Unsteady State Denudation

Trimble (*1*) presents some very interesting information on sediment storage in river basins of the southeastern United States, and he correctly concludes that the sediment exported from these large river basins is not equal to erosion on upland slopes and on the tributaries. However, he continues by stating that a steady state condition cannot be assumed since European settlement. In his words, a steady state condition would exist in a drainage system when "the solid material transported from stream basins is considered approximately equal to that eroded from upland slopes." The rhetorical question in his title ("Denudation studies: Can we assume stream steady state?") implies that he is challenging an established tenet of geomorphology. However, recognition of a dynamic equilibrium or a steady state within a drainage system depends largely on the time span and the area considered (*2*). The steady state concept, as defined by Trimble, might be applied to large drainage systems during long periods of geologic time. That is, if climatic and diastrophic changes are ignored, then over the millions of years required for the erosional reduction of a landscape, sediment produced within the system will eventually leave the system, but at any one time storage or flushing of sediment will predominate, depending on the progress of drainage basin evolution. Of course, the morphology of the drainage basin is irreversibly altered during long periods of geologic time and so a geomorphic steady state is not possible.

Studies of alluvial valley-fill deposits present clear evidence of episodes of storage and flushing of sediment from drainage basins throughout the Quaternary (*3*) and this is occurring at present in the western United States (*4*). In addition, during experimental studies of drainage network evolution (*5*) sediment was stored and then flushed from the main valley of a 9 by 15 m watershed as the drainage network responded to rejuvenation. Hence, both field and experimental investigations of drainage basin evolution indicate that it is not possible to consider an entire drainage basin as being in a steady state, as defined by Trimble, at any time during its erosional evolution. In fact, it appears likely that the sediment which accumulated in the valleys of the Piedmont following European settlement would have been remobilized whether or not agricultural practices improved, as the slope of the valley-fill deposits increased with time and approached a geomorphic threshold of instability (*6*). Therefore, the answer to Trimble's question has always been an emphatic negative.

Additionally, at least some investigators who have used sediment yield data (*7*) have been aware of and have been concerned with minimizing the influence of man's activities on the data by selecting sediment yield records for areas of little agricultural activity. Denudation rates calculated from such data provide useful estimates of past rates of regional erosion, although it is apparent that the modern rates may be several times those of the past (*8*).

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I am grateful to Schumm *et al.* for their comments on my report, but their observations seemingly overlook my main point: systems analysis (denudation rates) based merely on systems efflux (sediment yield) may have little meaning unless storage (alluvium and colluvium) is considered. Studies that attempt to correlate basin erosional factors (such as vegetation, climate, and land use) with only sediment yields may be suspect: under disturbed conditions (in most present basins) sediment yield may be more a direct function of storage than of present upland erosional phenomena.

This is further demonstrated by my present research (*1*) in the Driftless Area of Wisconsin, where 2.3×10^{-2} km^3 of modern alluvium is found in a basin of about 400 km^2. This storage alone represents 5.7 cm of basin erosion over a period of about 120 years. Sediment yield, measured between 1935 and 1938, would total only 1.0 cm if extrapolated to the same 120-year period. Thus, the sediment yield is about 20 percent of the storage. At present, upland erosion is greatly mitigated, but sediment yield remains high, evidently coming in part from channel erosion (storage loss), a process that may be inversely correlated with upland erosive factors. So what does efflux from this basin tell us about present-day denudation rates, regional erosion, or upland erosional processes? Not much. Indeed, these ideas do challenge an established tenet of geomorphology.

Ahnert (*2*) has stated that denudation studies dependent on sediment yields are "based on the tacit assumption that the rate of rock waste production, and of transport of that waste, within the drainage basin is during the short period of measurement in equilibrium with the rate at which this rock material is removed from the basin." Is this steady state? Not by a strict physical definition, but common usage seems to have it so. Morisawa (*3*), for example, states that "when the rates of import and export of material are equal, i.e., when the channel is stable and is neither eroded nor silted up, the stream has reached a steady state." Thus, steady state is here an equilibrium where net storage approaches zero. (Perhaps "equilibrium" is preferable to "steady state.") As to whether such streams can exist in reality, I have earlier presented evidence indicating that preagricultural Piedmont streams were fairly stable, with neither deposition nor scour being important (*4*). A similar case has been made for streams in the Driftless area (*5*).

Finally, we know that human activities may increase erosion and sediment yields. We must now consider man's effect on storage. Schumm *et al.* refer to the 1958 Langbein-Schumm study (*6*) as one in which sediment yield records were selected for areas of little agricultural activity. In fact, much of the sediment yield data for that study came from the humid United States, where agriculture has been widespread and sediment storage may be significant.

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