CONTRIBUTION TO REGIONAL WATER TABLE FROM TRANSMISSION LOSSES OF EPHEMERAL STREAMBEDS

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WALNUT Gulch experimental watershed is a 58-sq-mile outdoor hydrologic laboratory operated by the Agricultural Research Service (USDA). Many interrelated phases of hydrologic research are being carried on simultaneously. The major projects include flood runoff, sedimentation, and net water-yield studies, as these are influenced by precipitation characteristics, vegetation, soils, land use, and geology. An important part of the research is a study of streamflow losses and their relation to ground-water conditions in the region.

The watershed is located in southeastern Arizona near Tombstone (Fig. 1), in basin and range topography typical of the Southwest. Elevations of mountains on the watershed range to 6,000 ft above sea level. The lowest point on the watershed is approximately 4,000 ft at flume No. 1, the watershed outlet. Terrace deposits form the major portion of the watershed. The terraces are deep. Exploratory drilling and seismic exploration by several mining companies place the depth of the alluvium at a maximum of 1200-1600 ft in the central part of the watershed.

Approximately 70 percent of the total annual precipitation for Walnut Gulch watershed occurs as summer (July, August, September) convective thunderstorms. These small-area cellular storms are often very intense, ranging up to 10 to 12 in. per hr for a 5-min duration (1)*. Heavy runoff results from these high-intensity, short-duration storms, producing flash flows over the dry channel beds. These flows are measured at various locations along the main channel of Walnut Gulch with precalibrated supercritical-depth flumes (2, 3).

Comparisons of the runoff records at tandem measuring stations for events, during which there is no tributary inflow, show large runoff volume reductions which are called transmission losses. Although losses of 50 acre-ft per mile of dry stream bed traversed have been observed (4), higher loss rates may occur for the most favorable combination of conditions (5). The disposition of these runoff transmission losses becomes a very important consideration in evaluating the total water yield of semiarid watersheds in the southwestern United States.

GEOLOGY AND ITS EFFECT ON GROUND WATER RECHARGE

Due to the extreme depths and lack of exploratory data, the exact age of the terrace deposits in the Walnut Gulch area is not known. At shallow depths in many places on the water shed, older alluvium is known to underlie more recent gravels and (younger) alluvial fill material. Very little difference in composition has been noted between the older and younger aluvium. The degree of cementation of the conglomerate beds located within the alluvial fill is one possible exception, with some of the older beds being more strongly cemented than the more recent material. The greater degree of cementation greatly restricts vertical moisture movement, thereby limiting potential ground-water recharge.

The terraces are composed of a variety of gravels, sand beds, silt and clay layers, and "caliche" conglomerates. The conglomerates range from gravel and cobble beds, loosely held together with sand, to very hard beds of poorly sorted gravels cemented with carbonates (mainly CaCO3). Particle size in these beds ranges from clay to boulders up to 3 to 4 ft in diameter.

For purposes of this report, the whole alluvial body is considered as a homogeneous body. In reality, it is composed of many lenses and layers of greatly varying composition and size. Therefore, data obtained will be average values.

Walnut Gulch meanders through this alluvial material for its entire length, being forced to alter its path near the edge of the town of Tombstone by an intrusion of Schieffelin granodiorite, which forms the southern bank of the stream for some 1¼ miles. Upstream from this, the stream follows the strike of a large normal fault for 1¼ miles. Displacement of the fault is not known, although it is believed to be greater than 1,000 ft.

Aside from these restrictive factors, the stream channel meanders for approximately 5 miles until reaching the San Pedro River at Fairbank, Arizona.

Surface and subsurface geology must be known to understand underground water movement. Stratigraphic changes, amount of clay present, and degree of cementation of the conglomerates all affect subsurface water movement. In this study, interest is centered mainly on the actual channel of Walnut Gulch;
FIG. 2 Isohyetal map of Walnut Gulch watershed in Arizona for storm of August 10, 1963. (Figures represent precipitation in in.)

hence, the major portion of geologic exploratory work has been near the channel and the area directly beneath it.

Transmission Losses as a Source of Recharge

An example of an event for which transmission losses were computed is shown by the storm of August 10, 1963. The isohyetal map (Fig. 2) for this event reveals a thunderstorm centered over the watershed. Of the 1.58 in. of rainfall which fell near the storm center during this event, 1.43 in. occurred in 57 min with 0.75 in. of this amount occurring in 12 minutes, causing a large amount of surface runoff. Runoff hydrographs for flumes 1 and 2 for this storm are shown in Fig. 3. The records for these two measuring stations which are located in the lower portion of the watershed illustrate a runoff event with large transmission losses.

The runoff volume of 73.9 acre-ft which passed flume 2 was nearly all absorbed by the 4.0-mile length of stream bed before reaching the watershed outlet at flume 1. The peak discharge of 840 cfs at flume 2 was reduced to only 240 cfs at flume 1. The 16.5-acre-ft-per-mile loss rate represents an average infiltration rate of 3.5 in. per hr. Infiltration rates in excess of 4 in. per hr have been observed for other events in this channel reach. These volumes are considerably greater than those reported by Babcock and Cushing (6) for Queen Creek in central Arizona.

Transmission losses from flow events, such as the example just described, are a primary source of ground-water recharge in the southwestern United States. Direct recharge through the soil profile is almost nonexistent because of the high potential evaporation and low precipitation. Soil moisture measurements on the Walnut Gulch area indicate maximum penetration to depths of only 3 to 5 ft, except in areas where

runoff is concentrated, such as the grass swales of small watersheds.

On areas draining less than 1 sq mile, an average of only six flow events occur each year, and the duration of flow for any event seldom exceeds 1 hr. Infiltration in the smaller tributary watershed channels is limited, primarily because of the infrequency of the runoff events. During the 10-yr period of record at flume 1, the number of flow events has varied from 2 to 18 annually. It is likely that the major portion of ground-water recharge occurs beneath the main stem of Walnut Gulch.

Using the double-tube method (7, 8), hydraulic conductive measurements were made in the channel alluvium near flume 1. With such measurements, it might be possible to determine order of magnitude of transmission losses in the channels of other watersheds with varying bed material. The particles comprising the bed material near the outlet of Walnut Gulch exhibit a logarithmic normal distribution with a geometric mean grain size of 0.5 mm. Of the total material, more than 30 percent is in the gravel range (> 2.0 mm). Because of the coarseness of the alluvium, it was difficult to maintain a seal during the tests between the inner and outer tubes of the hydraulic conductivity apparatus. The conductivity of the alluvium in this area was indicated to be at least 49 in. per hr for clear water.

Matlock (9) showed that infiltration in a stream bed decreased with time owing to sealing effects of fine sediment suspended in the flow. The infiltration curves from his flume studies had a shape similar to a soil infiltration curve that might be developed with an infiltrometer. This sealing effect may largely explain why the infiltration rates observed during actual runoff events on Walnut Gulch are lower than those obtained with the double-tube infiltrometer with clear water. The sealing effect reported by Matlock may also serve to explain the existence of the clay layers in the alluvium. The clay deposited near the surface is undoubtedly disturbed by the streambed scours of larger flow events, thereby creating a well-graded material on the surface of the stream bed.

Ground-Water Fluctuations

Using known relationships between infiltration in the channel for various antecedent moisture conditions and the peak discharge at the watershed outlet, the total annual amount of water absorbed by the channel alluvium in the vicinity of well No. 36 (located in the channel upstream from flume 1) was estimated. The estimated infiltration is shown, along with the water level in well No. 36, in Figs. 4, 5, and 6 for 1963, 1964, and 1965. The surface infiltration of 80 in. (including direct precipitation during the period) in 1963 was associated with a ground-
water rise of approximately 18 ft in the well. The estimated 83 inches of infiltration in 1964 appeared to produce nearly a 60-ft rise, and the 20 in. of infiltration in 1965 did not cause a water-level fluctuation. The small difference in infiltration between 1963 and 1964 has caused a large difference in the water-level rise. However, in the winter of 1963 and the spring of 1964, a precalibrated runoff-measuring flume was constructed to replace the older measuring station. The upstream cutoff wall of this flume extends into a conglomerate at depths of up to 20 ft, and may cause ponding of the water in the alluvium immediately above the flume. It may also limit axial flow above the clay layers during wet periods, and may explain the high ground-water rise in 1964. This cutoff wall may serve to create a type of artificial recharge mechanism by concentrating the transmission loss water in the area. More investigation is needed to unravel the complexities of the recharge mechanism in this area.

**Geologic Description of Well Test Areas**

The rapid rise and fall of the observation well in the channel following the 1963 and 1964 runoff seasons indicated that the material of the channel in this area probably had transmissivity much higher than the aquifer bed material. For this reason, geologic investigations were undertaken to determine the nature of the aquifer materials.

The area selected for the pumping test is at the lower extremity of the watershed. Here the Walnut Gulch stream channel is a wide (500 to 3000 ft) meandering stream bed (Fig. 7) with many small islands and an irregular cross section. Various small channels, caused by flows of differing magnitudes, are formed within the main channel.

An old meander loop is the main structural feature of the area. This ancient waterway has now been cut off from the main stem of Walnut Gulch, but the deeply dissected channel remains. The present-day channel has cut down enough so that no water flows through the loop, except at very high discharges, but some seepage from underground flow in the main channel may enter the loop. An observation well drilled downstream, where the loop re-enters the channel, indicated a slight amount of water at 40 ft being held up by a 1 1/2 to 2-ft layer of red clay. A small amount of free water was encountered at this depth, but was lost as the drill punctured the clay layer. Adequate information is not presently available to know whether the clay lenses are discontinuous or whether each lens causes a perched water table during periods when the transmission-loss water is moving downward toward the regional water table.

A pumping test was conducted in April 1966 to determine the transmissibility of the aquifer at the lower end of the watershed. The site chosen for the test was at the watershed outlet, just above flume No. 1, and approximately 400 ft from the main channel of Walnut Gulch. The wells were placed as follows: observation well No. 36 was drilled in the channel of Walnut Gulch; well No. 40 was 500 ft from the channel on a line normal to the channel. Well No. 75, the well to be pumped, was located 75 ft from well No. 40, and in line with well No. 36 (Fig. 7). The observation wells were drilled with a rotary drill by the mud circulation method. Holes were 3 in. in diameter and cased with 1 1/2 or 2-in. pipe welded into a continuous casing. The pipe was slotted from water level to the bottom of the holes. All holes were drilled into bedrock. The wells were then flushed by forcing clear water down the casing and the drilling mud up the wells outside the pipe. Wells were flushed until the water circulated was clear.

The well to be pumped was drilled by standard percussion or cable drilling rig. A 10-in.-diameter hole was drilled 60 ft and casing set in the well, with the casing slotted from the water level at a depth of 156 ft downward to 200 ft (Fig. 8).

The pump used for the test was a 3/4-hp submersible pump. The pump screen was set at 182 ft from the top of the well casing. Keck† water-sensing devices were installed in both observation wells and the pumping well. The pumping well was drawn down to 182 ft, at which depth the flow into the well was equal to the pumping rate; thus, the water level remained at this depth for the duration of the pumping. After 14 hrs of continuous pumping, at a rate of 8 gpm, no measurable change was noted in the observation wells (well No. 36 was 400 ft from the pumped well and well No. 40 was 75 ft from the pumped well). Therefore, the well was allowed to recover completely, then drawn down to 182 ft. Pumping was stopped and the recovery rate observed (Fig. 9).

With no prior work done on ground water in this area, and this being the first pumping test, capacities of the aquifers were difficult to estimate. It is believed, however, that the failure of observation well No. 40 to react was due to plugging of the area immediately surrounding the well by drilling

† Trade names are used to provide specific information for readers and do not imply endorsement by the USDA.

**Figures**

- **Fig. 4** Water-level record (1963) for observation well at flume No. 1 (Walnut Gulch experimental watershed in Arizona) and estimated channel infiltration.
- **Fig. 5** Water-level record (1964) for observation well at flume No. 1 (Walnut Gulch experimental watershed in Arizona) and estimated channel infiltration.
- **Fig. 6** Water-level record (1965) for observation well at flume No. 1 (Walnut Gulch experimental watershed in Arizona) and estimated channel infiltration.
mud. All sand and gravel beds were effectively sealed off by heavy drilling mud to prevent the hole from caving during drilling. A high-pressure pump forces the bentonite clay mixture into the walls of the drill hole for varying distances during drillings, depending upon the characteristics of the strata. This mud is extremely difficult to remove. Time did not permit cleaning the well again. Therefore, time-recovery data were taken from the pumping well.

From the data obtained, the specific capacity of the well was determined to be 0.30. Using the Jacob formula:

$$T = \frac{264 Q}{\Delta h'}$$

where

- $T$ = transmissibility (gpd per ft of width)
- $Q$ = aquifer pumping rate (gpm)
- $\Delta h'$ = change in residual drawdown for one log cycle (Fig. 8)

The aquifer transmissibility was found to be 60 gal per day per ft of aquifer width. Permeability was computed ($P = T/m$), where $m$ is aquifer thickness in feet, to be 2.51 gal per day per sq ft.

From the permeability figures obtained from the time-recovery data, the test well area must be classified as a poor aquifer, using the Todd designation (10). This would seem to be in sharp contrast to the actual channel bed of Walnut Gulch, where surface sands and gravels are porous and coarse enough to allow a substantial amount of water to infiltrate. With the test well area being 400 to 500 ft from the channel, this would indicate that gravel beds are not continuous from the channel outward (Fig. 7). It would seem that Walnut Gulch had cut deeply into the conglomerate during the earlier stages of the stream's life, then filled the trough with a porous mixture of sand and gravel in later years. This would provide a very permeability conduit of channel aggregate beneath the present-day stream bed, with limited lateral extent.

The impermeable conglomerates in most sections of the stream channel form a trough which effectively contains water from flow events. As the channel aggregate becomes saturated from summer flows, a subsurface flow slowly proceeds down the channel axis. In some areas where discontinuities exist in the conglomerate beds below the channel, the water percolates downward to the regional water table.

**Conclusions**

Well records for 1963-65 indicate an annual increase of subsurface water beneath the stream bed of Walnut Gulch if sufficient flow events are produced by summer precipitation. The years 1963 and 1964 produced enough flow events from summer storms to produce this underground movement of water in the channel. Flows were heavy and closely spaced during July and August and were sufficiently large to saturate the channel alluvium. In 1965, only one major flow event was recorded, with the rest of the summer precipitation coming in the form of small, less intense storms. This one moderate-sized flow was not enough to saturate the channel alluvium to the extent that a subsurface movement of water could be started.

The big difference in the observed rise in the wells between 1963 and 1964 indicates a possible means of increasing ground-water recharge in ephemeral stream beds similar to Walnut Gulch. The impermeable cutoff wall associated with the measuring structure at the watershed outlet seems to have increased recharge in the area immediately upstream. The effect of the cutoff wall on recharge downstream from the structure remains to be determined. Construction of a cutoff wall across the channel flush with the channel surface and extending down to an

![FIG. 7 Schematic drawing of cross section at the watershed outlet.](image)

![FIG. 8 Drilling log for well No. 73, 10-in. hole, 6-in. casing (200 ft).](image)

![FIG. 9 Walnut Gulch watershed time-recovery curve for well No. 73.](image)
impermeable stratum would be a possible means of greatly increasing the ground-water recharge upstream from the wall.

References