To settle this question, I investigated the barriers constructed by ancient man, with the help of Dr. Asher P. Schick in Israel. Nabatean culture in the period 300 B.C. to 100 A.D. developed highly sophisticated hydrological knowledge, as proven by Shanan et al. (1950). Of particular import in the present discussion is the construction of many barriers or check dams in the vicinity of Avdat where these investigators have reproduced the agricultural methods and productivity of the Nabatean culture. The age of the dams we studied is not definitely known, but one stone mound in the general area is known to be of the Byzantine period, though similar agricultural practices are of much greater antiquity.

The dams we surveyed were built in alluvial valleys in the Negev Desert of Israel where the sporadic rainfall averages about 100 mm annually. The dams were part of a complicated floodwater farming system in which the drainage area was treated by clearing the surface of stones, which were placed in long rows of stone mounds. Conduits were constructed to lead runoff water directly to a field formed on the wedge of deposition upstream of a dam. "These conduits artificially increase the catchment area for a particular field. They cover tens of thousands of dunams (100 m² area) and drain every square meter of the Abde (Avdat) region" (Shanan et al., 1950, p 113).

The typical dam is about 1 m high, consisting of rock blocks laid without mortar, stretching across the alluvial valley with dam length varying from 29 to 46 m. Figure 1 shows the downstream face of a typical dam. The sediment wedge behind each dam feathered out at the base of the next dam upstream, so that ancient people knew from experience the grade of deposition above a barrier.

The stone-free nature of the deposit above a dam was good for growing crops, especially because it received runoff water from the hillslopes. The deposits behind the dams in Havat Yehuda can be seen in Fig. 2. Some of the dams had complicated stone structures to lead the runoff water over the crest. In Fig. 3 there are carefully squared stones on the top of the dam spaced in a way that suggests they divide the runoff and keep it from concentrating in one place. So also in Fig. 4, a carefully constructed shallow channel lined with rocks can be seen just upstream of the dam, seeming to direct runoff into a chosen zone in contrast with the apparent spreading action of rocks in Fig. 3.

The valley of Havat Yehuda has 17 dams along its length served by a drainage area of 0.79 km². The
Another dam surveyed was Hazel Bunch, consists of 38%.

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Fig. 5. Longitudinal profile down a segment of the valley of Havat Yehuda, near Avdat, Israel. Seven of the 17 dams are shown, with the surveyed wedges of deposited sediment behind each dam. The dotted line is the profile of the original valley floor.

Fig. 6. Longitudinal profile of the farming area that was surrounded by a rock wall within which 7 dams were built at Havat Baruch, near Avdat, Israel. Crops were grown on the sediment deposited behind the dams.

difference that may not be significant. Observing these structures and their location suggests that in some manner the slope of the affected reach is related to the width. If width is not changed, the slope of deposition is comparable to that of the unaffected channel.

In most of these ancient dams the ratio of the gradient of deposition to that of the valley floor is of the same order as in more recent check dams studied in the United States (Leopold and Bull, 1979). It can thus be stated unequivocally that, as concluded by Leopold, Wolman, and Miller (1964), the gradient of deposition becomes stable in a short period of time and does not change with time thereafter, even over a period of 1000 or more years.

This is of great theoretical importance in geomorphology. It is one example of the fact that the effect of base level extends upstream only a very short distance. Self-regulating feedback mechanisms must operate to balance the contribution of each of the adjustable hy-

Fig. 7. Well-preserved dam of uncremented rock blocks built by the Nabateans about 2000 years ago. It is one of 2 dams that are 130 m apart in the wadi of Kurnab, Negev desert, Israel. Few ancient dams have survived for such a period of time. Photo by the author.

draulic factors. We now know that such adjustment governs the hydraulic geometry tending toward a condition of minimum variance among those factors. But how such adjustment requires such a large change in channel slope over the depositional wedge is not known.

U.S.A., CA. 1950

The problem from the standpoint of hydraulics and geomorphology is to understand how the sediment produced upstream can be carried over the flat gradient of the deposited wedge. No procedure has been developed that can predict quantitatively the gradient assumed by a channel even when values of the apparently requisite parameters are known. In fact, few authors have attempted to do this. Hack (1957, p. 60) derived an empirical relation for streams in Virginia expressing slope as a function of drainage area (a surrogate for discharge) and bed particle size. If drainage area is equated to 1 cfs per mi², the mean annual discharge for eastern U.S., his diagram is surprisingly good. But in the mountains of New Mexico, Miller (1958) found no such relation. Though the gradient assumed by a channel may be dependent primarily on discharge and bed material size, this is too general to be a quantifiable tool for prediction. Even where those parameters are controlling, it is not clear what discharge or what particle size are the determinants.

It is highly desirable to obtain quantitative values of hydraulic parameters in actual conditions behind dams. This is not easy because many field sites where check