Water Management On Semiarid Watersheds

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It is a pleasure and an opportunity for me to discuss water management on semiarid watersheds, on the occasion of this Eleventh Annual Arizona Watershed Symposium.

Semiarid watersheds throughout the Southwest are of substantial economic importance from the standpoint of both range forage production and water yields. However, they frequently receive a total annual precipitation, or have a seasonal distribution of precipitation, which is critical from the standpoint of grazing and, especially so, from the standpoint of their yield of water for off-watershed uses.

In 1955, a Senate Select Committee on Water Resources predicted that, without importations, about one-third of the area of the nation, extending from the Canadian boundary to the Mexican border, and extending eastward from the northern Rockies to Minnesota, and from the lower Pacific coastal range across west Texas, would be out of water by the year 1980. The map in Figure 1, based on the U. S. Geological Survey's records of streamflows, shows that about three-fourths of the land in this water-deficient region, or an area more than 8 times that of the State of Arizona, yields less than an inch of water a year to major streams. The major water-producing areas are the relatively very small higher mountain areas, which are generally forested.

The map in Figure 2 indicates that only approximately 10 percent of the area of the State of Arizona yields as much as an inch of water, and that approximately 75 percent yields less than one-half inch of runoff per year. Approximately 13% of the land area yields between 0.1 and 0.5 inch to streamflows, aggregating about 11% of the State's total surface water supply.

Comparing this water yield map with a precipitation map (Fig. 3), shows that this 0.1- to 0.5-inch water-yield zone corresponds generally to the 12- to 16-inch annual rainfall zone. Thus about 22,000 square miles of rangeland in Arizona receive an average annual rainfall and sustain rainfall fluctuations from year to year which are critical to forage production. Also, the potential for water yield per unit area of this land is relatively low. However, because of the extent of these semiarid rangelands, their *total* production of water is important. And, with improved management, I believe

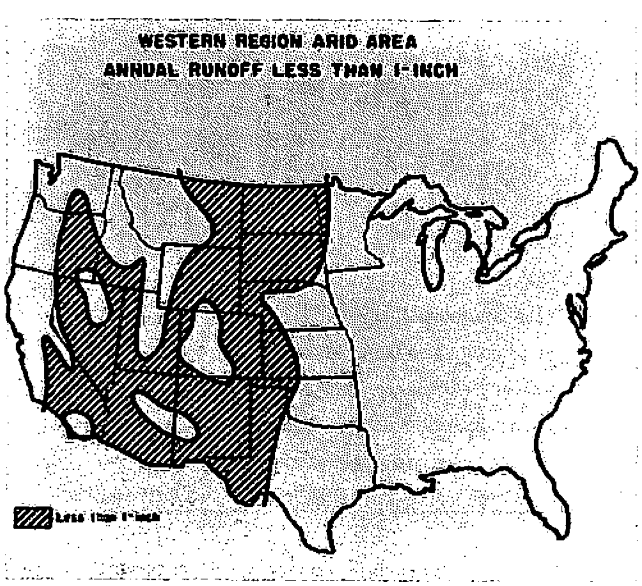

Fig. 1. Area in U.S. 8 times size of Arizona yields less than 1 inch of water a year to major streams.

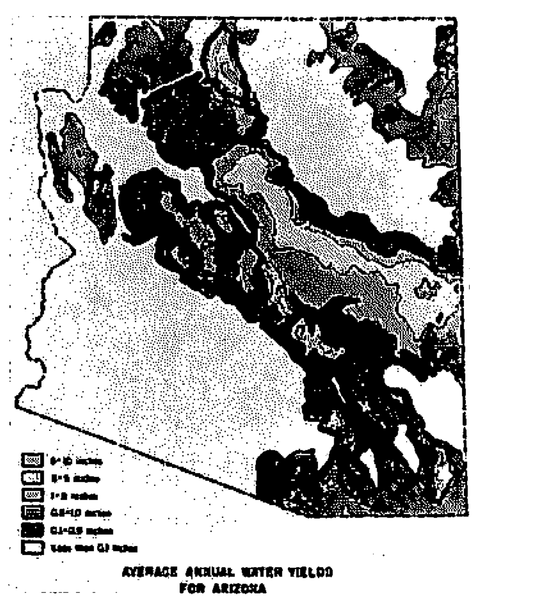

Fig. 2. 90% of area of Arizona yields less than 1 inch of water per year to major streams. (From SCS Map No. 6-P-12501-A-1(3), 1951.)

they offer possibility for significantly increased yields of both forage and water.

Another aspect of the problem of water management on semiarid watersheds is their erosion and sediment yields. A generalized map by the Soil Conservation Service indicates that over a broad area of the Western United States, an average of about 2 tons of soil per acre, per year moves into the major streams. Compared with some parts of the country, with much heavier rainfall, the total sediment yield is not high. However, because the sediment is transported in streams that have relatively low flows, the *concentration* of sediments in streamflows from arid and semiarid lands is extremely high. It averages about 20-25 tons per acre-foot of water in major streams, and in tributary streams which drain the semiarid rangelands, several times that concentration frequently occurs.

Water management on semiarid watersheds would seem to imply two things: (1) Optimum utilization of the available water, either on or off the watershed; and (2) control of flash flood and sediment damage. It is research with a view to these two major objectives, being conducted on semiarid rangeland watersheds in the Southwest, which I shall briefly describe.

This research is conducted by the Agricultural Research Service's Southwest Rangeland Watershed Research Center, located at Tucson. The work is in cooperation with the Agricultural Experiment Stations and other water research oriented groups in the Land Grant Universities of Arizona and New Mexico. While our field research is now all being done in these two States, I should mention that certain theoretical laboratory aspects are being carried out also in cooperation with the Water Research Laboratory of the Utah State University at Logan. Our research effort is being planned in close cooperation also with the U. S. Department of Agriculture's Soil Conservation Service, in support of its action programs, working with the State Soil and Water Conservation Districts in the Southwest.

This research was originally initiated by the Soil Conservation Service, and was transferred to the Agricultural Research Service, in 1954. We are continuing to measure rainfall and runoff on a number of small watersheds, a square mile and less in area, in the vicinities of Safford, Arizona, and Albuquerque, New Mexico, which were started by the Soil Conservation Service approximately 30 years ago. Much of the value of these data derives from their length of record. A major part of our work is now being conducted on larger watersheds, including the 58-square-mile Walnut Gulch Experimental Watershed at Tombstone, Arizona, and the 67-square-mile Alamagordo Creek Experimental Watershed, in eastern New Mexico (Fig. 4).

Watersheds are *complex* systems, and as such are about as individual as are persons. It is not possible generally to draw conclusions based simply on the *overall* performance of particular watersheds under study, and consider those watersheds as being typical or representative of numerous other watersheds or major problem areas. It is possible, however, to de-

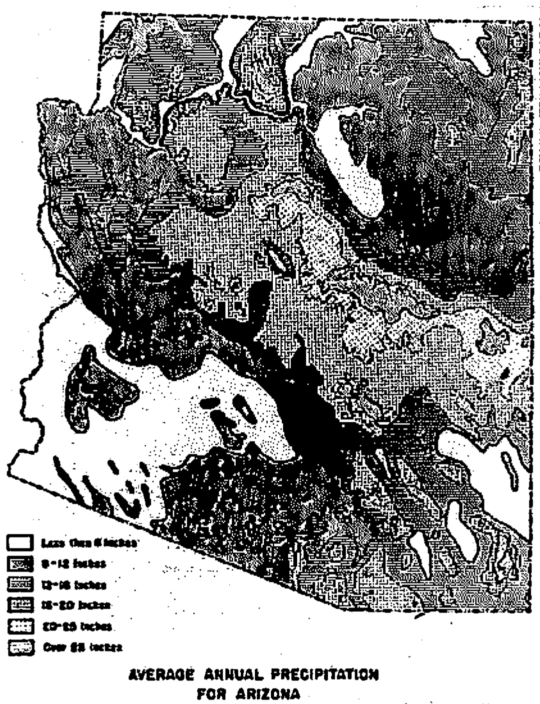

Fig. 3. 0.1-to 0.5-inch annual water yield zone corresponds generally to semiarid areas, 12- to 16-inch annual precipitation. (From SCS Map 6-P-12501-A-2(3), 1951.)

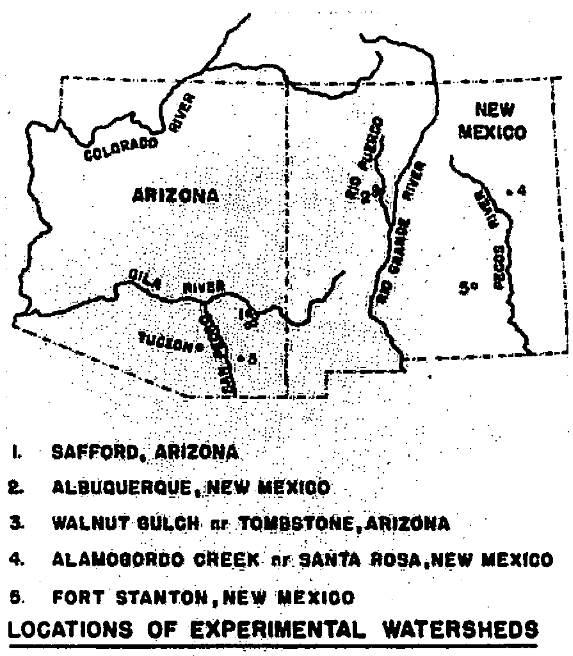

Fig. 4. Water management on semiarid rangelands is being studied on experimental watersheds at 5 locations in Arizona and New Mexico, by Southwest Watershed Research Center, U.S. Dept. of Agriculture, Agricultural Research Service, Tucson, Arizona.

velop an understanding of the basic hydrologic processes which go on in a watershed, and which combine to make up its total behavior; and based on such understanding, to adjust the hydrologic processes as they are affected by varying conditions and recombine them to predict the behavior of other watersheds. In our research on the Walnut Gulch watershed at Tombstone, Arizona, we are employing this kind of an approach. We are studying there the basic hydrologic processes involved, how they are interrelated, and how they are affected by various watershed conditions, particularly those which might be changed by the management of a watershed. We are then concerned with using this basic information for predicting and improving the behavior of other semiarid rangeland watersheds, throughout the Southwest.

One very important factor which strongly influences the behavior of semiarid watersheds is their extreme variability of rainfall. Practically all the runoff from such watersheds results from intense summer thunderstorms. These thunderstorms usually cover only a small part of the watershed, and their amounts and intensities vary widely from place to place within the storm area (Fig. 5). To determine these rainfall variations, and study their effects on the runoff and sediment yield from the Walnut Gulch Experimental Watershed, we have installed there a dense network of 92 recording rain gages.

For eleven years of record, 1955 to 1965, the average annual rainfall over the entire Walnut Gulch Watershed varied from 7.1 to 14.2 inches, with a mean for the period of 11.2 inches. However, the annual rainfall at particular points in the watershed during that period varied from 5.0 to 20.6 inches. The intense thunderstorm rainfall, from June through September, has varied over about the same range, being generally about 2 inches less than the total annual rainfall.

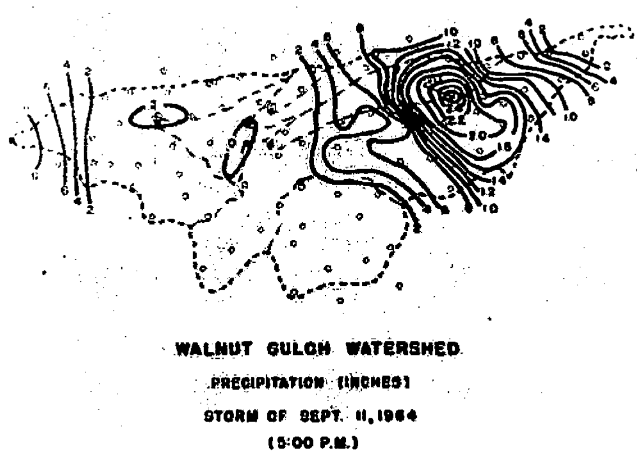

Fig. 5. Runoff-producing storms on semiarid watersheds are typically small-area, intense, summer thunderstorms. This storm produced runoff from about 1/3 of 58-sq.-mile Walnut Gulch Experimental Watershed, near Tombstone, Arizona.

The summer-season rainfall in any year varies widely in different parts of the watershed; and, while there may be a somewhat prevalent pattern, the distribution of rainfall has varied considerably from year to year, being dominated usually by a few, or even one, major storm (Figs. 6 and 7).

Thunderstorms may be centered anywhere on the watershed, or outside its borders; and the amounts and intensities of rainfall vary greatly within a distance of a mile or less. Two inches of rain falling at the storm center is fairly frequent. Generally the duration of runoff-producing intensities does not exceed about 20 minutes. A very rare incident was recorded on September 9, 1967, when 3.6 inches of rain fell in one storm at one of our gages. The high intensity rainfall in this case persisted for about 45 minutes. Even in this storm, however, the amount and intensity diminished greatly within a short distance from the storm center. Runoff probably occurred from less than a third of the watershed.

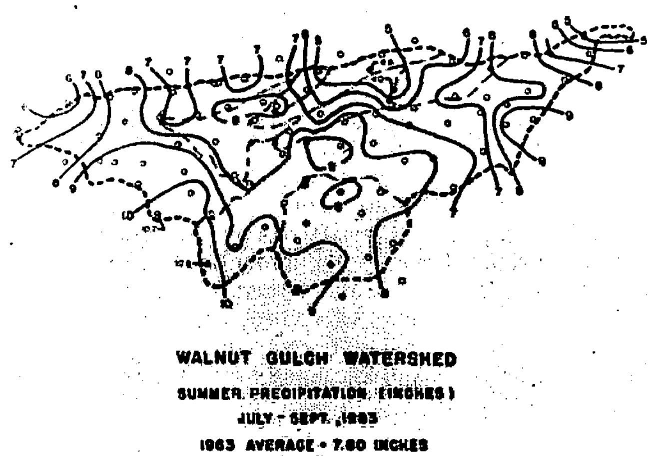

Fig. 6. Summer-season and annual precipitation on semiarid watersheds vary widely from place to place, as shown here within 58-sq. mile area.

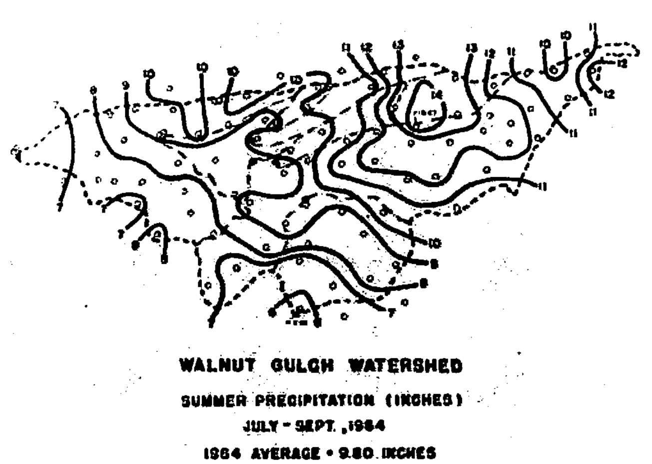

Fig. 7. Summer-season and annual precipitation distributions also vary widely from year to year. Compared with Fig 6, high rainfall areas in 1963 were low, and vice versa, in 1964.

Runoff from a storm covering only a portion of a semiarid watershed usually is substantially diminished, and frequently entirely lost, as a result of the water being absorbed into the ground as it moves sometimes for many miles through a dry channel system. The expectancy of net yield and of peak rates of runoff, per square mile of watershed area, are reduced as the watershed size increases. Exactly what these expectancies should be, enters into the engineering planning and design of any kind of water control or conservation structure; and is especially important for those involving large investment or possible hazard.

To study this transmission loss influence on the runoff reaching downstream points, we have divided the Walnut Gulch watershed into a number of smaller subwatersheds, and channel segments, to measure the flow of water at various points as it moves downstream. We now have there 11 large runoff-measuring stations which record the flows from various sized areas, ranging from about a square mile to the total of the 58-square-mile watershed (Figs. 8 and 9). Also, there are a number of smaller measuring stations for the study of areas ranging in size from small plots 6 x 12 feet up to several acres. Sediment load measurements are also made in the flows at various points in the channel system, with respect to the size and conditions of the drainage area.

Initial runoff from the point of rainfall, measured from 6- x 12-foot plots (Fig. 10), is on the order of 2-3 inches per year. However, the annual average runoff from the total 58-square-mile watershed has never reached an inch in 11 years of record, and has averaged about 0.3 inch. Some important findings of our research so far, have been the amounts of water that are actually lost in moving through the channel systems and some indications of how these are affected by the channel conditions, the sequence of flows, and other factors. We have found that the rate of loss depends greatly on antecedent moisture in the channels, on channel size and shape, on the nature of the bed and bank materials, and on the depth and duration of the flow. Loss rates measured in the channels on Walnut Gulch have been as high as 31 acre-feet per mile, abstracted from the runoff from a 36-square-mile portion of the watershed. We estimate, with higher flow, that loss in that particular channel reach could be as much as 75 acre-feet per mile. Such information is extremely important in estimating water yields for planning of downstream uses.

We are concerned also with what becomes of the water which is lost from the surface runoff. Our soil moisture studies show that none ever penetrates below the root zones, except along the stream channels, where the bed material is a coarse-textured deep alluvium, into which the water can penetrate rapidly to considerable depth. We have drilled a number of wells, to determine the nature and extent of water bearing substrata and to observe ground water levels. The objective is to determine subsurface flows and changes in the storage of ground water beneath the watershed. This past summer, an extensive seismic survey was also undertaken to determine the thickness and nature of ancient sediments covering the bedrock, which in some places is 1500-2000 feet deep. The seismic survey information will be used in planning of additional drilling exploration and measurement of groundwater levels.

Our studies so far indicate that of the water lost from channel flows, considerable amount percolates to some depth under ground, and that some of this eventually reaches the regional ground water. In some

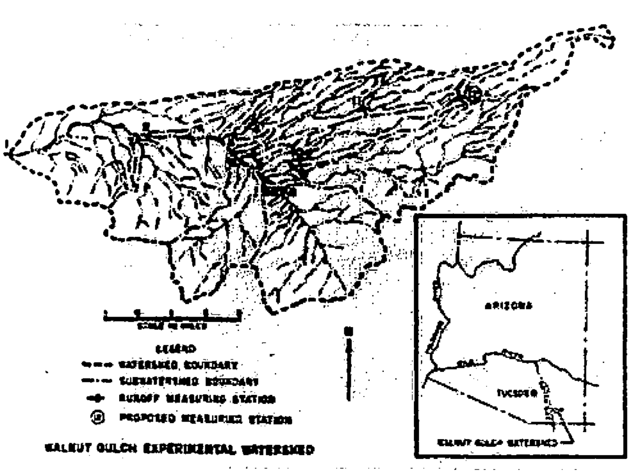

Fig. 8. Walnut Gulch Experimental Watershed is subdivided for separate measurement of runoff from various parts of the watershed and study of transmission losses in several stream segments. Eleven large measuring structures now on main channel system.

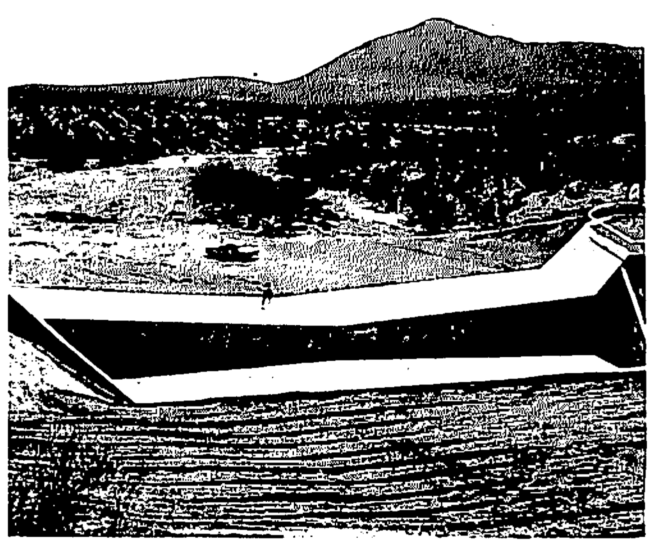

Fig. 9. Runoff measuring flume at outlet of 58-sq.-mile Walnut Gulch Experimental Watershed. 25,000 cu. ft./sec. capacity. Largest known precalibrated runoff-measuring structure in the U.S.

channel reaches, part of it flows laterally through the streambed gravels to reappear as surface flow downstream. However, geologic conditions along other channel reaches are such as to prevent percolation or underground flow, and here water lost from streamflows is retained in perched water tables near the surface for considerable lengths of time. Much of this water is consumed by riparian vegetation. (Fig. 11)

Where such geologic conditions exist, it may be possible to significantly increase the water yields of semiarid watersheds. Transmission losses might be reduced by control of the riparian growth; and it might even become feasible, under future economic conditions, to prevent these losses by sealing the channel beds and banks. Another possibility, and one probably more immediately feasible, would be the salvage of the water now being lost, for high-value local uses. For example, water from small, isolated shallow aquifers might be pumped for irrigation of grass nurseries, for production of the seed needed for range improvement.

Runoff transmission losses not only occur in the major channels, but may be substantial also in the very uppermost parts of the watershed. It is apparent from our measurements on the Walnut Gulch Experimental Watershed that much of the water which runs off from the points of rainfall is trapped in sediment deposits in the upland swales, where it is nonbeneficially consumed by brush and scrub trees. Also, it has been found that there is a significant difference in the amount and depth of penetration of water entering the soil between a ridgeline and points just a few hundred feet down the slope, indicating that water running off over the land surface contributes to the soil moisture as it moves down the hillside, and thus may be considerably diminished before it reaches even any minor channel.

This has an important bearing on the possibilities for applying range improvement and conservation practices without adverse effects on downstream water supplies. Range treatment measures which might retain on the land, for improved forage production, some part of the rainfall which would otherwise run off, but which would not in any case reach a major stream, would have no effect on downstream water supplies.

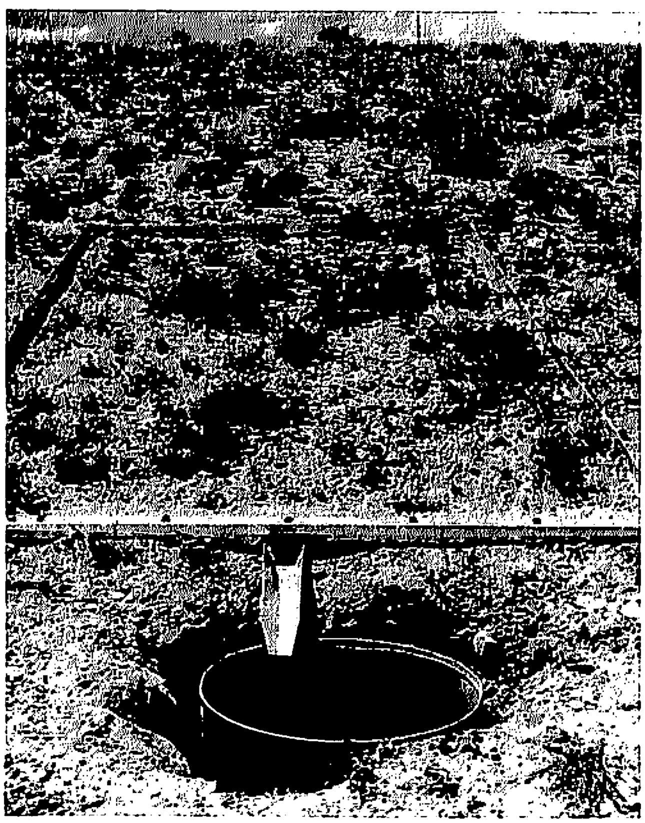

Fig. 10. Initial runoff at rain site is indicated by measurements from small plots. Generally reduced about 80% enroute to a major stream.

Fig. 11. Studies on Walnut Gulch Experimental Watershed to determine final disposition of water abstracted from the runoff in moving through channel system, including nonbeneficial consumption by riparian vegetation.

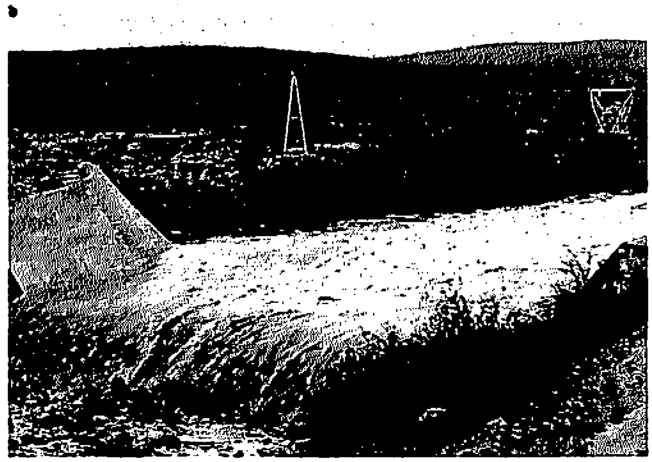

Fig. 12. Sampling runoff for sediment load determination at Flume 6, Walnut Gulch Experimental Watershed. Men on cableway are operating suspended sampler.

It appears that considerable benefit to forage production might derive from measures designed to merely attain a more uniform distribution of that water which is now being abstracted from the runoff in the headwaters areas, and consumed there.

Our studies are pointed primarily to evaluation of water yield potentials of semiarid watersheds for planning water utilization improvements. However, they are also providing some needed information for planning runoff control and upstream watershed protection measures. Probably because very few such measurements have heretofore been available, our records indicate some surprisingly high discharge rates for small watersheds (in a size range such that an intense thunderstorm may be centered to cover all or most of their area). Very soon after building a runoff-measuring flume at the outlet of an approximately 3-square-mile, dominantly grassed watershed, we recorded a flow that peaked at approximately 1700 c.f.s. per square mile. This is a much higher discharge per unit-area than has been commonly used in engineering design of small upstream water-handling structures.

In our studies on the Walnut Gulch watershed, we are attempting also to determine how much and what factors affect the amounts and kinds of sediments being transported out of semiarid watersheds into major streams (Fig. 12). Today, only rough estimates are possible of the amount of sediment storage needed, in determining the feasibility and designing of reservoirs. From our limited information to date, we believe that in some cases these estimates have been substantially incorrect. This may be particularly true with respect to the heavier fractions of sediments which are not carried by suspension in the water, but slide and skip along on the streambeds. There has been very little field measurement of this bed-load fraction of the sediment in transport, and it is generally estimated empirically in relation to the measured suspended fractions. We believe the bed-load materials may be a much higher portion of the total sediment transported by small southwestern streams than has been generally estimated. We have for several years been carrying on a considerable program of suspended sediment measurement in the flows on the Walnut Gulch watershed. And this year, we have started a program also to get some actual measurements on the bed-load.

It is very important to consider the interrelation of erosion and sediment movement in semiarid watersheds and their yields of water. As storm flows are diminished by transmission losses in moving through the channel systems, the concentration of their sediment loads increases and deposition takes place. The more numerous small flows deposit sediments, some of which are later picked up and moved downstream by the less frequent larger flows. The deposits left in the channel system in this stepwise movement of sediments have a capacity for soaking up large amounts of water. Much of this water is lost to any beneficial use, being consumed by brush and trees.

Not only is the water yield of the semiarid watersheds themselves greatly affected by sediment deposition in their channels, but their sediments also have additional effect on the major streams into which they flow. There the sediments tend to be deposited at the inlets of reservoirs, from which point they build back upstream, eventually clogging the channels for many miles above the reservoirs. These depositions upstream from reservoirs produce ideal conditions for the growth of salt cedar, as has occurred on a tremendous scale in the Middle Rio Grande Valley above the Elephant Butte reservoir, and above the San Carlos reservoir in Arizona. So it is not only from the standpoint of sediments robbing storage space from reservoirs, and sediment moving into distribution canal systems, that water-users must be concerned. A large part of the water loss sustained by the streams supplying their reservoirs is also directly related to the sediment that is being carried into, and transported by, those streams. Thus, we see that control of erosion and sediment movement into tributary stream channels from semiarid watersheds is of great importance to sustained downstream water supplies, as well as to the sustained capability of the semiarid rangelands to produce forage.

In summary, our studies on the Walnut Gulch Experimental Watershed have produced considerable information on the basic hydrologic factors and interrelated processes involved in water management on semiarid watersheds, and have helped to define overall limits that prevail in the relationships between rangeland conservation and the availability of water for downstream uses. We have learned of possibilities for (and are working now to more precisely evaluate the potential and feasibility for) increased utilization of the water from such watersheds. And, although some of the things that we might think of, and try in our research, for better local water utilization or to increase the yield of water for downstream uses from semiarid rangelands, would not *today* be economically feasible; some may prove highly feasible by the year 2000, or even possibly by the year 1980. We do not know now, for example, if weather modification may in the future increase the rainfall of the present semiarid zones. However, some of the research we are now doing on the Walnut Gulch Experimental Watershed will provide needed answers regarding the economic feasibility of weather modification as it might relate to areas of Arizona which now receive rainfall adequate only for limited production of either forage or water. It will also give answers to some questions about what effect additional rainfall might have on the erosion and sediment problems of those areas.

Although some of our research considers future possibilities, our main concern is with today's problems—with the present climate and the existing economy. We need to learn to make the best possible use of the total resources of our semiarid watershed lands, and to also preserve their potentials for *future* production of both forage and water.