1939

Some effects of geology on the relation between rainfall and run-off

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SOME EFFECTS OF GEOLOGY ~~TO~~ ON THE RELATION BETWEEN RAINFALL AND RUN-OFF

BY

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A

THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

Degree of

ENGINEER OF MINES

Rolla, Mo.

1939

Approved by Garrett A. Muilenburg
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ILLUSTRATIONS

ACKNOWLEDGMENTS

In the preparation of this thesis the author has endeavored to discuss the many effects which geology has on the relation between rainfall and run-off. The first four chapters discuss the more important geologic factors which modify and reflect this relation. The remaining five chapters are devoted to actual watersheds which illustrate this relation of geology to hydrology.

Numerous references including textbooks, publications of various technical and scientific societies, the United States Geological Survey, and of the various state surveys, have served as valuable guides and references. All references used in the preparation of the thesis have been acknowledged by the use of footnotes.

The author wishes to acknowledge his indebtedness to Mr. Paul V. Hodges, Hydrographic Engineer, U. S. Indian Service, for his valuable assistance and suggestions. To Dr. G. A. Muilenburg, Professor of Geology, School of Mines and Metallurgy, University of Missouri, who reviewed the original manuscript, and to all engineers and geologists who on many occasions have supplied data and constructive criticism, the author expresses his sincere gratitude.

James S. Reger

Amarillo, Texas
April 21, 1939

CHAPTER I

INTRODUCTION

Hydrology has been defined by Mead as the fundamental basis of hydraulic engineering. It is essentially a study of hydro-meteorology, physiography, and hydro-geology and their relations to the occurrence, distribution, variation and disposal of rainfall and the run-off resulting there from in drought and flood. Hydrology might also be defined as that science which treats of the laws of the occurrence and distribution of water over the earth's surface and within the geological strata. It discusses hydrography and physiography in relation to the distribution and circulation of water over the earth's surface and of the physical features that modify and influence distribution. It discusses hydro-geology, or the occurrence of water in the strata, and the laws of its occurrence and flow.

In making studies and reports on the available water supply for proposed dams and reservoirs, the engineer, in many instances, is seriously handicapped by a lack of data pertaining to the run-off and climatological features of the drainage basin in question. This is especially true of work encountered in the southwest and western portions of the United States. Stream gauging records in these areas are few in number, often of short duration, and they are in many cases inaccurate.

Leading hydrologists have from time to time attempted to evolve formulas for the derivation of run-off from rainfall and other physical data. C. C. Vermuele derived several formulas for calculating the annual and monthly run-off of streams, based on certain relations between retention and run-off which he claims to have discovered.* J. D. Justin derived a formula to compute run-off, based on a study of the rainfall of a watershed, and taking into consideration the slope of the watershed (found by dividing the maximum difference in elevation on the drainage area by the square root of the drainage area.)** Mr. Justin recommends the use of his formula only in the Eastern part of the United States.

A. F. Meyer has presented a method of computing run-off from rainfall and other physical data;

* Vermuele, C. C., Water Supply; Geological survey of New Jersey, Vol. 3, 1894.

** Justin, J. D., Derivation of run-off from rainfall data; Trans. American Society of Civil Engineers, Vol. 77, p. 346.

however, it requires a more complete set of physical data regarding a watershed than is usually at the disposal of the engineer.* The method is quite involved, and is made applicable only by the acceptance of certain evaporation, soil storage, transpiration, seepage, and other curves, derived by the author, which in turn depend upon a detailed knowledge of the peculiarities of flow over the drainage area.

The above mentioned authors, as well as others who have attempted to derive formulas for computing run-off, admit very frankly the short comings of their work. They strongly advise that any formula must not be depended upon to give the correct results, but that they can be used to supplement actual stream flow data. No formula can be derived which takes into account, in a satisfactory manner, all the factors of prime importance which affect annual run-off. It is believed, however, that a <u>method</u> can be evolved which will take all factors into account.

For the past five years, the writer has been engaged either directly or indirectly in the

* Meyer, A. F., Computing run-off from rainfall and other physical data: Trans. American Society of Civil Engineers, Vol. 79, p. 1056.

investigation of water supplies. Studies and observations made in Texas, Oklahoma, Colorado, and New Mexico, have brought to his attention the importance of geology to hydrology. This is especially true in reference to the relation between rainfall and run-off. In all texts and other publications relating to hydrology, the importance of geology to the subject is hardly more than mentioned. In the absence of actual stream flow records, many engineers resort to either the "direct comparative method", or the "rainfall percentage method", in estimating the average annual yield of drainage basins. When making use of the direct comparative method, the measured run-off per square mile of a drainage area that has been gauged, is assumed to apply directly, pro-rata, to the area in question. "The rainfall percentage method" differs in that the percentage of run-off to rainfall is determined from actual gaugings for some area, or areas, for which the rainfall and all other physical conditions are assumed to be the same as the area for which the run-off is to be estimated. Both methods have one common weakness, in that the engineer does not always know that the physical conditions affecting run-off (other than rainfall) are the same for the two areas. The engineer is probably more to blame for this weakness since differences in physical characteristics can be identified and corrected by close field examinations.

The writer is of the opinion that a combination of the two above mentioned methods is the most practical method for the average engineer to employ when estimating yields of basins in the absence of actual stream flow records. Furthermore, the writer believes that a careful comparison of the topographic, climatological, as well as other physical features, is not sufficient for comparative purposes, unless, a careful study of the geology of the areas is also included.

CHAPTER II

DEVELOPMENT OF LAND FORMS

The geology of any drainage area and its accompanying topographical, structural and stratigraphical characteristis greatly modify its hydrological phenomena. On the following pages a summary of the more important geological conditions which influence hydrology will be presented, together with brief discussions.

The importanse of topography to run-off is well understood. An understanding of the relation between geology and topography will certainly not give the engineer any additional information regarding the actual topography of any drainage area. However, an understanding of this relation, aided by intelligent interpretations, will often produce information regarding many areas which will greatly assist the engineer in making his investigations.

The chief agents active in shaping land forms are running water, wind, volcanoes, diastrophism, glaciers, waves and ground water.

TOPOGRAPHY RESULTING FROM RUNNING WATER

Of these agents running water is probably responsible for a much larger proportion of the familiar topographic forms than any other. This agent produces land forms of two types; namely, those resulting chiefly from its erosive ability, and those brought about by the deposition of this material.

A. Deposits made by running water.

Streams with high gradients in mountainous areas, emerging into valleys or foothill plains, have their velocity so checked that much of their sediment is dropped. This causes the building of cone shaped or fan-shaped deposits of debris closely analogous to deltas, differing of course in that they are built on land rather than water. Such deposits are called alluvial cones if they are very steep and alluvial fans when they are flat or approximately so. Streams which are heavily laden with sediment, will often choke up their own channels when flowing across such alluvial deposits. This causes streams to break out new lines of flow, thus forming numerous distributaries or discharge channels. These new channels often become braided. Some streams often disappear through sub surface drainage in the upper and coarser part of an alluvial fan, only to reappear as springs or seeps farther down the base of the plain. When fans coalesce and lose their individual identity, they produce a "piedmont alluvial plain". The greatest number of such deposits are found in the arid west, where most of the rainfall in the mountains is lost in the basins either by evaporation or seepage.

It frequently happens that a stream fills its valley with a varying thickness of alluvium after its valley is well established, only to reverse its activity and entrench itself in the alluvium which it deposited. This process of re-entrenchment produces well defined benches. These are known as alluvial terraces and should be thoroughly defined in searching for proposed dam sites.

B. Erosion by running water.

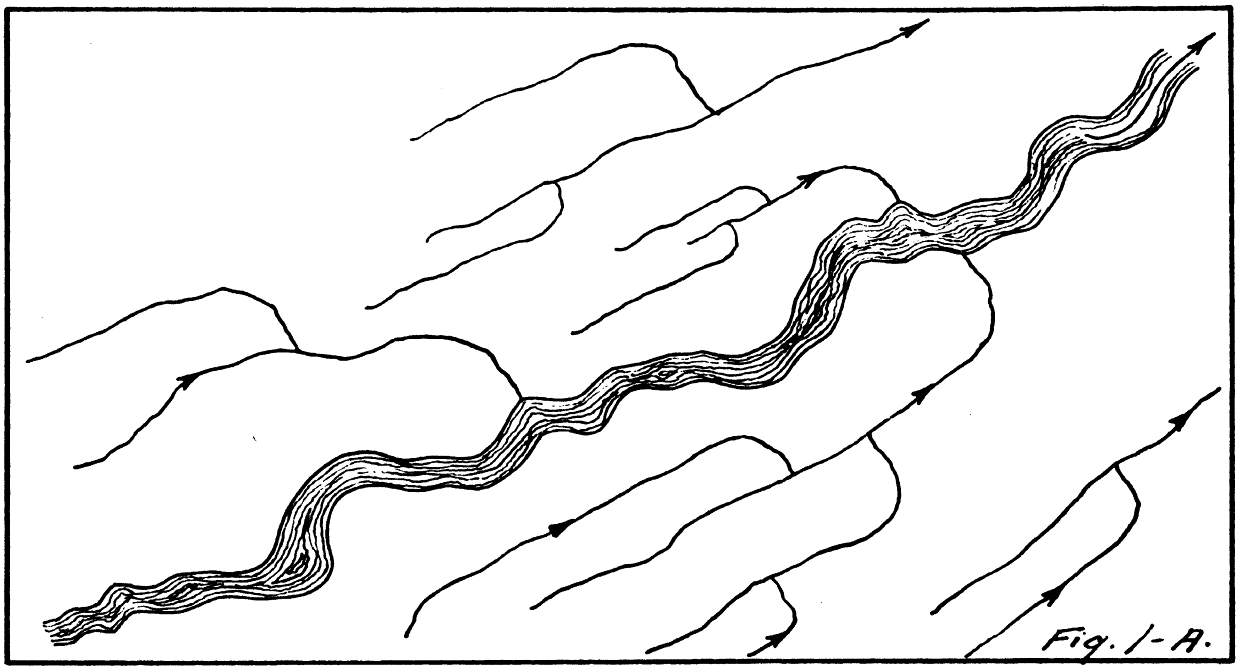
Much topography is caused by running water. Topographic features of an area, when they are the result of erosion by this agent, are often indicative of structure. The cycle, or erosion history of an area, is probably not of great importance, but it is important to recognize the topgraphic results of erosion by running water. It is to topography of this origin that we often look for an interpretation of structure.

EFFECT OF ROCK HARDNESS ON DRAINAGE PATTERNS

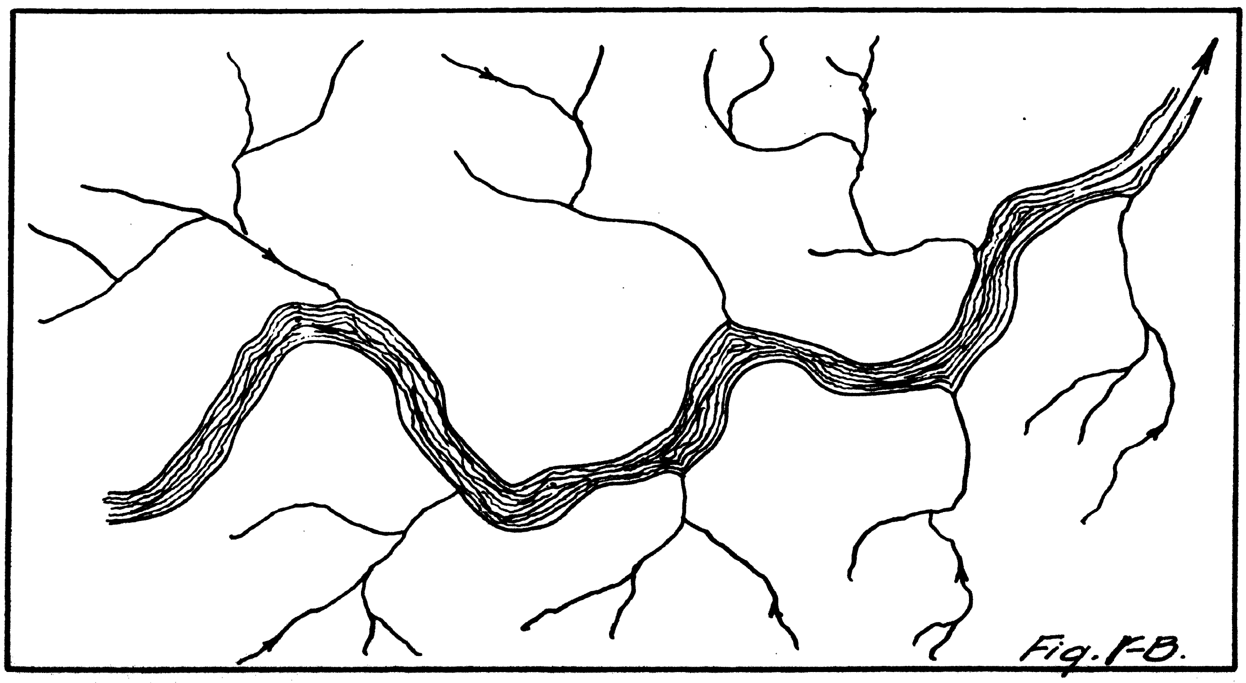
Rocks of unequal hardness, or rather of unequal resistance to weathering agents, give rise to many familiar topographic forms. In many cases such forms play an important part in run-off, with alternating layers in horizontal position, the soft beds wear back undermining the harder rocks, thus producing rock terraces on the sides of valleys. Of greater importance are mesas topped by a hard cap, such as a lava flow. These forms may be interpreted as meaning harder rocks overlying softer ones.

DENDRITIC AND TRELLISED DRAINAGE

In a region where the geological formations are either horizontal, or nearly horizontal, the tributary streams encounter no notable differences of hardness, and if the slope is not too great, they branch in all directions about equally. These tributaries are termed "insequent". They are not sequent or dependent upon any obvious structure. Such a drainage pattern (Fig. 1-~~A~~B) is termed "dendritic". For the same reasons, igneous rocks, such as a large lava flow, can and do produce such a drainage pattern. Again the same pattern can take place on



A- Trellised Drainage.



B- Dendritic Drainage

formations which are tilted, provided the various formations are of equal or approximately equal hardness. If, however, tilted formations are of unequal hardness, and outcrop in narrow parallel belts, the tributaries etch out the softer layers, leaving the harder ones as the divides. Such tributaries are termed subsequent (dependent on sub-structure) and such a drainage system (Fig. 1-~~B~~A) is spoken of as being trellised. A series of parallel faults can also produce this type of drainage pattern as a result of erosion along crushed or brecciated zones. A drainage area over which this is the case, will probably not have as high a run-off in acre feet per square mile as one over which the trellised drainage is the result of tilted formations of alternating hard and soft layers. For this reason the engineer should be able to distinguish both causes. This pattern of drainage when caused by faulting can usually be determined by examination, as the system is less intricate and closely spaced. The pattern on the main blocks between the rift valleys is notably dendritic.

TOPOGRAPHY RESULTING FROM DIASTROPHISM

Many familiar topographical features are the combined results of diastrophism and erosion.

Diastrophic features unmodified by erosion are rare. The effects of erosion on diastrophic features very often result in topographic forms which will give the engineer clues to structure; therefore this subject will be treated in the section on "Relation of Land Forms to Structure".

TOPOGRAPHY RESULTING FROM GROUND WATER

The work of ground water is a vital phrase of geology. It plays a very subordinate part in the development of land forms; however, it does play one important part--the development of sink holes.

CHAPTER III

RELATION OF LAND FORMS TO STRUCTURE

There is a distinct relation between land forms and the geologic structure of an area. Likewise, the structure of an area often plays an important part in the relation between rainfall and run-off. For this reason an understanding of the relation between land forms and structure is a valuable aid to the engineer.

The causes for the development of "dendritic" and "trellised" drainage patterns ha~~s~~ve already been discussed. From this discussion, it follows that one can tell something of the structure of a region through an examination of its drainage pattern, even in the absence of both geologic or contour maps. Referring again to Fig. 1-~~A~~B, typical dendritic pattern suggests either horizontal sedimentary rocks, massive igneous rocks, or a region of crystalline metamorphics. The engineer is cautioned furthermore not to conclude definitely without field examination that the region is underlaid by horizontal formations.

Figure 1-~~B~~A might rather safely be interpreted as having been formed on a tilted or folded group of alternating hard and soft strata.

Several minor features of drainage patterns are also in some instances related to structure. A stream, for instance, which is antecedent to a dome, which in turn is uplifted so slowly that a valley is cut with the uplift, will do one of two things:

1. If the uplifted strata are alternating series of hard and soft beds the stream may cut through the soft layer on to the inclined surface of a hard layer, where it will naturally cut laterally more easily than downward, thus developing a meander around the structure.

2. If the beds are of nearly equal resistance, the stream will merely cut through the structure without producing a curve.

From this it is readily seen that all bends or meanders in a stream do not suggest such a structural condition. If several minor streams show parallel curves the assumption of such a structure becomes almost a certainty. Any pronounced bend in a stream that does not appear to be meandering, or any bend that is obviously not a meander, should be investigaged. An old granite knob, or a fault block consisting of material more resistant to erosion than the surrounding formations, can also produce bends.

Another minor drainage feature of structural significance is the number and length of tributaries flowing into opposite sides of a longitudinal or strike river. The beds on one side of such a stream dip toward the stream valley and on the other away from it. If the beds are of alternating hard and soft strata such a stream will tend to shift down the dip, making the valley asymmetrical. One side of the valley will be an escarpment resulting from the sapping of soft beds under hard ones, and the other a dip slope on the surface of a harder layer from which the soft bed has been stripped. On the escarpment side of the valley the tributaries will be few, short and steep, while on the dip slope side they will be longer, more numerous and of a gentler gradient. This relation can often be relied upon to indicate the direction of dip. For instance assume a stream flowing in a south easterly direction. If the tributaries on the north east side of the valley are more numerous, longer, and perfected than those on the southwest side, then a southwest dip is indicated.

The Kaiparowits region in Utah and Arizona offers many examples which will illustrate the relation of streams to structure.* This region lies mostly in Garfield and Kane Counties, southern Utah, but it also includes a small part of Coconino County, Arizona. Its south and southeast boundary is formed by Glen Canyon, Canyon of the Colorado River; its west and north boundary follows the valley of the Paria River, the edge of the Paunsaugunt Plateau, the west base of the Table Cliff Plateau, and the rim of the Aquarius Plateau to its junction with the Waterpocket Fold. Its northeast boundary is Halls Creek.

Many of the small streams and some larger ones are obviously related to structure. Halls, Pine and Cottonwood Creeks occupy valleys that have been developed in weak strata on monoclinal folds. In the Circle Cliffs dome area, the streams flow radially outward down dip slopes, and from the crest of the Waterpocket Fold streams follow tilted strata to Halls Creek. The east fork of the Sevier River flows northward down the slope of the beds that comprise the Paunsaugunt Plateau. Three other small streams, although they flow in a direction opposite to the dip of the beds, occupy shallow synclines.

* Gregory, H. E. and Moore, R. C., The Kaiparowits Region: Professional Paper No. 164, U. S. Geo. Survey, p. 131, 1931.

Although much of the minor drainage is well adjusted to structure, some of the larger streams are independent of such control. They flow in and out of cliffs, cut through mesas, transect monoclines, cross faults from the down thrown to the upthrown sides, and make their way through tilted strata regardless of the direction of dip.

CHAPTER IV

GEOLOGIC INVESTIGATION OF DRAINAGE AREAS

It is impossible to determine the exact results which the geology of a drainage area will have on the relation between rainfall and run-off. The effects of geological conditions are important and sometimes furnish explanations of quantitative differences in flow not otherwise explainable. In view however of the importance of geology, the engineer should carefully investigate geological conditions and evaluate as nearly as is possible their effect on run-off. This is especially true when comparing a drainage area of measured discharge to one of unknown discharge for estimating purposes. In studying the geology of a drainage area the following subjects should be investigated:

A. Topography

The important features are the degree of inclination and the character of the area, whether smooth or rugged.

B. Geology

Surface soils and rocks.

Impervious rocks, such as shales and granites, are conducive to high run-off. Pervious materials, such as sands, sandstones, gravels, and cracked or fissured rocks, conduce seepage and retard run-off. The difference in unit run-off of the Wisconsin River above Merrill and Necedah, Wisconsin, as shown by the hydrographs on Figure 2 is probably due to the effects of granite rocks above Merrill which produce a maximum run-off, while the pervious Pottsdam deposits over the lower part of the drainage area and under the bed of the lower stream probably conduce a considerable seepage loss into the stratum and away from the channel.*

In comparing geological formations the engineer must keep in mind that a high degree of porosity does not always mean a high degree of permeability. Many formations have a high porosity, but a low permeability on account of the porous spaces not being connected.

2. Relation of topography to geology.

3. Structural geology of area.

This is especially true when the surface soils and rocks are pervious in their nature. If such deposits are underlaid by an impervious formation they

* Mead, Daniel W., Hydrology: McGraw-Hill Book Co., figure No. 266, p. 449, 1919.

Hydrographs of the Wisconsin River at Various Stations

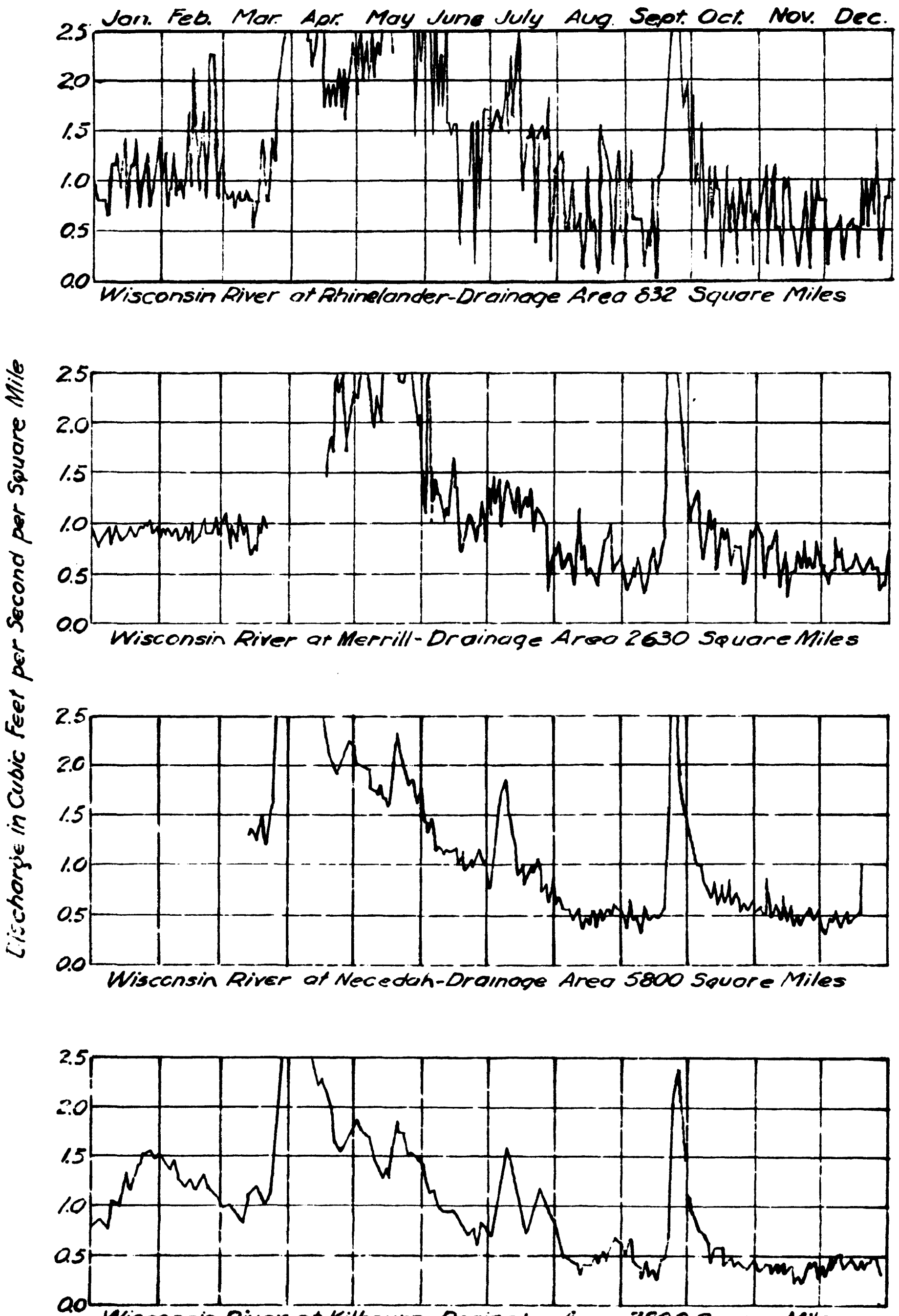


Fig. 2.

will usually provide underground storage, which impounds water away from the conditions which permit evaporation. Ground water discharge is an important feature in run-off studies, and a general knowledge of the structural conditions is essential.

The effect of structure is well illustrated in parts of the Toyah Basin in western Texas. In general, the Toyah Basin is the broad valley surface that overlies the broad synclinal structure known as the Deleware Basin. The Toyah Basin comprises the watershed of the Pecos River from approximately the Texas-New Mexico boundary, southeastward to Crane county, Texas.

In the central part of Toyah Basin lies the watershed of Toyah Creek. This stream originates in the Davis mountains, in Jeff Davis county, and flows in a northeasterly direction through Reeves county, where it joins the Pecos River at a point which is about 10 miles east of Pecos, Texas. Investigation by the writer has determined that very little surface run-off from the rugged Davis mountains ever reaches the Pecos River by way of Toyah Creek.

To a great extent this condition is the result of the structural conditions prevailing over the watershed. In the upper reaches of the watershed, the Davis mountains, ranging from 4000 to 6000 feet above sea level in elevation, are capped by Tertiary lavas. These rocks are very porous because of their fractured and jointed condition, and therefore they absorb much of the rainfall. The volcanic rocks usually rest on impermeable Upper Cretaceous clays. Where this contact is above the gradient of main drainage channels most of the water absorbed by the volcanics is fed into the surface drainage or gravels within the mountain area. Underlying the impermeable Upper Cretaceous clays are the relatively permeable limestones of Lower Cretaceous age. In some localities the water stored in the volcanics reaches the limestone by moving downstream to structurally high areas in which the gravels lie directly on the limestone. Paralleling the base of the Davis mountains in a belt from two to five miles in width, and extending in a northwest-southeast direction for about 15 miles, the Lower Cretaceous limestone is either at the surface or immediately under the gravels.

This area of outcrop of the Lower Cretaceous limestone is essentially a faulted anticline. This structure has been carved by erosion into a broad valley which is adjacent to the front of the mountains and lies athwart the courses of a number of streams which originate in the mountains. The anticline plunges to the southeast and the limestones finally disappear beneath the stream deposits that underlie the surface in many parts of the valley area.

Actual stream measurements have shown that the streams lose water heavily when crossing this anticline.

Practically all of the water that enters this limestone reservoir is discharged through large springs located several miles on downstream. Downfaulting of the impermeable Upper Cretaceous clays against the cavernous Lower Cretaceous limestone has created a barrier against the horizontal movement of the water, thereby causing it to rise to the surface. These large springs are the source of much water used for irrigation purposes in the vicinity of Balmorhea, Texas.

Farther downstream along Toyah Creek, the watershed becomes a part of a large general area along the Pecos River over which there are deposits of sand and gravel, ranging from 200 to over 1000 feet in thickness. The writer has examined a large number of oil well logs throughout and adjoining the general area and has found that there is a large fault which apparently outlines the area of deep gravel deposits. The faulting was probably caused by the dropping of overlying formations due to the solution of vast salt deposits in the underlying Permian formations. The resulting sands and gravels, which were later deposited in the structural depression are very porous in character, are not conducive to surface run-off, and are excellent water bearing formations.

4. Stratigraphy.

This subject, as well as historical geology in many cases, is quite complex, and for the engineer who has not had geological training, is difficult to solve. Where possible to obtain this information, he should do so, as it is often of much assistance in determining the possibility of ground water discharge into streams. This will be further explained below.

5. Ground Water.

All ground waters are derived directly or indirectly from the rainfall. The low water flow of streams is due entirely to ground water. Conditions favorable to the storage of ground water and to its delivery to the stream are essential to the maintenance of dry weather flow. This part of the combined run-off of a stream is entirely dependent upon the geology of the drainage area. On drainage areas where a pervious deposit is extensively developed much rainfall is absorbed and becomes a part of the ground water. This pervious deposit might be the surface deposit, laying horizontal, or nearly so, over the area, or it might be the outcrop of a similiar deposit which is tilted. Where the latter is the case, and the engineer finds that the deposit is very pervious and suitable for sub surface storage, he should attempt to determine the extent of the deposit and its relation to the overlying formations down stream. Ground water usually has outlets in the lower portion of the drainage area appearing as springs along the banks and in the stream channel itself. In the above mentioned case the ground water may become deep seated, and may follow the pervious deposit to distant outlets, even on other drainage areas.

Extensive pervious deposits on a drainage area generally produce a high degree of regularity in the flow of a stream, provided of course there is an outlet into the channel. Over such areas the rainfall is rapidly absorbed and becomes a part of the ground water. It flows slowly toward and, dependent upon the character of the deposit, reaches the stream only after a period of days or months.

Heavy rains on a pervious watershed increase the velocity of flow and thereby augment the flow both during and after the period of rainfall. Following the period of rainfall the gradient slowly decreases as the water drains from the pervious deposit into the stream. The velocity and quantity of flow becomes less, thereby causing a decrease in stream flow. This decrease is very gradual, and usually sufficient water is in storage to continue the flow until augmented by the next rainfall. Under favorable conditions the ground water flow will continue for several months, and the flow is commonly regulated to a greater degree by this mean than by any other natural condition on the watershed.

CHAPTER V

WEST QUARTERMASTER CREEK
NINE MILE CREEK
ROGER MILLS COUNTY, OKLAHOMA

This is a preliminary report regarding the water supply for two proposed dams located respectively on West Quartermaster, and Nine Mile Creeks, in Roger Mills County, Oklahoma. Roger Mills county is located in the central part of the extreme western portion of Oklahoma and adjoins the eastern border of the Texas Panhandle. The proposed dams in Roger Mills county are specifically located as follows:

West Quartermaster: E½ Sec. 12, Range 21, Township 14.

Nine Mile: SE¼ Sec. 31, Range 21, Township 14.

In view of the close proximity of the drainage areas and similarity of physical conditions governing the relation between rainfall and run-off, the two drainage areas treated, will be combined in one report.

GENERAL

West Quartermaster Creek originates in the northeastern part of Roger Mills County and flows in a southeasterly direction into Custer County, where it joins the Washita River at a point about three and one-half miles below the proposed dam site. The principal tributaries are Hay Creek, Dry Branch, and several unnamed streams.

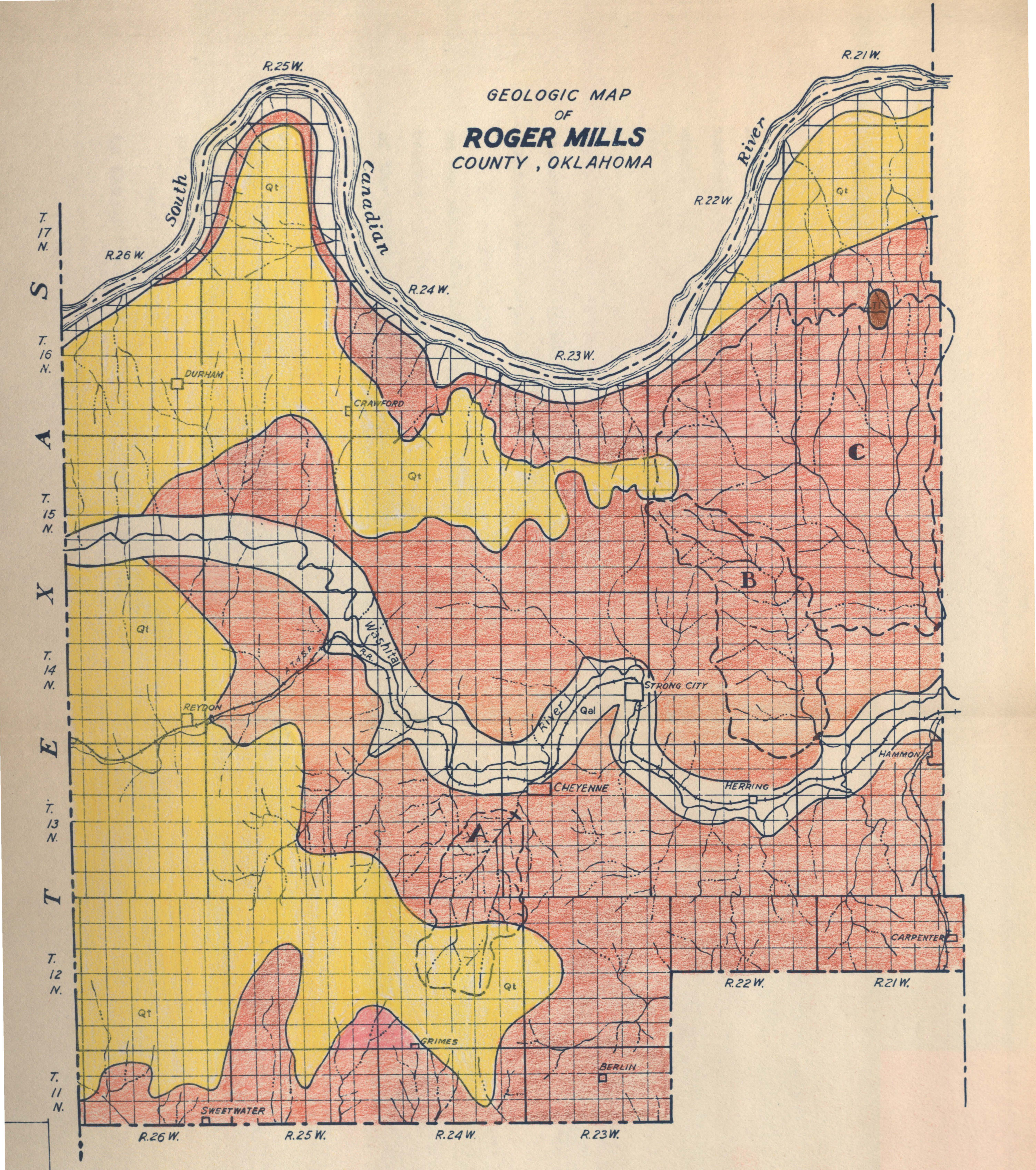
Nine Mile Creek originates approximately five miles south of the south bend of the Canadian River, and just west of the West Quartermaster drainage area, and flows in a southeasterly direction. It joins the Washita River at a point approximately one and one-half miles below the proposed dam site.

DRAINAGE AREAS

As shown on Figure 3, the drainage area of each stream is as follows:

Stream	Drainage Area	
	Sq. Miles	Acres
West Quartermaster	102	65,300
Nine Mile	36	23,000

These drainage areas were established through actual field survey by personnel of the Water Resources Division of the Oklahoma State Planning Commission. They in turn have been substantiated by field reconnaissance. All of each area is contributing to run-off.



LEGEND

QUATERNARY
- Qal — Alluvium
- Qt — Terrace deposits

TERTIARY
- Tl — Late Tertiary

Permian
- Red Beds

A SERGEANT MAJOR CREEK

B NINE MILE CREEK

C WEST QUARTERMASTER CREEK

TOPOGRAPHY

Topographical features of Roger Mills County are the result of erosion and grading. Within the county are two general types of topography: a relatively smooth plain or upland, remnants of an ancient plain which at one time covered the entire county, and two areas of lowland along the Canadian and Washita River basins. The topography of the upland may be described as being undulating to gently rolling. In places the valleys are of sufficient depth to render the surface moderately rolling, and in many places they are quite hilly.

The escarpment which borders the Washita basin on the north extends from a point on the eastern boundary of the county approximately 15 miles north of the Washita, west about seven miles, and it consists of a belt of broken, rough country about two miles wide. It then continues in a southeasterly direction to the valley of the Dead Indian Creek, and it is in this section of the escarpment that Quartermaster, Nine Mile and Wild Horse Creeks originate.

Dead Indian Creek originates on the high plain to the northwest, however, like Quartermaster, Nine Mile and Wild Horse, most of its drainage area is southeast of the escarpment.

From Dead Indian Creek the escarpment extends southward to a point one mile north of the Washita where it then turns and follows the river channel in a northwesterly direction.

A large part of the lowland is a relatively smooth area, but the border belt between it and the high plain or upland is very rough, broken and hilly.

GEOLOGY

The surface geology of both drainage areas is very much the same, and it warrants close attention because of its influence on the probable annual yield and maximum flood.

Tertiary sands and gravels, which practically cover the Texas Panhandle to the west, are almost wholly absent over the entire area. Information secured from a geologic map of Roger Mills County compiled by the Oklahoma Geological Survey, substantiated by field reconnaissance, indicates one small area of late Tertiary gravels, comprising less than one section.* This occurs as the surface

* Six, Ray L., Oil and Gas in Oklahoma: Oklahoma Geological Survey, Bulletin No. 40, Vol. 2, p. 385.

formation in the extreme north central portion of the Quartermaster drainage area. In the extreme northwestern part of the Dead Indian drainage area, terrace deposits of Quaternary age cover approximately nine sections. With these two exceptions the surface of the combined areas under discussion is covered with rocks of Permian age, commonly referred to as the "Red Beds".

The Quartermaster formation, consisting of dolomites, massive lenticular sandstones, highly cross-bedded sandstones and sandy and calcareous shales, is the predominating surface formation. In places the main streams and tributaries have eroded through the Quartermaster and exposed the Cloud Chief Gypsum which is also of Permian age. This is especially true of the West Quartermaster and its main tributary, as well as the extreme lower reaches of the Nine Mile and the Dead Indian.

Due to the physical character of the Quartermaster formation, and the climatic environment, erosion has produced a characteristic topography over the area consisting of red sandstone "hillocks", ranging from 20 to 50 feet in height and in most instances are void of vegetation.

CLIMATOLOGICAL

Precipitation

The following tabulation of data recorded by several stations of the U. S. Weather Bureau located within close proximity to the general area under discussion should be of value in estimating an average annual rain-fall.

Station	No. Years Record	Average Ann. Rainfall
Arapaho	37	28.52 inches
Arnett	19	25.84 inches
Cheyenne	8	27.15 inches
Hammon	18	26.99 inches
Rankin	17	25.07 inches
Average annual rainfall for all stations		26.17 inches

On the basis of this information it is reasonable to estimate the average annual rainfall over the entire area to be 26 inches.

Approximately 81 percent of the average annual rainfall falls during the period from April first to November first. This amounts to 21.12 inches. The months of April, May and June contribute a combined average of 37 percent, amounting to 9.64 inches. The period from July first through October contributes 44 percent or 11.48 inches.

Evaporation

There are no known records of evaporation covering the general area under discussion. The United States Weather Bureau station at Dalhart, Texas, has maintained records for the six summer months for a period of twelve years, and the average for this period has been 52 inches. The average annual evaporation at Amarillo, Texas, is estimated as about 65 inches, and it is reasonable to estimate about 60 inches evaporation for the drainage areas of West Quartermaster and Nine Mile Creeks.

YIELD

There are no stream discharge records available of West Quartermaster and Nine Mile Creeks. In order to arrive at some conclusion regarding the relations between rainfall and run-off over their entire drainage areas it will be necessary to make comparisons with another stream of known discharge, and whose drainage area is similar in physical characteristics. For this purpose the Washita River has been selected.

The Washita River originates in the western part of Hemphill County, Texas, and flows in an easterly and southeasterly direction through southwestern Oklahoma. On its upper reaches, in Texas, the Washita is only a small creek, and its drainage area is covered with sands and gravels of Tertiary and Quaternary age. In this portion of the drainage area the run-off in acre feet per square mile is rather small, due to the absence of steep slopes and especially due to the presense of a porous soil covering. Here the run-off is about two percent of the average annual precipitation.

Approximately 5 miles east of the Oklahoma-Texas line there is a change in physical conditions, and from this point on, the Washita and its drainage area lies almost entirely in the Permian Red Beds. It has been pointed out in the discussion of the geology of the area that these formations are much less permeable than the sands and gravels to the west, and they will allow a greater run-off in acre feet per square mile. In addition, the Permian formations which are at the surface have developed the usual "red bed" topography with gypsum hills predominating.

For the years of 1936 and 1937, that being the only record, the average annual discharge of the Washita River at Clinton, Oklahoma, amounted to 125,000 acre feet. The precipitation over the watershed during these years was practically normal. The drainage area of the watershed down to the Clinton gauging station is 2100 square miles, therefore the average annual yield over the entire watershed amounted to 59.5 acre feet per square mile of drainage area.

To assume, however, that this degree of run-off was constant over the entire watershed would be incorrect, because of the differences in physical characteristics of different parts of the drainage area.

The upper reaches of the drainage area lies in that physiographical province known as the "High Plains." The eastern boundary of this province crosses the watershed in a north and south direction, near the Texas-Oklahoma boundary. At approximately this location the Washita leaves the "High Plains" and flows over the "Osage Plains" province, which is quite different in geology and other physical characteristics from the "High Plains" to the west. It therefore seems reasonable that the gauging records should be properly distributed over the entire watershed to arrive at a reasonable estimate for the watershed of the Quartermaster, and Nine Mile Creeks, which lie in the Osage Plains portion of the Washita drainage area.

Of the total drainage area down to the Clinton, Oklahoma, gauging station, 445 square miles lies in Texas and in the High Plains. Run-off on the southern portion of the High Plains has been rather carefully estimated to be approximately two percent of the average annual precipitation. (Refer to chapter No. 6 - Running Water Draw, Curry County, New Mexico) and the same approximate percentage should exist for this upper portion of the Washita watershed. The mean annual precipitation has been record by the United States Weather Bureau at the following stations located on or near this portion of the watershed.

Station	Portion of Watershed Represented	Length of Record	Average Annual Precipitation
Miami, Texas	37.0%	29 yrs.	23.30 inches
Canadian, Texas	52.9%	25 yrs.	22.97 inches
Cheyenne, Oklahoma	10.1%	8 yrs.	27.15 inches
	Weighted Average - 23.51		

Refer to fig. 3-A.

A two percent run-off over this 445 square mile portion of the watershed, having the above weighted precipitation, will produce 25 acre feet per square mile, or 11,125 acre feet for the entire portion. Subtracted from the average discharge of 125,000 acre feet, as recorded at Clinton, this leaves 113,875 acre feet distributed run-off from the remaining 1,655 square miles of drainage area which amounts to an average annual yield of 68.8 acre feet per square mile.

For this portion of the watershed the weighted average precipitation has been calculated from data recorded by the United States Weather Bureau:

Station	Portion of Watershed Represented	Length of Record	Average Annual Precipitation
Cheyenne, Oklahoma	34.80%	8 yrs.	27.15 inches
Camargo, Oklahoma	5.10%	17 yrs.	24.81 inches
Hammon, Oklahoma	25.80%	18 yrs.	26.99 inches
Elk City, Oklahoma	8.30%	9 yrs.	26.07 inches
Oakwood, Oklahoma	.80%	22 yrs.	26.73 inches
Clinton, Oklahoma	25.40%		27.99 inches*

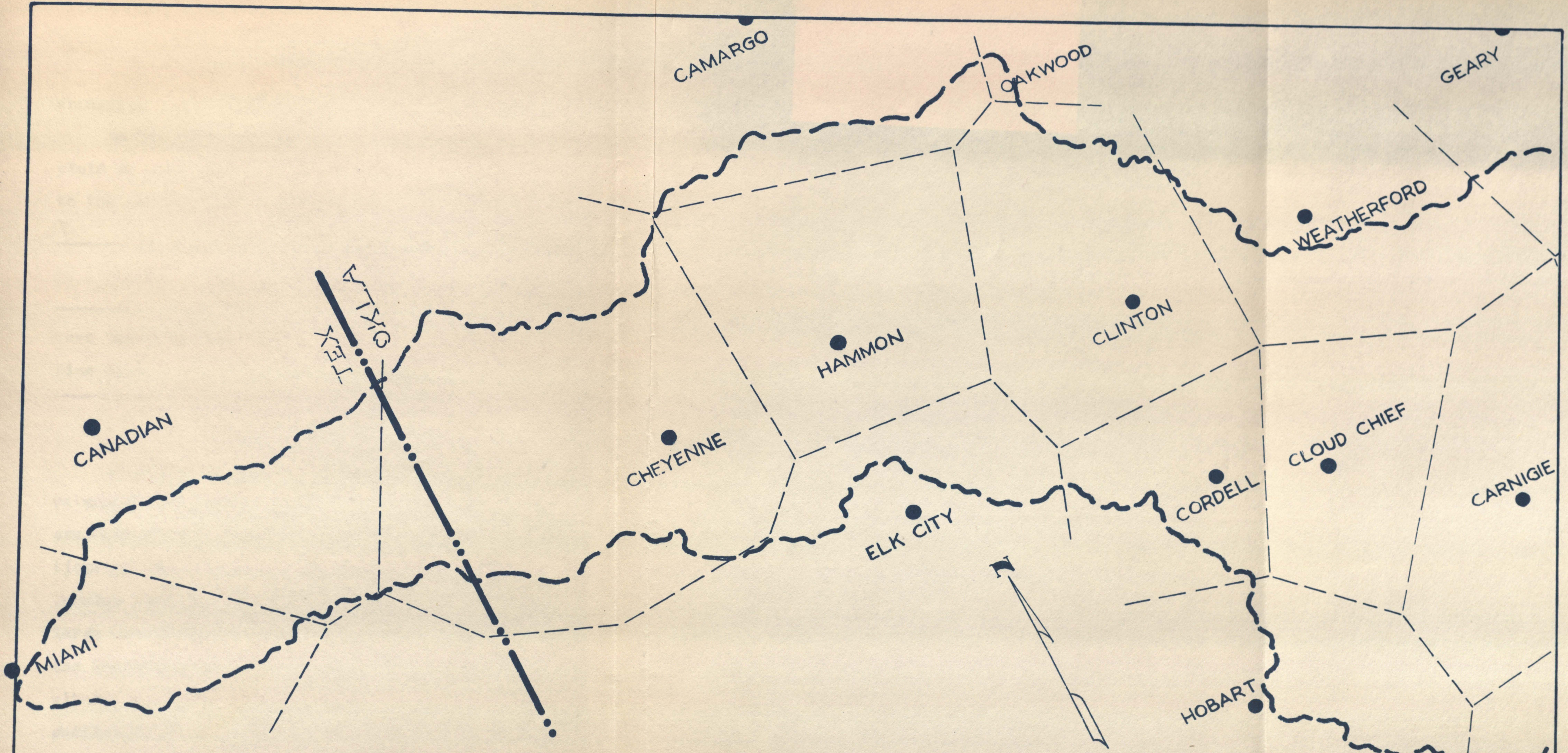
Weighted Average - 26.96

Refer to fig. 3-A.

*Computed by averaging records of Hammon and Weatherford stations.

With the above stated average annual yield of 68.8 acre feet per square mile of drainage area, over this portion of the watershed having a weighted average precipitation of 26.91 inches, the resulting run-off will therefore amount to 4.75 per cent of the pricipitation.

It is therefore believed that this relation between rainfall and run-off will exist over that area of the upper Washita watershed covered with Permian "Red Bed" deposits. The watersheds of the Nine Mile and West Quartermaster Creeks are all located in this portion of the Washita drainage area, and the run-off over these watersheds is therefore estimated to be 4.75 percent of the precipitation, which has been found to be 26 inches



MIAMI	165 SQ. MI.	CAMARGO	88 SQ. MI.
CANADIAN	235 " "	CLINTON	441 " "
CHEYENNE	642 " "	CORDELL	185 " "
HAMMON	448 " "	OAKWOOD	13 " "
ELK CITY	144 " "		
HOBART	173 " "		
CLOUD CHIEF	281 " "		
WEATHERFORD	216 " "		
GEARY	80 " "		
CARNIGIE	464 " "		

UPPER REACHES OF
WASHITA RIVER DRAINAGE BASIN
SHOWING
PRECIPITATION STATION AREAS

Fig. 3-A.

annually.

On the basis of this data, the average annual yield of surface run-off for these watersheds down to the proposed dam sites will be as follows:

Stream	Drainage Area Square Miles	Annual Yield Per Square Mile Acre Feet	Total Average Annual Yield Acre Feet
West Quartermaster	102	65.6	6,691
Nine Mile	36	65.6	2,362

GROUND WATER

As stated in the discussion of the geology of the watersheds in question, the surface formations are composed of the Quartermaster and Cloud Chief formations of Permian age. Generally speaking, the Permian "red bed" formations do not yield water in large quantities. Both streams have eroded through the Quartermaster and exposed the Cloud Chief gypsum without encountering ground water in quantities sufficient to produce a continual flow. Some seepage water finds its way into the stream channels from time to time, however, this ground water increment is not of sufficient magnitude to be considered in the annual yield.

CHAPTER VI

SARGENT MAJOR DRAINAGE BASIN
Roger Mills County, Oklahoma

While engaged in making studies of the three drainage basins described in Chapter five the writer also had occasion to investigate the Sargent Major drainage basin. Sargent Major Creek originates in the south central part of Roger Mills County and flows in a northerly direction where it joins the Washita River about one and one-half miles north of the town of Cheyenne.

This basin, although it is small in size, demonstrates very clearly the importance of geology in the relationship between rainfall and run-off. As shown by Figure 3, the drainage area down to the dam site consists of 18.25 square miles. This drainage area was compiled from aerial photographs and later substantiated by field reconnaissance. The entire area is contributing to run-off. In general, the topographical features are the same as described in the previous chapter concerning West Quartermaster and Nine Mile Creeks. Precipitation is likewise the same.

GEOLOGY AND RUN-OFF

The same regional geology of the above mentioned basins applies to the Sargent Major, however, there are local conditions which prevent this basin from yielding the same percentage of run-off. The upper 6.8 square miles of its drainage area are covered at the surface by Quaternary terrace deposits of sand and gravel which in this part of Roger Mills County are of sufficient thickness to produce domestic water supplies. This surface formation, however, is not conducive to a high run-off, and for that portion of the basin covered by this formation, the percentage of run-off is estimated to be two percent. After leaving these upper reaches the stream has eroded through the Quaternary deposits, leaving the remainder of the drainage basin lying on the Permian "red beds". This part of the basin, constituting 11.45 square miles, is assigned a run-off factor of 4.75 percent of the precipitation. This is the same factor as applies to the West Quartermaster and Nine Mile Basins.

In the upper reaches of the basin the stream in cutting through the Quarternary deposits has encountered the water table, causing it to flow continuously. This flow has been found to be approximately one quarter of a second foot which when stored at the dam site would be approximately 180 acre feet annually.

On the basis of the foregoing findings the average annual yield would be summarized as follows:

	Drainage Area Sq. Miles	Run-off Factor	Yield per Square Mile AF	Total Average Annual Yield AF
Upper	6.80	2.0%	27.7	188
Lower	11.45	4.75%	65.6	751

Annual Yield - Surface run-off	939
Annual Yield - Ground water	180
Total average annual yield	1,119

CHAPTER VII

RUNNING WATER DRAW
New Mexico

The drainage basin of Running Water Draw in Curry County, New Mexico, is characteristic of many basins located within the High Plains. While engaged in making a study of this basin with relation to the possible construction of a dam across the Draw the writer recognized the effects which geology as well as physiography has upon the relation between rainfall and run-off.

Running Water Draw is an intermittent stream which makes up the Brazos River in Texas. It originates near the town of Field, New Mexico, which is specifically located in the west central portion of Curry County. Curry County is located in the east central part of the state. The stream flows slightly south and east through Curry County and crosses the Texas-New Mexico line at a point about eight miles north of the town of Texico. The proposed dam site was located approximately twenty three miles down stream from Field.

TOPOGRAPHY

Drainage Basin

The consequent character of the stream is evident. It flows in a long, parallel, nearly straight course down the original slope with a noteworthy absence of dendritic tributaries.

The entire drainage basin above the dam site is located on the Llano Estacado, a remnantal plateau of the High Plains province. Similar to numerous other streams on the High Plains the watershed of this stream is limited laterally not only by watersheds of adjacent streams but also by numerous natural sinks. Figure 4 is a map of the watershed which has been compiled by the writer from aerial photography and later substantiated by field reconnaissance. It will be noted that the watershed consists of two distinctly different types of drainage, hereafter known as "A" drainage and "B" drainage. "A" drainage is that drainage which is directly contributing to the stream bed of Running Water Draw. The total amount of this type of drainage area has been planimetered and found to be 96 square miles.

"B" drainage, is that drainage within the watershed which is non-contributing to the stream bed. There are three square miles of this type of drainage in the watershed.

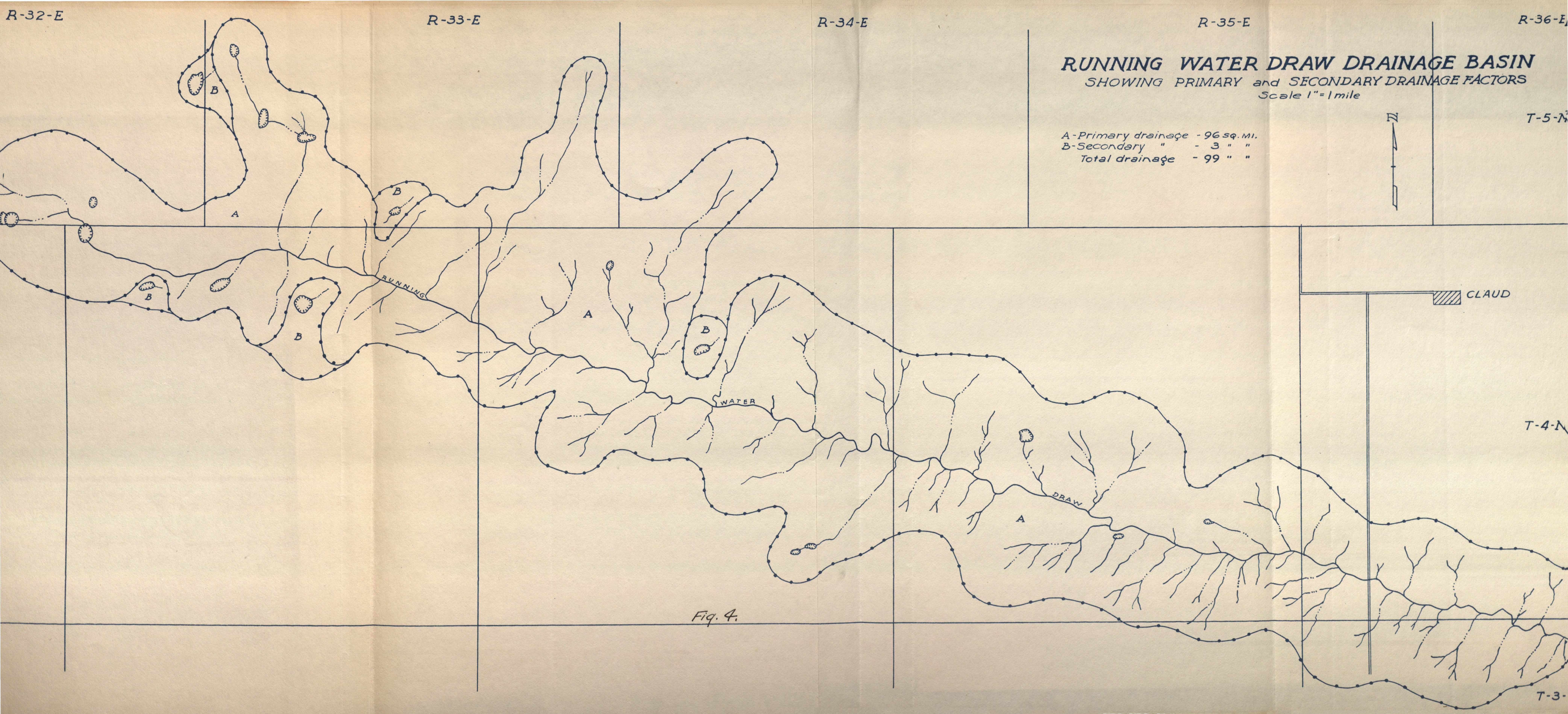

R-32-E
R-33-E
R-34-E
R-35-E
R-36-E
RUNNING WATER DRAW DRAINAGE BASIN
SHOWING PRIMARY and SECONDARY DRAINAGE FACTORS
Scale 1" = 1 mile
A-Primary drainage - 96 sq. mi.
B-Secondary " - 3 " "
Total drainage - 99 " "
N
T-5-N
T-4-N
T-3-
CLAUD
RUNNING
WATER
DRAW
A
B

Fig. 4.

TOPOGRAPHY

The Llano Estacado is a nearly flat and level table land or mesa surrounded on all sides by more rolling eroded plains of lower elevation. It is dissected very little by stream erosion.

GEOLOGY

As previously stated the entire watershed lies within the High Plains section of the Great Plains Province. The general geology of the area is not complex. The entire surface of the watershed is covered with the Ogalalla formation which is composed of alternating sands, gravels, clays and calcareous sands and gravels.* In places the Ogalalla rests upon thin beds of Comanche (Lower Cretaceous) rocks, but in general, the Ogalalla rests directly upon the Santa Rosa sandstone, a member of the Dockum Series (Lower Triassic). The regional dip of the strata is to the southeast.

From the standpoint of the hydrology of the area the Ogalalla formation is of importance. This formation (Tertiary Age) consists chiefly of alternating layers of clay, sand and gravel. It is

* Winchester, Dean E., Oil and Gas Resources of New Mexico: New Mexico School of Mines, State Bureau of Mines and Mineral Resources, Bulletin No. 9. p. 116, 139.

generally believed that the material which comprises these rocks was derived largely from the Rocky Mountains, and that it was spread out in the beds of streams which in times past flowed from the mountains and were lost on the plains. These streams left deposits of sand, clay and gravel, which in time were covered by other deposits, sometimes of the same, but more often of other material. From this it will be understood that the greater part of the beds must necessarily be irregularly lens-shaped in cross-section, and in most cases will not be found continuous over large areas.* In general, it seems that the deposits near the base of the Tertiary have a greater proportion of coarser material consisting of sand and gravel beds, and at higher levels they have clays and silts in greater abundance. These deposits at one time covered the entire Llano Estacado as well as other sections of the High Plains, and they are today, the chief sources of ground water. While the Ogalalla is locally cemented with lime and silica it is in general a very porous formation and not conducive to high surface run-off.

* Fenneman, Nevin M., Physiography of Western United States: McGraw Hill Book Co., first edition, p. 13, 1931.

SINKS

Included in the total drainage area of 99 square miles are three square miles of drainage area which are non-contributing to the main channel and which are referred to as "B" drainage. These physiographic features known locally as "Sinks", "Buffalo wallows", "dry lakes" and "depressions" are not only characteristic of the Llano Estacado but of the Plains in general. These saucer-like depressions are scattered at irregular intervals over the relatively flat surface of the Plains. In size, they vary from very small "depressions" to large lake basins often draining several miles. These depressions are in general thought to be the result of ground settlement.* Beds of salt and gypsum in the underlying Permian and Triassic sediments have been removed in solution by ground waters and caverns thus formed, and the later caving of the roofs has caused the depressions. In making hydrological studies with reference to estimating water supplies for proposed reservoirs on the High Plains, it is of utmost importance that the extent and amount of these

* Johnson, W. D., The High Plains and Their Utilization: U. S. Geol. Survey, 21st. Ann. Rept., pt. 4, p. 704 and 710.

sinks, or the total non-contributing drainage area which they comprise in a given watershed be measured or closely estimated. While the percentage of this type of drainage area is small in the Running Water Draw basin, there are numerous watersheds on the Plains of which ten to fifty percent of the total drainage area is non-contributing to the main channel.

CLIMATOLOGICAL DATA

The United States Weather Bureau has recorded precipitation data at several stations on or near the watershed.

Station	Portion of Watershed Represented	Length of Record	Average Annual Precipitation
Clovis, N. M.	18%	20 yrs.	17.97 inches
Pleasant Hill, N. M.	20%	11 yrs.	18.59 inches
Field, N. M.	52%	11 yrs.	17.59 inches
St. Vrain, N. M.	10%	19 yrs.	17.17 inches
Entire Basin - Weighted average 17.8 inches			

The gross annual evaporation for this general area is about 78 inches. When one takes into consideration the mean annual precipitation of 17.8 inches, the net average annual evaporation may be expected to be approximately 60 inches.

RUN-OFF

There are no known discharge records available of Running Water Draw. In order to make any estimate regarding the average annual yield it will be necessary to compare this watershed with basins of similar physical characteristics and with measured discharges.

For the purpose of comparison the following streams of known discharge have been selected:

Stream	Gage location	Length of record	Average annual rainfall	Drainage area square miles	Average annual run-off in acre feet	Yield acre feet per square mile	Run-off coefficient
North Fork of Republican River	Haigler Nebr.	7	19"	2,042	37,830	18.5	1.8%
South Fork of Republican River	Benkleman Nebr.	12	17"	2,786	38,500	14.0	1.6%
Cimarron River	Garrett Okla.	3	19"	2,100	44,000	21.0	2.00%
Sappa Cr.	Oberlin Kan.	2	18"	1,050	8,520	8.0	0.8%
Smoky Hill River	Ellsworth Kan.	20	20"	7,777	138,000	17.8	1.8%

All of the above basins are located within the Great Plains province, and with some exceptions, which will be discussed, are comparable in physical characteristics to the basin of Running Water Draw.

The Cimarron River originates in the north eastern part of New Mexico and south eastern part of Colorado, and practically all of its drainage area down to the gauging station lies within the Raton Section of the Great Plains province.* This section of the Great Plains differs from the High Plains in that it is a trenched peneplain surmounted by dissected, lava-capped plateaus and buttes. Lava flows, which have been dissected, have given rise to very conspicuous topography buttes, giving the section a rough and broken topography. It is therefore evident that the two percent run-off of the Cimarron River should be considered somewhat high for comparison with Running Water Draw.

The North and South Forks of the Republican River originates on the High Plains section in eastern Colorado, and all of their drainage basins down to the listed gauging stations lie totally within the High Plains section. Sappa Creek likewise originates on the High Plains in northwestern Kansas, and

* Fenneman, Nevin M., Physiography of Western United States; McGraw-Hill Book Co., First Edition, p. 38, 1931.

all of its watershed down to the listed gauging station is within the High Plains. It is therefore logical to compare these streams with Running Water Draw, taking into consideration that allowances should be made, however, for any physical differences noted in the comparisons.

Physiographically, the watersheds of the above streams are very similar to the watershed of Running Water Draw. There are however some minor differences in surface geology which are very likely to cause differences in run-off.

The North and South Forks of the Republican River originates on the High Plains, in Colorado, and for the greater part, the Ogalalla and other porous Tertiary formations constitute the surface geology of their watersheds. Upon approaching the listed gauging stations the streams have eroded through the Tertiary mantel, and exposed over considerable areas, the relatively impervious Pierre shale of Cretaceous age. This formation is relatively impervious as compared with the highly porous Ogalalla, and therefore more conducive to a higher surface run-off. This is an important factor which cannot be overlooked when comparing these watersheds with that of Running Water Draw, as the latter watershed is completely covered at the surface by the Ogalalla.

Sappa Creek is very similar to Running Water Draw with some exceptions worthy of comment. Practically all of its watershed is covered with Quaternary alluvium which is extremely porous, and which probably accounts for a low percentage of run-off.

Another factor to consider when making comparison with these streams is the increment of ground water run-off. Running Water Draw is a young stream and does not intersect the water table at any point above the proposed dam site. All run-off into this channel must therefore be limited to surface run-off. Both Forks of the Republican River have succeeded into cutting through the Tertiary mantel and exposing the Pierre Shale. As the Tertiary is relatively porous, and the Pierre shale relatively impervious, springs are quite common along the line of contact. For this reason both forks of the Republican River have become perennial streams, and part of their measured flow is due to the increment of ground water run-off. Sappa Creek, while not having cut entirely through the Tertiary mantel, has cut sufficiently into the Tertiary to encounter some ground water which finds its way into the channel. The amount of this increment is not known, although it is possibly not as large as that of the Republican.

The Smoky Hill River originates on the High Plains in eastern Colorado. A large part of its drainage area down to the Ellsworth, Kansas, gauging station, lies within the Plains Border Section of the Great Plains province. This section of the Plains province is a submaturely to maturely dissected plateau. In addition, over a large part of the watershed the stream and its tributaries have stripped the surface of its Tertiary mantel and exposed large areas of relatively impervious Cretaceous rocks. Likewise, the stream in cutting through the Tertiary has intercepted the water table and therefore has a perennial flow of ground water.

In view of the similar physical characteristics existing between these watersheds and that of Running Water Draw, it is logical to assume that their rainfall-run-Off relationships will apply very closely to that of the stream in question. Certain allowances, however, must be taken into consideration for minor differences in physical characteristics which have been shown to exist between the measured streams and Running Water Draw.

It seems reasonable to assume that the percentage of run-off from the Smoky Hill-North Fork Republican and South Fork Republican watersheds is slightly higher than would be expected from that of Running Water Draw. This appears logical in view of the minor differences in the surface geology and ground water conditions. Likewise, the percentage of run-off from the watershed of Sappa Creek is possibly lower than that which would be expected from Running Water Draw because of the large amount of alluvium present in and near the main channel, a condition which does not exist over Running Water Draw.

The general average of percentages of run-off for the comparative streams is 1.5 percent of the average annual rainfall. This average, however, includes three percentage factors which are believed to be high, and only one which is believed to be too low for Running Water Draw. It is the opinion of the writer that the percentage of rainfall which will appear as surface run-off over the watershed of Running Water Draw will closely approximate 1.25 percent of the average annual precipitation.

CHAPTER VIII

ALAMOSA CREEK

In the introduction of this thesis it was stated that a general knowledge of the historical geology of watersheds is, in some instances, of prime importance. The engineer is handicapped in that this information is not always available, if and when, in his opinion, it is needed. When making the reconnaissance survey the engineer should watch closely for any irregularities in the general structure of the drainage system, such as stream piracy, trellised or dendritic systems, or other phenomena which might have important effects upon the percentage of run-off.

Alamosa Creek, a small intermittent stream in southern Quay County, New Mexico, drains a watershed which, in the writer's opinion, illustrates the importance of this subject. This stream originates in the extreme west central part of the county and typical of most streams in this section of the High Plains it flows in a southeasterly direction. However, after flowing for approximately thirty five miles, Alamosa Creek very abruptly turns to the southwest and later drains into the Pecos River. This is the result of stream piracy on the part of the Pecos River. This report will not consider the entire basin of the stream, but only that part down to where it abruptly turns to the southwest.

GENERAL GEOLOGY

The entire surface of the watershed is covered with sands and gravels of Tertiary age, ranging in thickness from thirty to about seventy feet. Underlying the Tertiary, in places, are deposits of Cretaceous age. The extent of these formations into the watershed are not exactly known, although it has been established that where present, they are rapidly thinning to the south. Prior to the deposition of Tertiary deposits the Cretaceous formations were subjected to extensive erosion. The next oldest series in stratigraphic order is the Triassic, represented in this area by the Dockum group, which consists of approximately 1,200 feet of alternating red clays, shales, and sandstones. Underlying the Triassic beds, are the Permian "red beds".

Structurally, the northern two thirds of the watershed lies in a basin with pronounced anticlines on both sides striking almost north and south. Approximately 10 miles upstream from the point where the stream turns to the southwest these folds seem to flatten out and disappear.

HISTORICAL GEOLOGY

About seventy five miles southeast of the approximate center of the Alamosa watershed is the Portales valley, a broad valley with gentle slopes and a northwest-southeast trend. In this valley is found the Portales shallow water area, and water produced from it is used rather extensively for irrigation. That this valley was once the course of a rather large stream, which was later abandoned and re-shaped, was first noticed by Baker.* It has, in fact, been traced farther southeast into Texas, where no doubt it at one time drained into the Brazos River. Apparently, in early Pleistocene time after the deposition of the Tertiary, a stream having the same general course of the present Pecos River above Fort Sumner, New Mexico, continued southeastward across the High Plains through the present Portales Valley and on into Texas. The old Pecos River, then below Fort Sumner, encroached

* Baker, Charles Laurence, Geology and Underground Waters of the Northern Llano Estacado: University of Texas No. 57, p. 52-54, 1915.

to the north, and northeast, and beheaded the Portales stream, therefore depriving it of its waters from the mountains.

After the beheading of the old stream its rather deep valley, as well as those of the major tributaries, probably presented a rugged type of topography similar to that now seem near the "breaks of the Plains". That the present valley of the Alamosa was either the northern extension of the old Portales valley, or a major tributary, is evidenced by these facts:

1. Capture of Alamosa Creek by the Pecos River.
2. The present Alamosa Valley contains a shallow area with water in quantities sufficient for irrigation; this area being very similar to the Portales area.
3. Geographical location with respect to the Portales Valley.

Deprived of their water, these old valleys became dry beds, subject to erosion by wind and rainfall. As time progressed, erosion by these agents caused large deposits of talus to accumulate on the slopes and which later filled the channels. Later accumulations and further erosion resulted in shaping the valleys to their present form, the steep slopes giving away to the more gentle ones.

The large deposits of talus which filled the old valleys and channels were excellent aquifers. They were later charged with water resulting from the seepage of local precipitation. Wells, in both areas, encounter red broken clay and red water worn gravel, indicating that the ancient rivers had eroded entirely through the Tertiary and into the underlying Triassic.

The structural conditions, previously described, are reflected in surface topography in the northern part of the Alamosa watershed. Several miles north of the head waters of the creek lies the great Conebia Basin, a large natural sink similar to those common to the Plains province with the exception of size, it having a drainage area of over one entire township. If and when it ever became filled to capacity with surface run-off, the overflow would drain to Alamosa Creek. Southeast, several miles from the town of House, the Alamosa drains directly into Caballo Basin, another natural sink whose capacity is seldom exceeded. It therefore seems reasonable to state that only in times of very excessive rainfall would the Alamosa Creek contribute any surface run-off past the Caballo Basin due to the seepage of precipitation to the ground water reservoir, and to the presence of Caballo Basin.

CHAPTER IX

MIDDLE RIO GRANDE VALLEY
New Mexico

As previously mentioned complex structural and stratigraphic conditions often materially affect the relationship between rainfall and run-off. These effects are widely demonstrated in the middle Rio Grande Valley of New Mexico, where many streams with watersheds of varying geological characteristics discharge water into the Rio Grande River.

The middle section of the Rio Grande Valley includes the Rio Grande and tributary valleys from the Colorado-New Mexico state line to San Marcial, which is located at the head of Elephant Butte Reservoir, a stream distance of approximately two hundred and seventy miles. The upper half of this section of the Rio Grande is flanked by the southern extension of the Sangre de Christo Mountains, which maintain their high altitudes as far south as Glorietta Divide east of Santa Fe. On the west, the Conejos Mountains extend southward between the Rio Grande and its principal New Mexico tributary, the Rio Chama. South of the Conejos Mountains are the Jemes Mountains.

South of the Jemez Mountains on the west, and Santa Fe on the east, there is a change in some physical characteristics.* The mountains decrease in height and there is a marked change in the character of precipitation. Heavy winter snows on the higher northern peaks give place to sporadic downpours, mostly in the summer, on the lower southern ranges. It is therefore from that part of the drainage area north of the Rio Chama that the Rio Grande receives the greater part of its water supply, as south of the Rio Chama the tributary streams are largely torrential in character and produce only a relatively small total run-off.

The Rio Grande enters a canyon immediately north of the Colorado-New Mexico state line which gradually increases in depth south of the line. In this area the principal tributaries are the Rio Colorado, Rio Hondo, Rio Taos, and Embudo Creek, all of which are from the east, rising in the Sangre de Christo Mountains. A short distance below Embudo the river enters Espanola Valley which is some twenty five miles long and one to three miles wide. Here it is joined by

* National Resources Committee, Regional Planning, Upper Rio Grande: U. S. Gov't. Printing Office, Washington, D. C., Part 6, p. 20-21, 1938.

the Rio Chama from the west and the Rio Santa Cruz from the east. At the lower end of Espanola Valley the river enters White Rock Canyon, a narrow gorge some twenty miles long, and leaving this at a point almost due west of Santa Fe it enters a long narrow valley bounded on each side by mesas which rise abruptly to a height of three hundred to five hundred feet above the valley floor. Then they slope gently upward to the foot of the mountains. This is the principal valley of the middle section, and it extends fifteen miles south to San Marcial Narrows, broken only by short canyons or narrows at San Felipe, Isleta, and San Acacia. The principal tributaries in this valley are Santa Fe and Galisteo Creeks entering Santa Domingo valley from the east, Jemez Creek from the west, a few miles below San Felipe Narrows, and Rio Puerco and Rio Salado from the west, just above San Acacia Narrows, sixty five miles south of Albuquerque.

The entire middle section of the Rio Grande watershed is complex in that the master stream flows from basin to basin through canyons or other restrictions. The mountains and highlands that border the Rio Grande depression not only receive a greater precipitation, but they also have a higher proportionate rate of run-off than the intervening basins. They consist largely of consolidated rocks whose pore spaces are small and moderate in number. Generally these rocks are fissured and jointed and may in places be covered by a mantel of soil. Under these conditions there is some storage of water in the weathered portions of the rocks, however, even under favorable conditions storage in most of the formation is small. Because of the steep slopes and deep canyons, discharge from such underground reservoirs is easy, and at the end of long dry summers it may be almost complete. The largest ground water recharge occurs in some of the limestones and basalts.

The Sangre de Christo and Culebra Ranges in Colorado are very high with steep slopes and narrow drainage basins. For the greater part the rocks are Pre-Cambrian granites and schists which have been stripped clean by glaciation. There is thus a quick run-off and little ground water storage and most of the streams have only a small low water flow. In New Mexico, however, this range is wider, and in the enterior there are belts of Pennsylvanian limestones, shales, and sandstones. Thus in spite of lower altitudes and less precipitation many of the creeks have relatively sustained low-water flows.

The Jemez Mountains are about forty miles square and are comprised of two unlike portions. The west side is the Sierra Nacimiento consisting mostly of granite and schist flanked on the west by upturned sedimentary rocks. The north end of the range, San Pedro Mountain, has a summit area of about one hundred square miles above ten thousand feet. Here the deep winter snows and ground-water storage provide a water supply for creeks draining into the Chama River to the North, the Rio Puerco to the west and the Rio de las Vacas, a tributary to the Rio Jemez. The eastern part of the range consists largely of volcanic rocks. The most extensive formation is a rhyolite tuff which is very open and porous. It forms great plateaus with a small direct run-off and large ground water storage. Springs that break out at the base of the tuff furnish the low flow of the Jemez and other streams.

The following table is a summary of the run-off of the more important streams flowing into the middle section of the Rio Grande:

Stream	Drainage Area-Sq. miles	UNIT RUN OFF A. F. per Sq. mile	S. F. per Sq. mile	Depth in Inches
Rio Lucero	17	994	1.37	18.6
Rio Pueblo de Taos	68	316	.437	5.92
Rio Taos	359	197	.272	3.70
Embudo Creek	305	200	.230	4.48
Pueblo Creek	116	268	.370	5.02
Rio Santa Cruz	86	290	.400	5.44
Santa Clara Creek	45	69.6	.096	1.31
Nambe Creek	37	286	.395	5.36
Tesuque Creek	13	208	.237	3.90
Rito Tesuque	8	115	.159	2.16
Santa Fe Creek	20	375	.518	7.03
Jemez Creek	477	180	.248	3.38
Bluewater Creek	235	52.7	.073	.99
Rio Puerco	4,795	17	.023	.33
San Jose	2,765	7	.009	.13

This table shows a wide variation in unit run-off per square mile of the drainage area. There are many factors which produce this wide variation and among them <u>geology</u> plays an important role.

Before discussing the effects of geology, however, it must be made clear that in view of the lack of precipitation data over the mountainous areas no effort is made to compute the percentage of run-off. There are considerable run-off records and precipitation records are quite numerous over much of the general area, excluding the mountainous portion. Precipitation, as well as run-off, increases with altitude. The location of mountain masses with relation to the prevailing winds affect the distribution of precipitation and also the resulting run-off. Within the middle section of the Rio Grande basin the streams draining the western slopes appear to have larger unit run-off than those draining the eastern slopes except where affected by a mountain mass. For instance, Rio Lucero, Rio Pueblo de Taos, Embudo Creek, and Rio Santa Cruz drain the western slopes of the mountains and have higher unit run-off than El Rito Creek, Santa Clara Creek, and Bluewater Creek which drain the eastern slopes. Nambe Creek, Rio Tesuque, and Santa Fe Creeks drain the western slopes of the mountains, but the precipitation and resulting run-off is appreciably less and appears to be affected by the Jemez Mountains lying to the West. James Creek, draining the south and west slopes of Jemez mountains has a unit run-off comparable to those streams having the higher run-off. It would be valuable to know the percentage of run-off, but as precipitation records for the high mountain areas is lacking, the relation cannot be computed.

It is interesting to note however, that many of the streams whose watersheds are within close proximity, show wide variations in unit run-off. This is especially true in the Truchas Range. This Range is a part of the southern extension of the Rocky Mountains in New Mexico. The Rockies in New Mexico extend far south in the state as a series of high ridges consisting largely of granites and other crystalline rocks of Pre-Cambrian age, overlain by Carboniferous limestones and sandstones. The range is relatively narrow, having a width of about twenty five miles in Taos County and thirty five miles east of Santa Fe.* The principal structural features is an anticline, or series of anticlines. The sedimentary rocks arch over most of the higher parts of the range, but in some areas, they have been removed by erosion, revealing the underlying granites.

* Darton, N. H., Geologic Structures of Parts of New Mexico: U. S. Geol. Survey Bulletin No. 726-E., p. 200, 1922.

An example is the difference in unit run-off between Santa Fe and Nambe Creeks. Santa Fe Creek originates on the southern slopes of Lake Peak, one of the peaks comprising the high Truchas Range, and flows south and southwest, running through the City of Santa Fe. It has a unit run-off of approximately 375 acre feet per square mile of its drainage area of 22 square miles as measured at the Santa Fe gauging station. At least seventy five percent of its drainage area consists of granite and quartzitic rocks at the surface, which are conducive to high run-off. East of Santa Fe the stream leaves those igneous rocks and flows across a small area of Carboniferous limestones, sandstones and shales known as the Magdalena group. Immediately before entering the City of Santa Fe the stream leaves the Magdalena group and flows over the Santa Fe formation which is upper Miocene and lower Pliocene. This formation consists largely of unconsolidated sand and gravels.

Nambe Creek originates on the northern slopes of Lake Peak and flows north and west near the village of Nambe. Near Nambe the average annual discharge has been approximately 286 acre feet per square mile of drainage area, which is 89 acre feet less than the unit run-off of Santa Fe Creek. Over this part of the Nambe drainage area the surface formations are similar to those of the Santa Fe Creek Watershed, however, the distribution is different. Approximately 25 percent of the upper reaches is covered at the surface by granite and quartzite. The Magdalena group of sandstones and limestones outcrop over about 55 percent of the area, and the remaining part of the watershed is covered by the sands and gravels of the Santa Fe. As close as can be determined both watersheds have very similar climatological conditions, therefore the difference in unit run-off is no doubt the result of the differences in the distribution of the igneous rocks over the watersheds.

Immediately north of the Nambe Creek watershed lies the watershed of Rio Santa Cruz. From its upper reaches in the Truchas Range down to the gauging station located near the village of Santa Cruz, the geology is practically the same, including the distribution of surface formations as that of the Nambe drainage area. The annual average run-off per square mile of drainage area is approximately 290 acre feet or very near the same as that of the Nambe watershed.

North of Rio Santa Cruz is the watershed of Embudo Creek which also originates on the Truchas Range. On its upper reaches the geology is similar to that of Rio Santa Crúz, and Nambe and Santa Fe Creeks, the upper tributaries originating on Pre-Cambrian granites and quartzites, then across the Carboniferous limestones and sandstones, and finally flowing across the Santa Fe gravels. The unit run-off down to the gauging station at Dixon, averages approximately 200 acre feet per square mile of drainage area. This is considerably lower than the unit run-off of the previously discussed streams although the climatological conditions are quite similar. This difference is partly accounted for by the fact that the greater portion of the watershed is covered with sands and gravels of the Santa Fe formation. Another factor is the presence of a small area in the extreme upper reaches, which is covered by a highly fissured and broken basalt flow which is not conducive to a high run-off.

The Rio Puerco, Bluewater Creek, and Rio San Jose have the lowest recorded unit run-off of all streams listed in the table.

The Rio Puerco originates in the extreme north central part of Rio Arriba County, where in its upper reaches it drains the west flank of the Nacimiento Mountains. In this section of the Nacimiento uplift the beds on the west side are upturned very steeply, constituting the east or southeast margin of the great San Juan Basin.* Along the west slope of the mountains there exists a major zone of faulting. Most of the fault planes dip to the east showing that the mountain mass has been overthrust to the west.** Outcropping over the upper reaches of the Rio Puerco are formations of Triassic, Jurassic, and Cretaceous ages, consisting of shales, sandstones and some limestones. Throughout this portion of the watershed the unit run-off is no doubt much higher than for the other areas farther downstream in view of greater precipitation, steeper

* Dane, Carle H., Geology and Fuel Resources of the Southern Part of the San Juan Basin New Mexico: U. S. Geol. Survey Bulletin No. 860-C., p. 31, 1936.

** Renick, B. Coleman, Geology and Ground Water Resources of Western Sandoval County New Mexico: U. S. Geol. Survey Water Supply Paper No. 620, p. 71, 1931.

slopes and the presence of more impervious surface formations. It is very probable, however, that much of the surface run-off is lost by seepage into the westward dipping formations previously mentioned.

Also in its upper reaches the drainage from the west and north is from a large area which is covered at the surface by sands and gravels of the Santa Fe formation, which probably produce little run-off.

Approximately 15 miles southwest of the town of Cuba, the stream leaves the Santa Fe gravels and drains an extensive area of which Cretaceous shales and sandstones are the predominating surface formations. Practically the entire watershed down to the gauging station at Rio Puerco is a typical bad land area. A number of mesas and buttes, all of which are erosional remnants, form conspicuous land marks. In the central part of the watershed the stream separates Mesa Prieta from Mesa Chivato, which owe their existence to the presence of a resistant cover of basalt. This basalt ranges in thickness from 50 to 200 feet and forms part of a lava flow that probably connected the mesas at one time. It is badly fractured and yields little surface run-off.

Over the entire area the general dip of the formations is to the west. Where the Cretaceous sandstones are the surface formations, it is possible that much of the surface run-off may be lost by seepage into the underlying formations. Run-off is much greater over the large areas covered by shales of the same age, however, much of this run-off is lost by evaporation.

In general, the unit run-off of the Rio Puerco, 17 acre feet per square mile, is as one would expect for this type of watershed. The stream drains an arid country, characterized by hot summer winds, and as it was previously discussed, the heaviest run-off in the upper north east reaches is probably lost by seepage while crossing the westward dipping sandstones and limestones.

Bluewater Creek, draining the northeastern slopes of the Zuni Mountains, has a unit run-off of approximately 53 acre feet per square mile of its 235 square miles of drainage area, down to the gauging station near the town of Bluewater. The Zuni mountains are the result of hard rocks uplifted by an extensive anticlive or elongated dome. This uplift has steep dips on its west side where the strata pass under the Gallup-Zuni coal basin, and very gentle dips on the north and northwest sides into the San Juan Basin. Towards the south east the flexure flattens into a broad monocline. The uplift is relatively regular although the dip varies from place to place, and there is considerable faulting in parts of the area.

Over that part of the uplift drained by Bluewater Creek, the Pre-Cambrian granites are exposed in two areas, one of which is rather large. Sedimentary formations which are exposed due to the uplift are: Abo sandstone and Chupadera limestone gypsum, and sandstone of Permian age, and the Moenkopi and Chinle shales of Triassic age. For the greater part the main stream flows in a strike valley following the outcrop of the Chinle red shale and sandstones. Several of the main tributaries, however, flow down the dip slopes, cutting across various north dipping formations before they reach the main channel. In doing so much water is lost by seepage, and this condition appears to be one factor in the relatively small unit run-off of Bluewater Creek. In making a study of the run-off of Bluewater Creek before and after building the Bluewater dam the following table was computed:

Bluewater Creek near Bluewater

Period	Average Precipitation Inches	Average yearly run-off	
		A. F.	Percent
1913-1927	13.60	12,392	7.26
1928-1937	15.52	8,197	4.21

Bluewater Creek and its tributaries comprise the upper reaches of the San Jose River. It is interesting to note that at the Suwanee gauging station the San Jose has a unit run-off of approximately seven acre feet per square mile of drainage aree, in spite of the fact that it drains the south side of Mt. Taylor which rises to about 13,000 feet above sea level. This low run-off is greatly accounted for due to the presence of extensive basaltic lava flows which are badly fractured and therefore absorb much of the run-off.

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