Field Data: The Interface between Hydrology and Geomorphology

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In 1904 the California Miners' Association adopted in convention a memorial forwarded to the President of the United States, who in turn referred it to the U.S. Geological Survey. It was a request for a study of the relationship between the hydraulic debris in California and problems of flood control and sedimentation. The Geological Survey assigned their most prominent geologist, G. K. Gilbert, to conduct the investigation. He soon became convinced that, although it was possible to make reasonable estimates of the amount of the debris accumulated in the various portions of the valleys and basins of the rivers flowing out of the Sierra Nevada, there was simply not enough known about the principles of sediment transport to determine with surety how the accumulated debris was going to react over time to the passage of floods. Nor was it possible to determine whether the structures that had been built for the containment of this debris were going to operate satisfactorily as planned. Some of the structures were actually under construction at the time Gilbert was making his investigation, and he was able to map the sediment accumulation before and after one of the important structures had been raised in height. The concrete and log dam, called Barrier No. 1 on the Yuba River, was one of those studied in detail by Gilbert. He expressed concern with the erosion at the toe resulting from water deprived of its sediment load pouring over the structure and scouring downstream from the dam.

As a result of these considerations, Gilbert instituted his famous experiments on the campus of the University of California, Berkeley, the data from which have been a major source of information on transport mechanics.

One wonders whether, if the same problem faced modern hydrologists, there would be an equally sophisticated understanding of how the lack of specific data would prevent any useful solution to the problem at hand. On the basis of experience of the last several decades it would be reasonable to forecast that the modern hydrologist would have begun with a dimensional analysis and from that he would construct a theoretical set of equations that would purport to relate sediment transport rate to hydraulic factors. The prospect of 2 yr of laboratory work probably would deter the initiation of an investigation for the collection of basic data.

Even if the modern hydrologist were wise enough to choose a course of action that would involve the collection of a long series of carefully planned basic data, it is unlikely that he would find a place to publish the data themselves. One cannot imagine a modern organization willing to publish a report that totaled 263 printed pages, including not merely the summarized data but also the original observations themselves. In the Gilbert report on his sediment-transport experiments the tabulations of the basic observations involve 16 printed pages, which include the direct observations as they were actually recorded. A whole chapter of the report is devoted to what Gilbert called "Adjustment of Observations," in which 12 printed pages are devoted to a retabulation of the same basic data. In his words, "The observational values were subjected to a process of adjustment, whereby the sequences were freed from irregularities. The irregularities are made manifest by the comparison of the sequences of two variables, and first consideration will be given to those of capacity and slope" (1914, page 55).

There follows in the report retabulated data organized for specific comparisons such as the grouping of a particular discharge at a particular width and tabulated such that the relationships, in this case between capacity and slope, could be plotted easily for further analysis.

Finally, after 218 pages of detailed analyses of the data, there is a chapter in Gilbert's report that deals with the application of these laboratory experiments to natural streams. Further, it must be understood that in addition to the report on his experimental work, there is a separate report on the mining-debris problem, to which he had been assigned originally. This report, U.S. Geological Survey Professional Paper 105, consists of 153 printed pages. In the latter paper, "Hydraulic-Mining Debris in the Sierra Nevada," Gilbert deals with the matter of tides and the tidal prism in San Francisco Bay. He made detailed measurements of the relationship among velocity, water-surface slope, and gauge height, as well as channel geometry of a small tidal estuary in the southern portion of San Francisco Bay. To include a study of tides and their effect on the estuarine geometry in a report on hydraulic mining is an interesting aspect of the bredth of Gilbert's thinking about a particular problem.

Many of the problems that Gilbert faced remain incompletely solved. Some of the most important current problems are those that lie at the interface between hydrology, hydraulics, and geomorphology.

Over the years there has been a series of studies of the gradient of deposition of sediment trapped behind a dam or barrier. From these field observations it is now well known that the gradient of deposition of sediment behind a barrier, not in a reservoir but behind a check-dam, large or small, will in all cases be less than that of the original valley floor. Observations on this matter had not previously been made. Gilbert's statement about this matter is as follows (1917, page 53):

The initial slope of the river bed in the vicinity of the barrier was about 16 feet to the mile, and there was a rapid increase upstream to 2 feet to the mile . . . At Marysville, near the mouth of the river, where the chief material is sand, the slope is about 6 feet to the mile, and it increases upstream as the material changes successively to a coarse sand, fine gravel, and coarse gravel. The erection of the first 6 feet of the barrier in 1904 caused a filling during the flood stages of the ensuing winter which extended at least 1 1/2 miles upstream and probably somewhat more, reducing the average slope in that region to about 12 feet to the mile. When the second unit was added to the barrier, increasing its height 8 feet, deposition again began, and the flood of January, 1906, in filling the newly formed basin, extended its deposit upstream about 1 3/4 miles, reducing the average grade for that distance to about 9 feet to the mile. The subsequent storms of the same winter extended the area fill somewhat farther upstream and nearly restored the slope of 12 feet to the mile which had been created by the floods of the preceding winter.

Gilbert's diagram (1914, page 59, Figure 7) is the first quantitative observation of the difference in the depositional grade behind a barrier from the gradient of the original stream before the barrier was built. He did not attempt to forecast what would eventually happen if the barrier did not fail, but there is no indication in his report that he expected the depositional wedge to extend upstream indefinitely. He did not specifically say this, but the implication in his report is that a form of equilibrium had been established; he did not take the matter any further. Many subsequent reports have noted the same result, and it has been a matter of concern to geomorphologists ever since consideration of the hydraulic reason why the sediment wedge does not continue to extend itself upstream indefinitely. The latest discussion of this matter is that by Leopold and Bull (1979), which includes the first attempt to provide a hydraulic explanation of this observed fact.

This matter is important because it bears on the interaction of those factors that determine the gradient of a river channel through any particular reach of the river. This involves both hydraulics and geomorphic history and probably is one of the central questions of fluvial geomorphology even at the present time. The slope of a stream in a geologic or geomorphic sense involves the interaction of eight (or possibly more) variables and cannot be completely solved in an analytical fashion. Improved understanding will depend on obtaining a series of field observations that include factors not ordinarily measured at stream-gauging stations, especially water-surface slope and its relation to the pool and riffle sequence and to river curvature. It is nearly impossible to imagine that any so-called model or computational scheme would be effective because there are not requisite field data on which the model might be predicated.

Another problem now taking up the time of many hydrologists and some geomorphologists is the estimation of the effect of forest practices on water quality and sediment production. In recent years the tendency for timber harvesting to be conducted by clear-cutting has posed the possibility of long-term deterioration in water quality, which depends to a large degree on slope stability and channel stability. Formerly it was thought that the best practice for erosion control requires the maintenance of the soil profile in forested areas. It is now claimed that silvicultural efficiency in coniferous forests of the western United States demands that the surface soil be stirred, mixed, and churned. This means the destruction of the forest soil profile. To what extent the destruction of the soil profile is going to alter water quality over a period of years, and to what extent it will change the rate of sediment production, remains to be seen. But theory expressing the leaching by infiltrating water, the cation adsorption on mineral particles, the effect of soil structure on erodibility, and other processes make it impossible to use any known analytical technique to forecast how water quality will change over the next several decades, downstream from areas that have been clear-cut of their forest cover. The amount of water yielded from a clear-cut area and the timing of runoff have been investigated in many areas, but concurrent studies of sediment deposition, its location, form, effect on stream channels, and water quality are few. Long-term field observations will be needed to ascertain wnat principles are the governing ones.

Considering the experimental work done in forested watersheds, the record shows that much effort has been spent in watershed research attempting to forecast the effect of various forest practices on water yield. It is interesting to note that, in the actual management of our national forests, there are few instances of management practices either governed by or even greatly influenced by the need to increase water yield, even in relatively water-short areas. Rather, forest management practices in recent decades have been governed by timber production, recreation, and wildlife--timber production being given the greatest weight. It appears then that most of the hydrologic research on forested watersheds has been and still is being directed toward what is theoretically an important problem but which in actual practice is not given much weight in forest administration.

The point here is that much hydrologic research is directed at problems that are not necessarily the most significant ones in theory, on the ground, or in practice.

Where, for purposes required by recent legislation, it is necessary to assess changes in water quality and sediment yield, especially in connection with environmental impact statements, most of the effort is on office compilations and theoretical constructs rather than on the collection of field data. The lack of surety and even the lack of confidence in most environmental impact assessments come from the fact that the effort is on fulfilling the requirements of the report rather than on the collection of those data that might actually yield the desired answers.

These same remarks might be applied to a whole list of problems in hydrology, but especially those that have an interrelation with geomorphology. A short list of such problems might include the following:

1. *Channel stability* The effect of man's work--agriculture, forest management, grazing--on channel stability is essentially an area of unknowns. A classification of stability based on field measurements with associated information derived from soil mechanics, pedology, and hydraulics is needed.
2. *Rate of bank-cutting and lateral migration of rivers* There is no common body of knowledge dealing with factors controlling bank erosion even though large amounts of money are expended for river revetment, especially at highway crossings.
3. *Erosion by overland flow* Though the hydraulics of thin films are well known, variations in rates caused by nonuniformity of surficial materials and the effect of vegetation cannot be solved by analytical techniques. Direct field observations under various conditions are needed.
4. *The profiles of hills* A great deal of theoretical work has been devoted to constructing equations purported to express the longitudinal profile of hillslopes. This problem is a peculiar combination of hydraulics, hydrology, geomorphology, pedology, and soil mechanics.
5. *The effect of sediment availability in rivers on sediment-transport rates* With the recent development of the Helley:-Smith bedload sampler it appears possible to obtain actual measurements of bedload-transport rates. Difficulty exists, however, in interpreting measurement data because the sediment-transport rate may be limited if the sediment is not available for transport. Therefore, actual river data on sediment-transport rate may not appear to follow the usual empirical relations. Little is known about how to estimate whether sediment is available in the stream channel for movement.
6. *Effect of heterogeneities in geologic materials on groundwater movement* The usual equations dealing with transmissibility, specific yield, permeability, and porosity assume that the geologic material is essentially homogeneous. The inhomogeneities alter both the direction and paths of groundwater flow. Present methods of geologic mapping for groundwater purposes are inadequate to assess the form and effects of heterogeneity in the geologic materials. This is a problem involving a combination of hydraulics, geomorphology and geomorphic history, sedimentology, and hydrology.

It would seem desirable to keep in mind the most important theoretical and practical problems facing the hydrologic science, especially as it relates to associated sciences or sub-sciences. A study of the title of grant proposals in the field of earth sciences related to hydrology and geomorphology evokes a certain surprise that most of the research projects deal with problems that are not of general interest. One knows from experience the history of most research proposals and how they are often determined by the preferences of the granting agencies. But these preferences are the result of consideration by competent scientists. The scientific view of what is worth working on, however, is usually expressed in terms so general that even poor projects might appear to qualify under the general headings listed as priority items. It would appear far more practical to express priority items for research funding in terms of the questions to be answered rather than a general category of work. As an example, a priority item for a funding agency might be listed as "the problem of urbanization." It would be readily agreed that the hydrologic results of urbanization constitute a large class of problems worthy of study. But that general class could be broken down into specific questions such as, how many tons of sediment per square kilometer will be contributed by housing construction using construction methods that are typical of the area near Washington, D.C.? The answer is not likely to result from present theory, but would require a set of specific field observations designed to answer this specific question.

It appears that the hydrologic science is making only slow progress at the present time because of the choice of the questions being researched and the tendency to study only questions amenable to known theory with the minimum of field measurement.

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