Fluvial Processes and Settlement in Arid Environments

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Abstract: The impact of fluvial geomorphic processes on settlement in deserts is tied to two conflicting factors: the extreme rarity of geomorphic events on the one hand, and the violence of the geomorphic forces coupled with a minimal resistance to erosion on the other. The unique character of desert floods calls for a careful geomorphic evaluation in the siting of settlements and transportation facilities. On the beneficial side, the geomorphic processes involved enable, under some conditions, the local exploitation of floodwaters which percolate in the alluvium of the upper tributaries, as well as the utilization of the hydraulic geometry for estimating discharge characteristics.

On a larger scale, human interference often disrupts the delicate quasi-equilibrium between erosion and sedimentation in deserts. Although our poor understanding of many aspects of the mechanism of response makes it difficult to separate the effects from those of climatic changes, enough information is available to document the detrimental effect of inconsiderate management on both the regional and local levels.

Introduction

Contrary to humid regions, in which most of the geomorphic work is accomplished by events of medium-size magnitude (Wolman and Miller 1960), arid regions are dominated to a much larger degree by major catastrophic events (Baker 1977). Such events are rare, they tend to be scattered also in space, and their scientific documentation is mostly inadequate. Researchers have to rely on surveys made after the event without a basis before it to which comparisons are possible. Some examples of studies in this line are Beatty (1968), Glancy and Harmesen (1975), Leopold (1946), Schick (1971), and Woolley (1946). Although the great development in remote sensing techniques in recent years has improved the situation somewhat, a good data base for the study of low-frequency geomorphic events in truly arid areas is still a world-wide need.

Because settlements and other structures in deserts are also widely scattered, a spatial combination of the area affected by a violent desert flood with an area of settlement is relatively rare. However, such events seem to be less infrequent during recent years than in past decades. One reason for this is undoubtedly the great expansion of economic activity, mainly various forms of mining, in deserts. There are currently more objects to be affected in the desert, they are more widely distributed, and, furthermore, they are served by a much more widespread and organized network of roads.

Because of the foreseeable further increase in the development of desert resources in future, we need a better level of knowledge and awareness of desert floods and their geomorphic effects. Besides affecting Man such processes also present an important dimension in guiding planners in opting alternatives of siting. If interpreted judiciously, diagnostic landforms such as high flood marks and terraces on the one hand and low-flow marks such as inner bars on the other, can convey valuable information on hydrologic characteristics.

This paper proposes to present a number of examples on the impact of fluvial processes in arid areas on environmental planning. Most of these examples will be drawn from regions of extreme aridity, i.e. with a mean annual precipitation of 50 mm or less, such as the southern Negev and the Sinai.
Fluvial Processes

In small mountainous watersheds in the truly arid regions, rainfall and runoff show extreme variations both in time and in space (Sharon 1972; Sharon et al. 1976). In Nahal Yael, an 0.5 km² watershed in the Southern Negev, mean annual rainfall over a recent ten-year period was 31.6 mm, with annual extremes of 1.6 mm and 66.9 mm (Schick 1977). More than 20% of this ten-year rainfall became runoff inside the watershed, but ultimately less than 5% flowed into the higher-order channel downstream. Practically all the intermediate losses were by infiltration into channel alluvium. The significance of infiltration of such a magnitude is of a major importance in developing local small sources of water supply.

The geomorphically significant runoff over that decade was caused by seven major events. The longest interval between subsequent major events was over 45 months, and the two shortest intervals were 4 and 8 hours. If each of the last-mentioned “double” events are regarded as one event, it can be said that a major geomorphic event in extremely arid regions such as Nahal Yael occurs, on the average, once in two years. This frequency decreases with increasing drainage area (Schick 1971).

In the 3100 km² watershed of Wadi Watir in Eastern Sinai, a major geomorphic event which activates the entire fluvial system probably occurs only once in 4–5 years. In still more arid areas such as in the core regions of the Sahara, even longer intervals seem to apply (Dubief 1954).

Most of the runoff events are short-lived and have a highly peaked hydrograph (Schick 1971). Peak discharges for small (50–100 ha) upstream watersheds exceeded 10 m³/sec/km² several times during the decade. Peak discharge per unit area decreases with increased drainage area.

The entrainment of suspended sediment by the flow generated by a major event is rapid. This is remarkable considering the eolian activity which effectively cleans the desert surface of silt and fine sand. For a major event in Nahal Yael, only the smallest uppermost tributaries have a suspended sediment concentration of less than 10000 ppm. This concentration increases with event magnitude and with length of alluvial channel traversed by the flow. At the mouths of intermediate size watersheds (10–100 km²) in the Eastern Sinai it often exceeds 1000000 ppm. Extreme values around 400000 ppm were recorded (Schick and Sharon 1974), and indicate a combination of high-energy flows with water losses by infiltration into the channel bed.

In the Nahal Yael ten-year geomorphic sediment budget, bedload accounted for about one-third of the roughly 2000 tons of material transported out of the watershed (Schick 1977). Although this figure cannot be regarded, at present, as being very accurate, it probably reflects a reasonable order of magnitude. The source of the bedload is almost exclusively the scour layer, which more or less doubles the depth of higher flows, and some lateral cutting of older bars and of terrace slopes. Bedload particles were observed rolling down the 5% channel slope when only partly submerged during a medium-low water stage. Mean distances of transport of bedload particles (size 20–80 mm b–axis) is about 65 meters per event. As the main alluvial reach of Nahal Yael is about 1000 m long, it takes about 15 major events (i.e. 20–30 years) for a single particle to be evacuated from the watershed. However, a few individual particles were transported up to 8 times the mean distance in a single event. Such a transport may be associated with the “wall of water” mechanism (Leopold and Miller 1956) which is probably sustained by infiltration of the flood front into the alluvial channel bed (Schick 1971). Also, events of truly catastrophic proportions (recurrence interval of 100 years and over) are capable of completely cleaning out small arid watersheds of nearly all the available sediment (Schick 1974).

Landform changes which result from the runoff and sediment regime described above are very often subtle and difficult to detect over humanly short time spans, but on occasion assume monumental proportions. Detailed sections recurrently surveyed between fixed bench marks showed that the 7800 m² fan of Nahal Yael aggraded, over a six-year period, by a volume of 10.6 m³, i.e. a mean aggradation of 1.4 mm only (Schick and Sharon 1974). On the other hand, the 6200 m³ alluvial fan of Wadi Mikeimin was formed literally overnight at the outlet of the 13 km² watershed in Eastern Sinai. This fan was the result of a highly localized intense rainstorm which created a peak flow of 70 m³/sec down the Mikeimin, only to dissipate quickly in the bed of the large Wadi Watir, whose drainage area was unaffected by the event. Wadi Watir was actually impounded by the Mikeimin fan for the duration of 22 months, during which the Watir was geomorphically dormant. During this period only small amounts of underflow collected as a small natural pond behind the Mikeimin fan-alias-dam, which extended all the way to the opposite side of the Watir valley. The event of November 1972 created a peak flow of about 400 m³/sec at the site of the Watir-Mikeimin confluence and obliterated the 1971 fan (Lekach 1974).

Geomorphic evidence shows that remnants of tributary fans which clogged trunk stream valleys in mountainous deserts such as the Sinai are not unique. These obstructions must have served as temporary dams for the subsequent fluvial event in the trunk stream. In fact, due to the difference in time lag between rainfall and runoff in small tributaries versus the large stream channel, damming fans of the Mikeimin type undoubtedly develop, and are subsequently breached, during one single event. This process contributes to the peaking of the hydrograph, as the breach of the dam is in reality a “wall of water”.