WATERSHED YIELDS
ARIZONA AND NEW MEXICO

As you all know, we are faced with a controversy between those primarily concerned with the conservation of watershed lands and those whose livelihood depends on available water supplies. It is only natural that the water users view with suspicion any program that might take part of their supply although these same water users are sold on the necessity for conservation.

Regardless of the "rights" or "wrongs" of the case we in the Soil Conservation Service long have felt that a great need exists for more knowledge concerning the sources of our water supplies, the reasons why certain areas are high water producers and other areas are low producers, and what effect conservation programs might have on the present supply. Certainly a clear understanding of the fundamentals involved in any controversy is necessary to intelligently seek a solution.

During July of 1950 we were authorized to collect and analyze all available information and data concerning watershed yields in the states of Arizona, New Mexico, Colorado and Utah. We have completed this work in Arizona and New Mexico. Today I would like to outline certain facts and conclusions that have developed from this study. Incidentally, I might mention that thus far we have compiled records from some 800 rainfall measuring stations and 340 stream gaging stations. To make this appear more impressive I might add that those records represent some 24,000 station years of precipitation records and 5,000 station years of stream flow records.

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I would like to start by discussing precipitation, since after all this is the source of all of our water supply, and will be until ways and means can be devised to utilize water from the oceans. As many of you know, within the states of Arizona and New Mexico the average annual precipitation ranges from about 3.5" in southwestern Arizona to some 50" in the highest elevations of north-central New Mexico. I might add that the highest annual precipitation we have found in these four states is approximately 60" in the headwaters of the San Juan River in southwestern Colorado.

At the present time we have completed isohyetal maps of Arizona and New Mexico. In order to get an idea of the total amount of water being precipitated each year in the two states we developed the weighted average annual precipitation for each. Considering each state as a whole, Arizona receives about 13" of precipitation and New Mexico receives some 14.7" of precipitation each year on the average.

Translating this supply into terms of acre feet, which is the commonly used term in considering irrigation water supplies, we arrived at a figure of some 174,000,000 acre-feet of water being precipitated in the two states each year on the average. Considering the average annual yield of major watersheds such as the Salt River of Arizona, the Rio Grande in New Mexico and others, it is readily evident that only a small proportion of this supply becomes available for irrigation. The relative proportion of the watershed yields that occur from various physiographic and climatic zones of the two states is the major topic of discussion today. Certainly when such a small proportion of the precipitation becomes available for consumptive use on irrigated lands it is of utmost importance to determine the source of this water.

19,080,000 acre

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The map (maps 3 and 4) before you shows the sources of irrigation-water supplies within the states of Arizona and New Mexico. The original scale is $\frac{1}{500,000}$ or about 8 miles to 1 inch. The yellow color represents an annual water yield of less than 0.10" from the land surface. Following through, the various zones are 0.10" to 0.50"; 0.50" to 1.00"; 1.00" to 2.00"; 2.00" to 5.00"; 5.00 to 10.00"; 10.00" to 20.00"; and 20.00" to 30.00". The yield of water ranges from less than 0.10" to around 30.00" within the two states, the highest yielding area producing some 300 times as much water as the very low yielding areas. Of considerable interest also is the proportion of the precipitation appearing as yield within the various zones. For example, watersheds of high elevations may yield as high as 80% or more of the annual precipitation whereas areas at low elevations seldom produce more than 2 or 3% of the supply. Not only is the precipitation much greater in the mountains but a much greater proportion becomes available for irrigation use.

As mentioned heretofore, the primary purposes of our study have been not only to determine the sources of irrigation water but also the reasons why such remarkable differences in watershed yields exist. Certainly it is not difficult to understand why a great deal more water is received from areas having high precipitation and a large part of the precipitation appearing as yield. The question is, however, just why should 80% of the precipitation appear as yield from one area yet only 2 or 3% appear as yield from another? This question is well worth exploring.

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First I would like to discuss the climatic and physiographic characteristics of the mountainous, high yielding areas which result in the large proportion of precipitation appearing as water yield:

One of the foremost of these characteristics is the low evapotranspiration potential found in the mountains. By evapotranspiration potential I mean the amount of water that could be evaporated and transpired under a given set of climatic conditions. Studies of evapotranspiration potentials in the Southwest have shown that the potential at high elevations seldom amounts to more than 15" to 25" of water. When we consider that the annual precipitation often is 30" to 50" it is abvious that a considerable proportion of the precipitation must appear as yield. I might mention that in the areas of low rainfall this potential reaches 50 to 60 inches.

A second reason for high proportionate yields is the distribution of the precipitation in the mountainous areas. Ordinarily the greater proportion of the year's precipitation occurs during the period November - April inclusive when evapotranspirational potentials are low and there is less opportunity for the water to be lost. For example, at Cumbres, Colorado, at an elevation of about 10,000 feet, some 64% of the annual precipitation occurs from November to April. This can be contrasted with the distribution at Albuquerque (elevation 5,300) where only 32% of the annual precipitation occurs during the same period. During the hot summer months when evapotranspirational potentials are the highest the proportions are reversed, Cumbres receiving 22% and Albuquerque 41% of the annual precipitation during the period July - September.

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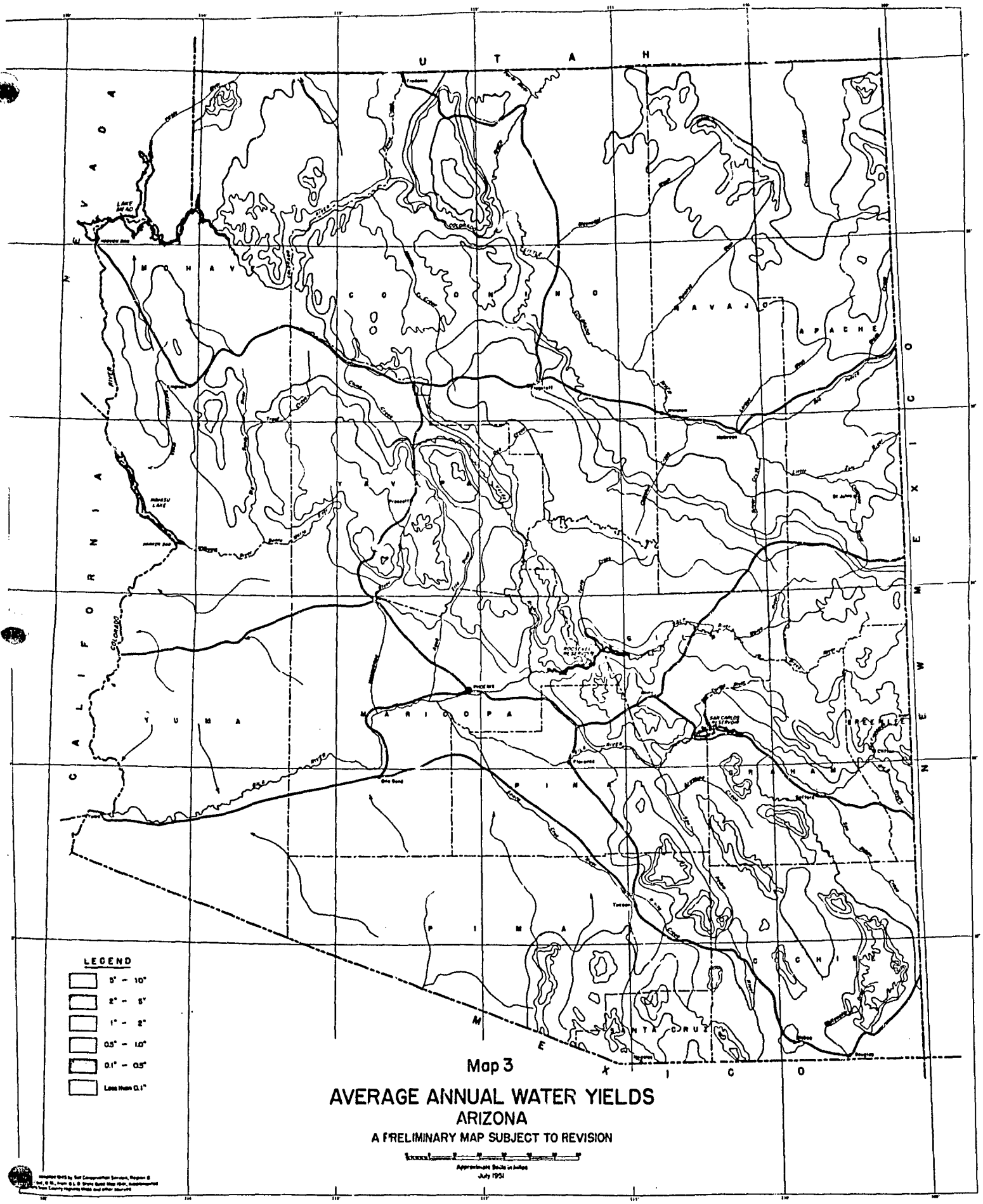


Map 3

AVERAGE ANNUAL WATER YIELDS

ARIZONA

A PRELIMINARY MAP SUBJECT TO REVISION

Approximate Scale in Miles

July 1951

CYRIL LUKER, DIRECTOR

Base Revised July 1951

6-P-2501-A-2(3)

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A third reason for high proportionate watershed yields in mountain areas is the characteristic predominance of shallow soils or soils of low water holding capacity. The profound influence of this characteristic was rather forcibly impressed on us when we attempted correlations between watershed yields and physical characteristics. During the first field trip into Colorado our soil scientist broke down the various watersheds into the proportions of each which had shallow, medium and deep soils. In attempting to correlate precipitation with yield we began to find areas where extreme differences in yield could not be explained by differences in precipitation. We noticed, however, that yields appeared to materially increase whenever the percentage of shallow soils increased. We then attempted to correlate watershed yields and shallow soils with the following results:

The first chart on the left (Figure 1) is a plotting of the water yields in percent of precipitation against the average annual precipitation occurring over the watersheds. There are 47 stations in the plotting which represents all of the areas that were inspected on the field trip. It isn't necessary to point out the almost complete lack of correlation between the precipitation occurring over each area and the resulting yields. Seldom have I seen a more classic example of a "shotgun" pattern. You can understand our perplexity when we first attempted such correlations.

I would like now to refer you to Figure 2 on the right. We have used the identical stations as were plotted in Figure 1 but have plotted the watershed yields against the percentage of shallow soils within each watershed.

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Instead of a rather hopeless looking "shotgun" pattern we find that the shallow soils-water yield relationship is highly significant. I would also like to point out the extreme range in yields with about the same precipitation that were "brought into line" when shallow soils were the criteria. For example, in this watershed the precipitation was 25" and the yield 11% while in this watershed the precipitation was 25" yet the yield was 77%. As another example this watershed had a 35" precipitation and a yield of 28%. While this watershed also had a 36" precipitation yet the yield was 67%. Yet in both cases the yield correlated nicely with shallow soils.

Another interesting and significant fact is that the watersheds used in the plottings represent extreme variations in vegetative and physiographic characteristics. Although the characteristics of the various areas may change as much as have the percentages of shallow soils yet the depth of soils appears to completely dominate the yield relationships.

It appears, therefore, that one of the most important characteristics in the consideration of watershed yields is the ability of a watershed to initially retain water. Certainly this characteristic predominates insofar as those particular watersheds are concerned. Perhaps in the past we have been too much concerned with the role of transpiration in the hydrologic cycle.

Perhaps watershed vegetation is present only because the water can be held there and if the water cannot be retained within the area then the vegetation cannot exist. In any event it appears to be something like the chicken and egg proposition as to which came first. Frankly, I wonder if this matters much.

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FIGURE I

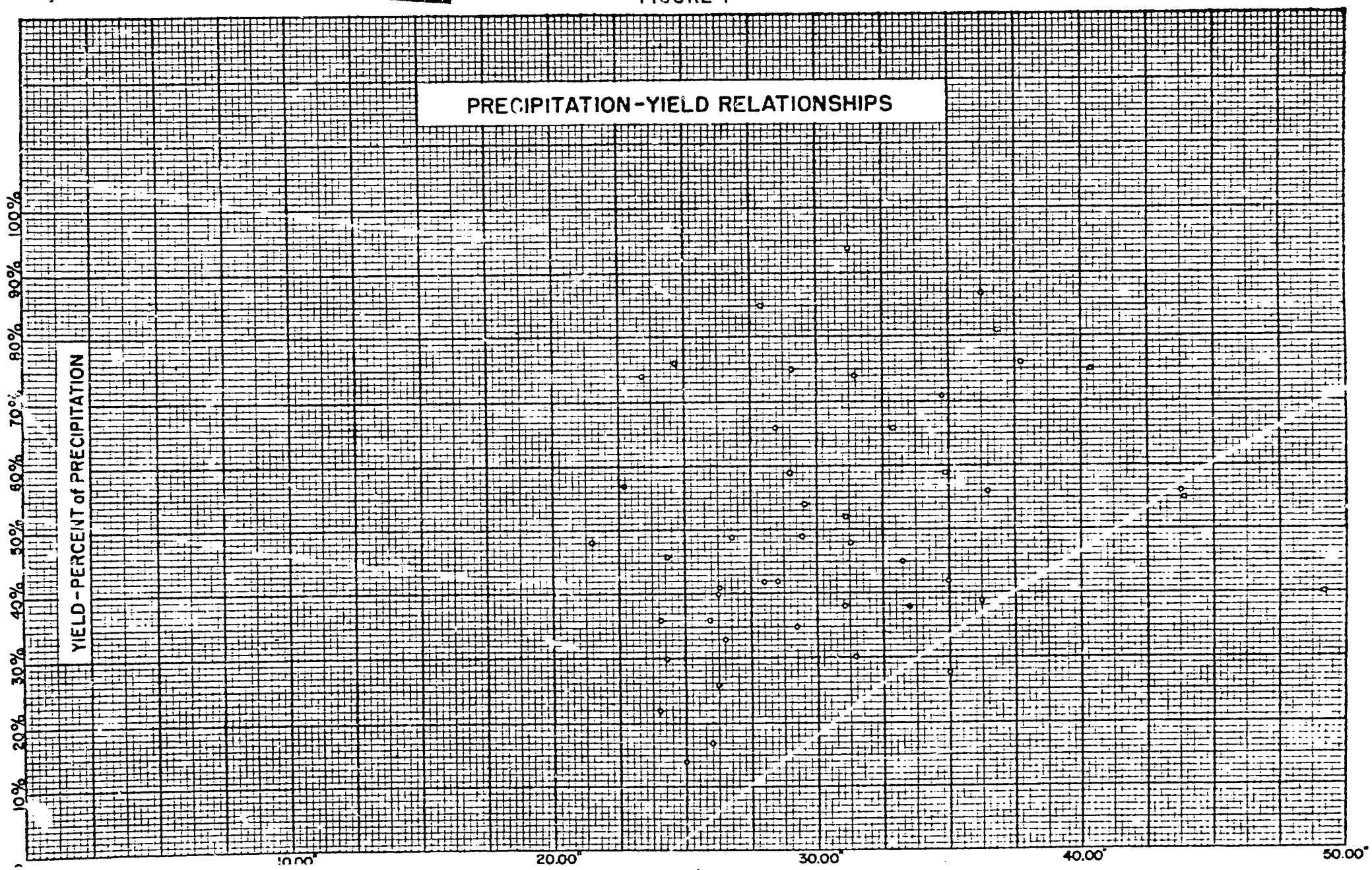


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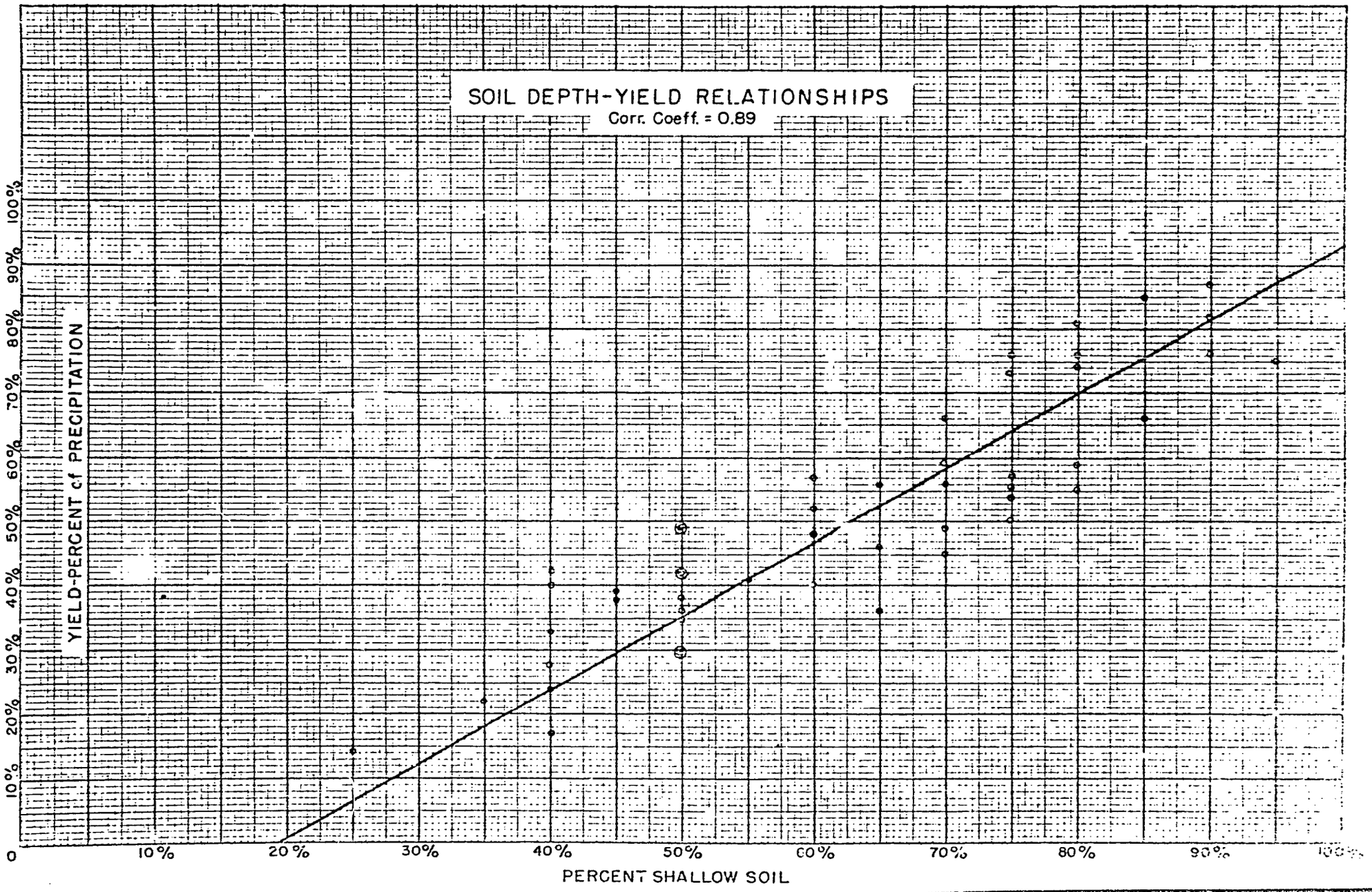
FIGURE 2

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In discussing the influence of shallow soils on water yields I do not intend in any way to discount the importance of evapotranspiration potentials. All other things being equal this factor exerts a profound influence. You will note from the first figure that although there are great differences in yields, almost without exception the yield percentages are high in these zones of low evapotranspiration potentials. Within any major area, however, where evapotranspiration potentials are similar there may be tremendous differences in watershed yields depending upon the ability of particular watersheds to initially retain water.

Now let us take a look at the characteristics of the low-yielding arid and semiarid areas where the precipitation averages only 10" or 12" annually. I am purposely going to extremes in order that you may follow through with the range of conditions that exist. As I have stated heretofore the yield from such areas seldom averages over 2 or 3% of the annual precipitation, and there are very good reasons for this.

The evapotranspirational potential also exerts a profound influence in arid and semiarid areas. It is not at all uncommon for this potential to reach 50" and in certain instances 60" or more of moisture would go to evaporation and/or transpiration if the water was available. When we consider that this potential is operating in conjunction with an average annual precipitation of only 10 or 12 inches it is not difficult to understand why all water not immediately leaving an area will be subsequently consumed by evaporation or transpiration. Not only is the potential much greater than

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the supply on an annual basis but the deficit exists throughout the year in such semiarid zones. In summation it might be said that whenever moisture is available the potential exists to remove it.

Another characteristic of low-lying areas, which has an adverse affect on water yields, is the predominance of deeper soils. The vast areas of alluvial valleys and plains within the two states almost always contain soils of sufficient depth to retain all of the meager precipitation that occurs during the average year. Thus, the relative amounts of deep soils are not of major importance in low-lying areas since a sufficient depth of soil is ordinarily present to retain all water that does not immediately leave the area.

A third reason for low water yields from semi-arid areas is the way in which precipitation normally occurs. Although the annual totals are low, even this small amount of water ordinarily results from a rather large number of precipitation periods. For example, an annual rainfall of 10 to 12" may be composed of some 50 different rains. Of these rains 50% total less than 0.10"; 80% total less than 0.25" and 90% of the rains total less than 0.50". Fewer than 1% of the rains that occur in areas of low annual precipitation exceed 1 inch in amount. The combination of deep soils with a high water-holding capacity and the occurrence of many small rains obviously is not conducive to a high water yield.

A fourth and also very important reason for low water yields in semiarid areas is the tremendous loss in water that takes place between the point of origin of runoff and the point of use.

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Characteristically, surface runoff does not occur in such areas except in association with high-intensity thunderstorms. Such storms seldom cover large areas and more often than not the runoff originating from such a storm must travel great distances over terrain that has not been wetted. Since there is virtually always a sufficient evapotranspirational potential to consume the available moisture any such runoff in these lower areas that enters the ground through channel or overland flow and does not go to ground-water recharge will be subsequently evaporated or transpired.

I would like to cite an example to show how enormous these losses can be. For the past 12 years we have conducted a series of runoff studies within the San Simon basin of southeastern Arizona. The study has been directed toward determining the precipitation and runoff occurring on four small watersheds within the basin. The areas average somewhat less than one square mile in size and are quite representative of the general watershed conditions that prevail within the San Simon drainage.

In an effort to learn more about transit water losses in semiarid areas we averaged the annual water yields from the four watersheds for the period of record, then translated this information into terms of acre-feet of water yield per square mile. For the same period of record we took the actual yield of water at the mouth of San Simon basin - 2260 square miles in size- and converted this figure into terms of acre-feet per square mile. We found that almost 80% of the water originating from the small areas never reached the mouth of the San Simon. In other words only some 20% of what was

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originally a low proportionate water yield actually reached a point where it might be used for irrigation. I might add that other information we have collected indicates that these high transit water losses are common.

To summarize: the high potential evapotranspiration, deep soils, scattered precipitation patterns and excessive transit losses amply explain why the watershed yield from semiarid areas represents but a very small fraction of the precipitation.

In closing I would like to discuss the precipitation and water-yield relationships of the San Simon watershed mentioned heretofore. This basin is a rather classic example of an area that once produced tremendous volumes of livestock forage and which now is in a badly deteriorated condition. Originally, the alluvial valley was for the most part a well grassed, undissected waterway grazed by thousands of cattle. Today there is very little good vegetation of any kind and the valley is dissected by one large gully and many deeply entrenched tributaries. By no stretch of the imagination could the watershed now be considered as being in good condition.

A look at the present precipitation-water-yield relationships, however, shows some very interesting facts. The weighted annual precipitation over the 2,280 square-mile area is 12.87", which represents about 1,560,000 acre-feet of water received on this watershed. The average annual yield or residual runoff from the watershed at its mouth during the available period of record is only about 9,000 acre-feet. This means that about 1,551,000 acre-feet of water now never reaches the mouth.

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I would again like to call to your attention the fact that this watershed is now in a deteriorated condition. It produces but a small part of the livestock forage which was produced prior to the onset of deterioration. Yet today the watershed retains more than 99% of the available water supply. To put it another way, of the 12.87" of precipitation occurring over the watershed 12.79" stays there. Were we able to hold all of the water within the area there would be available only an additional eight one-hundredths of one inch.

Obviously we cannot expect a material change of any kind on this watershed by the addition of less than 1 percent more water. Equally obvious is the fact that the originally excellent grass cover could not have been maintained because the fraction of an inch of water now running off was then being held within the watershed.

This fact then poses the question as to how there could have been a good stand of perennial grasses originally with about the same water supply that is now available. To me the answer is relatively simple. As mentioned heretofore, the evapotranspirational potential within such areas as the San Simon is probably 50". The distribution of this potential throughout the year is such that any water that does not immediately leave the area will be subsequently lost to evaporation from bare ground surfaces or transpired by plants. Today, large areas of this watershed support only weeds, shrubs, and other undesirable types of vegetation instead of the perennial grasses of high forage value that formerly occupied the area. Sizeable

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portions of the watershed have no cover whatever. Virtually the same water supply which in the past supported the erosion-resisting perennial grasses of high forage value now supports a great variety of undesirable types of vegetation. Where no ground cover is present this water supply is lost by direct evaporation. It is difficult to escape the conclusion that if the water is in the area something will grow to use it.

This, I am convinced, is the story of the San Simon. The question therefore, is just how do we plan to use that part of our water supply, the water that naturally remains in such a watershed, regardless of vegetative conditions. Whether this water grows grasses to fatten livestock and hold the soil in place or is wasted on worthless weeds and evaporation from bare soil, seems to make little difference in the yield of water for downstream beneficial uses.

Prepared for presentation by John M. Dorroh, Jr. before the New Mexico Section of the American Society of Civil Engineers at Albuquerque, New Mexico, on November 2, 1951.

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