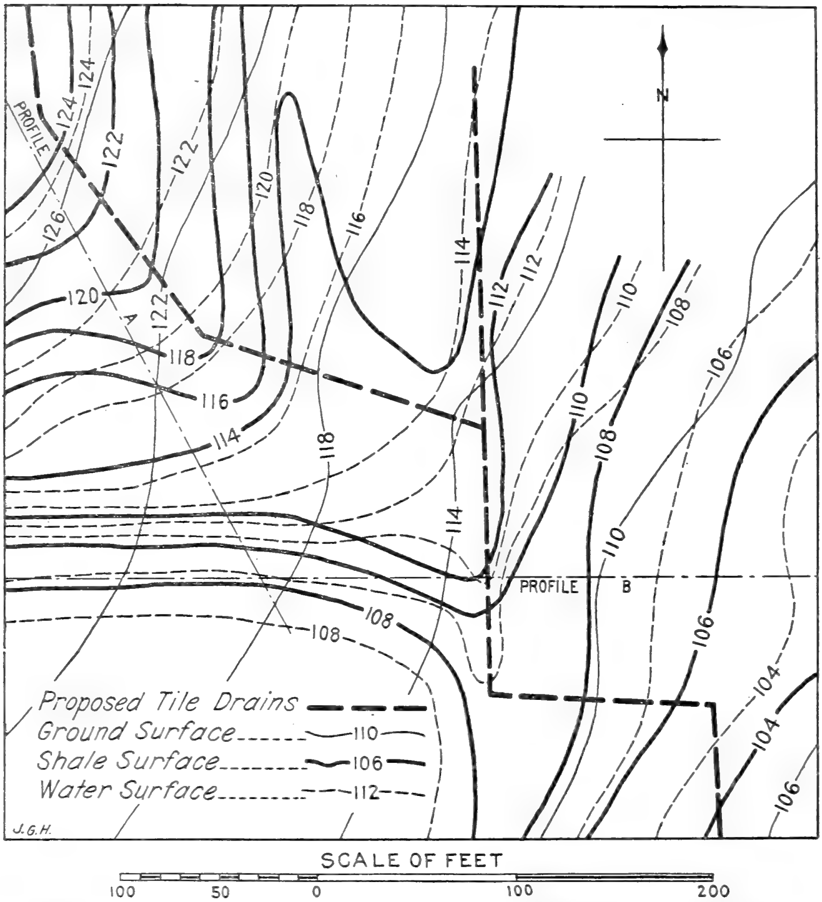

FIG. 4.—Four-acre tract near Canon City, Colo., showing plan of drainage.

The shale is comparatively soft, from dark blue to reddish brown in color, and carries considerable water. The water apparently comes from the north, following along the joints in the shale strata, although it is believed that the extreme wet condition of the northwest corner is due in part to the movement of the water in the top soil from the tract to the west, which also is very wet. The underlying shale ridges on this tract are not well defined; they are broad and flat. A rather broad shale ridge comes in at the northwest corner and extends to the center of the tract and thence south, where it is well defined. Along these ridges the water table always was nearest the surface.

Several years prior to the draining of this tract a drainage system was installed on the tract south and east. Four-inch tile were used and branches were placed at frequent intervals, but the depth was not much over 4 feet. While the surface of the ground is not wet, the trees are beginning to show the effect of a high water table and a number of them are already dead. One of these 4-inch tile branches was used as an outlet for the system under discussion in order to cut down expenses, but it would have been better if an outlet of larger tile had been constructed.

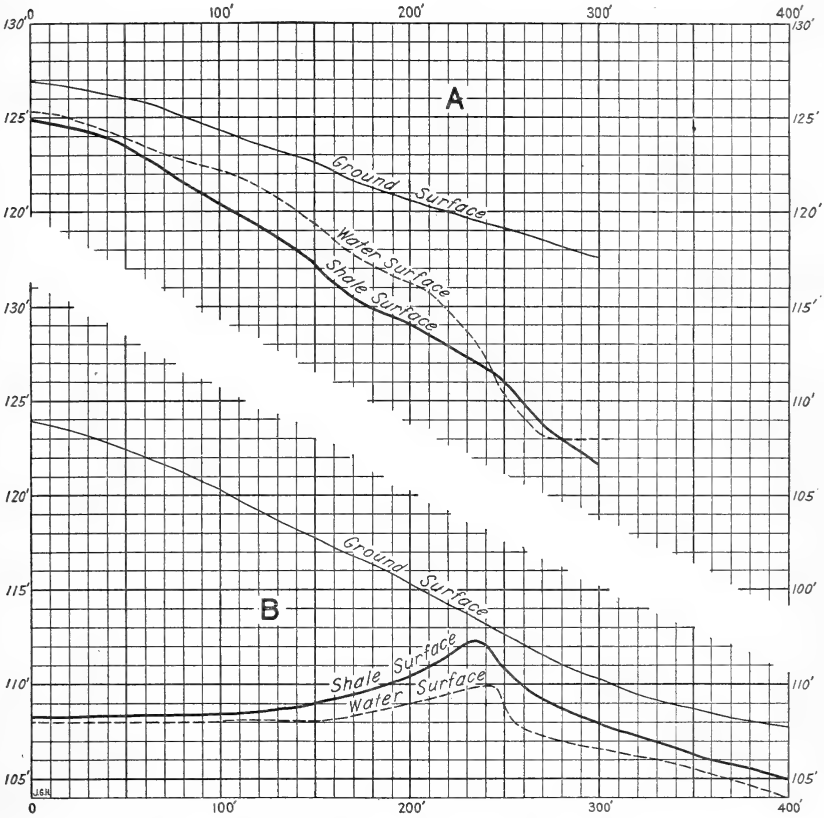

FIG. 5.—Typical profiles across tract shown in figure 4.

The system was laid out as shown in figure 4, an attempt being made to follow the shale ridges. The depth of the system ranges from 6 to 7 feet. As nearly all of the trenches were in shale, very little difficult construction was encountered. In some places the banks of the shale trenches broke off in large pieces and it became necessary to put in occasional braces to hold them. The drainage of this tract could have been better accomplished by immediate drainage of the entire affected area, which includes several acres on the west, but the owner of the latter tract was not ready at that time. While the tract is not yet free from alkali, the surface has become fairly dry and the rushes have disappeared; however, the road on the west side of the tract still remains impassable.

EXAMPLE IV.

Twenty years ago the farm shown in figure 6 was considered one of the best in the vicinity of La Junta, Colo. The gradual rise of the water table and subsequent accumulation of alkali salts have seriously damaged 700 acres of land in this vicinity. Much of it is not farmed at all and none of it yields profitable crops.

The tract is located in a circular basin which contains approximately 3,000 acres, all of which is irrigated. Just below this tract the basin narrows down to a draw which bears north about 1¾ miles to a creek. This draw is the only feasible drainage outlet. There are two irrigation canals running through this district. More than 78 second-feet are furnished to the land in this basin. Water runs during the entire year in one of the canals. The irrigation season is very long, and many people practice winter irrigation, which contributes largely to the damaging seepage water. The quantity of water used is no doubt considerably over 4 acre-feet per acre.

The soil varies from a fine sandy loam to a sandy adobe. Gypsum is very abundant. It occurs in partly disintegrated crystals and flakes, often very nearly pure and imparting a mealy character to the soil. This constituent seems to have been derived largely from decomposition of the shales. A layer of gypsum always was found just above the shale and it seemed to carry water freely. On the south half of this tract, near the surface, is found a series of alternating beds of limestone and calcareous shales. The shales are very compact, and borings showed that while the upper layers, which had partly disintegrated and contained gypsum crystals, usually were moist, they became very hard and dry with depth. The water-carrying capacity of these shales may be considered as negligible.

The idea is prevalent among the people of this section that the trouble is due to loss from the irrigation canals and that the proper method of drainage is to construct an intercepting line just below the canal. While these canals doubtless contribute to the underground water, most of it is due to loss from laterals, to failure to take care of waste water, and to the use of excessive quantities of irrigation water. The injury due to excessive irrigation lies not only in the swamping of large areas of lower lands, but also in the ruin of large tracts from the accumulation of alkali salts on the surface.

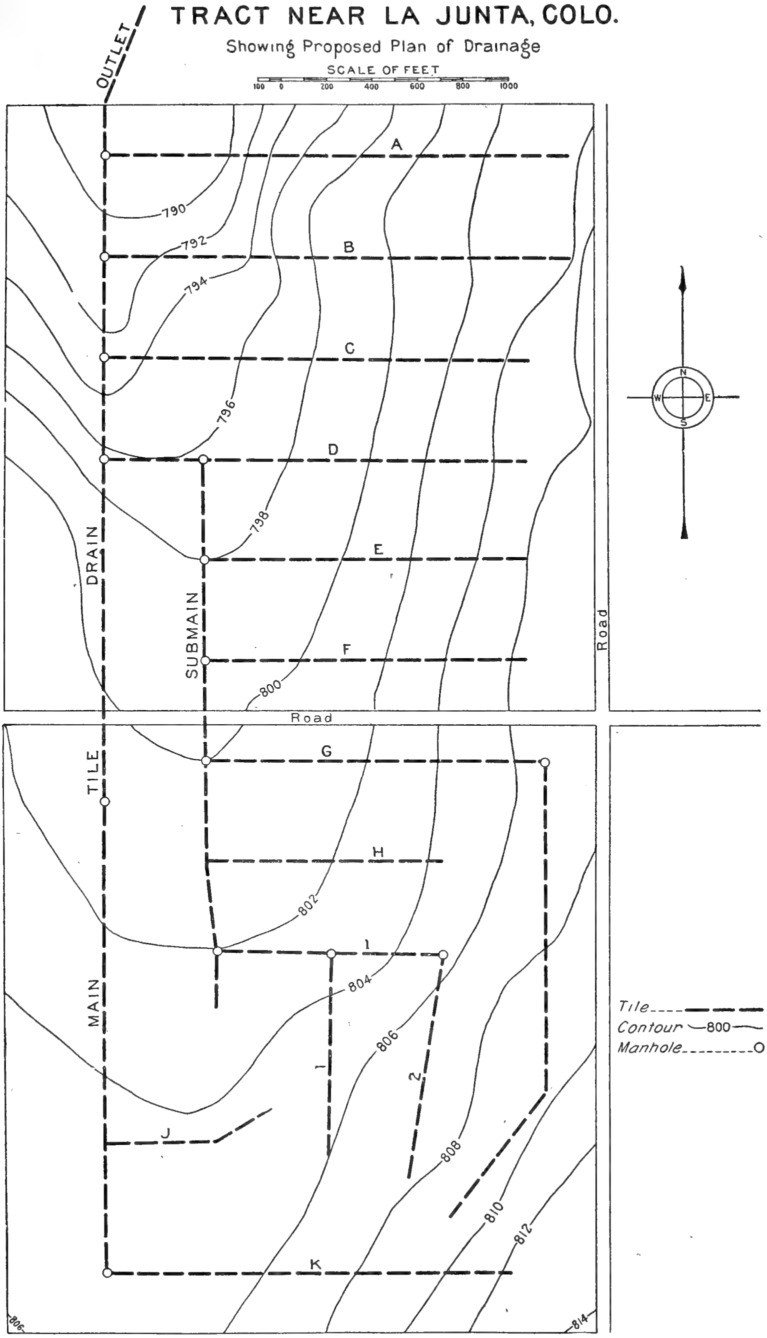

Fig. 6.—Tract near La Junta, Colo., showing proposed plan of drainage.

The first point to be taken up in the reclamation of this tract is the disposal of the waste water. The soil on the north half is mostly Fresno fine sandy loam, and the conditions are fairly uniform. The method of relief drainage should be used with six branches of 6-inch tile, running east, about 400 feet apart. The drainage of the south half is a more complex problem; a combination of the relief and intercepting methods should be used. Branches "G" and "K" (fig. 6) are intercepting drains. The peculiar arrangement of the other lines is due to the irregularities in the seepage conditions and to the fact that limestone is found near the surface in some places, as an attempt was made to locate the lines so as to prevent rockwork in the trenching. The average depth of the system should be not less than 7 feet, and in no place should a line be less than 6 feet deep.

EXAMPLE V.

An investigation was made on this tract during the early part of the year 1915. A large number of test wells were drilled and a topographic map of the underlying shale and water surface was made, as shown in figure 7. A pronounced shale ridge was found, and there was a marked resemblance between the shale and water contours (see figs. 7 and 8). As figure 8 indicates, the point of the shale ridge was discharging water into the soil beyond. At the time of the examination only a small portion of the alfalfa was affected between the point of the underlying shale ridge and the south fence line. A tile line reaching well into the shale point was staked out, as shown on the map. The owner was unable to install the line at that time; and the tract was visited again in the early part of 1916, when it was found that the affected area had spread over the entire south half of the tract.

EXAMPLE VI.

It is not known just when trouble first became apparent on the 40 acres shown in figure 9, but from all indications it must have been at least three or four years before the time of making the preliminary examinations in the spring of 1913. At that time about 20 acres, extending north and south through the center of the field, were very wet and badly alkalied (Pl. VII, fig. 2). The whole 40 acres were at one time in alfalfa, and on both sides of the alkali strip alfalfa was still growing, with the stand about normal except immediately adjacent to the wet land, where it was thinner and more spotted.

The land to the north and west is higher than the tract under consideration, especially to the west, just across the road, where it rises to an elevation some 20 or 30 feet higher and culminates in a little ridge running north and south. Excessive irrigation on this ridge has been one of the chief sources of the seepage water, al-

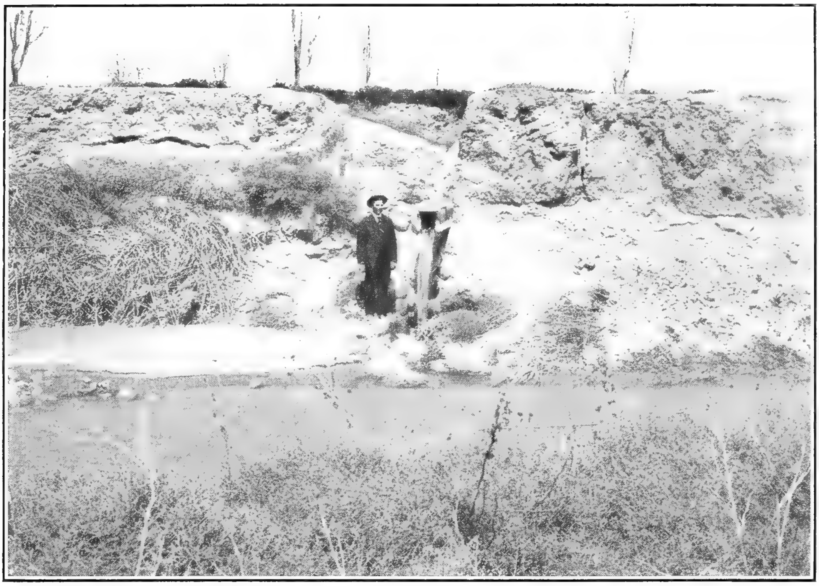

FIG. 1.—OUTLET OF DRAIN, SHOWING QUANTITY OF WATER DEVELOPED.

FIG. 2.—ALKALIED CONDITION OF THE LAND.

YOUNG PEAR ORCHARD, WET AND ALKALIED ALTHOUGH ALMOST ON THE BANK OF A WASH 12 FEET DEEP. (SEE EXAMPLE VII, PAGE 34).

FIG. 1.—PRIOR TO DRAINAGE, ORCHARD WAS DYING AND LAND NOW IN ALFALFA WAS BARREN.

FIG. 2.—DRAINED SHALE LAND UNDER CULTIVATION.

RESULTS OF PROPERLY INSTALLED DRAINS ON SHALE LAND.

FIG. 1.—DRAINED SHALE LAND UNDER CULTIVATION.

FIG. 2.—ALL THE IMPROVEMENTS SHOWN HAVE BEEN MADE SINCE A DRAINAGE SYSTEM WAS INSTALLED.

RESULTS OF PROPERLY INSTALLED DRAINS ON SHALE LAND.

though poorly constructed waste ditches and a small reservoir to the north have contributed.

Lateral A, as indicated in figure 9, was installed with the view of intercepting the seepage from the west, while the main tile drain

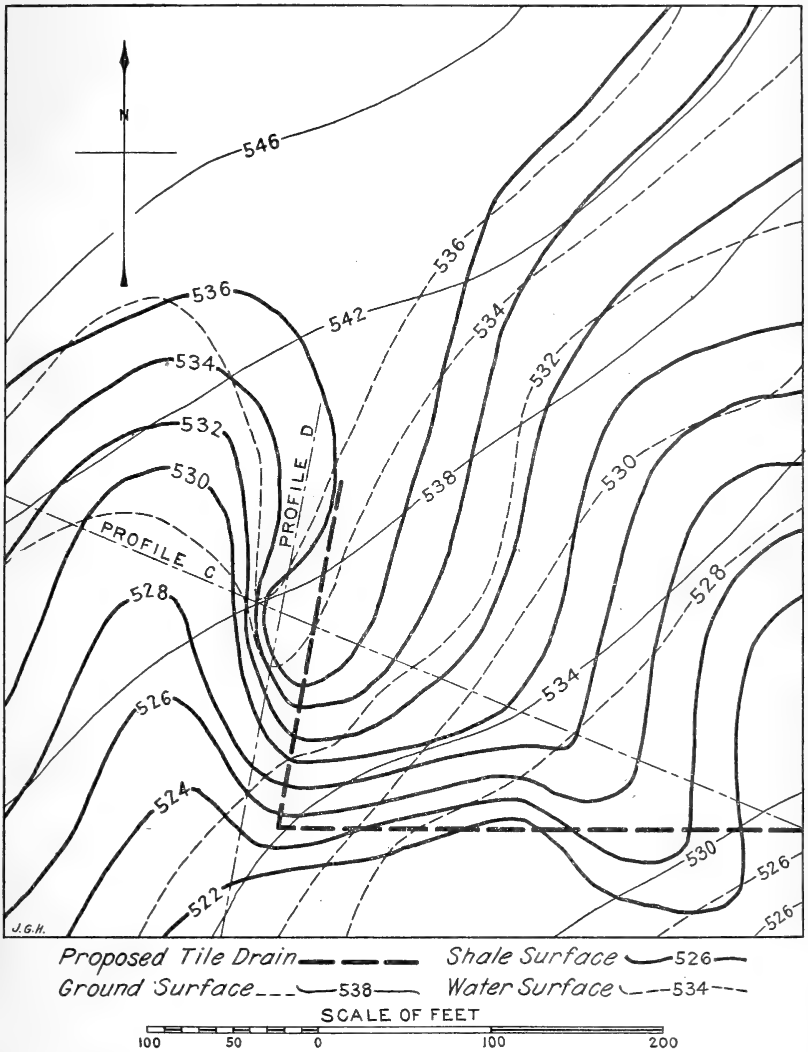

FIG. 7.—Five-acre tract near Canon City, Colo., showing plan of drainage.

was constructed next to take care of the waste water from the north and was indispensable for this purpose. However, so far as any actual benefits from drainage are concerned, the results from both of these drains were negligible and offer the most convincing evidence presented by any of the examples in this bulletin of the failure of both the relief and the intercepting principles of drainage as ordinarily understood when applied to shale lands—this notwithstanding the fact that both of the tile lines were 6 feet deep and that a complete system of relief wells was installed in conjunction with lateral A. Particular attention is called to the system of drainage as it was worked out later. This embraces branch A–1 and laterals B and C with their branches. Branch A–1 follows closely the lower margins of a broad shale point, only one edge of which is shown on the map. Branches B–1, B–2, and B–3 are located up the backbones of three very narrow points. Branches C–1 and C–2 are located up the two sides of a broad shale point. Relief wells were installed every 15 to 20 feet along the tile lines in the shale points. This method of intercepting the seepage from the shale has been entirely satisfactory and has afforded all the relief expected. The quality of water developed by this drainage system has been above the average in salt content and is represented by sample C in Table I.

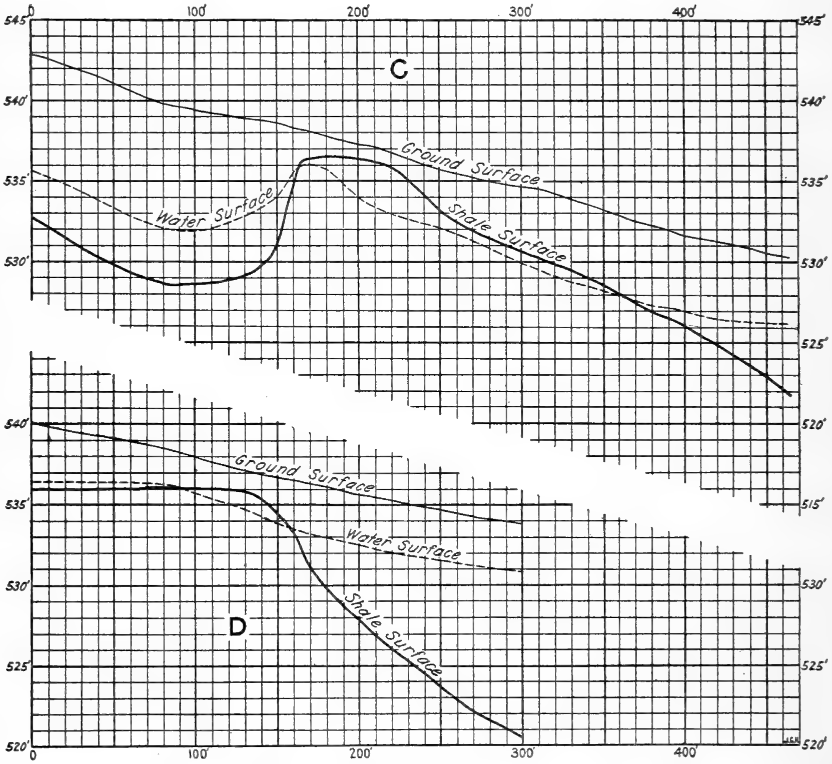

FIG. 8.—Typical profiles across tract shown in figure 7.

EXAMPLE VII.

The project shown in figure 10 is of peculiar interest in that the existence of the wet spot almost on the bank of the wash, 12 feet deep (Pl. VII, fig. 1), illustrates very clearly that a drain improperly located may be absolutely worthless, no matter how deep. The project is also interesting owing to the extreme rapidity with which the seepage trouble developed. In the season of 1913 about 4 acres near the center of the tract, upon which a young pear orchard was growing and which was seeded to alfalfa, became so wet that the first crop of hay was harvested with difficulty. By midsummer water had risen to the surface of the ground and was running off through the irrigation furrows and waste ditches, and by late fall many of the pear trees and most of the alfalfa were dead (Pl. VII, fig. 2).

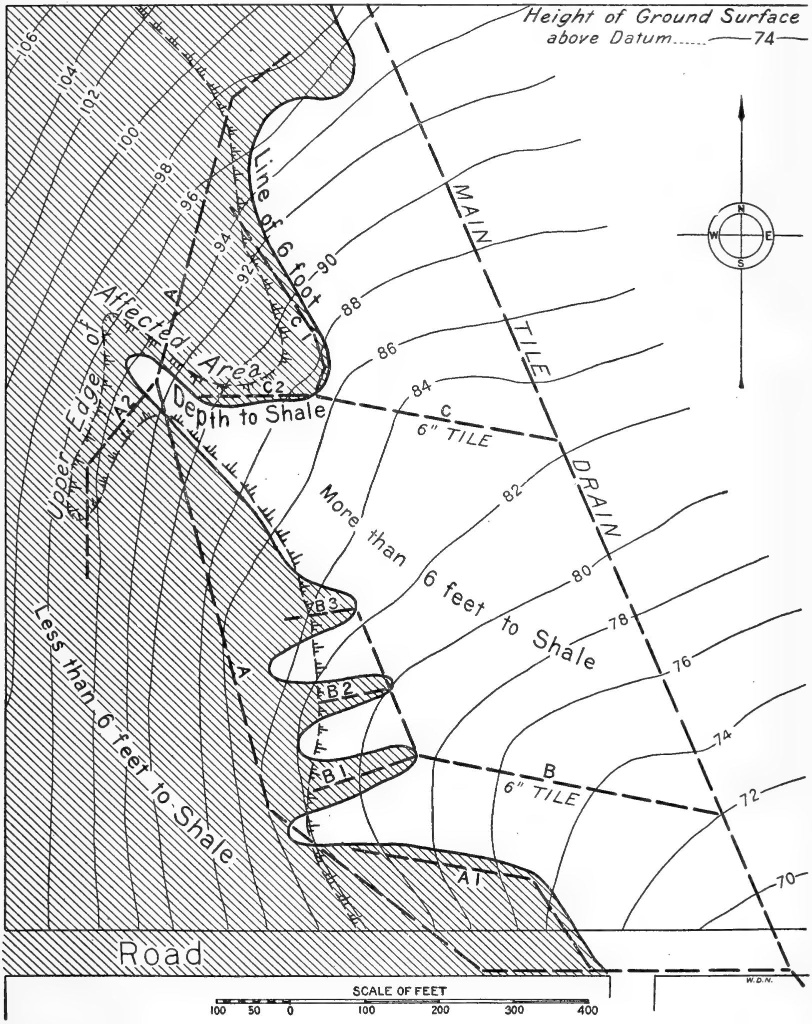

FIG. 9.—Forty-acre tract near Canon City, Colo., showing plan of drainage.

The land immediately northwest, north and northeast is irrigated. It is higher than the tract under consideration and is underlain by shale that outcrops in many places. As indicated on the map, a shale ridge extends from these higher irrigated areas, and the trouble first became evident over the backbone of this ridge and near the point. In designing the drainage system one tile line was located so as to follow up the backbone of this ridge and one along each edge of the ridge. The system was installed in the spring of 1914. The tile were put at an average depth of 6 feet and connected with relief wells 2 inches in diameter that were bored into the shale to depths of from 6 to 12 feet below the bottom of the trench, where the water-bearing strata were encountered. One of these wells, of which there are 35, was installed every 17 feet, and practically the entire flow of water discharging at the outlet of the tile system comes from them.

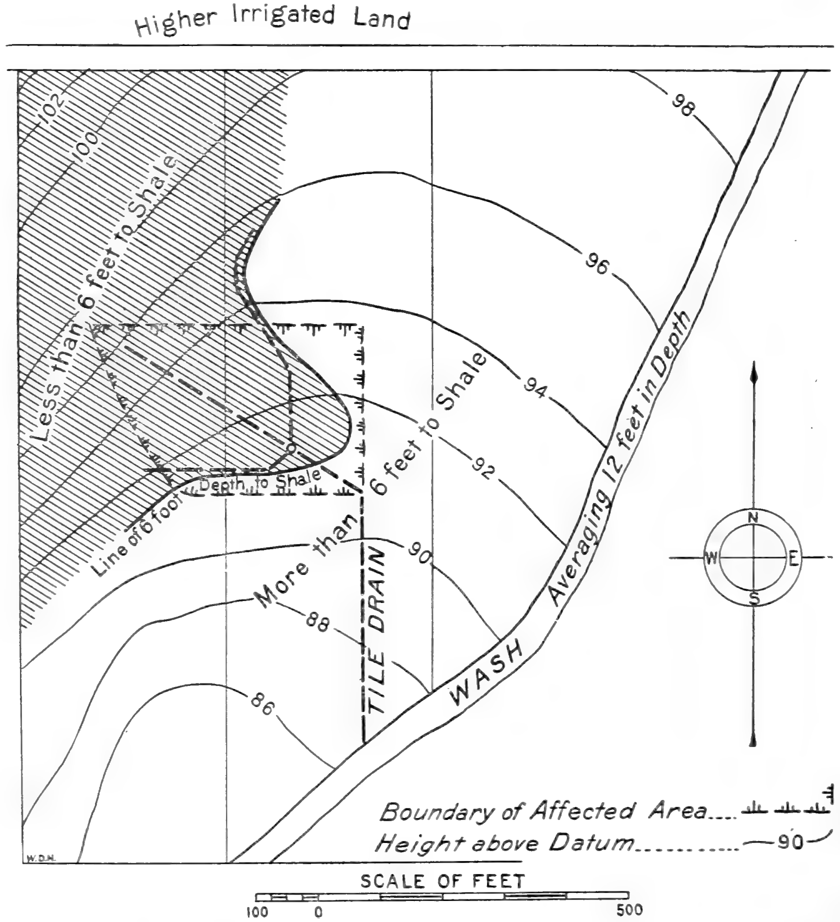

FIG. 10.—Twenty-acre tract near Grand Junction, Colo., showing plan of drainage.

For the first year the discharge from this drainage system averaged 43 gallons per minute, or about 0.095 of a cubic foot per second, practically the entire quantity of which was collected by the 35 relief wells in about 1,000 feet of tile. The hydrograph shown in figure 11 was plotted from measurements at the outlet of the system made at irregular intervals during the first 14 months after the drains were installed. It indicates the discharge in gallons per minute and shows a marked seasonal fluctuation. As determined from this hydrograph, the flow from the relief wells has averaged 1.2 gallons per minute per well. The quality of the drainage water is indicated by analyses F and G in Table I.

Considering the size of the affected area, the quantity of water developed is unusually large for this type of land, and would indicate the source of supply to be either leakage from the canal one-half mile north or the seepage of water supplied on not less than 20 or 30 acres of the higher-lying lands in the neighborhood. In either case, before reaching the drains the water must pass through shale for several hundred feet. While the upper 3½ feet of soil on this tract has been dried out thoroughly, the efficiency of the drainage system would have been increased by installing the main drain up the backbone of the shale ridge 8 feet deep instead of 6; moreover, another lateral drain with relief wells is needed, beginning 400 feet north of the outlet of the system, where the main tile line

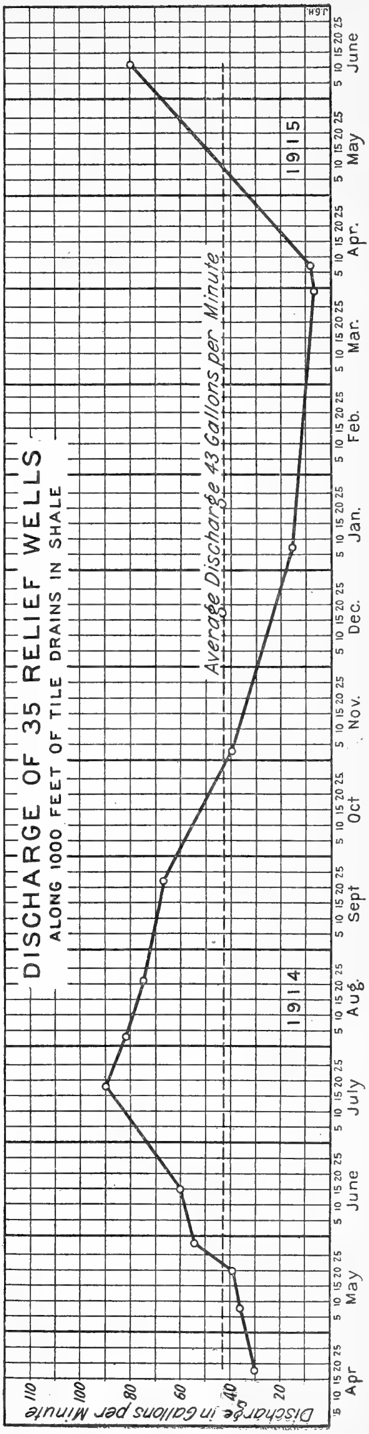

FIG. 11.—Hydrograph of discharge from drainage system shown in figure 10.

makes its first turn, and running a little east of due north for about 200 feet.

EXAMPLE VIII.

The tract shown in figure 12 exemplifies the method of drainage as applied where a broad, flat shale ridge contributed the seepage water. Lateral A was installed two seasons prior to drilling the relief wells, and no benefits whatever resulted from the drain. Both sides of the trench were very wet almost to the surface of the ground wherever the trench was opened for the purpose of connecting the relief wells with the tile lines. After the wells were installed a marked improvement became apparent almost immediately and the tract was put under cultivation the following season with satisfactory results. The depths of the most effective relief wells are indicated on the map. Attention is called to the distances between wells, from 150 to 200 feet, which are unusually great. Generally speaking, this project was one of water-logging rather than of alkali. The analysis of the water discharged at the outlet of the tile system after completion is represented by A in Table I.

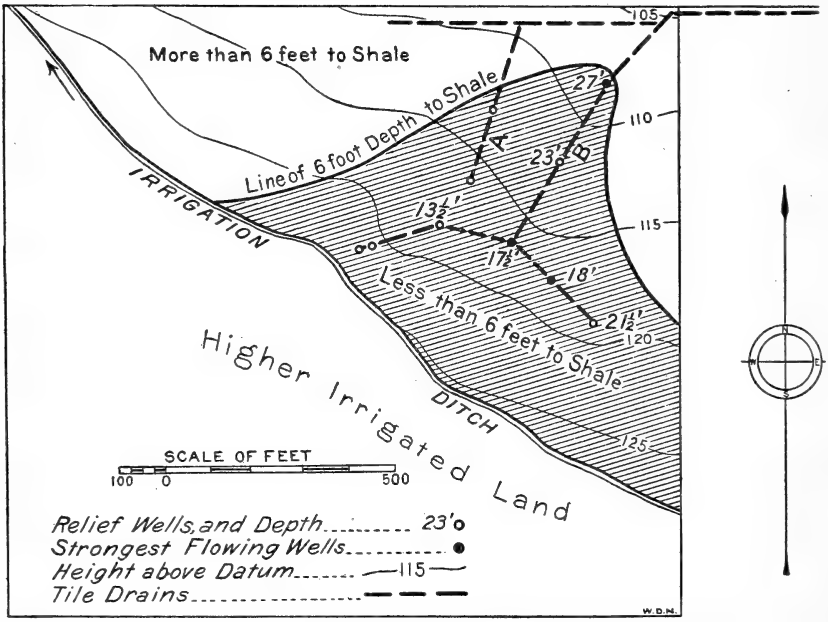

FIG. 12.—Forty-acre tract near Montrose, Colo., showing plan of drainage.

RESULTS OF DRAINAGE.

Drainage of any type of agricultural land is successful only to the extent that the land increases in productivity after the completion of the drainage system. As illustrative that adequate drainage of shale lands will fulfill this requirement, attention is called to Plates

VIII and IX. All the lands represented had become water-logged, alkalied, and unproductive. They have been reclaimed by drainage to the extent that the crop yields are normal again. Before drainage the orchard shown in the background of Plate VIII, figure 1, was dying, while the land now in alfalfa was barren. Since the completion of the drainage system no trouble has been experienced on this tract. All the improvements shown by Plate IX, figure 2, were made after the drainage system was installed and the benefits to the land evident to the owner.

CONCLUSION.

Outcroppings of shale and lands immediately underlain by shale, as treated in this bulletin, are found in northern New Mexico, in southeastern Arizona, in large areas of Colorado, in the eastern portion of Utah, in the extreme eastern part of Idaho, in Wyoming, Montana and in the western parts of Nebraska and the Dakotas.

Shale is an important factor in the movement of underground water, especially in those areas where uplifts and displacements have occurred.

Three different ways by which shale becomes a factor in the movement of seepage water have been considered: (1) Over the top of the undisturbed and impervious strata; (2) between the layers; and (3) through joints, faults and cleavage planes.

The minor features of the surface of the underlying shale are frequently quite irregular and are masked by the overlying soil. They can be determined only by soil borings.

The source of the seepage water is deep percolation, resulting from irrigation and from seepage losses from canals and laterals.

Artesian conditions exist usually where the seepage water moves through the shale, although the pressure may be low owing to a large number of areas of leakage in the confining medium.

There is a relation between the seepage areas and the topography of the underlying shale. The affected areas usually occur near shale ridges and points. This is due to the fact that there is greater porosity in the shale ridges than in the deeper zones, the former having sustained the effects of weathering and therefore being more shattered and fractured and the joints more open and greater in number. Furthermore, the soil covering is shallowest over the ridges.

The deeper zones carry most of the water, owing to continuity and greater area of cross section, and the general movement of the water is parallel with the main jointing systems of the shale.

Practically all the shales run high in alkali salts, and the seepage waters leach out large quantities. Consequently many of the waters discharged from drainage systems in shale carry a salt content as high as 2 and 3 per cent, in which are many nitrates. Because of this condition of the seepage water the soils of shale lands that have become water-logged develop a severe alkali problem rapidly.

The drainage of shale lands can not be accomplished by ordinary methods of drainage, due to the movement of the water through the shale under pressure and also to the extreme retentiveness of the overlying adobe soil.

The three essential factors for successful drainage of shale lands are: (1) Proper location of drains, (2) sufficient depth, (3) relief wells.

Drains must be located so as to tap the contributing shale features, such as ridges, points, knolls, etc. To so locate drains necessitates careful and complete preliminary examinations.

The amount of shale reached and the amount of water developed are augmented by increasing the depth of the drains. These depths never should be less than 6 feet, and generally depths of 7 and 8 feet and greater are essential to success.

A system of drainage in many of the shales will be incomplete and unsuccessful without relief wells.

The area of influence of relief wells is small; this necessitates that they be closely spaced—in many cases 5 or 6 to 100 feet of trench.

The most efficient depth for the wells has been found to range from 6 to 20 feet below the bottom of the tile drain.

The major portion of the water developed by most of the drainage systems in shale comes from the relief wells.

A diameter of 2 inches has been found to be sufficient for the relief wells, and in most of the shales they have been installed with the soil auger. Frequently, however, hard strata require the use of a churn drill.

For trenches in shale ranging from 6 to 7 feet in depth, and with labor at $0.25 per hour, unit costs for excavating, laying tile, and back-filling, together with the cost of installing the relief wells, have ranged from $0.12 to $0.25 per linear foot of trench. This does not include the cost of any material for the drains.

The acreage costs of drainage of the lands referred to in this bulletin have ranged from $13 to $100 per acre for the area actually affected.

Once seepage trouble has developed in shale lands, the affected area increases rapidly. The quantity of the alkali salts at or near the surface of the ground also increases rapidly in water-logged lands of this type. As a result of these conditions, the drainage problem and the one of removing the excessive salts are simplest, the construction most economical, and the results most satisfactory if the drains are installed at the first indication of trouble.

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