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GEOMORPHIC FEATURES AFFECTING TRANSMISSION LOSS POTENTIAL[1/] ON SEMIARID WATERSHEDS

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ABSTRACT

Water yield studies and flood control surveys often necessitate estimating transmission losses from ungaged watersheds. There is an immediate need for an economical method that provides the required accuracy. Analysis of relations between stream order, drainage area, and volume of channel alluvium existing in the various orders is one means of estimating loss potential. Data needed for the stream order survey are taken from aerial photos. Stream order is analyzed using stereophoto maps. Stream lengths taken from the maps are combined with average channel width and depth data (determined by prior surveys) to estimate volumes of alluvium involved. The volume of channel alluvium in a drainage network is directly related to the stream order number of its channels. Thus, a volume of alluvium within a drainage network (with a known transmission loss potential) may be estimated by knowing the order of each length of channel and the drainage areas involved. In analyzing drainage areas of 56-mi^2 or less, 70 to 75 percent of the total drainage network length is contained within first and second order channels; yet, these constitute less than 10 percent of the total transmission loss potential of the areas. Analysis of stream order and drainage area versus volume of alluvium relations allows preliminary estimates of transmission loss potential to be made for ungaged areas.

INTRODUCTION

Water needs become more critical each year in the southwestern United States. Increasing urban demands as well as expanding industry and agriculture are putting more pressure on existing water supplies. Flood prevention and control are also an inherent part of the problem. Thus, it becomes essential to be able to estimate present and potential water yield from these developing areas.

Much of the streamflow from watersheds in the semiarid Southwest occurs between July and October as a result of intense convective storms. The channels are dry most of the year, but when flow occurs, it is often flash flood type. Often, the infiltration rate is so high that the flow is completely absorbed by the channel aggregate within a short distance (Renard; Burkham, 1970). These channel "transmission losses" can be significant contributors to ground water from the higher order channels (Wallace and Renard, 1967; Osborn and Renard, 1973).

The influence of each order channel on the transmission loss potential in the complete drainage net is the subject of this study. We made no attempt to separate the influence of antecedent moisture or "prior wetting" of the channels at this time; rather, we have attempted to estimate maximum loss potential.

Runoff from semiarid watersheds becomes proportionately less as area increases (Keppel, 1960). Geomorphic data taken from watersheds under study by the Science and Education Administration (SEA) indicate these changes may be a means of predicting the amount of transmission losses as drainage area increases.

AREA DESCRIPTION AND PARAMETER SELECTION

The Santa Rita Experimental Range (50,000 acres), located some 30 miles south of Tucson, and the Walnut Gulch Experimental Watershed (38,000 acres), located near Tombstone, were data collection sites for this study (Fig 1). Both are situated on broad sloping bajadas with well-developed drainage systems. Elevations range from 2900 to 4500 feet in the Santa Rita Range to 4000 to 6500 feet at Walnut Gulch. Annual precipitation ranged from 10 to 20 inches in the Santa Rita Range, while that at Walnut Gulch ranges from 5 to 18 inches.

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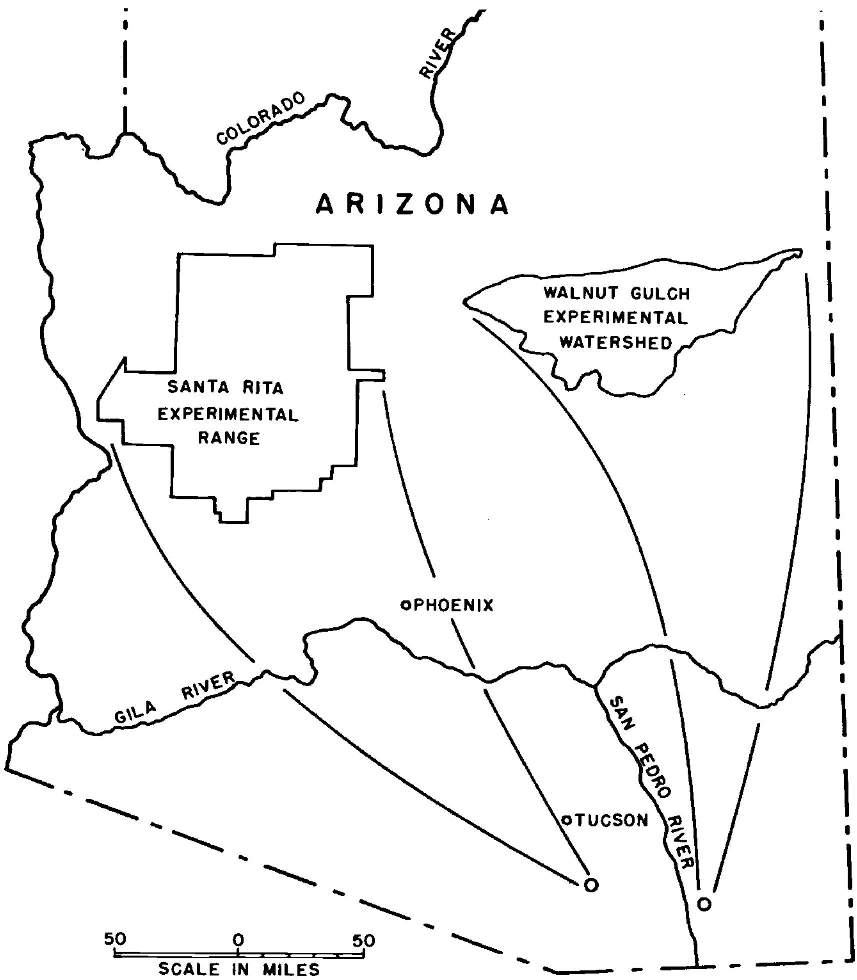

Fig. 1. Location of Walnut Gulch Experimental Watershed and Santa Rita Experimental Range.

Vegetation on the Santa Rita Range watersheds is mostly mesquite, cacti, and other shrubs, with limited grass cover. Walnut Gulch vegetation is predominantly shrubs and varying amounts of grass, with lesser amounts of mesquite and cacti.

Soils of the two areas are generally poorly developed over alluvial gravels and coarse sand, with clastic materials derived from the surrounding mountains. The stream channels are filled with clay, sand, gravel, boulders, and caliche conglomerate, with an overall average porosity of 36 percent (Murphey, Lane, and Diskin, 1972). These highly porous reaches of channel alluvium are natural storage reservoirs for the runoff from summer storms.

Photo-topographic maps and stereo pairs of the photos of both Walnut Gulch and the Santa Rita Area were used to delineate individual watershed boundaries and drainage networks. A standard Horton-Strahler stream order analysis (Strahler, 1957) was made on each area, with a first order stream being defined as the smallest channel with a sand bottom. The individual lengths of each order segment were measured directly from the photo-topographic maps. Stream widths were measured by field survey at the time the depths were determined. Depth of channel aggregate in the stream-beds was determined by excavating to the impermeable material in the lower order streams. When the depth became too great to dig (>5 feet), a smooth steel rod was driven into the channel bed until we encountered the subsurface conglomerate. The depth driven was then scaled off the rod. For the times when the contrast between loose channel aggregate and resistant beds was not sufficient to determine depth, we excavated by shovel or back-hoe.

Throughout the study, even in areas where we felt the rod method worked extremely well, we verified it by excavating to confirm its accuracy. In the deeper regions (fourth or fifth order channels), a portable seismic refraction unit was used to determine the depth to conglomerate or bedrock. This was verified by running seismic traverses in previously drilled or known areas, and we used all existing well log data.

DATA AND RESULTS

The relation of drainage area to basin order is well documented (Leopold, Wolman, and Miller, 1964). Figure 2 illustrates this relation for areas discussed in this work. In general, ephemeral streams in the semiarid Southwest are characterized by a uniform width and depth of alluvial fill with stream order (Figs. 3 and 4). Geologic or geomorphic anomalies, like a large width-depth ratio or near surface bedrock or dikes, which may change normal drainage patterns, can cause alterations in the evolutionary process. Also, order numbers may differ due to mapping scales, although the slope of the lines (Figs. 3 and 4) usually remain the same. In this case, stream order of the mapping done from photo-topographic maps increased by 3 to 4 orders for areas larger than 10 acres as compared to the smallest order represented on USGS 7 1/2 minute quadrangle maps. Smaller-area maps were naturally done in more detail, although the resulting curves were again similar.

The area contained within the drainage network (length x width of all channels) developed within the areas studied is directly proportional to the total watershed area. This relation was consistent for the wide range of areas tested (Fig. 5). An average width and depth value was determined for each order channel and combined with length to determine the volume of alluvium contained within each order channel.

This total volume of channel alluvium contained in the drainage networks studied is related to drainage area, as shown in Figure 6. The relationship between drainage area, A, and cumulative volume of channel alluvium, ¥, is

$$¥ = 4.96A^{1.32} \quad (1)$$

From this, the rate of change of volume of alluvium with changing watershed area is

$$\frac{d¥}{dA} = 6.19A^{0.32} \quad (2)$$

which is a measure of how alluvium volume increases with area.

The total volume of channel alluvium contained in the drainage nets is related to stream order, as shown in Figure 7. The relationship between stream order, u, and cumulative volume of alluvium, ¥, is

$$¥ = 14.9e^{0.75u} \quad (3)$$

where stream order, u, is a positive integer and ¥ is in acre feet of alluvium. From equation 3, the rate of change of volume of alluvium with changing stream order is

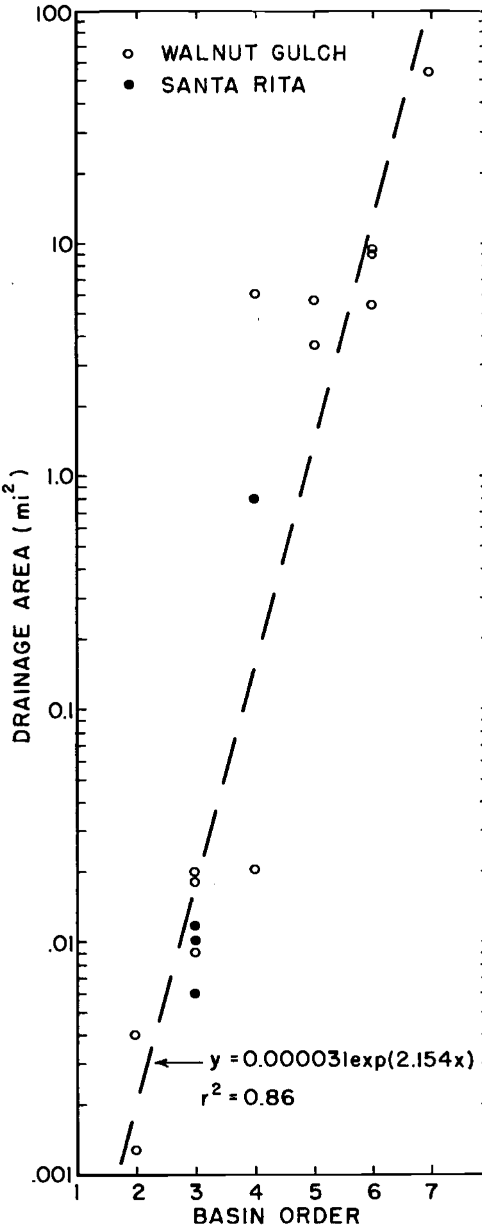

Fig. 2. Relation of highest order stream in basin (basin order) to drainage area of basin. Areas are all within Walnut Gulch Experimental Watershed or Santa Rita Experimental Range.

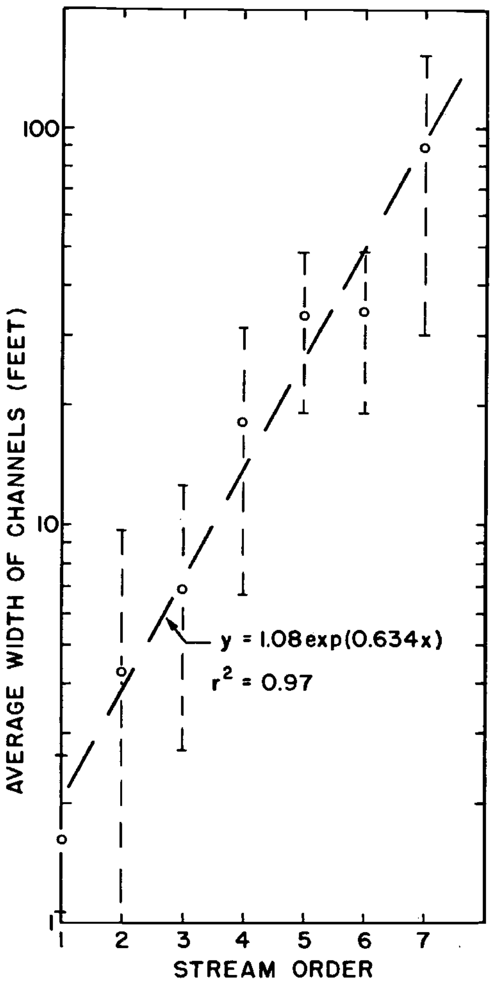

Fig. 3. Relation of mean width of channels to channel order for the Walnut Gulch Experimental Watershed.

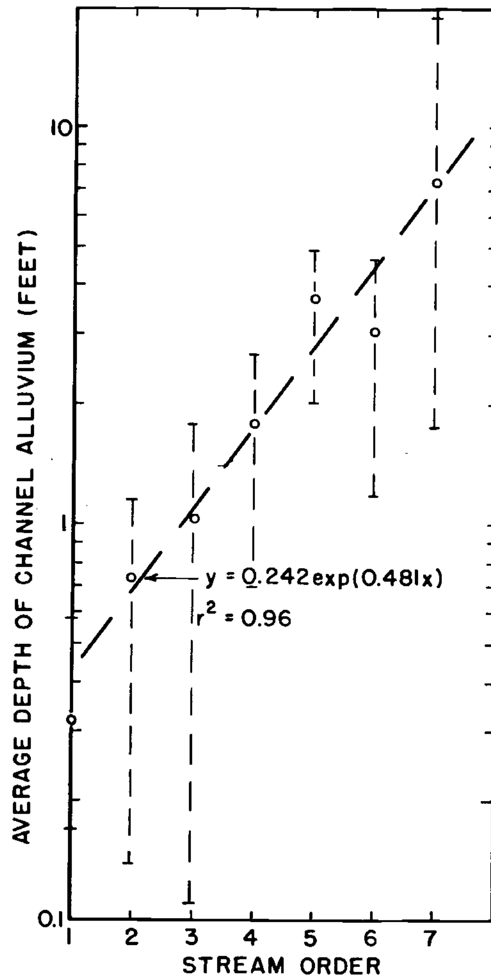

Fig. 4. Relation of mean depth of channel alluvium to stream order for the Walnut Gulch Experimental Watershed.

$$\frac{d¥}{du} = 11.2e^{0.75u} \tag{4}$$

which is a measure of how channel alluvium volume increases with higher order streams.

An essential step in expanding the results here to areas other than those studied is to determine if the relation between ¥ and u (Fig. 7 and Eq. 3) and the relation between ¥ and A (Fig. 6 and Eq. 1) are appropriate, and if so, how the coefficients in equations 1 and 3 vary within broad geographic regions.

The volume of alluvium within the drainage net can be combined with a porosity and specific yield value to estimate the "transmission loss potential" of an area. A sampling of the channel aggregate in the drainage net at the time of measuring width and depth of channel fill can be used to determine a mean porosity for the area. Mean specific yield can then be estimated from porosity versus specific yield curves (Eckis, 1934). First and second order channels, although representing an average of 70 to 75 percent of the total length of the drainage net length (Fig. 7), contain only 20 percent or less of the total volume of channel alluvium within the drainage net (Fig. 8). Thus, the higher order channels

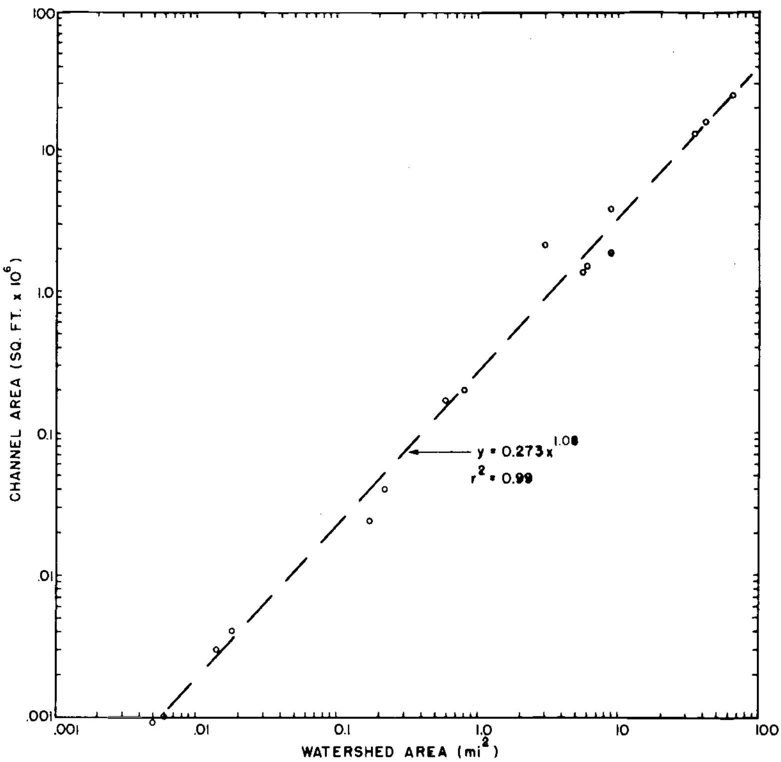

Fig. 5. Relation of area contained within the drainage network to total watershed area.

have a much greater potential for abstracting runoff from flow events. For example, 47 alluvium samples were collected during a previous survey by Murphey, Lane, and Diskin (1972). The porosity of the samples varied from 30 to 45 percent with a mean of 36 percent and with an estimated specific yield value of 28 percent. Losses computed from two flow events in a 4.13-mile reach of channel in Walnut Gulch were 16.5 and 17 acre-feet, or about 4 acre-feet/mile of channel. These data were from a fifth order watershed. Axial streams in the larger watersheds tested were fifth or higher order channels. A fifth order channel, tested by Murphey, Lane, and Diskin (1972) in the Southwest, was found to be capable of transmission losses of 7 acre-feet/mile. Using volume of channel alluvium estimates from data on Walnut Gulch Experimental Watershed, we determined that fifth through seventh order or larger channels have a potential for transmission losses to a maximum of 85 acre-feet/mile at the outlet of Walnut Gulch watershed.

The influence of the two variables, watershed area and stream order (although intercorrelated), can be compared using the multiple regression equation

$$\forall = 6.475A^{1.27}e^{0.032u} \tag{5}$$

From this equation, we can readily determine that the influence of stream order is small as compared with the influence of watershed area. For example, the change in volume of channel alluvium of a third order drainage area ($e^{0.032(3)} = 1.1008$) as compared with a seventh order area ($e^{0.032(7)} = 1.2511$) is small (a 0.15 change) in comparison with the change in volume of channel alluvium with increasing area. For example, a 0.17-miles square drainage area (third order) contained a volume of channel alluvium of 0.31 acre-feet as compared with 1275 acre-feet of channel alluvium contained within the drainage system of a 56-miles square (seventh order) area.

Thus, quantitatively speaking, area is dominant in the predictive equation with stream order exerting little influence. However, the high correlation of channel width and depth with stream order and the relation of drainage network area to watershed area both lend credibility to the use of drainage area alone in the predictive equation.

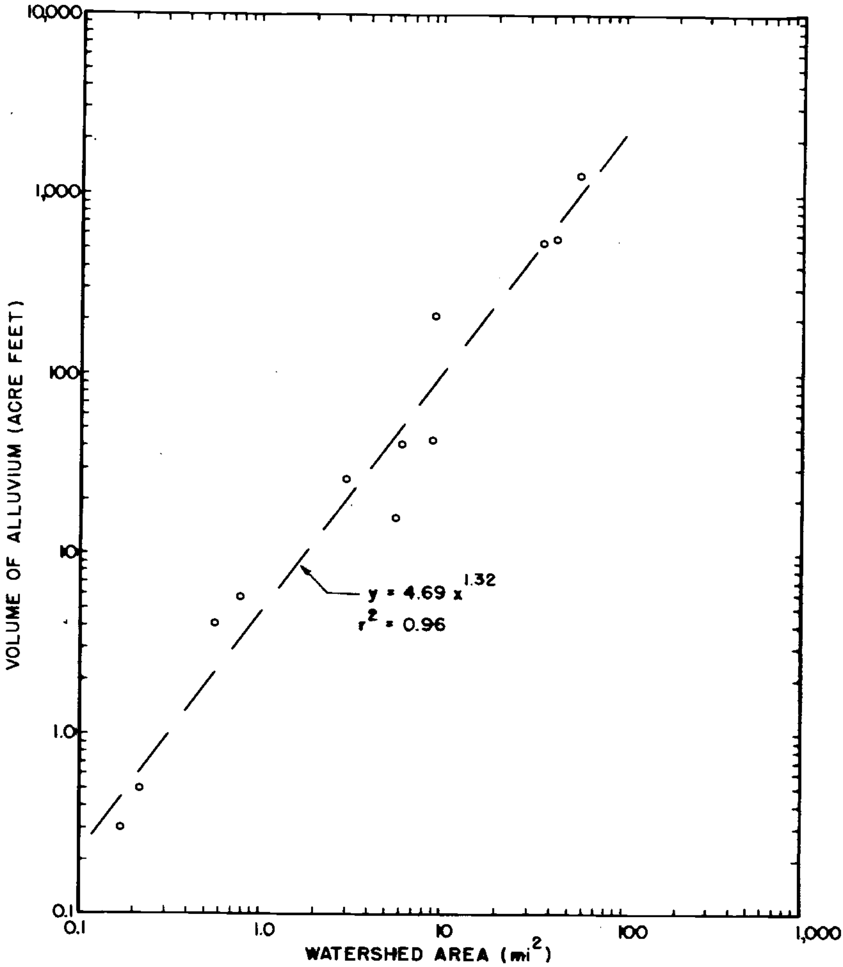

Fig. 6. Relation of cummulative volume of channel alluvium to watershed area.

LIMITATIONS

Geologic or geomorphic anomalies, like an extreme width-length ratio or near surface bedrock and dikes, may change normal drainage patterns and cause alterations in the evolutionary process. These must naturally be taken into account when estimating channel alluvium volumes. These can often be isolated on aerial photos and field verified later.

Changes in channel slope must be carefully considered, also. This is more difficult to evaluate without field study. An abrupt increase in slope can change a channel with a sand and gravel depth of alluvium of 3 to 5 feet to a large boulder-strewn channel with essentially no finer grained alluvium. A lessening of channel slope can also cause dramatic changes in alluvium texture and volume. Drainage may become discontinuous, creating large dump areas and sand bars, with gullies and headcutting starting the whole cycle over again at a point immediately downstream.

DISCUSSION AND SUMMARY

The data and results presented here are an attempt to devise a workable method of estimating the volume of channel fill or stream gravel in ephemeral drainage networks in southeastern Arizona. These data can then be combined with average porosity and specific yield values to estimate the maximum transmission loss potential for the channel networks.

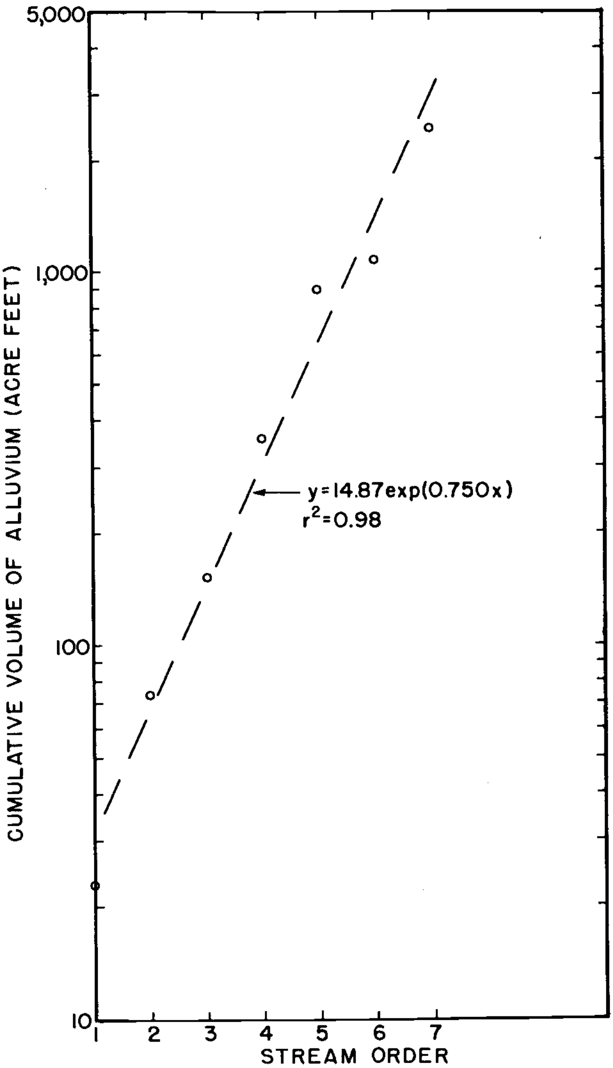

Fig. 7. Relation of cumulative volume of channel alluvium to stream order for Walnut Gulch.

From the limited number of watersheds presently tested, watershed area proved to be the dominant variable. As compared with the effect of the watershed area, stream order did not exert any great influence on the equations derived. However, the credibility of using drainage area alone in the predictive equations has been enhanced by the analysis of relations existing between width and depth of ephemeral channels versus stream order and those existing between drainage network areas versus watershed area.

We made no attempt to account for prior wetting of channels, antecedent soil moisture, or the various changes in infiltration rates due to alluvium layering and the sealing due to colloidal material in infiltration during and after each flow event. Also, opportunity time or duration of channel wetting will influence the amount of loss possible from differing runoff events. Because of the inherent short duration of flow characteristic of ephemeral runoff events, the maximum loss potential would very likely never be reached. However, the potential for management practices, like water harvesting and recharge enhancement within the larger channels, make these types of data extremely valuable.

The application of this method to other land resource areas has yet to be determined. Geologic and geomorphic anomalies within the areas measured have varying degrees of effect on the accuracy of the method. Any variations within the drainage system will necessarily detract from the accuracy of the estimates made; thus, the value of the method is greatly increased by any additional data available, like soil surveys, geophysical data, or any existing well logs of the area in question. The method is believed sufficiently accurate to use as a tool for estimating transmission loss potential in preliminary site evaluation and land resource surveys.

REFERENCES CITED

Burkham, D. E. 1970. Depletion of Streamflow by Infiltration in the Main Channel of the Tucson Basin, Southeastern Arizona. Geol. Survey Water Supply Paper 1939-B, p. 14.

Eckis, R. 1934. South Coastal Basin Investigation; Geology and Ground Water Storage Capacity of Valley Fill, Bull. 45, Calif. Div. Water Resources, Sacramento, 279 pp.

Keppel, R. V. 1960. Water Yield from Southwestern Grassland. Arid Land Symposium 4, "Water Yield in Relation to Environment in the Southwestern United States," Southwestern and Rocky Mountain Divisions, AAS, Sul Ross College, Alpine, Texas, pp. 51-63.

Leopold, L. B., Wolman, M. G., and Miller, J. P. 1964. Fluvial Processes in Geomorphology. W. H. Freeman and Company, San Francisco and London, 522 pp.

Murphey, J. B., Lane, L. J., and Diskin, M. H. 1972. Bed Material Characteristics and Transmission Losses in an Ephemeral Stream. Hydrology and Water Resources in Arizona and the Southwest, American Water Resources Association, Arizona Section -- Arizona Academy of Science, Hydrology Section, Proceedings of May 5-6, 1972 Meeting, Prescott, Arizona II:455-472.

Osborn, H. B., and Renard, K. G. 1973. Management of ephemeral stream channels. J. Irrigation and Drainage Division. Proc. ASCE 99(IR3): 207-214.

Renard, K. G. 1970. The Hydrology of Semiarid Rangeland Watersheds. USDA-ARS 41-162. 26 pp.

Strahler, A. N. 1957. Quantitative Analysis of Watershed Geomorphology. Am. Geophys. Union Trans., V:38, pp. 913-920.

Wallace, D. E., and Renard, K. G. 1967. Contribution to Regional Water Table from Transmission Losses in Ephemeral Streambeds. Trans. ASAE 10(6):786-789 and 792.

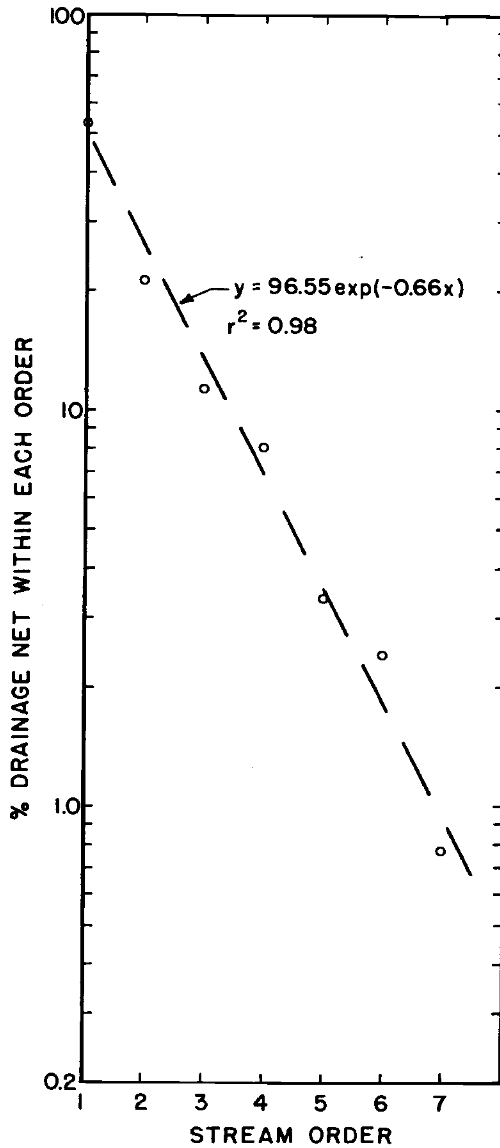

Fig. 8. Relation of percent of the total drainage network length within each stream order to stream order.