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BED MATERIAL CHARACTERISTICS AND TRANSMISSION LOSSES IN AN EPHEMERAL STREAM [1/]

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INTRODUCTION

Walnut Gulch is an ephemeral tributary to the San Pedro River, joining it near Fairbank, Arizona. The upper 58 square miles of the Walnut Gulch watershed are under intensive study by the Agricultural Research Service of the U.S. Department of Agriculture (Fig. 1). This bed material study deals with Hughes Draw, a 5.98-square-mile subarea of Walnut Gulch. The watershed has a youthful drainage system incised into a high foothills alluvial fan. Alluvial materials range from clays and silt to well-cemented boulder conglomerates. The mixed brush-grass vegetation is typical of southeastern Arizona and southwestern New Mexico rangeland. Elevation varies from 4000 feet at the outlet to about 6200 feet at the upper boundary in the Dragoon Mountains. Most of the streamflow occurs between July and early October and is derived from intense convective storms. An average of 6 to 13 such flows are recorded annually at the gaging sites. Most flows last less than 6 hours, and the channels are dry 99% of the time.

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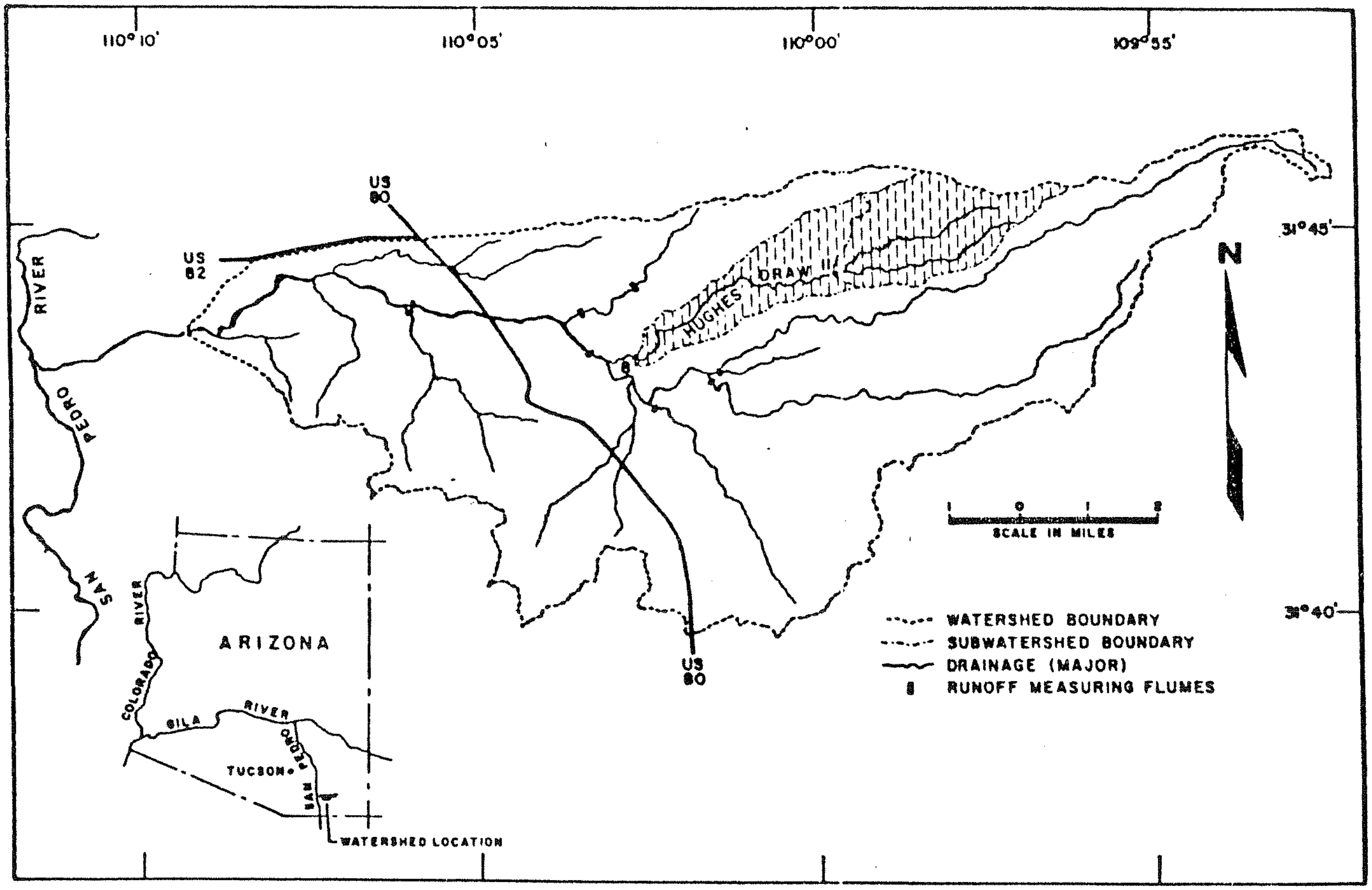

FIGURE 1. WALNUT GULCH EXPERIMENTAL WATERSHED

The channel material is characterized (Wallace and Renard, 1967) as a dry alluvium which yields high infiltration rates (transmission losses) during flow events. The major static limitations to transmission losses are: (1) nature (type and configuration) and volume of alluvium beneath the channel; (2) available total porosity and specific yield of that alluvium. Antecedent moisture conditions before a flow event also limit transmission losses. Pre-existing moisture conditions may be considered virtually "static" except where two flows are separated by only a few hours. Hydraulic conductivity of the bed material and possible sealing effects of suspended sediment during flows are also important, but this paper is restricted to a description of the limiting factors imposed by the geology and geomorphology of the channel.

DATA AND RESULTS

The subwatershed known as Hughes Draw is defined by Flume 11 at its upper end and Flume 8 at its lower end (Fig. 1). The area gaged at Flume 8 encompasses 5.98 square miles with a principal waterway about 8 miles long. Flume 11, approximately 4 miles upstream from Flume 8, gages the upper 3.18 square miles. The channel between the two flumes has only two significant tributaries and is the area on which the investigation was made.

The whole Walnut Gulch watershed is covered by a dense rain gage network of about 1 gage per 0.64 square mile. The Hughes Draw location was chosen because of the regular morphology and long narrow shape. It is therefore easy to select convective thunderstorms of limited areal extent that produce runoff at Flume 11 with little or no tributary inflow below the flume.

Transmission losses, measured as the difference in the hydrograph volumes at the two flumes, can therefore be related to the characteristics of the channel between the flumes.

Geology of the Area. Igneous, sedimentary, and some metamorphic rocks are exposed in outcrops on about one quarter of the surface area of the watershed. Their ages range from Pre-cambrian to Quaternary. Combined with rocks of the same formations which are exposed in the Dragoon Mountains to the east, they comprise the parent material of the Tertiary and Quaternary alluvial fill which covers the remainder of the watershed. Recent seismic surveys (Libby, Wallace, and Spangler, 1970) have shown this alluvium to be greater than 3000 feet deep in the northern portions of the watershed. This alluvium consists of disconnected layers and lenses of sands, gravels, and conglomerate. Some layers are unconsolidated. Others are highly cemented with $CaCO_3$ in the form of caliche. This caliche conglomerate is essentially impermeable when compared to the channel alluvium. There appear to be a number of lithologically similar, but stratigraphically separated, caliche conglomerate horizons. Some of these cemented layers form steep cliffs due to faulting, thus affecting local drainage patterns.

The geology of Subwatershed 63.008, the watershed contributing to Hughes Draw, is comprised solely of Quaternary and Tertiary alluvium with the exception of a small olivine basalt plug near the outlet. Two conglomerate series are beneath the recent alluvium of the Tombstone Pediment* in the subwatershed studied.

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* The term "pediment" as used here is obviously not compatible with the classic definition of the term, as bedrock is nowhere near the surface. "Tombstone Pediment" is the stratigraphic name given by Gilluly (1956) to the thick veneer of coarse gravels which overlie the basin alluvium.

The younger conglomerate crops out along the upper third of the 4.13-mile channel reach. Although separated from the pediment surface by only a slight disconformity, it appears considerably older than that surface. The older Tertiary conglomerate lies unconformably below the younger one and crops out along the lower third of the channel reach. Along the middle third of the reach, the upper conglomerate is interrupted by an outlier (or facies zone) of thinly-bedded red silty sandstone. Conglomerates beneath and surrounding the red sandstone persist in lenses to depths of over 1,200 feet. However, the discontinuous nature of the conglomerates makes the alluvium fairly permeable (on a long-term basis), and there are probably locations along the channel where water seeping into the channel bed can percolate to the regional water table some 425 feet below.

Geomorphology of the Channel. Geometric surface properties of the reach were examined to determine the effect of the geology on the channel regimes and on the flows. A detailed slope course survey was performed, and 46 cross-sections were measured. The slope and cross-section data revealed that the surface drainage pattern could be divided into three zones roughly conforming to the geologic outcrops mentioned above (Fig. 2). It was also apparent that while the channel slopes (a mean slope of 1.14%) showed little sensitivity to any geologic change, the variations in channel cross-sections were highly correlated to changes in regime and bedrock (caliche conglomerate) outcrop patterns.

The drainage pattern in the upper third of the reach is a slightly entrenched meander with younger conglomerate exposed on the outsides of the bends (Fig. 2). The channel follows either an old drainage channel or

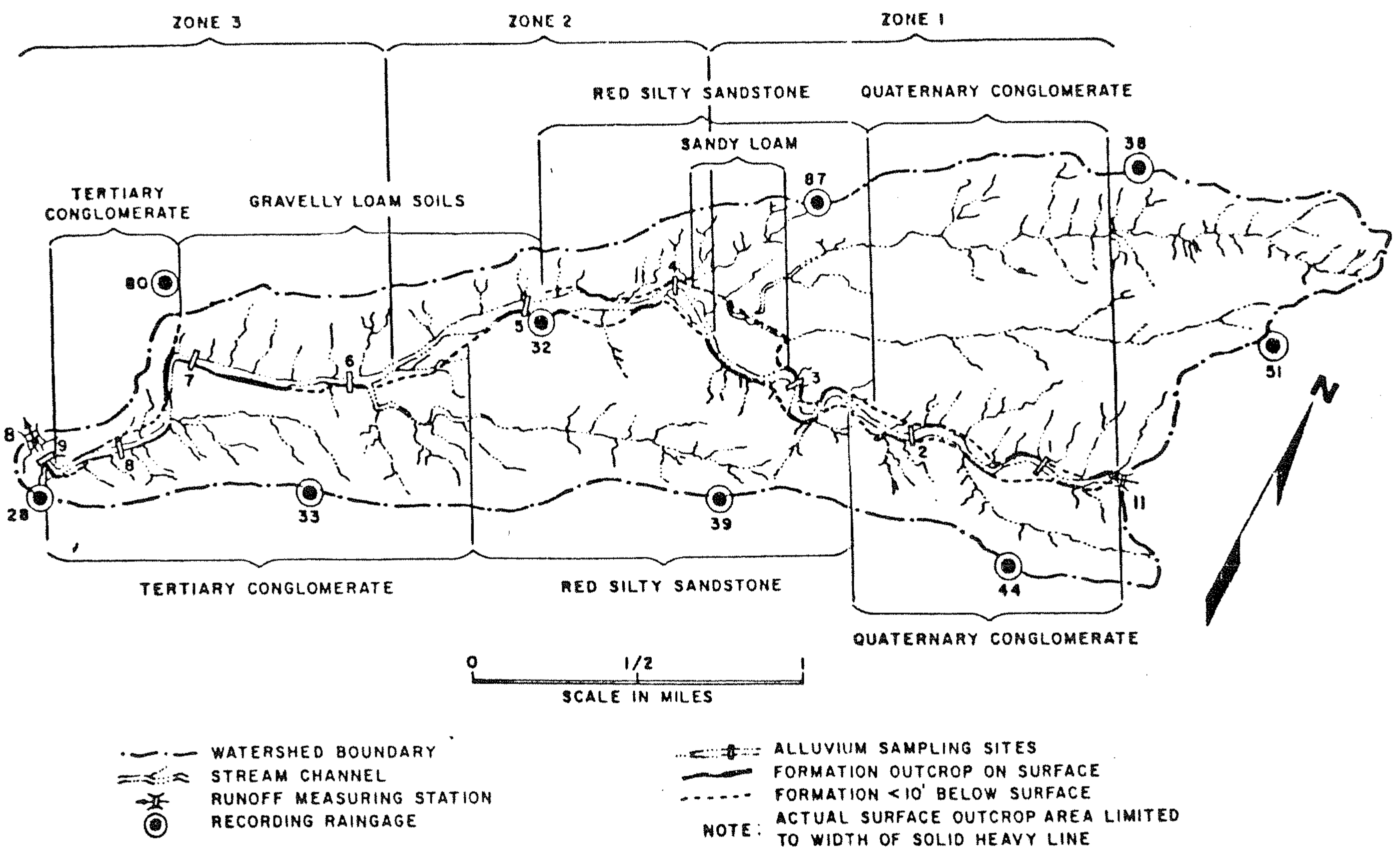

FIGURE 2. CHANNEL SURFACE GEOLOGY, SOILS, AND SAMPLING SITES.

alternates between the more easily eroded grout zones of two parallel or en echelon fault systems having trends striking N85°W and N45°E. The average channel width at low flows was about 38 feet in the upper section. Cross-sectional surveys indicate that during large runoff events, the wetted perimeter or inundated channel width increases by no more than 50%.

The middle third of channel traversing the red silty sandstone is very different from the other portions. Because of the high degree of sandstone erodibility, this reach is a series of low, multiply-braided channels and sand bars (Fig. 2). The 33-foot low-flow wetted perimeter in this section could increase to over 200 feet during the larger floods. When this occurs, the enlarged wetted perimeter produces very high transmission loss rates.

The channel in the lower one third of the reach traverses the old Tertiary conglomerate and has a narrow constricted channel usually bounded on one side by steep conglomerate walls (Fig. 2). The reaches are straight, and the direction changes are abrupt, suggesting entrenched, fault-controlled drainage. There are four major trends of channel orientation or faulting in the last channel mile above Flume 8. The average channel width in this lower section is only 36 feet, and the maximum increase in width at flood stage would not be more than 50%.

The relationship between the geology and the channel regime would therefore seem to be very important as the channel regime directly controls the width of the cross-section of the channel and this, in turn, controls the magnitude of the wetted perimeter. Therefore, channel geology and morphology are highly correlated with the potential transmission losses.

Volume, Porosity, and Specific Yield of Alluvium. A sampling program was initiated after the geometric configuration of the channel was determined to quantify the "static" limiting parameters of the bed material. Total volumes of alluvium beneath the wetted perimeter at various discharges were determined and the porosity of the samples (disturbed and re-compacted) were measured in the laboratory. When combined with a particle size analysis, specific yield was computed using the method described by Eckis (1934).

A previous investigation (Qashu and Buol, 1967) of the alluvium in an ephemeral channel downstream from the study area revealed the existence of a layer of higher clay content which could have a limiting effect on transmission losses. The results, however, were based upon samples taken from one pit. In the present study it was hypothesized that such clay lenses would have to be extensive to affect transmission losses, and therefore, a more complete and representative sample was obtained.

Nine pits were dug in the channel at roughly half-mile intervals to determine alluvium characteristics and depths (Fig. 2). These sample pits were dug to either bedrock (caliche conglomerate) or to the seven foot limit of the backhoe used. Bed material in excess of this depth was probed with steel rods until they struck an unyielding horizon. Large boulders buried in recent alluvium could be differentiated from the conglomerate by characteristic differences in their reaction to impact. The probe tips were pointed and slotted so that the material would be forced through the slot while the rod was being driven. The material last probed by the rod tip remains in the slot upon withdrawal. In all cases, caliche was the indicated bedrock material. The bedrock depth determinations were supplemented with surface observations at the 46 cross-sections to determine the configuration of the "impermeable" sublayer (Fig. 3).

Using the dimensions obtained from surface surveys, cross-sections, and depth determinations, the alluvium quantity available for infiltration for discharges less than about 50 cubic feet per second (cfs) was calculated to be approximately 106 acre-feet. For discharges between 50 and 140 cfs, the alluvium volume available for infiltration during flows would increase to about 111 acre-feet.

Above 140 cfs, overbank flow begins,and the total volume of alluvium beneath the wetted area increases rapidly. Except for the sand bars in the braided section, this volume of alluvium is probably less significant with regard to infiltration rates because duration of out-of-bank flow is short, and depths of inundation are shallow. In addition, the bank alluvium permeability is much less (Holtan, et al., 1968) than that of the channel material.

Forty-seven samples were collected from the 9 sample pits in the channel with the number per pit varying from 2 to 7. Measurements were made of each sample's moisture content, porosity, and particle-size distribution.

The porosity of individual samples varied from 30% to about 45%, with a mean of 36%. The corresponding mean specific yield, estimated from porosity versus specific yield curves (Eckis, 1934) was 28%. The median particle diameter for individual samples varied between 0.31 mm and 20 mm, with a mean value of 3.2 mm. The composition was roughly 53% gravel (greater than 2 mm), 42% sand (< 2mm and > .063 mm) and 5% silt and clay. The bank alluvium adjacent to the upper 5 sampling sites is predominantly

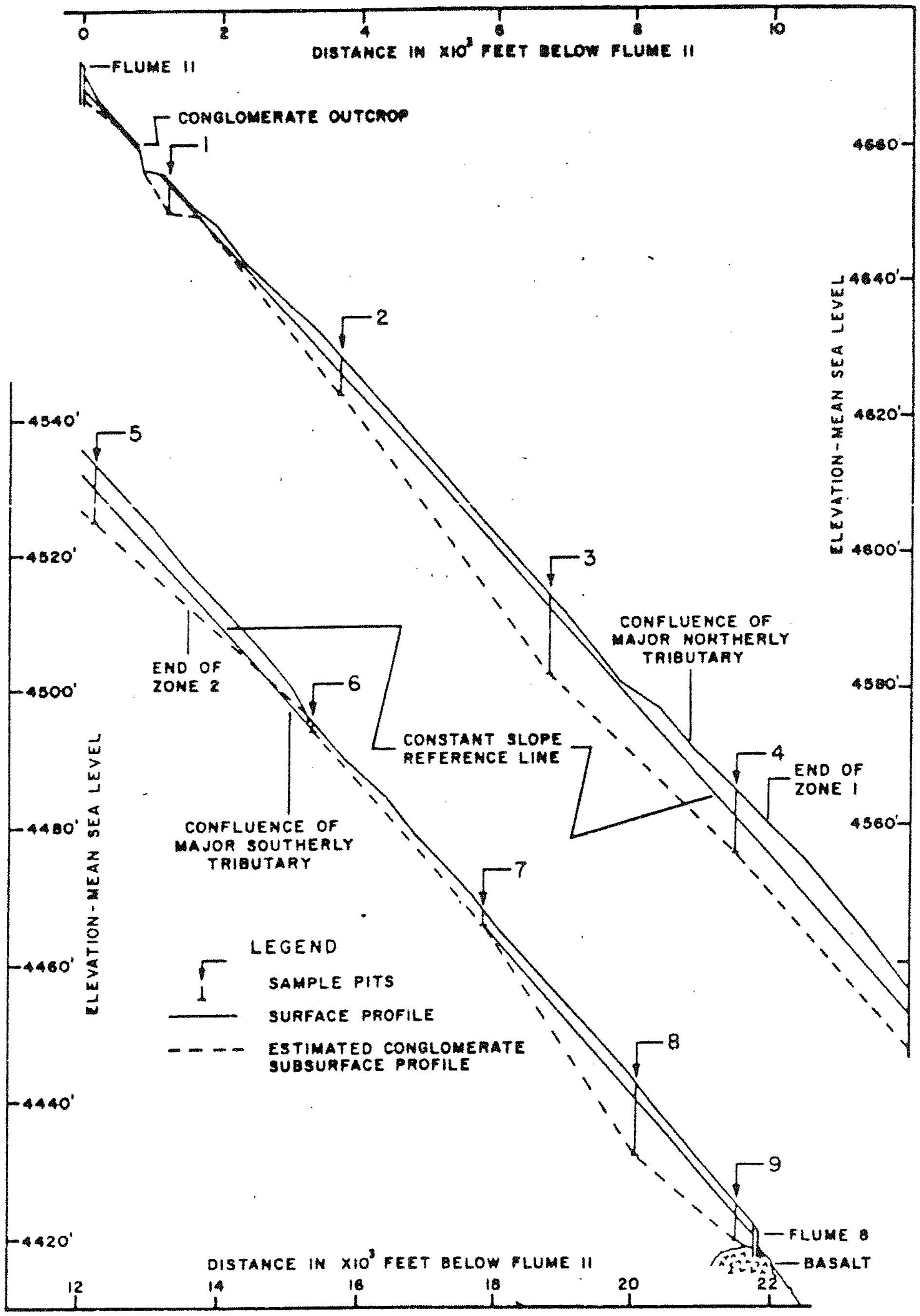

FIGURE 3. HUGHES DRAW-CHANNEL SURFACE AND SUBSURFACE SLOPE COURSE PROFILES.

Hathaway-Bernardino gravelly loams and for the lower 4 sites is exclusively Rillito-Laveen gravelly loams (Gelderman, 1970). Holtan, et al. (1968), found mean total porosities in both soils to be about 43%, but the mean specific yield values derived from their data were 17.7% in the upper stretch and 20.5% in the lower stretch. Analysis indicated that the specific yield for the channel material in the upper portion of the reach is 57% higher than that of the bank alluvium, and in the lower portion is about 31% higher than the bank alluvium. These findings, combined with the greater relative time required for moisture content changes in loams than in sands, reinforce the statement that infiltration losses to overbank-flow-inundated bank material represent a small percentage of the quantity of water lost to the channel alluvium. Tables 1 and 2 show the characteristics of the bed material samples with respect to sampling sites and depth of sampling, respectively.

Sample porosity in the channel was found to be positively correlated to the percent silt and clay of the sample and to the depth and negatively correlated to percent gravel. However, percent silt and clay was positively correlated to the depth of the sample, and percent gravel in the sample was negatively correlated to the depth. No linear relation was found between the depth at which the sample was taken and the median particle size. No clay lenses capable of limiting infiltration were found.

Analyses of variance of porosity indicated no significant variation with sampling site, but the variation with sampling depth was significant at the 5% level. This suggests the finer material from the surface layers is washed out or down (by eluviation) during the passage of small flood

TABLE 1.--Summary of results for bed material survey -- channel reach between Flumes 11 and 8, August 1969.

Sampling site no.	Depth to conglomerate	Number of samples	Mean porosity	Mean estimated specific yield	Median particle size
	(ft)		(%)	(%)	(mm)
1	4.9	5	36	25	1.7
2	5.5	4	37	28	3.5
3	11.4*	6	38	26	5.8
4	9.5*	6	36	30	1.7
5	8.7*	6	36	30	2.2
6	1.3	2	32	26	11.8
7	1.8	4	33	27	4.9
8	10.5*	7	38	28	1.8
9	5.7	7	38	26	2.2

* Note: Samples were taken only from the top seven feet.

TABLE 2.--Characteristics of bed material in the ephemeral channel reach between Flumes 11 and 8, August 1969.

Mean sample depth	Number of samples	Median particle size	Percent gravel	Percent sand	Percent silt and clay	Mean porosity	Mean estimated specific yield
(ft)		(mm)	(>2 mm)		(<063)	(%)	(%)
0.2	9	2.4	50.3	46.1	3.6	34	28
0.6	9	4.1	52.6	43.7	3.7	35	26
1.4	7	2.9	44.9	50.0	5.1	37	27
2.6	8	4.1	64.9	30.0	5.1	37	27
4.0	7	3.1	47.8	42.3	7.9	40	27
5.5	7	2.9	56.1	37.5	6.4	38	31
Mean of all samples		3.2	53.1	41.6	5.3	37	28

waves. During larger flows the upper few inches of the bed are probably disturbed, lifted, and moved along with the flowing water. The short duration of high discharge minimizes the movement for the heavier particles, while the smaller and lighter particles are carried off.

Data from the various sampling sites were regrouped to form sampling site subsets separated by more than 0.5 mile to test the sampling interval needed. Partitioning of the data in this way indicated the results were significantly changed by the coarser sampling scheme. Such a coarser sampling scheme would not yield the same results as were obtained with the half-mile sampling interval. Unfortunately, whether or not the half-mile interval was small enough could not be determined.

Transmission Losses. With approximately 106 acre-feet of alluvial material having a mean specific yield of 28%, the maximum water-absorbing capacity of the channel reach is about 29 acre-feet or 7 acre-feet per mile. The actual transmission losses in the channel reach studied were found (Lane, Diskin, Renard, 1971) to be highly correlated to the volume of the inflow hydrograph at Flume No. 11. They found the relationship between transmission losses, L, (in acre-feet) and inflow volume, V, (in acre-feet) for storms with no rainfall between Flumes 11 and 8 was

$$L = 0.36\ V + 2.29 \qquad (1)$$

with coefficient of determination, $R^2 = 0.94$, and standard error of estimate = 1.5 acre-feet. This relationship holds true provided the inflow volume is at least 3.6 acre-feet. For smaller inflow volumes all runoff is usually lost in the 4.13-mile reach.

The maximum transmission loss recorded in the reach was 82 acre-feet for a flood wave of 128 acre-feet having a 1960 cfs peak discharge. This flow, however, covered an extensive portion of the flood plain and all of the braided zone of the channel. The second and third highest floods in the channel in 7 years of record were 44 and 40 acre-feet with corresponding peak flows of 1074 and 725 cfs. These flows remained within the stages for which available volumes of alluvium were computed. The transmission losses for the two flows were 16 and 17.5 acre-feet, respectively, or about 4 acre-feet per mile of channel. These two losses each represent some 60% of the computed capacity of 29 acre-feet. The presence of a significant quantity of pre-existing moisture in the reach material would of course reduce the transmission loss capacity of the channel by an amount proportional to the volume present.

SUMMARY AND CONCLUSIONS

The bed material investigations were carried out in the Walnut Gulch Experimental Watershed in a portion of an ephemeral channel draining the 5.98 square miles of Hughes Draw. Channel slope appears insensitive to changes in the geologic material beneath it or to changes in the flow regime. The channel cross-section, on the other hand, appears highly sensitive to changes in both geology and flow regime. The geology and flow characteristics control the width and configuration of the channel which, in turn, governs the magnitude of the channel wetted perimeter. Both ultimately control the magnitude of potential transmission losses to the bed material in the channel.

The bed material in this channel reach had a 3.2 mm mean particle size. The composition was roughly 53% gravel (greater than 2 mm.), 42% sand (< 2 mm and > .063 mm.) and 5% silt and clay. The 5% clay fraction present was not found arranged in lenses that would limit infiltration.

The thickness of the unconsolidated alluvium in the channel varied from practically zero to more than 11 feet with a mean of 6.5 feet. A caliche conglomerate underlies the channel and persists in randomly spaced layers to great depths. The conglomerate's overall effect is that of an impermeable seal which lies at the bottom of and limits the volume of highly porous and permeable channel alluvium in the reach. Transmission losses in this alluvium are not trapped there but, due to the lateral discontinuous nature of the conglomerates, eventually may percolate to the water table 425' below. Surface extractions such as evaporation and transpiration of course take their toll of this potential recharge during the time the percolating water is still within the root zone.

The total volume of unconsolidated alluvium in the 4.13 miles of channel was estimated at 106 acre-feet. The material mean porosity was estimated at 37% with a 28% mean specific yield. The maximum water absorbing capacity is about 7 acre-feet per mile of channel. This capacity was exceeded only by the largest flow event recorded in the reach which had a considerable amount of out-of-bank flow. The second and third largest events had losses measured at 60% of this maximum capacity.

Porosity of bed material increases with depth. It is believed the sifting processes which occur during runoff events tend to sort the surface layer. The transmission loss factors (infiltration, porosity, etc.) are primarily controlled by the texture and amount of material underneath the channel. The total alluvium in the valley is important only during periods of long-duration overbank flow. An ephemeral stream such as that studied here is characterized by short-duration flows with limited overbank flow.

Actual transmission losses were found to be highly correlated to the volume of the inflow hydrograph. This should be expected because the magnitude of the inflow hydrograph directly controls infiltration by controlling the width, depth, and time of inundation of the channel reach, and because the potential loss volume exceeds the alluvium storage volume for most flows. Exceptions to this rule would occur only with flows large enough and long enough to exceed the capacity of the channel alluvium, or where antecedent moisture content is still high enough from a previous flow to limit the potential absorption capacity of the alluvium to a volume smaller than the limit imposed by the inflow hydrograph itself.

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