University of Nebraska - Lincoln
DigitalCommons@University of Nebraska - Lincoln

Historical Materials from University of Nebraska-Lincoln Extension

Extension

1934

RB34-6 The Relation of Drouth to Water-Use in Nebraska

G.E. Condra
University of Nebraska at Lincoln

Follow this and additional works at: https://digitalcommons.unl.edu/extensionhist

Part of the Agriculture Commons, and the Curriculum and Instruction Commons

Condra, G.E., "RB34-6 The Relation of Drouth to Water-Use in Nebraska" (1934). *Historical Materials from University of Nebraska-Lincoln Extension*. 1863.
https://digitalcommons.unl.edu/extensionhist/1863

This Article is brought to you for free and open access by the Extension at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in Historical Materials from University of Nebraska-Lincoln Extension by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.

THE RELATION OF DROUTH TO WATER-USE IN NEBRASKA

By G. E. CONDRA

BULLETIN 6
CONSERVATION DEPARTMENT
of the
CONSERVATION AND SURVEY DIVISION
UNIVERSITY OF NEBRASKA

By Authority of the State of Nebraska
Lincoln, Nebraska
November, 1934

THE UNIVERSITY OF NEBRASKA
EDGAR A. BURNETT, Chancellor

BOARD OF REGENTS

HON. FRED A. MARSH, Archer
HON. FRANK A. TAYLOR, St. Paul
HON. EARL CLINE, Lincoln
HON. STANLEY D. LONG, Grand Island
HON. A. C. STOKES, Omaha
HON. MARION SHAW, David City

CONSERVATION AND SURVEY DIVISION
G. E. CONDRA, Dean and Director

As defined by law, the Conservation and Survey Division of the University includes the following state departments and surveys: Soil, Geological, Water, Biological, Industrial, Conservation and Information Service. Its major purpose is to study and describe the state's resources and industries for use in development. Reports are published in three series, i.e., Nebraska Soil Survey, Nebraska Geological Survey, and the Conservation Department.

The Relation of Drouth to Water-Use in Nebraska

By G. E. Condra

Three severe drouths have occurred in Nebraska and adjacent states within the past eighty years, and less severe ones have come at moderately regular intervals. Their influence on the agricultural development of the state is well known, but their relation to water supply in general is not so well understood. This paper is a brief review of the relation of drouth to soil moisture, surface water, and groundwater supplies.

Drouths are recognized as a climatic feature of the central part of the United States, but the fundamental cause of their origin and periodic occurrence has not been established. However, scientists believe that their causal elements are *low relative humidity, hot winds, high soil temperature, excessive evaporation,* and *deficient rainfall* which is the dominant factor. It is also recognized that some of these elements are the accompanying effects of drouth. Consequently, the term drouth denotes both the conditions and the effects, but more generally the latter.

RAINFALL

Rainfall (precipitation) is the primary source of all our water supplies.

There is considerable fluctuation in the quantity of the seasonal and annual rainfalls for the state as a whole and also local variation from the average rainfall. The rainfalls and snowfalls are not very uniform in volume and distribution, whereby some places receive precipitation at opportune times, and others receive little or none. The erratic rainfalls seem to be most marked during the dry periods.

The immediate cause of the low rainfall and drouth is probably due to the abnormal development of the storm areas (cyclones) and the shifting of their tracts or courses, but, as noted before, the primary cause of these changes, which seem to cause drouth, has not been established beyond doubt. This means, of course, that there is no reliable basis for dating the recurrence of dry periods and wet periods in the future. Nor

is the rainfall subject to increase by any means known to man, but means and agencies are known whereby it can be conserved and more effectively utilized.

The phenomena whereby rainfall and dew are transferred from the atmosphere to the land, and whereby water is returned to the atmosphere by evaporation and by the transpiration of living organisms are not generally understood. It is known, however, that precipitation occurs irregularly and that dew, which is of use to plants and animals, forms under certain conditions but sparingly during drouth. We also know that moisture passes back to the air in largest quantities during hot weather. The restoration of atmospheric vapor from the land, water surfaces, and from living things is constant in the state, and, no doubt, some of it, augmented by replenishment from the Gulf and areas to the west, is precipitated here again and again in the cycle. Vast quantities of the atmospheric moisture are carried eastward and northeastward beyond Nebraska. Our rain-water supply, therefore, is of both local and distant origin.

Volume of Rainfall. The area of our state is about 77,300 square miles or 49,472,000 acres on which there is an average annual rainfall of about 33 inches in the southeastern counties and gradually less westward and northwestward to about 16 inches at the Wyoming line. The average annual rainfall for the state as a whole is about 23½ inches, which gives about 96,882,666 acre feet * of water per year. The quantity of water would form a column about 264 feet high on a county 24 miles square. It would cover a strip one mile wide the length of the state to a depth of about 518 feet or more at the east and decreasing to about 259 feet at the west. Unfortunately, the volume of our rainfall varies considerably from year to year. About eight per cent of it is supplied by snowfall.

Rainfall Shortage. The rainfall record in Nebraska has been kept for many years. According to Professor Thomas A. Blair of the U. S. Weather Bureau, it is as follows for the period occupied by the recent drouth:

* An acre foot is the amount of water that would cover one acre of surface to a depth of one foot.

1931 precip., 19.63 in., 3.87 in. below normal, deficit	15,954,720	acre ft.
1932 precip., 20.95 in., 2.55 in. below normal, deficit	10,512,800	acre ft.
1933 precip., 20.11 in., 3.39 in. below normal, deficit	13,975,840	acre ft.
1934 precip., 9.31 in., 8.24 in. below normal, deficit (to Sept. 1)	33,970,773⅓	acre ft.
Total acre feet below normal	74,414,133⅓	acre ft.

The state's precipitation from January first to September first averages about 17.55 inches, but this year (1934) it was only 9.31 inches, a deficiency of about 47 per cent. The deficiency below the average for the 3½ years just past was about 20 per cent. This was the main cause of the last devastating drouth, during which low rainfall and other associated unfavorable weather elements influenced the soil moisture and the water supplies generally.

SOIL MOISTURE

Soil moisture is the capillary phase of groundwater accumulation. Because of its bearing on agriculture, it is, perhaps, our most economically important water resource. There is drouth when and where the soil moisture fails during the growing season.

The soil moisture is absorbed largely from the rainfall, most ideally from frequent slow rains, and is depleted by evaporation and plant growth, and some of it (gravitation water) penetrates downward, becoming groundwater proper.

Plant Moisture Requirement. Plants require large quantities of moisture for their growth. According to Professor T. A. Kiesselbach of the College of Agriculture, corn requires 267 to 400 pounds of water for each pound of dry matter produced; wheat, 264 pounds or more; oats, 414 pounds or more; and alfalfa, 858 pounds or more per pound of dry matter. In other words, 6.2 acre inches of water are required for a crop of 50 bushels of corn per acre; 5.5 acre inches for a crop of 30 bushels of wheat per acre; 6.4 acre inches for a crop of 60 bushels of oats per acre; and 22.6 acre inches for a yield of 2½ tons of alfalfa hay per acre. These requirements are for soil moisture and not for rainfall, much of which is lost by surface run-off, evaporation, and percolation. When the soil moisture supply is less than the rainfall requirement, the crop yield is decreased.

Moisture Capacity. The soils of the state differ greatly in their capacity to absorb and hold rainfall, some being essentially drouthy, and others quite drouth resistant. The open-textured sandy soils (Figure 1) drain much of the rainfall downward to beyond the reach of plant roots, whereas the heavy types shed much of the rainfall as direct run-off, but absorb some and release it slowly to plant roots. Both types are comparatively drouthy.

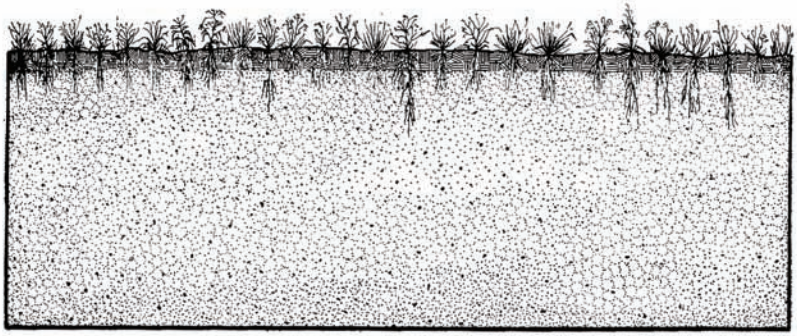

FIGURE 1.—Cross-section of a thin soil on sandy land in which there is no claypan and the water table is deep. Much of the rainfall is absorbed, but most of it penetrates downward to beyond the reach of plants. Such a soil is effective in conserving the rainfall as groundwater, but is drouthy. It is better suited to growing native, drouth-resistant grasses than cultivated crops. Thin soils on sandy bedrock react as the above agriculturally.

The soils on the loess deposits of the state are largely silty. They have a high water-holding and a high moisture-releasing capacity, making them drouth resistant. Other soils high in organic matter content absorb and hold moisture well and release it favorably for plant growth and are also drouth resistant.

Claypan subsoils check the downward movement of gravitation water, thus tending to conserve moisture within the reach of plants (Figure 2). The soils with deep claypan layers are drouth resistant, whereas those with a shallow claypan are comparatively drouthy, due to a lack of moisture storage capacity.

The thin soils have low capacity to absorb and store rainfall, and the thicker or deeper types have greater capacity for water storage. About 40 per cent or more of the average soil

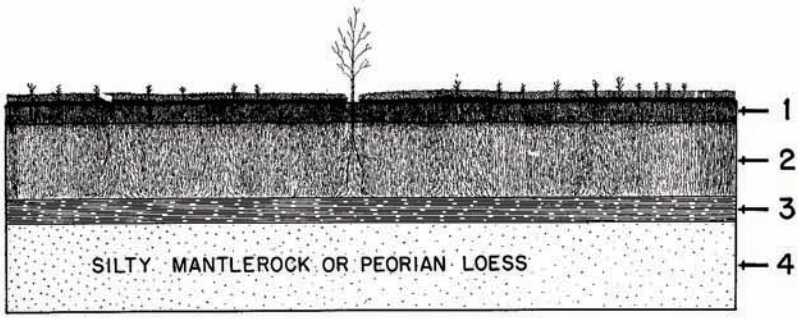

FIGURE 2.—Cross-section of a deep, silty soil with a claypan layer three or four feet below the surface. This claypan or layer (3) retards the downward penetration of moisture and is thus a factor in the storage of moisture in zone 2. In other words, the topsoil (1) and zones 2 and 3 absorb and hold rainfall. Zone 4 is below the soil proper. It represents loess. The soil is typical of the Marshall, Moody, Holdrege, and Carrington series of the smooth uplands of the Loess Hill, Drift Hill, and Loess Plain regions of the state. The Crete and other soils with shallower claypan are more drouthy than those with a deep claypan because they have a smaller capacity for moisture storage.

is pore space, occupied by air and moisture. The most ideal relationship for plant growth is where 50 per cent or more of this pore space is filled with capillary water. Drouth exhausts the soil moisture to the point where the plants wilt and die.

At most, the soils afford only limited storage of moisture, which, without frequent replenishment from rainfall, becomes depleted to the danger point by evaporation, plant use, and percolation. In other words, the frequency of rainfall is an important factor in the agricultural use of land, and a relatively long period without precipitation during the growing season becomes a drouth.

Soil Moisture and Farming. The conservation of soil moisture for use in effective agricultural production is an important problem in our state. It is a complicated subject involving technical knowledge of soils, soil moisture phenomena, crop adaptation, and effective methods of seeding and cultivation.

Fortunately, our best agricultural soils absorb rainfall comparatively well, but their moisture content now is low, and it will take considerable rainfall and time to restore this de-

pleted water supply. In this connection, it is recognized that the rainfall alone does not fully determine the producing capacity of soils, because the same quantity of rainfall on each of two or more soils shows different and sometimes extreme results. For example, there are soils in the state on which a precipitation of 20 inches will produce better results than 30 inches on another soil. Furthermore, the nature and time of rainfall are often the dominant factors in production. Consequently, the procedure in farming must relate to the specific conditions regarding the soils, soil climate, distribution of rainfall, and the per cent of it that can be conserved for use in a soil. These factors force the conclusion that the lands must be utilized on a basis of their possibilities and impossibilities in which the water-holding capacity of the soils and the drouth hazard are given consideration. In other words, the conservation of soil moisture from the rainfall for agricultural use is a major subject for investigation by the agricultural experiment stations and the College of Agriculture, and is a subject for adjustment by farmers.

FIGURE 3.—A scene in Boone County in July of 1934 when the corn began to wilt. Note the spots shown by 1 to 6. They are where sheet erosion has made the soil thin and drouthy. Observe that the corn is thickest and tallest on the lowest ground (A, B, C and D) where the soil is deepest, containing most humus and moisture.

Amount of Soil Moisture. The amount of soil moisture varies greatly in the different parts of the state depending in part upon the amount of rainfall and upon the use that is made of the land. It fluctuates during the year, being highest after rainy weather and spring thaws, and lowest during

drouth. The smallest quantities of water occur in the thin sandy soils and in those that have been impoverished by sheet erosion (Figure 3), and the largest amounts occur in the deep types having a large content of organic matter. Usually, the silty soils of the bottom lands and terraces have a higher water content than those on the hilly lands. The moisture content is higher in the soils of the eastern counties than in those farther to the west. Through irrigation, surface water and well water are spread upon the land becoming in part soil moisture. Through subirrigation, quantities of ground water become *capillary fringe water* within the reach of plant roots (Figure 4).

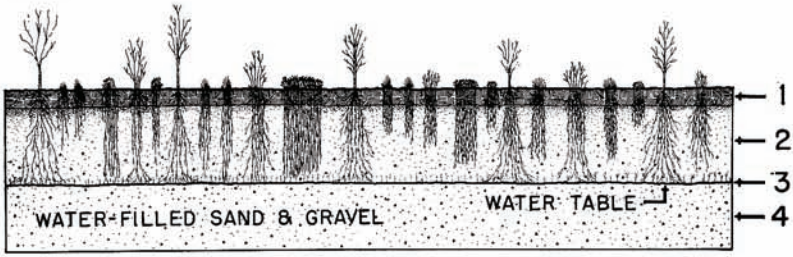

FIGURE 4.—A generalized cross-section of a bottom land soil with a deep, black top layer (1) on sand (2 and 4) in which the water table (3) is at a depth of about four feet. This soil is sub-irrigated. The capillary fringe water rising from the water table (3) into the lower part of the sandy subsoil (2) becomes available for absorption by plant roots. Such soil is drouth-resistant where the water level is maintained at the proper depth by underflow. There are many square miles of soil and land of this kind in broad valleys of the state.

The volume of the water content of our soil and subsoil ranges from about one inch in certain thin sandy types to about one foot in the deeper heavier types. Its average for the state as a whole is about 13,000,000 acre feet of capillary water, which does not include that in the mantlerock between the subsoil proper and the water table.

The recent severe drouth reduced the volume of soil moisture storage to a low minimum, but the rains of late have increased the content in the central and eastern parts of the state. However, the soils on the tablelands of the western counties are still dry, due to lack of rain, and much of the wheat seeded there in the fall has not germinated,* and no

doubt some of this land will blow badly, due to the dry soil and the lack of plant cover.

SURFACE WATER

This includes the intermittent and permanent streams, marshes, ponds, lakes, and reservoirs, all of which receive water directly or indirectly from the rainfall and are affected by evaporation and other losses. In addition to the surface run-off, most of the creeks and rivers derive a part of their flow from the groundwater, and the surface of most of the sandhill lakes represents the exposed water table.

Area of Surface Water. The combined area of the intermittent lakes of the state is about 230 square miles. That of the permanent lakes averages about 163 square miles, and that of the permanent streams about 495 square miles. The combined maximum area of the surface water, not including floods, is about 890 square miles. The drouth of this year reduced the combined area of the surface waters to about 300 square miles, while the mean area, averaged over a period of years is thought to be about 640 square miles, with a volume of about 1,200,000 acre feet.

Effect of Drouth. The behavior of surface waters during wet periods and dry periods is an interesting subject, too much involved for full discussion in this paper. During drouth, the intermittent ponds, lakes, and streams are obliterated. The otherwise permanent creeks and rivers decrease in flow and become dry in places. While lowering, they draw heavily upon the alluvial groundwaters, especially where deep drainage canals have been installed. This year the Missouri reached its lowest stage since territorial days, and only those streams that are fed by abundant groundwater, as that from the sandhills, continued to flow during the drouth. About 1,000 of the shallow sandhill lakes dried to or near to their beds, and the more permanent lakes became shallower and smaller. Only the deeper sandhill lakes lasted during the peak of the drouth. However, when evaporation and transpiration decreased during the cooler weather, the sandhill lakes in-

* The time referred to is October 14, 1934.

creased in depth and area, and the streams fed by groundwater increased in flow, especially in their middle and lower courses.

The return flow from the irrigation areas was less this year than formerly, because adequate water was not available for use in irrigation and because heavy evaporation depleted the supply more than usual. Since the peak of the drouth, the return flow from the irrigated lands and the underflow from the sandhills (Figure 5) have established a surface flow in the Platte Valley eastward to Lexington, but the rainfall has not yet developed a flow between Lexington and Columbus (Figure 6). Because of the late rains in the eastern part of the state, run-off is again established in the streams that went dry. The groundwater is being recharged, and the water table is being lifted in the alluvial lands.

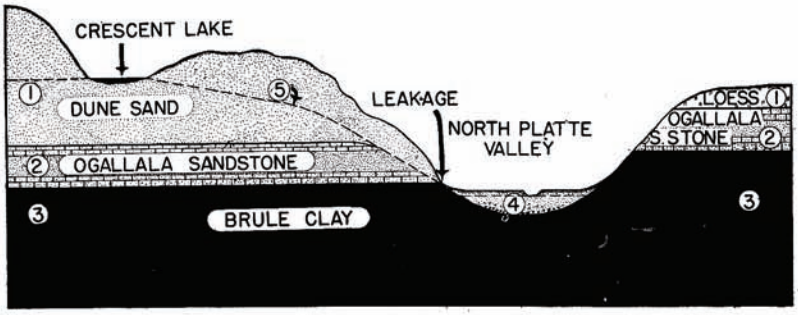

FIGURE 5.—Cross-section from Crescent Lake in Morrill County to the North Platte Valley, showing how the rainfall accumulates in the dune sand (1) and the Ogallala sandstone (2) above the impervious Brule clay (3), and underflows to the North Platte Valley, supplying irrigation water. Crescent Lake is at the surface of the groundwater, and wells could be had at most points in the area of this cross-section, except where the Brule clay outcrops in the valley-sides and water has drained away.

More marshes, lakes, and streams went dry this year than during any former drouth of record. There was a long period during the summer and early fall-time with no run-off in most of the creeks and rivers, and flow was gradually reduced in the permanent streams. The water surface of the state probably reached its minimum record. The shrinkage of the surface waters was detrimental to wild life, water power development, irrigation, and in a few places to rural and municipal water supplies.

FIGURE 6.—The dry bed of the Platte just west of the bridge on Highway No. 2, southeast of Grand Island, October 14, 1934. The water-table at this date was about 1¾ feet below the surface, the lowest it has been for years, but there is more than 100 feet of groundwater in the sands below, the result of storage in years past.

During most years the intermittent lakes on the Loess Plain Region and the tablelands contain considerable water in late fall-time and afford duck shooting, but this year, there was no water in most of them and hence no hunting. The reduced lake surface in the sandhills and elsewhere, and the nearly dry marsh lands also afforded little hunting. Many fish perished in the shrinking streams and lakes during the drouth. The exhaustion of surface water was also destructive to native plants, muskrats, birds, and many other forms of wild life.

GROUNDWATER PROPER

Our groundwater proper is supplied directly from the rainfall and indirectly from the streams and other forms of surface water. It is the free water that fills the pore spaces of the mantlerock and the openings in the bedrock.

Amount of Groundwater. The deep, sandy mantlerock of the state has large storage capacity. The amount of groundwater in the state is vastly greater than the surface water. That above the imprevious bedrock is about ten times the mean annual rainfall or more than 900,000,000 acre feet. This does not include the vast storage in the deep-seated formations, part of which is quite salty.

Movements of Groundwater. Sandy land absorbs much of the rainfall and passes it downward through the soil and

mantlerock, building up storage above the impervious bedrock. This water moves underground to points of escape in the valleys, and at the average rate of about three feet per day, while that of the major streams has an average of several miles per day. It takes years for the groundwater to move from central points in the upland to the seepage ways and springs.

Replenishment of groundwater lifts the water table, and the loss of it by underflow, transpiration, some evaporation, and by use, lowers it.

Water Table Level. The water table is the upper surface of the saturated or free-water zone. It is the uppermost level at which groundwater runs into a well or other excavation.

Occasionally it is reported that the water level has lowered markedly at some place within a short time. Usually, however, such reports are based on observations made at wells after heavy draft by pumping and really mean local "draw down" and not the lowering of the water table generally.

The low rainfall of the recent drouth did not recharge the groundwater normally, and this, together with the loss by underflow and the excessive use of well water, did considerably lower the water table in places. The water level in the alluvial bottom lands dropped from one to three feet at many locations and 15 feet or more along-side the drainage ditches of the southeastern counties. In the sandhills, it lowered very little where the groundwater is deepest and protected, but it dropped two feet to four feet at the lakes and in the valleys where evaporation and transpiration are most active.

The deep water table in the upland plains and tablelands lowered very little, due to the slow underflow, lack of evaporation, and the small use that is made of the water. However, at places in the state shallow, limited groundwater was nearly exhausted during the drouth.

Amount of Depletion. Groundwater proper is less affected by drouth than soil moisture and surface waters. The normal rainfall, as noted before, dropped off about 47 per cent this year between January first and September first, and the surface waters shrank to a low minimum, but the groundwater supply was depleted only about 4 per cent during this period,

and it would probably require a drouth of long duration to reduce the groundwater resources in most parts of the state to an alarming degree.

Such shrinkage and exhaustion as there was of the groundwater, influenced unfavorably the spring flow, stream flow, marshes, lake level in the sandhills, and the shallow well water supplies. Its worst effect was the exhaustion of the drinking water supplies in certain small areas of the state.

Groundwater Level Record. The State Geological and Water surveys, cooperating with the Groundwater Branch of the United States Geological Survey, are now measuring the water table levels in about 300 wells located in various parts of the state. These measurements are made at regular intervals and recorded for future use. It is planned to continue this activity indefinitely and for about the same reasons that the rainfall and the streams are gaged and recorded.

SPRINGS

There are a good many springs in the state, formed by the movement of groundwater to the surface over impervious clays and shales. Many of those originating in shallow groundwater ceased to flow during the height of the last drouth. However, those coming from more extensive and deeper water storage were not much affected by the drouth.

Several strong springs were developed for farm and community water supplies this year by trenching into their gathering grounds and making underground galleries for water storage. Precaution was taken to make the spring water free from pollution and therefore safe for drinking purposes. Fortunately, most of the springs, so developed, are located to serve as community water supplies for nearby areas having little or no well water.

WELL FAILURE

Most of Nebraska is underlain by groundwater capable of supplying abundant well water without much interference by prolonged drouth, but there are small areas without dependable well water at any time, and these are the places where groundwater shortage is most evident during dry periods. These defective areas are, for the most part, where impervious,

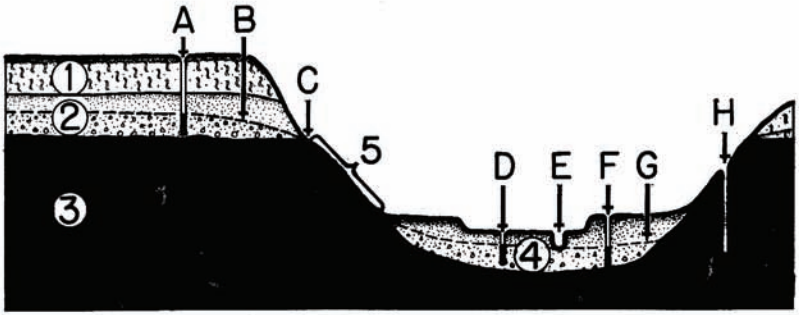

FIGURE 7.—Cross-section of the Republican Valley in Webster County. Note the dry, shaly land belts along the valley-sides (5) on shale (3). Observe the location of the thick, upland sands and gravels (2) in which there is a strong underflow from the Platte Valley with the water table at B. There is water-bearing alluvial land in the Republican Valley (4). The dependable water supplies here during drouth are obtained from the underflow along the Republican and from the sands that are recharged from the Platte Valley. Elsewhere in the area of the cross-section, there is little water except that found in the Dakota Sandstone at a depth of 400 feet or more on the valley floor and at greater depths in the uplands. The location of the river is at E; a bottom land well is at D and a terrace well at F, whereas a dry well is in the shaly land at H. The water table level is shown by G.

shaly bedrock outcrops in the valley-sides, causing the shallow groundwater to drain away. Narrow strips of nearly waterless ground occur in the uplands bordering the Republican (Figure 7), Big Nemaha (Figure 8), Little Nemaha, and the Missouri, and larger areas of the kind are found in the shaly lands of northern Sioux and Dawes counties.

The old saying, "You'll not miss the water till the well runs dry", was applicable to parts of Nebraska this year. The farmers lost their crops without much complaint, but when there was no water in the well for stock and home, they faced a really difficult situation. They became "thirsty" and water minded at once.

Our experience shows that some farmers and some towns use well water rather wastefully much of the time and that the wells so used are among the first to fail during drouth, due to over-draft of water not readily restored by rainfall (Figure 9). Since an adequate well water supply is essential on the farm, and since there is danger of the permanent exhaustion of the groundwater in certain horizons, more than

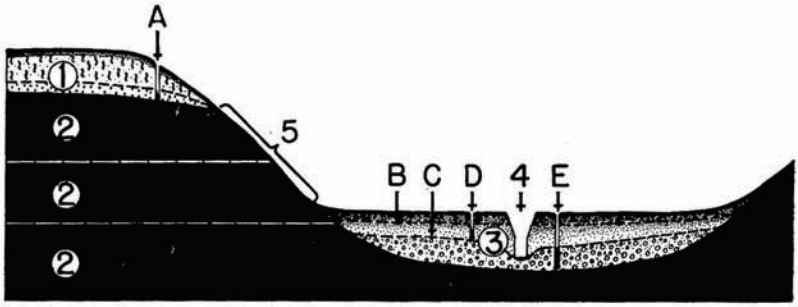

FIGURE 8.—Cross-section of the South Fork of the Big Nemaha Valley about four miles south of Dawson, Richardson County, showing the water-bearing formations and the areas without well water. Note that there is a thin water-bearing sand in the upland (1) in which the well (A) went dry during the drouth. The shaly land (5) carries no well water. The alluvial land (3) is the dependable source of water in this area during dry years. The location of the watertable here before drainage was installed and prior to the drouth is indicated by B., and its position after drainage and during the late drouth is indicated by C. The location of a shallow bottom land well that failed is shown by D and a well that was deepen by E.

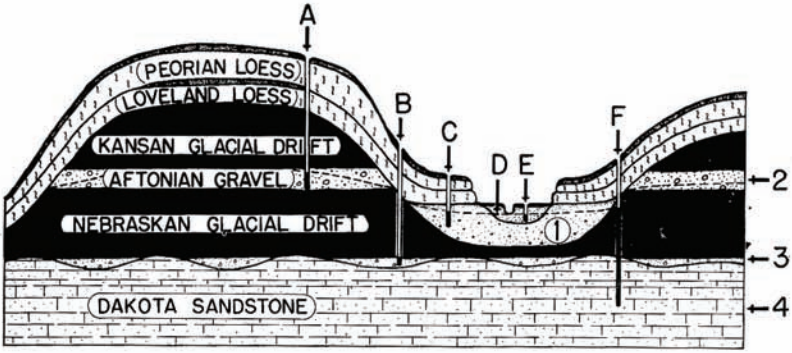

FIGURE 9.—Cross-section of a Loess hill in the northeastern part of Nebraska, showing the geological formations and the water horizons, which are the alluvial sands (a) of the bottom land, the glacial sands (B and C) and the Dakota sandstone. Unfortunately the water supply in the glacial sands are not now restored very much from the rainfall, due to the thick cover of loess. This water was accumulated in ages past. It can be exhausted by heavy pumping and wastage. When it fails, prospecting for a supply is done on the bottom land in which the groundwater is replenished by the run-off of the hills. Finally, the last chance for a dependable well water supply in much of the Loess Hill Region and in parts of the Drift Hill region is the Dakota sandstone to which many wells were drilled this year.

usual consideration should be given to the conservation of this supply for drinking purposes and the use of pond water for stock.

Water Service. The water-bearing formations of the state have been studied quite closely by the State Geological Survey, and the law requires the Water Survey Department of the Conservation and Survey Division to assist the farmers and municipalities of the state in locating and improving water supplies. These departments were very active this year, serving the areas having water shortage. Some of this service was carried on in cooperation with the Federal Emergency Relief Administration. Though there were many well failures,

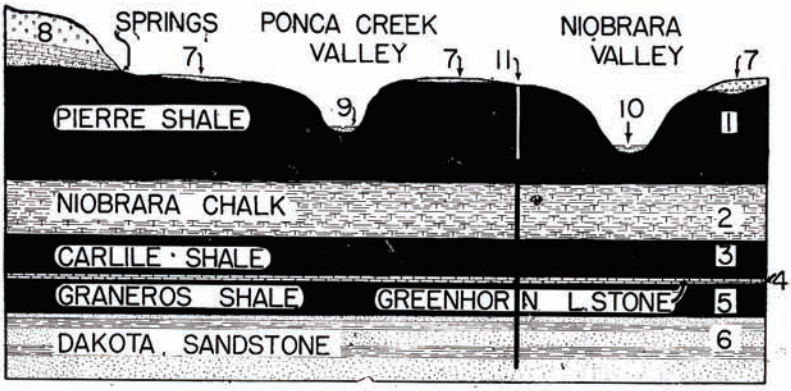

FIGURE 10.—Cross-section of eastern Boyd County and the Niobrara Valley, showing the geological formations and the water horizons. The region is underlain by the Pierre shale and other shaly and chalky formations, and quite deeply by the Dakota sandstone. There is no available water in the shales and chalk. The areas where the shale is at the surface carry little or no well water. The sandy, silty surface formations to the north (8) absorb considerable rainfall and store it above the impervious shale. This condition affords well water and springs. The thin surface sand (7) stores small amounts of rainfall from which limited water supplies are obtained during wet years, but the water is depleted by under-drainage, evaporation, and use during dry years. The run-off from the uplands stores water in the alluvial bottom lands (9 and 10), which are the most dependable sources of well water, except where the alluvium is thin and its water is not recharged during drouth. However, the Niobrara alluvium is supplied quite uniformly by water coming from the sandhills.

The last resort in obtaining water on the shaly land of the area represented by this cross-section, and at similar points farther east, is to make deep wells to the Dakota sandstone, from which, due to artesian pressure, the water lifts to near the surface, as shown by the well at 11.

in every case some measure of relief was found. The Federal departments made a number of emergency wells from which water was hauled for community supply until there was run-off to the ponds and creeks for stock water, and until the rainfall restored enough water in the farm wells for house supply.

DEEPENING WELLS

Drouth and drainage lower the water table in the bottom lands, sometimes below the depth of old wells, which then must be deepened to serve as a source of water supply where it is available; otherwise new wells must be made at points where there is lower water-bearing sand, probably at points farther out on the valley floor. The State Geological Survey passes upon the feasibility of deepening wells and on the location of wells.

On the recommendation of the State Geologist, a number of wells were drilled to deeper water-bearing formations this year as a last resort in finding a water supply (Figure 10). Especially has this been true in the northeastern part of the state, as between Knox and Douglas counties, where the wells were deepened to the Dakota sandstones and produce quite good water. However, there are many places in the state without deeper water, and they are often prospected at the instigation of "doodle bug" water locators at high expense and

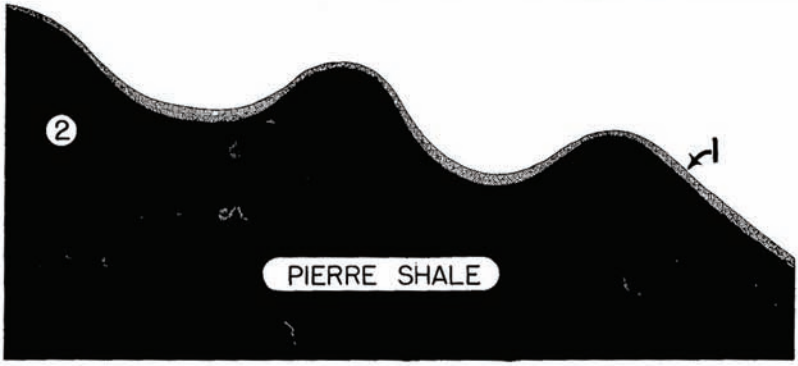

FIGURE 11.—Cross-section of a thin soil (1) on shaly bedrock (2), as in the Pierre Plains Region of northern Sioux and Dawes counties, and in smaller areas elsewhere in the state. This close-textured soil (1) sheds much of the rainfall as run-off. It has small capacity for moisture storage and is drouthy. Such land grows prairie better than cultivated crops.

with failure. Water "locators" seem to show up in largest numbers during dry periods, but because of their failure to make good, most of them did not survive the long drouth of this year. Plainly, no one with a simple device, like a forked willow stick, can locate water where there is none in the ground (Figure 11). The United States Geological Survey has described the uncertainty of water witching.

ARTESIAN WELLS

Of the 1,500 or more flowing wells in the state, more than one-half of them showed some reduction in pressure and flow during the last drouth. However, deeper wells of this kind were not affected. Notwithstanding this fact, reports were run in the daily papers occasionally to the effect that certain deep, flowing wells were more active during the dry period than formerly, which reports seem to have been based on faulty observtaion. Evidently, other water adjacent to the wells having dried up, the flowing wells appeared to better advantage with seemingly heavier flow, whereas measurements showed them to be discharging normally, or nearly so.

There are several artesian water horizons in the state in the Pleistocene, Tertiary, Cretaceous, Pennsylvanian, and yet older formations. The Dakota sandstones are perhaps the leading horizons from which artesian water is obtained. The water in some of the older formations is saline, and much of the artesian flow of Nebraska is being wasted.

A state law forbids the owners of flowing wells to permit the wastage of artesian water, but no department has been given the authority to enforce this law. However, the Geological Survey has assumed the duty of reminding the well owners of the statute and its purpose, and this has caused many of them to control the flow of this water. Apparently we should conserve the state's artesian water, and some department, probably the State Geological Survey, should be given the duty of carrying out the purpose of this law as is being done in other states. The Survey should also be authorized to direct the plugging of all deep salt wells in order to prevent the pollution of our shallow groundwater and surface water. This duty should be assigned by statute.

MUNICIPAL WATER SUPPLY IMPROVEMENT

One of the outstanding results of the drouth has been the extent to which the municipal water supplies of the state were extended and improved this year. Much was accomplished in this line, and places that formerly had restrictions on water use during the summer months, have located new sources of water and an abundant supply for the future. No doubt, Federal Emergency Relief was the main factor in this worthwhile improvement.

IRRIGATION

Drouth causes the people to become interested in irrigation, which is only a method of hoarding and applying water to the land, whereby soil moisture is recharged for use in cropping. The water-use here is through irrigation for farming.

Although there was a shortage of water, the results of this year's irrigation are outstanding compared with the failure in the non-irrigated farming regions. There was less snow on the mountains than usual, making too little storage in the Pathfinder Reservoir for use in the North Platte Valley.

The water shortage caused the irrigators in the North Platte Valley to view the situation with misgivings, and those in the central course of the Platte Valley were alarmed, but fortunately, there were rains in the irrigation areas during the crucial irrigation period, and they served to compensate in part for the lack of adequate irrigation water. However, the administration of the irrigation water supply was extremely difficult during the drouth because of the water shortage and the excessive need for water.

This year, as during other dry periods, much activity was inaugurated favoring the development of new and supplemental irrigation projects in the Platte, North Loup, Middle Loup, and Republican valleys. As a result, the Sutherland Power and Irrigation Project is being built, and action is pending on the Tri-County and other projects.

Many irrigation wells were made during the year and became a factor in drouth relief. They were sunk principally in the middle course of the Platte Valley, i.e., between North Platte and Columbus, most of them from Grand Island westward. Our surveys show that the water here is restored prin-

cipally from local rains and up-river water, and that the supply is sufficient for extensive well irrigation during normal years.

Drouth causes much water to be used generally in the state for the spray irrigation of gardens, trees, lawns, and golf courses. This growing use of water draws heavily on the rural and municipal well water supplies.

The transpiration and evaporation losses of groundwater account in considerable measure for the lowering of the water table in the river valleys and on the hay flats of the sandhills. When too little soil moisture is supplied by irrigation or by rainfall, the crops fail, transpiration is reduced, and the loss of such soil moisture as remains is dominantly by evaporation. Sub-irrigation passes much groundwater to the air through plant growth and evaporation, but this use of water decreases as the water table lowers, except where deep-rooted plants, such as alfalfa, sweet clover, and trees are grown.

CONCLUSIONS

1. Drouths have occurred at periods of ten or more years in Nebraska and adjacent states. They are caused by relatively low humidity, hot winds, high soil temperature, excessive evaporation and deficient rainfall.

2. The average volume of each of our leading water resources is estimated as follows: rainfall, about 98,882,666 acre feet; surface water, about 1,200,000 acre feet; soil moisture, about 13,000,000 acre feet; and groundwater, more than 900,000,000 acre feet, not including that in deep-seated storage.

3. The deficiency of the state's rainfall in 1931, 1932, 1933, and up to September first of 1934 was about 74,414,133 acre feet. It was greatest in 1934, being about 47 per cent below normal for the period from January first to September first.

4. Drouths deplete soil moisture, reduce the area of surface waters, lower the groundwater table, and cause the failure of springs and wells.

5. The native grasses, trees, cultivated crops, farm animals, and wild life generally suffer during severe drouths.

6. The drouth hazard is a factor in state development and we should plan for the "dry days" as well as for "rainy days".

7. Rain water builds up soil moisture, surface water, and groundwater.

8. During hot days evaporation is very active on bare, sandy ground and from shallow surface water. Its effect is augmented by wind and low humidity.

9. Uniform plant cover retards evaporation, direct run-off, and soil erosion, and furthers the absorption of soil and subsoil moistures.

10. Weeds retard evaporation, run-off, and erosion, but use much soil moisture in their growth.

11. Surface irrigation builds up soil moistures and stores groundwater. The deep, silty soils hold the irrigation water for plant growth, but the coarse sandy types drain much of it downward to groundwater storage and leakage as return flow.

12. The sandy lands conserve much groundwater from the rainfall. The Sandhill Region is outstanding in making this use of the rainfall and in releasing the water as uniform stream flow and as invisible underflow to the valleys.

13. Drouths show that our water supplies should be conserved for beneficial use.

14. Drouths make the people water-minded generally and cause them to appreciate the value of groundwater storage and reservoir storage for irrigation.

15. The worst local feature of a drouth is the exhaustion of drinking water supplies.

ACKNOWLEDGMENTS

In the preparation of this paper, the writer received information from Dean W. W. Burr and Professors T. A. Kiesselbach and J. C. Russel of the College of Agriculture; Dr. J. E. Weaver of the Department of Botany of the University of Nebraska; Frank A. Hayes of the U. S. Bureau of Chemistry and Soils; H.L.K. Wenzel of the U. S. Geological Survey; Hubert Waite of the State Water Survey Department of the Conservation and Survey Division; and R. H. Willis of the State Bureau of Water Power, Irrigation, and Drainage.