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DISCUSSION

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Substituting the value of E_1 from Eq. 26 and simplifying as before, it is seen that

$$\frac{h_j}{E_1} = \frac{y_0\ (1 + S) - \psi}{\cos\ \alpha \left(\psi + \frac{F_1^2}{2}\right)} \qquad (35)$$

It is interesting to see that for $S = 0, \psi = 1, \gamma_0 = 1$ and $\alpha = 0$

$$\frac{h_j}{E_1} = \frac{\sqrt{1 + 8\ F_1^2 - 3}}{(2 + F_1^2)} \qquad (36)$$

Eq. 36 is the dimensionless equation for jump occurring in horizontal rectangular channel.

Unfortunately, little material is available in the literature regarding the inner mechanism of the circular hydraulic jump. It would be beneficial if the work were to be extended to include a detailed investigation regarding distribution of pressure and velocities, and the nature and character of energy losses in cases of horizontal, sloping and rough surfaces. Nevertheless, it is worthy to comment that the authors have proved the application of the momentum theorem to the circular hydraulic jump.

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EVAPORATION FROM AN EPHEMERAL STREAMBED[a]

Discussion by Kenneth G. Renard

KENNETH G. RENARD,[4] M. ASCE.—The authors have reported on a most interesting project which has a great deal of significance for stream channel management in the inefficient channels of water-short areas. Surprisingly, the evaporation rates as measured in this work were low and amounted to only

[a] January, 1969, by Michael L. Sorey and William G. Matlock (Proc. Paper 6368).

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;% of the estimated annual groundwater recharge. It seems likely that the mbined recharge and evaporation in streambeds is still a small part of the al runoff absorbed in these beds. The amount of water transpired by ripar- ı vegetation (especially by the deep-rooted mesic plants) in some ephemeral ream reaches has been recognized as significant. It is generally difficult to ply the results of transpiration investigations under controlled conditions to ıeterogeneous watershed or channel segment. For this reason, estimates of e distribution of transmission-loss water between groundwater recharge, aporation and transpiration are at best "guesstimates" by trained scientists technicians.

The causes of the broad alluvial streambeds encountered in much of the uthwestern United States are not accurately known. Comparison of these reambeds with historical descriptions reveals that the beds that were once oad swales now contain wide alluvial deposits of coarse sand and gravel. osorption of flood runoff in these alluvial streambeds (generally referred to s transmission losses) is undoubtedly increasing as the bed width increases. ıbsequent removal of the transmission loss water by evaporation from the oarse alluvium and by transpiration from riparian vegetation is limiting roundwater recharge.

Increased demand for water, as well as an awareness of the amount of roundwater that is being "mined" in these arid and semiarid areas, has cre- ted an awareness of an impending disaster for the water supplies of such reas. Because of excessive groundwater use, further development of surface ater supplies, as well as efforts to enhance groundwater recharge, has be- ome necessary. But the key to full exploitation of the water resources of ıese areas is to increase the efficiency of existing processes for water use nd conveyance in the hydrologic cycle.

In ephemeral stream channels, reduction of flows by absorption of the wa- er by the channel alluvium is one of the most important facets in the hydro- ogic evaluation of these areas. Data from the Walnut Gulch Experimental Vatershed in southeastern Arizona demonstrate this. This experimental wa- ershed, which is operated by the Agricultural Research Service, USDA, is limatically very similar to the area in which the authors did their work. El- evations in the watershed range from 4,200 ft above mean sea level to over ,000 ft at the upper end. Channel material is similar to that of Rillito Creek, nd the annual precipitation of 14 in. is somewhat greater than that in the lower levations of the Tucson Basin but much less than that for the mountain ranges f the Basin.

"On-site" runoff (runoff generated where the precipitation falls) may aver- ge about 2 in. per yr on Walnut Gulch; yet, the net surface outflow from the entire basin is only about 1/4 in. per yr. This loss of 1.75 in. per yr repre- sents the transmission loss magnitude for this 57-sq mile area (11,12). Thus, the efficiency of the channels in Walnut Gulch for conveying water to a down- stream location is only 10% to 15%. Stated another way, only 10% to 15% of the on-site runoff ever appears as surface runoff at the watershed outlet.

Management of the stream channels is a possible way for increasing the water supply in arid and semiarid areas. In some reaches of stream channel, much of the transmission loss water is lost for beneficial uses by evaporation from the streambed and transpiration of riparian vegetation. The authors' data indicate that this evaporation loss amounts to only 800 acre-ft, or about 10.2 in. per unit area of streambed per yr, which is undoubtedly a small portion of the amount of the transmission losses. In other channel reaches, the underlying geology is such that the impervious layers beneath the channel limit the downward movement of water toward regional groundwater (13). By holding the transmission loss water in perched or local temporary aquifers, the evaporation and transpiration rates are increased. When saturated, as they often are later in the runoff season, these pockets provide little additional storage for transmission losses, and the runoff moves downstream essentially undiminished in volume. Management of these pockets formed adjacent to the stream channels is an area of watershed management needing further study.

Streambed treatments for enhancing or inhibiting transmission losses based on known groundwater recharge characteristics need further investigation. For example, the surface water yield of Walnut Gulch could be increased by about 90% by merely sealing the lower 6.8 miles of channel, and could be increased by about 67% by sealing only the lower 4 miles of the main channel. This channel sealing might have the deleterious effect of increasing the downstream flood damage potential because, in general, transmission losses decrease the peak discharge in addition to the flow volume. Therefore, channel sealing would have to be performed in areas where greater peak discharges could be handled without fear of flood damage. In all probability, the more practical way to accomplish these channel treatments would entail sealing tributary channels and increasing the infiltration of main channels. The authors developed their channel evaporation loss for only the main channels of the Tucson Basin and ignored the minor tributary channels. These tributaries are probably as important as the main channels for the water supply of the area, and the evaporation losses from these channels undoubtedly exceed that in the main channels.

On Walnut Gulch, tributary channels generally contain much less alluvial material than the main channel, but these tributaries are generally underlain by impervious or low-permeability material which holds the water near the surface. Evaporation from these beds would generally account for the dissipation of the transmission-loss water and eliminate any groundwater recharge from these channels.

In a stream morphology analysis, Malone (14) showed that due to their greater number, the lower-order streams (using Horton's stream numbering system) greatly exceeded the higher-order streams in surface area. His analysis also agreed well with that of Leopold and Miller (15). If the morphology of the Tucson Basin is similar to that found by Malone on the Harquahala Valley Watershed, the 9th and 10th order streams provide only 11% of the surface area of all of the streams in the basin (assuming the highest-order stream in the Tucson Basin is 10th order). Thus, rather than streambed evaporation losses of 1,100 acre-ft per yr, the losses may be 10,000 acre-ft per yr, which is then 20% of the estimated groundwater recharge of the basin.

The authors state that the average bottom width for the 115 miles of chanel in the Tucson Basin is 70 ft and base their basin evaporation on this figure. Analysis of these streams from 7-1/2 min USGS quadrangle maps reveals that the average width for Rillito Creek in the Tucson North Quadrangle is 210 ft; for Pantano Wash in the Tucson East Quadrangle, the average bed width is 320 ft; and for the Santa Cruz River in the Tucson Quadrangle, the average width is 150 ft. Therefore, the 70-ft bed width used by the authors may be too low, and if the average width were double their figure, the evaporation loss from channels in the basin would be 20,000 acre-ft (i.e., double the rate from the main channels, plus the losses from tributary channels).

Although the authors have not examined oasis effects on the evaporation rates from their small cylinders, it seems quite likely that the measured rates might be somewhat larger than the rate in a large stream channel with uniform wetting. Presumably, the cylinders were inserted flush with the ground surface in an unirrigated area, and any evaporated water would be quickly carried from the cylinder.

The data from Fig. 3 of the original paper are reproduced in Fig. 11 on logarithmic probability paper, along with an average bed material sample for Walnut Gulch. Such a graph has been found to be useful because it is possible to readily describe its properties with the mean and standard deviation (as-

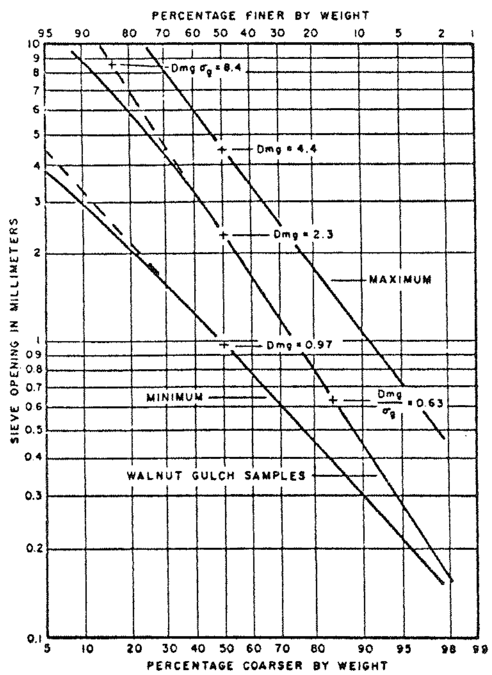

FIG. 11.—ENVELOPE CURVES OF PARTICLE SIZE DISTRIBUTION OF RILLITO CREEK BED SEDIMENTS AND SIZE DISTRIBUTION OF WALNUT GULCH BED SEDIMENTS

suming the sample plots as a straight line). The data for Rillito Creek and Walnut Gulch plot as a straight line, except for the extreme upper portion of the curve, indicating a close approximation of a log-normal distribution of particle size. Graphically, the geometric mean grain size (the value of sieve size for which 50% is coarser and 50% finer) is 0.97 mm, 2.3 mm, and 4.4 mm for the minimum, Walnut Gulch, and maximum bed material samples, respectively, with geometric standard deviations of 2.6, 3.6, and 2.9, respectively.

These values of the mean grain size and standard deviation are greater than those listed by Vanoni, Brooks, and Kennedy (16) for a large number of streambed materials. The values indicate a large mean grain size with a large scatter, and the values are undoubtedly indicative of many of the stream channels in the Southwest. It thus seems that the samples used in the test results are indicative of conditions found in many ephemeral streams in the Southwest.

The authors have chosen to use direct water-budget methods for measuring evaporation rates from coarse-textured alluvium. However, to estimate the losses from stream channels seems to be a research problem more suitable to heat-balance measurements or even to the use of equipment such as that developed by Sellers and Hodges (17). Instrument costs for such measurements may require a high capital expenditure, but the results may be considerably more representative of field heterogeneity and may provide more versatility.

A combination treatment for the channel alluvium in addition to management and treatment of upstream contributing areas will undoubtedly produce the ultimate means for optimizing water use in water-deficient areas. A combination of treatments including either water harvesting or land modification to enhance infiltration and produce more forage on upstream contributing areas, with concurrent channel treatments involving selective modification of the streambed to either inhibit or induce infiltration based onthe desirability of the area for groundwater recharge is undoubtedly the utlimate. Estimates of evaporation from the streambeds are an integral part of such a scheme, and the authors' work lends valuable insight to the magnitude of this evaporation.

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