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27

Performance of Local Aquifers as Influenced by Stream Transmission Losses and Riparian Vegetation

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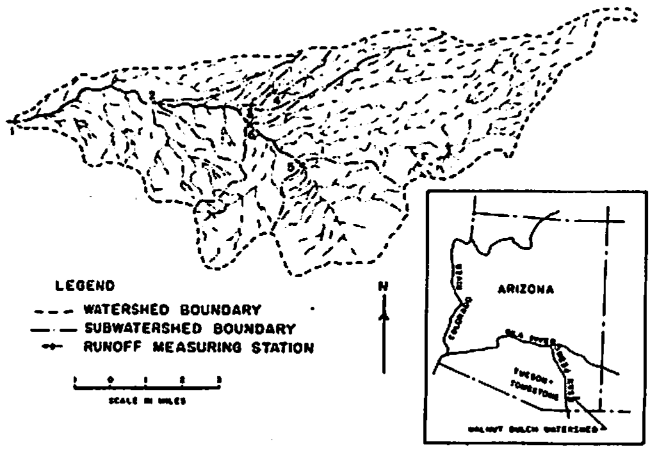

FIG. 1 Experimental watershed drained by Walnut Gulch.

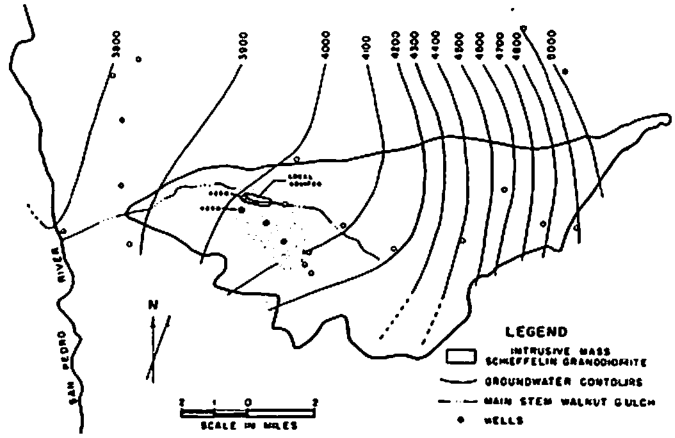

FIG. 2 Ground-water elevations, Walnut Gulch watershed.

IN THE semiarid regions of the southwestern United States, local, unconfined aquifers of limited extent are important sources of domestic and stock water for ranchers. Recharge of many of these aquifers results from absorption of surface runoff by coarse-textured alluvium in ephemeral stream beds. These aquifers may be grouped into two classes: the perched and the alluvial pocket aquifer. The perched aquifer has vertical occlusion from the regional water table. The alluvial pocket aquifer is found overlying the undulating surface of an igneous mass, and is occluded both vertically and horizontally from the regional water table. This paper discusses a local aquifer of the latter type located on the Walnut Gulch Experimental Watershed at Tombstone, Ariz.

The 58-square-mile experimental area is drained by Walnut Gulch, an ephemeral stream entering the San Pedro River at Fairbank, Ariz. (Fig. 1). The area is representative of mixed brush-grass rangelands of southeastern Arizona and southwestern New Mexico. Altitudes above mean sea level range from 4,200 ft at the lowest gaging station to 6,000 ft at the upper end. Nearly all of the streamflow occurs between July and early October, and results from intense, convective thunderstorms. During an average year, five to ten flows pass most of the gaging stations. However, the flows usually traverse dry channel beds, where they are often completely absorbed (1)*.

Regional Ground Water

Contours of the regional ground-water level under the experimental area and its immediate vicinity were constructed from measurements made over a period of several months in existing wells (Fig. 2). Positions of the measured wells are shown in the figure. Erratic spacing of the wells made extrapolation of the contours necessary. As shown by these contours, gradients of the ground-water level vary from 2.5 percent at the upper end of the watershed to less than 1 percent near the San Pedro River, thus indicating a general movement of ground water toward the river. Approximate water levels of local aquifers, as determined from measurements in two wells, are also given in Fig. 2. Although these wells are but 1,500 ft apart, they are situated adjacent to different channels and are separated by a geological barrier. In the early days of the city of Tombstone (about 1880), one of these wells served as the primary source of water for a population of several thousand people.

Geological Description of Local Aquifer

A series of alluvium-filled troughs lying on an undulating granodiorite plug characterizes the local aquifer under discussion. The aquifer occupies an area on both sides of the channel for a distance of about 3,000 ft upstream from runoff-measuring flume No. 2, which is founded on the granodiorite (Fig. 3). As one trough fills, water spills into the next lower one. Thus, depending upon the interval of times between flows, the water surface of the aquifer is continuous or discontinuous.

The area has two distinct materials: the Tertiary Schieffelin Granodiorite (2) and the overlying alluvium. The alluvium includes fine-grained sand and silt, a limey conglomerate, and the coarse sands and gravels of the channel bed.

Tertiary Schieffelin Granodiorite. Outcrops of the Schieffelin Granodiorite in this area form a series of hills. A pronounced characteristic of these hills, accentuating the subdued topography of rises and troughs (Fig. 4), is a covering of rounded boulders. Owing to the ease with which this rock weathers to a sand, the exposed surface of these boulders is very friable.

Alluvium overlying the granodiorite – conglomerate. Conglomerate overlies the granodiorite with unconformable contacts. In the area under discussion, the unconformity may be observed along the banks of Walnut Gulch. The most distinctive outcrops of conglomerate occur along the stream channel, although nowhere in this reach has a complete section been observed. Away from the channel, the surface is characterized by cobble-strewn boulders. Owing to the undulating topography of the underlying granodiorite, thickness of the conglomerate varies.

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* Numbers in parentheses refer to the appended references.

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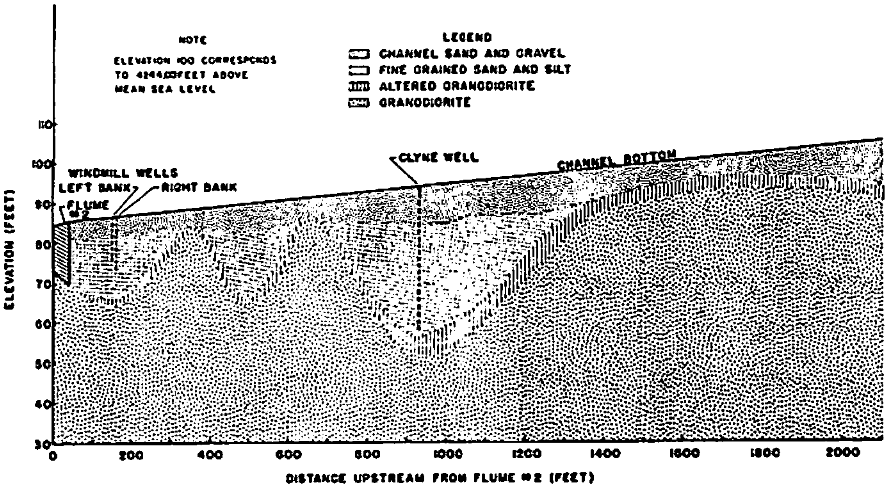

FIG. 3 Schematic longitudinal section along channel center line.

Fine-grained sand and silt. This material lies in troughs of the granodiorite where the local aquifer occurs (Fig. 3). Soil development on it is deeper than that on other parent materials of the area. Where these fine materials are traversed by a stream channel, the banks have steep faces, and lateral erosion of the banks is rapid. This erosion occurs principally during and immediately after a flow in the channel; the flow undercuts the bank, and the overhanging bank falls into the channel bed.

Channel sand and gravel. Depth of sand and gravel deposits in this reach of channel varies from 6 to 30 ft. Mechanical analysis of samples from this bed material revealed a wide range of particle sizes. Twenty-seven percent by weight was retained on a No. 4 sieve (4.7 mm); 94 percent on a No. 100 sieve (0.146 mm). Plotted on logarithmetic probability paper, these sieve-analysis data fell on a straight line, indicating a close approximation to a log-normal distribution of particle size. Geometric mean grain size, deduced graphically, was 2.7 mm. The geometric standard deviation of ±6.86 mm indicates a wide range in particle size.

Vegetation

Areas underlain by local aquifers are characterized by a cover of more mesic vegetation than that of the upland (Fig. 5). The dominant species of this cover is mesquite (*Prosopis juliflora* var. *velutina*). During dry periods, this mesquite, in contrast to the desert shrubs of the upland, remains green, thus sharply delineating the area. Growing along the channel, besides mesquite, are cottonwood, Arizona walnut, and seep willow. Dominant vegetation on the upland in this area is whitethorn, creosotebush, and tarbush.

Local Water Table Performance

General. As a flash flow moves over the dry alluvium of the channel system, large amounts of water are absorbed. Transmission losses of 25 acre-feet per mile of channel traversed have been measured in Walnut Gulch, and estimates of channel geometry and volume of alluvium indicate that they may be expected to approach 80 acre-feet per mile during a single large flow (1). Disposition of this water becomes an important consideration in the hydrology of the watershed.

From measurements in 17 observation holes, contours were constructed showing water levels of the local aquifer upstream from flume No. 2 for July 17 and September 5, 1962 (Fig. 6). The contours for July 17 represent the condition after 309 days without surface runoff; those for September 5 show the condition after the summer runoff season, the latest flow of which occurred the preceding day.

The July contours indicate that, except for a small depression in the subtending granodiorite, the water table had disappeared from the upper part of the area. Green leaves on the mesquite, however, contrasted with the still dormant condition of adjacent upland vegetation, showed that soil moisture was still available even here. In the area nearer the flume, the water table still persisted, and the contours indicate a hydraulic gradient and a consequent movement of water across two submerged granodiorite barriers (Figs. 3 and 4). Some water, also, may be leaking through fractures in the underlying granodiorite.

After a series of flows in the channel, as illustrated by the September contours, the water table reaches the channel surface in many places, and the gradient coincides with that of the channel. This condition results in the mounding of the water table immediately below the channel, which is typical of an influent stream. Piezometer measurements show that this is followed by gradual change to a condition in which the level is higher in the adjacent banks than it is in the channel. Two factors probably contribute to this change: (a) because of lower permeability of the bank materials, water movement down the gradient is less rapid than it is in the coarse-textured channel fill; and (b) since the water level is nearer the ground surface in the channel, direct evaporation is higher.

Subsurface inflow to natural lysimeter. A natural lysimeter supporting a cover of mesquite is formed by the deepest of the troughs in the granodiorite which underlies the channel (Fig. 4). Located in this trough is a dug well – Clyne's well (Fig. 3 and 4), from which continuous water-level records have been taken since 1954. The high permeability characteristic of the aquifer produces a rapid rise in the water level in this well following a surface flow event (Fig. 7). The rise continues at a diminishing rate after the surface event has stopped. This would indicate that subsurface flow into the Clyne well is occurring.

To determine this subsurface flow, two parallel rows of trough holes were drilled at right angles to the channel. These rows of holes are approximately 300 ft apart in the direction of flow. The hydraulic gradient between the two rows of holes was determined, and

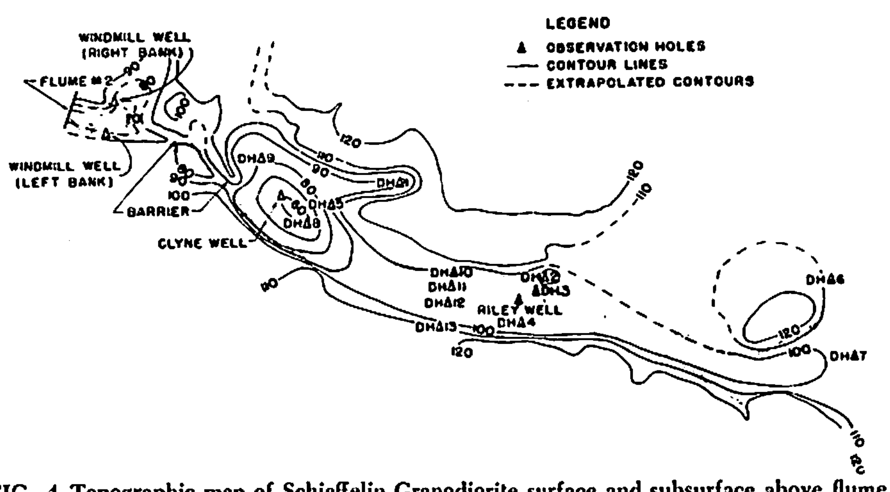

FIG. 4 Topographic map of Schieffelin Granodiorite surface and subsurface above flume No. 2, Walnut Gulch watershed.

the cross sectional area at the downstream line of holes was computed. Subsurface flow was computed by means means of Darcy's equation:

$Q = PIA$

where Q is discharge, gallons per day

P is permeability, gallons per day per square foot

I is hydraulic gradient, feet per foot

A is cross sectional area, square feet

Determination of a permeability coefficient for this calculation presented difficulty. Because of boundary conditions and variability of particle size, pump tests were impracticable. Permeameter tests of the channel surface material were run with a soil test apparatus, and coefficients ranging from 200 to 3,000 gal per day per square foot were obtained, a variation probably attributable to extremely wide variations in the channel materials. Comparison of data on particle-size distribution in the material encountered in these tests with data presented by Wenzel and Fishel (3), who compare particle-size distribution with associated permeability, indicated that permeability coefficients ranging from 3,000 to 4,000 gal per day per square foot might be expected. One of the four tests gave a coefficient of 2,000 gal per day per square foot; another, one of 3,000 gal per day per square foot.

The permeability coefficient for the finer-grained material adjacent to the channel was estimated through consideration of an unusual event that occurred in August 1961 at the Clyne well. Local runoff from an intense thunderstorm entered this dug well and raised the water level 5.2 ft in 25 minutes. From the time required for recession of this rise, permeability was computed by two different methods: the auger-hole method of Ernst (4) and Chow's method for solving the nonequilibrium equation for flow in an unconfined aquifer (5). By the former method, the permeability coefficient was 80 gal per day per square foot; by the latter, it was 115 gal per day per square foot.

Using Darcy's equation, subdividing the aquifer section and estimating permeability values for the subsections, daily values of subsurface flow for the period August 8 to September 11, 1962, were computed as follows:

$$Q_{daily} = P_1I_1A_1 + P_2I_2A_2 + \dots + P_nI_nA_n$$

During the period shown in Fig. 8, the computed flow decreased from 0.051 acre-foot per day on August 8 to 0.029 acre-foot per day on September 4. Just after the September 4 measurements were made, a surface flow in the channel recharged the aquifer, and the computed amount of subsurface flow rose sharply to 0.046 acre-foot per day. Thus it is seen that subsurface flow provides a significant amount of recharge to the pocket in which the Clyne well is located, and must be considered in a water balance for the lysimeter.

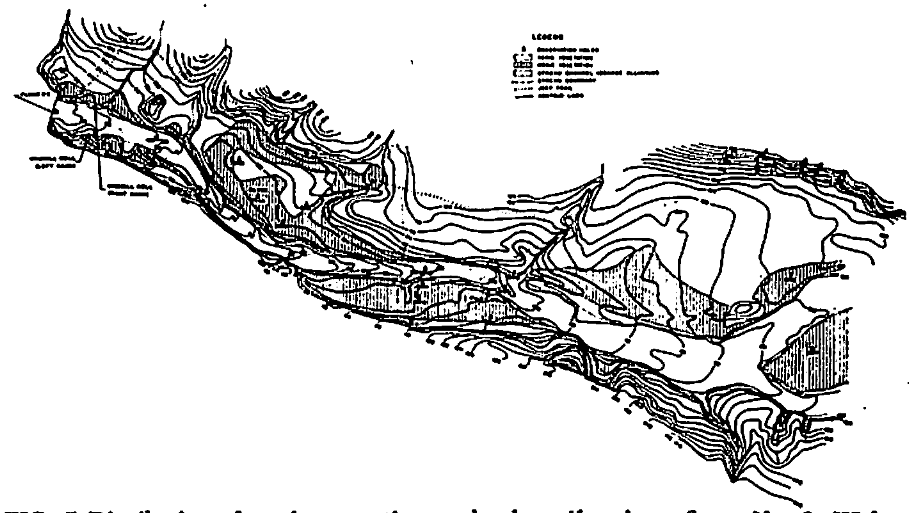

FIG. 5 Distribution of mesic vegetation on local aquifer above flume No. 2, Walnut Gulch watershed.

Subsurface outflow from the natural lysimeter. When the water level in the lysimeter, as reflected by the Clyne well water elevation, stays above elevation 92 for any length of time, a low sustained flow passes through the flume No. 2. The elevation of the invert of the flume is 85.5 ft above the datum level. Amounts of this surface flow through the flume during 1962 are given in the following table:

Base Flow – Walnut Gulch Flume No. 2 (1962)

Month	Volume, Acre Feet
July	0.560
August	0.470
September	0.018
October	0.010
November	0.005 (est.)

During the period (August 8 to September 4), in which subsurface inflow to the lysimeter varied between 0.051 and 0.029 acre-foot per day, the outflow from the lysimeter varied from 0.012 acre-foot per day to zero. This difference between inflow and outflow reflects changes in storage in the lysimeter and evapotranspiration.

Evapotranspiration from natural lysimeter. A four-year record at the Clyne well has shown an average decline in the water surface of 0.05 ft per day during May, June, and July, when the mesic vegetation was growing vigorously but before the beginning of the runoff season. In contrast, drawdown when the vegetation was dormant has averaged 0.01 ft per day. From these data, it is concluded that much of the water in this lysimeter is dissipated by evapotranspiration.

Diurnal variations in Clyne well. Diurnal variations of water level in the Clyne well have been observed for various periods, one of which – June 1 and 2, 1962 – is illustrated in Fig. 9. Drawdown, totaling 0.08 ft, began about 7:00 a.m., with the onset of heavy transpiration, and continued until about 7:00 p.m. The slight recovery between 3:00 and 6:00 p.m., June 2, corresponded with observed scattered clouds. This cloud cover can also be seen from the air temperature drop during the corresponding period. Recovery of 0.04 ft in the water level is attributed to water movement from surrounding areas in the aquifer, where the mesquite cover is not so dense as it is immediately adjacent to the well.

Summary and Conclusions

Local aquifers are important sources of water in the semiarid rangeland

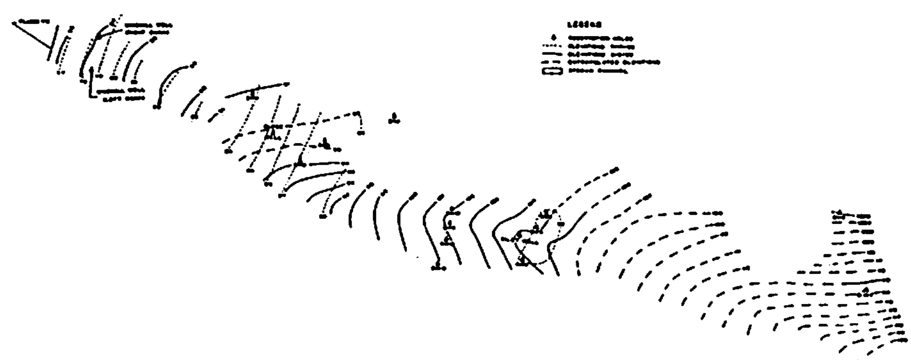

FIG. 6 Ground-water elevations of local aquifer above flume No. 2, Walnut Gulch watershed.

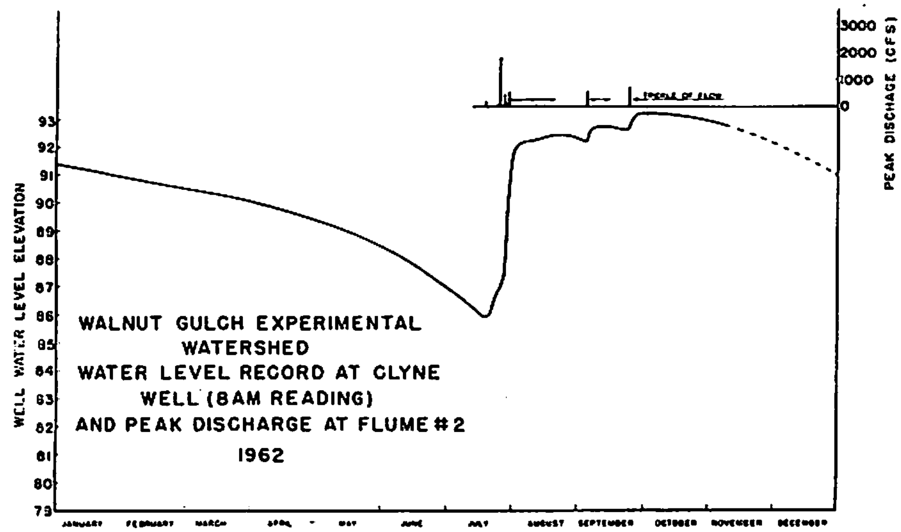

FIG. 7 Water-level record (1962) at Clyne well (8:00 a.m. reading) and peak discharge at flume No. 2 (Walnut Gulch experimental watershed).

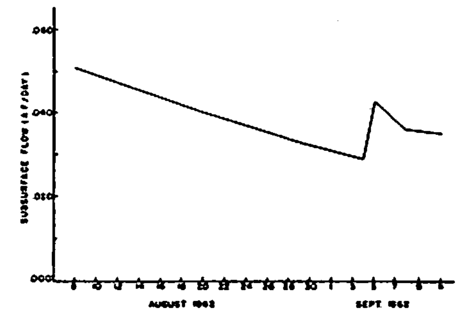

FIG. 8 Subsurface flow at geologic constriction above Clyne well.

areas of the Southwest. Recharge of these aquifers results mainly from stream transmission losses as reflected by the ground-water contours prior to and following a runoff event. Although recharge from direct precipitation has been experienced in the aquifer, the small increases in the water-surface elevation are insignificant when compared to those resulting from surface flow events.

Reduction of the riparian vegetation (in this case predominantly mesquite) should substantially increase the amount of water available for beneficial uses. The ratio of the decline in water surface during the growing season when compared to the dormant season is five to one.

When impervious material underlies the channel alluvium, lateral subsurface movement of water down the channel

FIG. 9 Clyne well, Walnut Gulch experimental watershed.

axis contributes to the storage in these aquifers. This explains the prolonged period of increasing water levels observed for several days following a surface runoff event.

Continuation and expansion of this phase of watershed research in the Southwest is expected to lead to better assessment of both the hydrologic and economic significance of small local aquifers, possibilities for increasing their storage for local beneficial water use, and their relationship to potential water yields for downstream use.

References

1 Keppel, R. V. and Renard, K. G. Transmission losses in ephemeral stream beds. Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers 88:(Hy. 3) 59-68, May 1962.

2 Gilluly, James. General geology of central Cochise County. Geological Survey professional paper 281, 1956.

3 Wenzel, L. K. and Fishel, V. C. Methods for determining permeability of water-bearing materials. Geological Survey Water Supply Paper 887, 1942.

4 Lecture notes of Dr. David K. Todd. Short course on aquifer-streamflow relations. Univ. of Calif., Berkeley, August 1961.

5 Todd, D. K. Ground water hydrology. John Wiley and Sons, Inc., 1959.