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13. Basco, D. R., "Optimized Geometry for Baffle Blocks in Hydraulic Jumps," *Proceedings*, 14th Congress, International Association for Hydraulic Research, Vol. 2, Sept., 1971, pp. B18-1–8.

RELATIONSHIPS BETWEEN MORPHOLOGY OF SMALL STREAMS AND SEDIMENT YIELD[a]

Discussion by V. J. Galay,[1] M. ASCE

The Task Committee on Relations Between Morphology of Small Streams and Sediment Yield has indeed taken on a formidable task.

The committee adopts an operational definition of a small stream or channel as "a permanent feature of the landscape that conveys water and sediment from the upland areas to the major channels and acts as a sediment source or sink, depending upon the dynamic characteristics of the water-sediment flow system." The committee further states that this small stream or channel is generally to be found in Schumm's Zone 1, that is, the sediment-source zone, or erosion zone. The majority of the paper then deals with aspects of channel morphology and discusses various regime theories and hydraulic geometry concepts for stable channels, which are generally to be found in Schumm's Zone 2, the transfer zone. Therefore, it would appear that the committee is attempting to develop relationships between the morphology of *stable, regime channels and sediment yield*. This is somewhat confusing since stable, regime channels generally do not occur in Zone 1.

The writer would like to have seen the committee address the dynamics of small streams within Zone 1 as this can be somewhat complex since the channel can act as a sediment source or sink. The writer would like to discuss this dynamic behavior in more detail with an example of a small stream in Nepal, as shown in Fig. 1. The stream emerges from a sediment source zone, or erosion zone, into a broad alluvial valley where the coarse sediment fraction drops out in what would be referred to as a deposition zone. The channel pattern is braided indicating a high degree of channel instability. Within the upper sediment-source zone there is probably no distinct relationship between water and sediment discharge, and various hydraulic properties (width, depth and slope) because the slope and width are controlled by geological formations. The sediment load would be highly variable depending upon characteristics of the basin, but, in any case, most of the sediment would be flushed

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[a]November, 1982, by Task Committee on Relations Between Morphology of Small Streams and Sediment Yield of the Committee on Sedimentation of the Hydraulics Divison (Paper 17450).

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FIG. 1.—Stream in Nepal, Emerging from Sediment Source or Erosion Zone into a Sediment Sink. Channel Pattern Becomes Highly Braided and Unstable

out since the transport capabilities are generally higher than the supply of sediment. Along the lower deposition reach, the sediment-sink reach, there again is no direct relationship between imposed water and sediment discharge and hydraulic properties since the channel is highly unstable.

Below this braided, sediment-sink reach, however, the channel does take on a stable, meandering character where the width and depth appear somewhat uniform and the slope is relatively flat. *It is within this reach, the transfer reach, that relationships can be developed between imposed flow of water and sediment with channel properties.* It is the writer's opinion that relationships between sediment yield and small stream morphology are very difficult to achieve since the system is highly dynamic.

In assessing relationships between morphology of small streams and sediment yield it seems important to outline sediment erosion processes and to summarize the present status of predicting sediment yield. The committee presents references listing recent simulation models for erosion and sediment yield but there is no summary or recommendation as to the relationships for the various types of basins that exist throughout the world. The reader has to first obtain all the references then evaluate them in order to arrive at the-state-of-the-art. Important studies have been conducted on the world-wide variation in suspended sediment yield for basins in three different climatic zones by Fournier (1).

There are also a number of recent studies on sediment yield that were not listed in the references; the papers are too numerous to list here, but some can be found in the proceedings of the following recent conferences:

1. "Erosion and Sediment Transport in Pacific Rim Steeplands," New Zealand, International Association of Hydrological Sciences Pub. No. 132, 1981.
2. "International Symposium on River Sedimentation," Beijing, China, 1980.
3. "Recent Developments in the Explanation and Prediction of Erosion and Sediment Yield," Exeter, U.K., International Association of Hydrological Sciences Pub. No. 137, 1982.
4. "Hydrological Aspects of Alpine and High-Mountain Areas," Exeter, U.K., International Association of Hydrological Sciences Pub. No. 138, 1982.
5. "Adjustments of the Fluvial System," 10th Annual Geomorphology Series, Binghampton, N.J., 1979.

The writer suggests that the committee should continue its review of various papers and reports in order to clarify erosion processes and explain variations in sediment yield.

Appendix.—Reference

1. Fournier, F., "Debit Solide de Cours d'eau, Essai d'estimation de la parte en Terre Subre par l'ensemble du Globre Terrestre," *International Association of Science and Hydraulic Publications*, Vol. 53, 1960, pp. 19–22.

Discussion by Jeffrey G. Whittaker[3]

The writer was disappointed by the omission from the paper under discussion of one important class of small stream, i.e., the steep mountain stream. These streams fit the adopted definition of a small stream perfectly.

An extensive review of the interactions between morphology and sediment transport in steep mountain streams is presented in Whittaker (8) and IAHS Publication No. 132 (5). The step-pool morphology of steep mountain streams has been given emphasis in Hayward (4), while Whittaker and Jaeggi (10) investigated the formative mechanisms of step-pool systems. Steps and pools are extemely stable. Transported sediment, which is usually derived from a few specific sites, is stored within the channel during its passage downstream. During floods sediment transported is thus often supply limited, and depends on the frequency of contribution from the input sites. Only at slopes less than about 5% does interaction between bedload transport and bed material commonly occur during floods.

With respect to sediment transport formulas, one consistent feature with respect to steep mountain streams is that none of them are appli-

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cable. This is of course because they are derived for considerably different conditions. The writer (8) attempted to adapt the Meyer-Peter/Mueller formula and Bagnold's stream power approach to predict sediment transport rates in a step-pool system, without success. This is not surprising in the light of the extremely nonuniform character of the flow in such channels.

A sediment transport formula for steep plane channels (with slopes up to 20%) has been developed in Zurich (6,7). Griffiths (3) gives an approach for estimating sediment yields from mountainous catchments.

Movement of sediment through a series of steps and pools exhibits spatial and temporal variations (9). This is consistent with observations made in field studies, such as those of Hayward (4) and Ashida, et al. (2). Whittaker and Davies (9) noted that this behavior parallels recent findings on the thermodynamics of nonlinear systems.

Appendix.—References

2. Ashida, K., Takahashi, T., and Sawada, T., "Sediment Yield and Transport on a Mountainous Small Watershed," *Bull. Disaster Prev. Res. Inst.*, Kyoto Univ., Vol. 26, No. 240, 1976, pp. 119–144.
3. Griffiths, G. A., "Stochastic Estimation of Bedload Yield in Pool and Riffle Mountain Streams," *Water Resources Research*, Vol. 16, No. 5, 1980, pp. 931–937.
4. Hayward, J. A., "Hydrology and Stream Sediments from Torlesse Stream Catchment," Tussock Grasslands and Mountain Lands Inst., Lincoln College, New Zealand, special publication No. 17, 1980, p. 236.
5. International Association of Hydrological Sciences, "Erosion and Sediment Transport in Pacific Rim Steeplands," *Proceedings International Association of Hydrological Sciences, Christchurch Symposium*, I.A.H.S. Publication No. 132, ed. by T. R. Davies and A. J. Pearce, Jan., 1981.
6. Smart, G. M., "A Sediment Transport Formula for Steep Channels," *Journal of the Hydraulics Division*, ASCE, 1983.
7. Smart, G. M., and Jaeggi, M. N. R., "Sediment Transport on Steep Slopes," *Mitteilung Nr. 64 der Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie*, ETH Zentrum, CH-8092, Zurich, Switzerland, 1983.
8. Whittaker, J. G., "Flow and Sediment Movement in Stepped Channels," thesis presented to Univ. of Canterbury, Lincoln College, in New Zealand, in 1982, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.
9. Whittaker, J. G., and Davies, T. R. H., "Erosion and Sediment Transport Processes in Step-Pool Torrents," *1st I.A.H.S. Scientific General Assembly* (Symposium 4: Recent Developments in the Explanation and Prediction of Sediment Yield), Exeter, United Kingdom, 1982.
10. Whittaker, J. G., and Jaeggi, M. N. R., "Origin of Step-Pool Systems in Mountain Streams," *Journal of the Hydraulics Division*, ASCE, Vol. 108, No. HY6, June, 1982, pp. 758–773.

Closure by Leonard J. Lane,[3] A. M. ASCE

The writer would like to thank Whittaker and Galay for their interest in the Task Committee report and the additions their discussions and

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cited references will make to the report and bibliography.

Both discussers listed publications that they suggest should have been included in the report. These references should supplement the bibliography. However, the nature of an assignment such as this is to sift through an enormous quantity of literature and select representative publications, which give an overview of the subject. Of necessity, due to time and space limitations, some important references are always omitted. In this matter, I accept full responsibility for the Task Committee. Finally, because many of the references the discussers suggest were not available at the time the committee was preparing the report, we appreciate the list of new references.

The Task Committee did not place special emphasis on steep mountain streams as Whittaker points out in his first paragraph. As noted on p. 336 of the report, Bathurst (1978) has investigated flow resistance of large-scale roughness and this analysis has direct application in some mountain streams. The "cobble" and "boulder" bed classifications of Osterkamp (Table 11) are also sometimes appropriate for mountain streams. The material presented on pp. 1349–1350 describes situations in which sediment load may be supply limited and emphasizes, as does Whittaker, that discharge in natural streams is spatially varied and unsteady.

Whittaker found that none of the sediment transport formulas are directly applicable to steep mountain streams. This is not surprising given their usual dependence on the normal flow assumption. It may be that Whittaker's references to formulas applicable to steep plane channels will contribute to the comprehensive guidelines identified on p. 1353 of the report.

Galay discussed the appearance of the Committee to exclusively develop relationships between the morphology of stable, regime channels and sediment yield. When the Committee first met, we had lengthy discussions in attempting to reach a compromise definition of a small stream. The definition we adopted was not perfect, so we called it an operational definition. We stated that our definition shared a common concept with Schumm's Zone 1 (lines 13 and 14, p. 1330) in that the small channel was seen as an integral part of the runoff sediment source area. We also described an "erosion approach" to determining channel morphological properties (p. 1349), the indeterminate nature of channel processes (pp. 1334, 1345, 1350, and 1352 through 1355), and additional research needs (pp. 1352–1355). These sections of the report were intended to show a broader perspective than regime channels and their associated sediment yield. However, and in spite of our intentions, it may be that we did overemphasize regime theory. If this is true, then Galay's discussion provides a valuable mechanism for emphasis of the "nonregime" topics indicated earlier.

We are in agreement with Galay's statement ". . . that relationships between sediment yield and small stream morphology are very difficult to achieve since the system is highly dynamic." Lines 9–23 on p. 1351 of the report express this same opinion and, in addition, point out the weakness in our ability to predict the upland inputs or to calculate sediment transport rates.

With respect to Galay's comments concerning the Committee's presenting references outlining erosion and sediment yield models without making specific recommendations, the discusser is correct in that we did not identify a "best" model. Rather, in this area, as in selecting a "best" sediment transport equation, we tried to present an assessment of the state-of-the-art and then briefly indicate where the reader might go to make his own evaluation. Choosing the "best" model or equation is difficult, if not counterproductive, because the utility often depends upon the user and his objectives. However, we did state our opinion that current simulation models were inadequate to fully utilize a dynamic sediment routing-channel morphology model (lines 7–10, p. 1350).

Members of the Committee will continue their research as individuals but our work as a Committee has terminated. Although we must allow the Committee report to remain as it is, we will continue our efforts to conduct research as summarized in the report and as suggested by the discussers.

On behalf of the entire Task Committee I thank the discussers for their interest in our work and for their comments and suggestions which should help the reader assess the current state-of-the-art in an important and interesting area of research.

Errata.—The following corrections should be made to the original paper:

Page 1331, third line from the bottom of the page: Should read: "This is most evident in the area of rainfall simulation to determine soil erosion"
Page 1348, Table 11, last entry in Col. 2: Should be "256 mm" instead of "2.56 mm"

Computation of Flow Patterns in Rivers[a]

Discussion by Robert Booij[3]

The authors rightly attach much importance to the coefficient of diffusion of momentum, used in the two-dimensional computation of flow patterns in rivers. To guarantee a stable computation, this diffusion coefficient must exceed a certain value in the scheme used by the authors. This value depends on the time step used and the velocities present, conforming to Eq. 5. The diffusion coefficient can have an important influence on the calculated velocity distributions, especially at the high values needed to avoid unreasonably large computation times. In the writer's opinion the diffusion coefficients, used by the authors, are too high to provide a useful reproduction of the velocity distributions oc-

[a]November, 1982, by C. B. Vreugdenhil and J. H. A. Wijbenga (Paper 17453).
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