Experimental Drainage Basins in Israel: Rainfall, Runoff, Suspended Sediment and Bedload Monitoring

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Abstract

Within the hyper-arid to semiarid areas of Israel three experimental drainage basins varying in area, climate, monitoring duration and type have been being research-monitored.

Lessons derived from a large number of published and ongoing research projects on these experimental basins focus on runoff and sediment in drylands. The effect of the spatial distribution of rainfall on runoff generation becomes increasingly important with aridity. Rainfall angle on hillslopes and storm intensity and direction derived from rainfall recorders and radar backscatter are crucial for explanation of runoff response. Runoff hydrographs have more bores, shorter-duration peaks, briefer recessions, longer dry periods, and are more variable in flood volume and flood peaks with increased aridity. Suspended-sediment fluxes, yields and concentrations are high in the semiarid realm, reaching maxima at the beginning of a flood season and after long, dry spells. Bedload fluxes are exceptionally high from dryland basins where hillslopes are minimally vegetated and where bedload transport takes place in channels lacking an armor layer. The bedload/ suspended-sediment load ratio increases with aridity and may rise to 70%. The depth of channel bed activity is indicated by a fluvio-pedogenic unit. Hillslope to channel connectivity is high in drylands. In the hyperarid region the finer suspended-sediment is derived from hillslopes while the sandy fraction derives from the channel bed.

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Introduction

The research watersheds are those of Nahal (stream in Hebrew) Yael, subdivided into five sub-basins, Rahaf-Qanna'im (main and tributary, respectively) and Eshtemoa. The basins have precipitation, runoff, sediment and fluviomorphological records. Each was conceived for differing purposes, but all share the common two objectives for continuous monitoring of water, sediment and morphology:

1) Many hydrological issues may be approached if, and only if, there are prototype databases on a wide spectrum of hydrological processes; and
2) There is a need for long-term records to assess large floods and subsequent hydrologic and geomorphic recovery.

This paper introduces these research watersheds as well some of the multitude of results that have arisen from prolonged monitoring. Whereas results from the Yael and Eshtemoa have been published in various outlets, those from Rahaf-Qanna'im have not (Cohen's dissertation).

The Research Watersheds

The Nahal Yael Watershed has been in operation for more than 35 years, is the smallest of the three and is located in the most arid region. The Rahaf and Eshtemoa are similarly sized, but vary in climate, soil cover and tectonic setting (Table 1). The Yael's instrumentation was novel when introduced in the 60's and onwards; that in the Eshtemoa and Rahaf is modern, with varied electronic sensors and digital recorders.

Table 1. Characteristics of the Israeli Research Watersheds. SD denotes standard deviation.

Watersheds	**Yael**	**Rahaf (Qanna'im)**	**Eshtemoa (Yatir)**
Drainage basin area (km^2)	0.6	79	112
Annual rainfall (mm)	27	50-130	280
Climate	hyper-arid	Arid	semi-arid
Soils	desert reg, rock outcrops, colluvium	Desert lithosols, reg, coarse alluvium	rendzina, loess in valleys
Rock	granite, schist, amphibolite	Dolomite, limestone, some chert	limestone with Nari, dolomite, chalk, chert
River pattern a outlet	shallow braided	Canyon, flat alluvial to braided	single thread, straight to meandering
Width of channel at station (m)	7	Variable, 30 at station	6
Mean bed slope	0.05	0.05 (0.017 Rahaf outlet and 0.027 at Qanna'im)	0.0075
Banks	alluvial, bedrock	Bedrock (limestone, marl, conglomerate), alluvium	loess, alluvium
# of events each year	0.6 arriving at outlet	2	3.1
SD of above	0.5	2	4.8
Max recorded discharge ($m^3 s^{-1}$)	3.7	775 (1987 estimate)	84
Mean annual runoff volume ($10^6 m^3$)	?	0.25 (min. estimate)	0.65
SD of above ($10^6 m^3$)		0.36	0.90
Typical suspended sediment concentration (mg l^{-1})	40,000 (only during stage rise)	1,000-55,000	34,000
Typical bedload discharge (kg $m^{-1} s^{-1}$)		0.1-10	0.3-2
Mean annual sediment yield (t $km^{-1} yr^{-1}$)	170	150 (estimate)	472

Results from the multi-year monitoring of water and sediment at these research watersheds is herein presented. Rather than being all inclusive, these are illustrated with examples.

Monitoring Methods

Rainfall was monitored using miniature accumulating gages, tipping bucket recorders as well as radar backscatter images acquired at intervals as short as 5 minutes. Runoff was measured in flumes (Yael), or else by continuous water depth monitoring using pressure transducers and surface velocity using floats up to bankfull discharge. Longitudinal water surface slope was monitored using a set of pressure transducers along the banks (Eshtemoa and Rahaf). Suspended sediment concentration was sampled manually, or automatically by a rising stage sampler (Yael) (Lekach and Schick 1982) or by a pre-

programmable pump sampler, as well as by hand sampling (Alexandrov et al. 2003a). Average suspended sediment concentration was also calculated based on reservoir sedimentation, dividing the mass of fine sediment deposited during an event by event runoff volume . Continuous suspended sediment concentrations were obtained from the deployment of turbidity sensors. The latter have a good response up to 80,000 mg l^{-1}; some may be calibrated in the lab and in the field up to 150,000 mg l^{-1}. Bedload was monitored continuously and automatically using a set of Birkbeck type slot samplers (5, 2 and 1 respectively at Eshtemoa, Rahaf and Qanna'im). These typically have a sampling efficiency of 100% until they are almost entirely full (Laronne et al. 2003). These samplers are excellent at separating bedload from suspended sediment for any size of sediment finer than the slot width.

Rainfall

Rainfall is very variable in hyperarid areas, even more so than in the semiarid realm. This is more pronounced during rainfall events (Figure 2), a derivative from the local convective origin of most rainstorms, giving rise to rainfall spottiness (Sharon 1972). Measurements of rainfall using a dense array of gages in the Yael has shown it to vary with aspect and wind velocity on hillslopes. Indeed, the difference between meteorological and hydrological rainfall is often considerable and significant with relevance to runoff production (Sharon 1980).

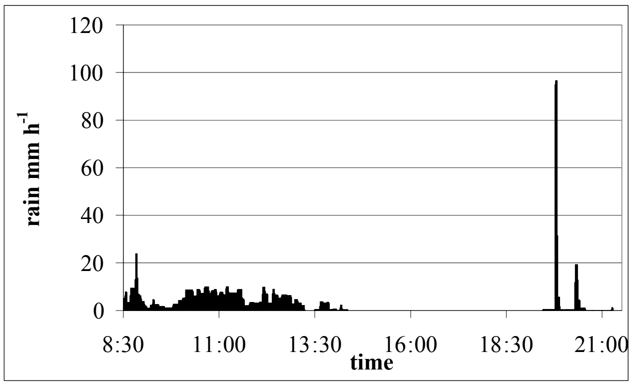

Figure 1. Short term rainfall intensity at Nahal Yael for locally-termed Event 12. It created two rises; the first was generated by medium rainfall intensities, the second by high intensity (96 mm hr^{-1}) lasting 4 min (see Figure 2).

Runoff

Similar to rainfall, runoff is very variable in time and space. Dryland channels are ephemeral, typically flowing merely 0.5-5 times annually. When they do flow, the rise is steep (Figure 2), often arriving as a bore (Reid et al. 1994). Longitudinal water surface slope varies considerably during a flow event, but the variation is not large enough to generate large differences in bedload discharge at rising and falling stages (Meerovich et al. 1998).

Suspended sediment

Unlike the relative ease of obtaining rainfall and runoff data in dryland watersheds, sediment monitoring is more difficult to obtain, because in the past it necessitated the presence of personnel at the site. Because rainfall and, therefore, runoff are spotty in nature, this has proven to be cumbersome, leading to no good databases (Luna Leopold, personal communication).

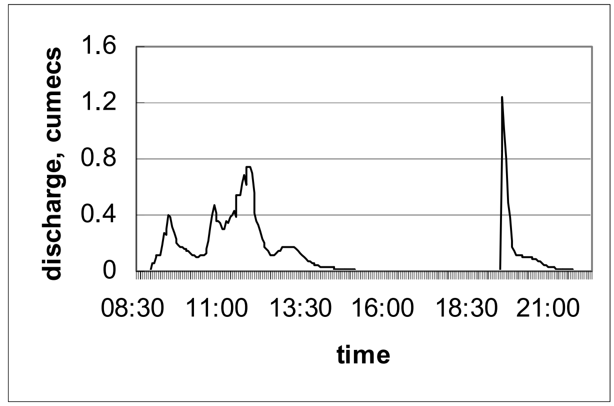

Figure 2. Discharge hydrograph of event 12 at Nahal Yael (see Figure 1). Note the bore on the second rise.

The sources of suspended sediment may be the hillslopes or else the coarser, sandy fraction derived from the channel bed (Figure 3). By tracking storms using radar backscatter, we have shown that the source of suspended sediment may be attributed to tributary inputs in the form of piggy-back rises, or else due to temporal increases in rainfall intensity.

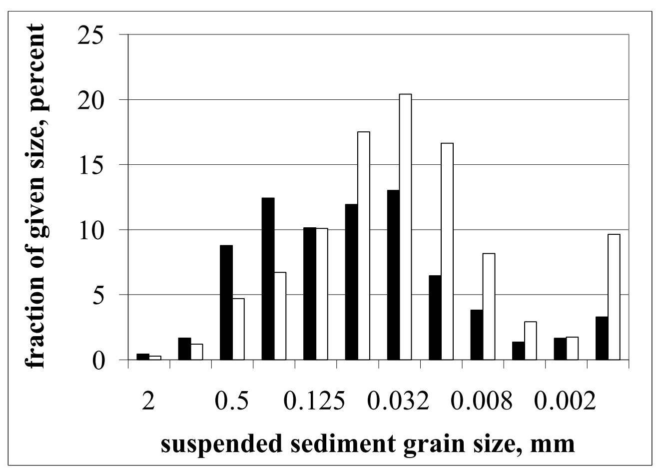

Figure 3.Grain size distribution of suspended sediment at an upper site (white) and at a lower site (black) in Nahal Yael. The source of sediment in the upper site are mainly the hillslopes, further downstream the alluvial channel contributes the coarser component.

During a flow event, the concentration of suspended sediment varies hysteretically with water discharge (Figure 4). There are group-types of response, and overall these relationships are complex. In general, concentrations of sediment are high (Table 1; see also Figure 4), at times exceptionally high, more than 200,000 mg/l. The high concentrations typify rises, especially after a long dry spell, during which much sediment has been weathered and is readily available.

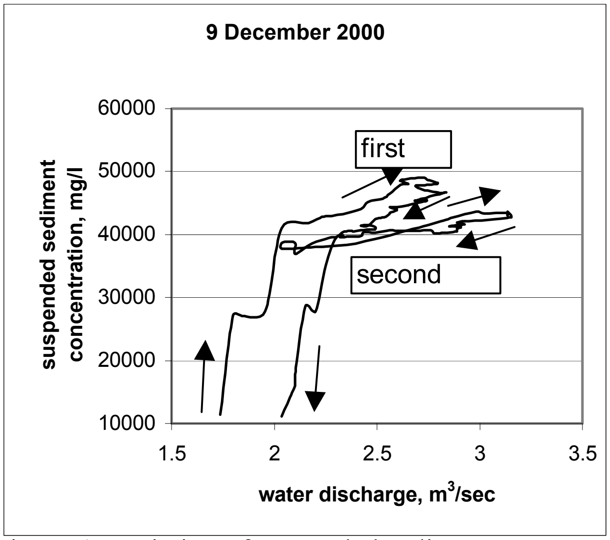

Figure 4. Variation of suspended sediment concentration with water discharge on December 9, 2000 at Nahal Eshtemoa. Concentrations were calculated based on calibration of turbidity. Note the high concentrations and the similar clockwise responses in both rises.

Although the suspended sediment-water discharge relationships are complex within events, the relationships are simple and well defined when averaged from entire events. This holds for concentration vs. flow volume and flow peak (Alexandrov et al. 2003b).

Bedload

Bedload was studied at the Yael using reservoir deposits, tagged clasts and scour chains. The sediment budgets at this hyperarid watershed vary temporally (Lekach and Schick 1993). It has been demonstrated that bedload moves in a scour layer that has a maximum depth, below which a stable soil horizon has developed (Lekach et al. 1998).

Bedload discharge in semiarid channels such as the Eshtemoa and the smaller Yatir are exceptionally high, orders of magnitude higher than in their more humid counterparts (Reid and Laronne 1995). This has been shown to occur due to the unlimited supply of coarse sediment that is unarmored (Laronne et al. 1994).

Bedload discharge responds directly to shear stress, such that the response is sympathetic, remindful of the relationships derived from flume studies. Indeed, the conditions of no armor development in such channels is often modeled in flumes. Our results demonstrate that bedload discharge varies in accordance with several flume-based equations, such as the 1948 Meyer Peter equation (Reid et al. 1996). Figure 5 demonstrates the bedload response mentioned above.

Conclusions

In Israel, the drainage area of monitored watersheds is limited, hence 3-4 additional representative basins covering areas of 300, 1000, 2000 and 8000 km^2 will likely be implemented in the next decade.

National and regional hydrological research needs will dictate future global monitoring in experimental, research basins. International collaboration may bring about considerable cost reduction by exclusion of monitoring aspects that can be evaluated based on the monitoring in other, similar conditions. Advanced international collaboration on validation and calibration of and consistency in monitoring means, as well as syntheses of lessons derived from international collaboration, such as from an International Watershed Research Network, are required for maximizing our understanding of water and sediment basin responses in varied global regions.

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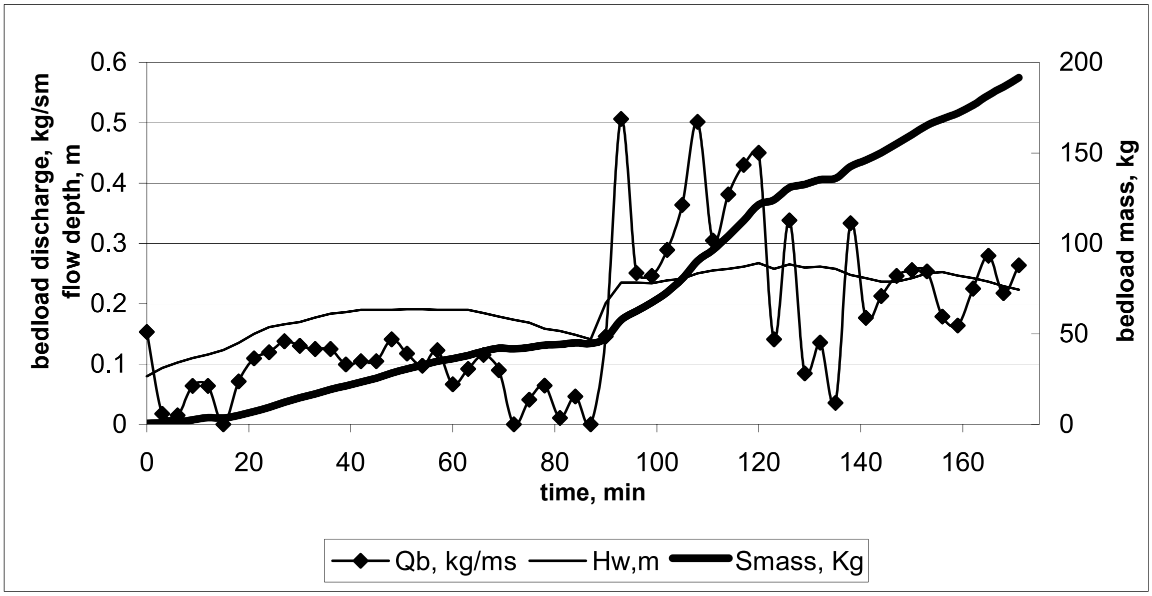

Figure 5. Bedload discharge (3 minute averaged) and cumulative bedload mass as monitored by the Nahal Eshtemoa left bank sampler on January 16, 1997. Observe that bedload discharge responds well to water depth (i.e. to channel average shear stress) and that it is very high even in this shallow flow. Bedload discharge averaged for shorter times is considerably higher.

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