Land use change, conservation measures and stream channel response in the Mediterranean/semiarid transition zone: Nahal Hoga, southern Coastal Plain, Israel

URI ROZIN

Department of Physical Geography, The Hebrew University of Jerusalem, Israel; now at: Division of Soil Conservation and Drainage, Ministry of Agriculture, 64739 Tel Aviv, Israel

ASHER P. SCHICK

Department of Geography, Hebrew University, 91905 Jerusalem, Israel

Abstract Photographs taken in 1917 by a Royal Flying Corps plane during an intelligence mission beyond the Ottoman frontline document, for the western part of the Nahal Shiqma catchment in the southern Coastal Plain of Israel, a barren, highly eroded landscape with patches of primitive cultivation, active badlands, and widely braiding stream channels. Nahal Hoga, a 65 km² catchment representative of this area. was selected to monitor and explain the fluvial transformation which affected the region following the abrupt changes in land use associated with the wave of Jewish settlement 50 years ago. This was accomplished through a detailed field, air photo, and GIS-based evaluation of the areal land use and stream channel geometry repeated at decadal intervals. While the 1945 channel morphology and land use were similar to those in 1917, subsequent transformations, caused by land use changes and conservation measures, were dramatic. Channels narrowed drastically and were stabilized by encroaching vegetation. The braided pattern was abandoned in favour of a single thread, quasi-meandering channel which deepened 1-3 m below its 1945 bed level. The processes responsible for this metamorphosis relate to the increased transport capacity of the ephemeral flows following a major increase in water and sediment storage associated with extensive conservation measures, which also caused a major decrease in the volume and frequency of flow events. Bank erosion, curbed by drastic reduction in grazing, was replaced by stable, vegetated banks and braids were gradually abandoned.

INTRODUCTION

Along with the growing awareness of processes caused by human intervention in nature and the resulting influence on the environment, considerable interest is emerging in experimental studies that attempt, in a carefully controlled way, to evaluate the effects of land use changes on the complex interrelationship between hydrology, fluvial geomorphology, and the erosion-sedimentation regime of the drainage basin (e.g. Overland & Kleeberg, 1991; Miller *et al.*, 1993; Neill & Mollard, 1982). The importance of these studies lies in their ability to identify the process tendencies caused by land use changes and to estimate the degrees of influence they have on other components of the environmental spectrum in the catchment. At the applied level, such studies enable the resource analyst to offer a more complete, well based, and longerterm estimate of the probable results of various land use policy options.

Due to the sensitivity of semiarid loess areas to soil erosion (Dendy & Bolton, 1976; Schumm, 1969) and to desertification (Toy & Hadley, 1987; Nir, 1983), and considering the size and location of such areas on most continents, a fuller understanding of the human-induced influence on these terrains is of great significance. However, detailed studies focusing on changes in the hydrological regime and erosion processes in large ($>10^2$ km²) semiarid loessial catchments have proved problematic. Indeterminancies arise because of the natural diversity and statistical variability that characterize such areas with regard to rainfall (Sharon & Kutiel, 1981), floods, and sediment yield (Bryan & Campbell, 1982). The natural variability in those parameters tends to blur the effects of human activities to the extent that a definite, statistically sound identification of their impact becomes far removed from an objective procedure (Rieger & Olive, 1991).

This study is based on direct measurement and indirect evaluation of the changes in runoff occurring over a period of 50 years, coupled with a careful estimation of the changes evident in the alluvial channel over that period. The alluvial channel proved to be a delicate sensor; it responded relatively fast to the changes in runoff and erosion that had occurred as a result of abrupt land use changes. Channel geometry and flow pattern underwent marked transformation, as monitored by aerial photography analysed in detail each decade, complemented by on-site surveys. The air photographs were also used to provide a GIS-based coverage of the land use in the catchment for each of the decades studied.

RESEARCH AREA

This research was conducted in the semiarid catchment of Nahal Hoga, located in the western part of the catchment of Nahal Shiqma – a 740 km² ephemeral stream system which drains part of the southern Judaean Mountains to the Mediterranean (Fig. 1). The Hoga catchment is 65 km² in area, has a relief of 158 m, and is composed mainly of highly erodible loess and grumusol soil. Mean annual of rainfall is 350 mm (Morin & Sharon, 1990), with a high interannual (Fig. 2) and spatial variability (Morin *et al.*, 1984; Kutiel & Sharon, 1981). The combination of high soil erodibility and occasional extreme rainfall intensities causes severe erosion (Rawitz *et al.*, 1983). Sediment mobilization from the badland areas and channel erosion have been assumed to be important sources of sediment supplied from the basin, while slope erosion is negligible (Seginer, 1966; Nir & Klein, 1974). The rapid changes in runoff and in erosion, eventually expressed in channel geometry and structure, as found in this study, lend credence to this assumption.

Nahal Hoga was selected for this study for several reasons. First, its modest size permits a relatively intensive analysis and avoids the problems of dealing with too large a catchment. Second, location and physical characteristics are such that the results can be taken as representative of the entire loessial northwestern, semiarid Negev. Third,



Fig. 1 Location map of the Nahal Hoga catchment and its vicinity, including streamgauging stations (squares) and reaches studied in the field (triangles).

data of various kinds, including dependable historical information, were available for Nahal Hoga to an extent not paralleled elsewhere in the region. Finally, most of the channels in this basin were never regulated, and remained so throughout the research period.



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METHODS

Comparison of aerial photographs

Aerial photographs from 1945 were compared with photos from 1992 in order to identify changes in the channel. During the feasibility stage of the study, 11 channel reaches in the Nahal Shiqma catchment and three in the adjoining Nahal Besor catchment (Fig. 1) were selected for comparing channel width, form, and vegetation cover. Field observations at each site were made to determine whether the identified changes were local or regional.

Ten-year interval land use and channel changes

Seven sets of mid-decade full coverage aerial photography, starting with the first one available (1945), were used to categorize the entire Nahal Hoga catchment at a scale of 1:15 000 into four terrain classes determined by degree of response to runoff and erosion, as follows: (1) land use conserving soil and water; (2) land use promoting runoff and erosion; (3) land use generating much runoff but little sediment; and (4) areas whose hydrological system was directly affected by engineering changes (dams, canals). Each category was divided into sub-units according to its level of influence on erosion and runoff. All areas were digitized and stored on computer.

In addition to the land-use based analysis of the entire catchment, three reaches of Nahal Hoga, measuring 1-3 km each, were selected for detailed study of channel change based on air photographs enlarged to a scale of 1:5000. Data pertaining to channel geometry, structure and pattern and type and areal cover of vegetation were mapped, digitized, and stored on computer.

Rainfall-runoff relationships

These were studied and analysed on the basis of the extensive databanks of the Israel Meteorological Service (rainfall amounts for numerous stations in and around the catchment) and the Israel Hydrological Service (streamgauging stations in and around the Nahal Shiqma catchment). Trends in the runoff-rainfall relationships over time and with reference to specific areas within the region studied were evaluated.

Old photographs

A run of aerial photographs of the area taken in 1917 by a British military reconnaissance plane was compared with later photos, to provide a longer historical view of the quasinatural state of the catchment and of its land use. Similarly, a number of ground photos taken during the establishment of the oldest kibbutz settlements in the area were evaluated.

Hydrological models and GIS procedures

Flows in the Nahal Hoga channel were estimated with the aid of the Manning formula and the Israel Soil Conservation and Drainage Department's maximum discharge estimation model (Garti *et al.*, 1981). Areal data on the aerial photographs were analysed by routine ARCINFO and AUTOCAD procedures.

Field procedures

A series of cross sections along Nahal Hoga, surveyed in the autumn of 1993, enabled the location of points identified on both the surveyed section and the relevant aerial photographs. The general picture obtained was one of consistent narrowing of the active channel from decade to decade - a feature which enabled the depth of the channel in each of the decades to be estimated, and the relevant flow geometry for each decade to be calculated. Consideration of bank location and other geomorphic features enabled the development of an evolutionary hypothesis for Nahal Hoga over the last 50 years. During the survey procedure a detailed vegetation reconnaissance was also undertaken. Vegetation types, % cover, and soil type were noted and mapped.

A large volume of material was procured by interviews with older residents, and from several archives and institutions owning old land use maps. This information proved an invaluable supplement to the data derived from aerial photographs alone. The main topics for which important information was obtained were methods of cultivation, crop varieties, quality of irrigation water, exact timing of the initiation of water supply schemes, and intensity of grazing.

RESULTS

Land use

The transformations of the land use in the Nahal Hoga catchment can be generalized into four periods (Fig. 3, Table 1):

- (a) Prior to 1948, the slopes, badlands and channels were completely bare (no vegetation) due to overgrazing. Afforestation is non-existent and cultivation occurs on very small areas and is predominantly traditional.
- (b) From 1948 to 1965 vegetation started to reappear, especially in the badlands and in the vicinity of the channels. Grazing was limited and controlled. Afforestation was beginning. Most of the agriculture is soil- and water-conserving cultivation.
- (c) From 1965 until the end of the 1970s an increase in grazing density (in terms of heads of sheep and goats per unit area) occurred, although grazing was still controlled and far removed from the overgrazing pattern of the 1940s. The soil- and water-conserving cultivation was gradually abandoned in favour of conventional cultivation, especially on the slopes. In the badland areas and along the channels conservation methods were continued.
- (d) From the early 1980s until 1992 the grazing areas were drastically reduced, and livestock numbers per unit area were also reduced. The vegetation in unused areas

increased in density. The badland area, which was always problematic for cultivation, became a nature reserve and afforestation was extended to new areas. The main conservation effort was redirected from the slopes to areas along the channels and to the badlands.

Rainfall-runoff relationships

While an evaluation of annual rainfall amounts shows a slight increase over the 50 years covered by this study (see below), a distinct decrease in the runoff ratio was identified



Fig. 3 Land use, Nahal Hoga catchment, 1945-1992: (a) total area; (b) land with conservation practices; (c) land with cover enhancing runoff and erosion.

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(Fig. 4). Subdividing this overall trend into shorter periods shows some variation. From the 1940s until the early 1960s a distinct decrease in the ratio is evident, with values reducing from a representative value of 9% in the 1930s and 1940s to about 2% in the 1960s. From the mid-1960s to the late 1970s a moderate increase in the ratio is suggested by the data, with a representative value of 3% for the 1970s. The downward trend in the runoff ratio resumed from the end of the 1970s and persisted to date. The representative value for the end of the 1980s and the beginning of the 1990s was around 1%.

Channel morphology and structure

Extreme changes in the morphology of the Nahal Hoga stream channel are evident on the temporal (1945-92) series of aerial photographs (Fig. 5). The area of the active channel in 1992 was only 16.7% of the 1945 value, and the mean width was reduced from 66 m in 1945 to 11 m in 1992. The channel pattern changed from braided to quasi-meandering. From zero vegetal cover in 1945, the active channel area became fully covered with vegetation by 1992, with the exception of the inner active channel bed. Field measurements tied to points identified on current and earlier aerial photographs revealed considerable entrenchment, which ranged, for the period of study, from 0.8 to 2.9 m. Mean vertical incision from 1948 to 1993 was calculated as being 1.65 m, or 3.5 cm year⁻¹ (Fig. 6). A modest decrease in channel slope is suggested by the data, e.g. from 0.0093 (1945) to 0.0086 (1992) in a relatively steep reach and from 0.0065 (1945) to 0.0059 (1992) in an "average" reach, but the change may not be significant.

Eleven reaches in the Nahal Shiqma catchment (outside the Hoga catchment) and three reaches in the neighbouring Nahal Besor catchment (Fig. 1) were analysed for comparison with the above findings. The changes identified in those reaches mirror in all aspects the changes described for Nahal Hoga.



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No.	Category	Land use	1954	1956	1965	1975	1986	1992
1	1	Nature reserves	0.0	0.00	0.00	0.00	1.84	4.08
2		Forested areas	0.21	2.10	9.32	9.25	13.15	12.79
3		Embankments	0.00	1.05	0.18	0.07	0.18	2.51
4		Channel vegetation	0.00	0.32	0.99	2.58	5.14	7.43
5		Untilled land	0.00	1.30	0.94	0.86	1.67	1.36
6		Conservation tillage	3.72	11.91	12.05	1.00	0.10	2.61
7	2	Badlands	22.92	0.67	0.23	2.20	1.27	0.32
8		Grazing	67.68	53.88	35.92	31.34	14.98	9.01
9		Irrigated tillage	0.00	4.46	7.51	14.33	16.83	16.61
10		Unirrigated tillage	5.06	16.83	22.90	28.42	34.83	32.05
11		Plantations	0.16	0.89	2.86	2.71	2.51	2.92
12	3	Built-up areas	0.24	0.31	0.83	0.96	1.25	1.85
13		Roads	0.00	0.25	0.25	0.25	0.25	0.42
14	4	Dammed and impounded area*	0.00	6.02	6.02	6.02	6.02	6.02
1		Total area, Hoga catchment	100.00	100.00	100.00	100.00	100.00	100.00
2	1	Total, soil and water conserving areas	3.92	16.68	23.47	13.76	22.07	30.79
3.	2	Total, areas encouraging runoff and sedimentation	95.83	76.73	69.42	79.00	70.41	60.91
4	3	Total, areas producing much runoff	0.24	0.57	1.09	1.22	1.50	2.28
5	4	Dammed and impounded area*	0.00	6.02	6.02	6.02	6.02	6.02

Table 1 Land use, Nahal Hoga catchment, 1954-1992, in % of total area (65.14 km²).

*As of 1952 this area had no hydrologic influence on the rest of the catchment.

Channel development – a reconstruction

The development of the Nahal Hoga channel can be reconstructed to provide the following six stages (Figs 7 and 8):

- (a) 1945: the channel is wide, bed topography is shallow and clear of any vegetation. The in-channel bars are not stabilized.
- (b) 1956: the beginning of a narrowing process is evident, with some development of vegetation on the banks, on channel segments abandoned by the active channel since 1945, and on some in-channel bars. The main channel is still quite wide, but its lateral bars are beginning to stabilize.





(c) 1965: some bars are already fully stabilized, with the density of vegetation on them increasing.

Narrowing of the channel progresses by the coalescing of previously distinct vegetated bars or flood plain tracts. The channel begins to divide into a number of narrow and incised sub-channels, although the main, wide channel is still very much in evidence.

- (d) 1975: The coalescing of the in-channel bars dominates. There are a number of flow trajectories between them. Vegetation expands overall and creates large continuous tracts, joining bars, flood plain areas, and banks.
- (e) 1986: Along most of the length of the Nahal Hoga there is a single channel, characterized by intense narrowing and deepening. The vegetation along both sides of this channel becomes very dense and now provides an uninterrupted longitudinal continuum.



Fig. 5 Representative cross section, Nahal Hoga channel. Points on graph are channel banks as identified both in the field and on aerial photographs for each of the six years shown.

(f) 1992: Along most reaches the narrowing and deepening trend is continued. Exceptions are certain reaches affected by the major floods of 1990-1991 and 1991-1992, in which the incision is accompanied by some widening. The vegetation is now clearly delimited in strips, with herbaceous and annual plants on the channel margins, various bushes somewhat higher on the banks, and an occasional, often large, tamarisk or sycamore tree in between. The narrow channel bed is bare, with a few sporadic *Acacia cyanophylla*. The appearance of a few remnants of pre-1945 fruit trees (vines, pomegranate, almond) reflect the dynamics of the lateral channel changes which had occurred since their planting.

The 1917 aerial photographs

A British military aircraft on an intelligence mission searching for a German army airstrip during the World War I Middle East campaign provided a series of nine photographs in the vicinity of the subsequently abandoned village of Huj. These rare photographs cover part of the catchment of Nahal Hoga. They were taken in the summer of 1917 and the terrain is completely bare. The only land use discernible is grazing, and the area is severely dissected by active badlands.

Four of the cross sections surveyed and evaluated for each of the six time horizons of this study coincide with the short segment of Nahal Hoga which appeared on the 1917 air photographs (Fig. 9). A comparison shows that the 1917 channel was essentially identical to that in 1945, with the 1917-1945 changes being negligible in relation to the 1945-1956 changes. Looking at the 1945-1975 changes (a period of 30 years, and of



Fig. 6 Stages in the development of Nahal Hoga: (a) 1945-1986; (b) 1992. There are two variants for the 1992 situation. Sections are shown with a schematic vertical exaggeration.

(a)





Fig. 7 Aerial photographs, Nahal Hoga channel: (a) 1945; (b) 1992.



Fig. 8 Channel geometry of Nahal Hoga, 1945-1992: relative narrowing and relative deepening. Bars are 10-year changes (except 1986-1992 – a six-year change) and relate to the total (100%) change.

nearly the same duration as the 1917-1945 period), one cannot fail to be impressed by the complete transformation which had taken place.

INTERPRETATION

Focusing on the effects of land use on water and sediment yields, the development scenario of the drainage basin over the last half-century can be divided into three major periods (Fig. 3):

- (a) During the period from 1948 until 1965 water and sediment yield from the catchment was drastically reduced. This reduction was caused by a sharp decrease in the number of sheep and goats per unit grazing area and a decrease in the total area over which grazing was permitted. This promoted the development of the vegetation cover which, in turn, gradually reduced soil erosion in the badlands and on the slopes, and increased resistance to bank erosion along the channels (e.g. Toy & Hadley, 1987; Takar *et al.*, 1990). An increase in areas subjected to conservation cultivation, including contour ploughing and afforestation, also contributed to this effect (Weindlum & Stekelmacher, 1963; De Ploey, 1981; Thorne, 1991).
- (b) From 1965 to 1975 a temporary increase in the sediment yield of the catchment and in its runoff volume took place. The main cause for this increase was a reduction in soil conservation activities, including the abandonment of the water and soil conserving cultivation (cf. Unger *et al.*, 1991). An increase in the density of foraging livestock also contributed to this increase.
- (c) As of 1975 the substantial decrease in sediment and water yields was resumed. A considerable increase in the area in which conservation was practised, and especially the introduction of new techniques of conservation cultivation (Morin *et al.*, 1984) which greatly increased the efficiency of these practices, were the main reasons for



Fig. 9 Nahal Hoga channel, 1917. Photographed during a World War I military mission by the British Royal Flying Corps.

the change. Most of the conservation effort was directed at the channels and their immediate vicinity, and included extensive afforestation and the formal designation of certain badland areas as nature reserves (cf. Thorne, 1991; Miller *et al.*, 1993). Areas and densities of pasture were reduced to nearly insignificant values.

Rainfall trends

The trends in rainfall amounts over recent decades in the southern Coastal Plainnorthwestern Negev area have been analysed by Ben-Gai *et al.* (1993) by comparing an early period (1938/39-1962/63) to a later one (1963/64-1984/85). They concluded that annual rainfall in the second period was 10 to 20% higher than in the earlier period. Furthermore, the same researchers found that the increase in rainfall amounts resulted mainly from an increase in rainfall intensities rather than from an increase in rain days. Such an increase in rainfall might be expected to generate an increase in both runoff and sediment yield. However, the findings of this study show the exact opposite. If a climate shift did indeed occur, as suggested by the Ben-Gai *et al.* (1993) study, it accentuated the change in runoff and sediment yield in the Shiqma-Hoga areas even more. It seems that the effects of land use change are so strong that they easily override even relatively significant climate shifts, as found also in other studies (e.g. Knox, 1977; Lewin, 1987; Miller *et al.*, 1993).

Channel morphology

The aerial photographs of 1917 show conclusively that there were no significant changes in channel form between 1917 and 1945. In contrast, the changes after 1945 were such that already in the first decade they were very significant, in tandem with major changes in land use in the catchment. These changes continue to the present, and were more marked in the first 30 years - a period during which land use changes were particularly evident.

Riparian vegetation

Until 1948, the channel was completely bare and had active bars that shifted from event to event. The braided pattern was associated with substantial bank erosion and the unprotected flood plain also contributed sediment. After 1948 some bars become partly stabilized by vegetation, the number of flow threads was reduced and incision began along semi permanent sub-channels delimited by stable bars. Vegetation development promoted the coalescing of bars and their linkage to the flood plain (Schumm & Lichty, 1963). Bank erosion was reduced and overbank sediment activity was minimized, even during large floods (cf. Ternan, 1983). Vertical incision of single thread channels became dominant, aided by the stabilization of even the high (>2 m) banks by vegetation. These banks succumb to slumping only where local lithology (aided by piping processes in the sandy alluvial material overlying the aeolian silt) permits, and thus promotes some localized widening.

The braided:guasi-meanders transformation

In 1945 Nahal Hoga satisfied all the criteria of a *braided* stream (Thorne, 1991). In 1992, the single thread, incised, vegetation protected channel can be termed *quasi-meandering*, since it shows a tendency to increase its length and decrease its slope. Land use effects in the catchment caused a decline in peak flows which transported much less sediment due to a dramatic increase in resistance to erosion caused by the conservation measures (Overland & Kleeberg, 1991).

The cause: climate change or conservation?

The above considerations lead to the conclusion that the channel changes had nothing to do with climate change, but were caused predominantly by land use changes. These changes affected runoff rates, sediment yields, and, via a new regime of fluvial processes, caused a reshaping of the channel to its new configuration. This configuration is characterized by: (a) the stabilization of the channel into a single thread, incised, vegetation-protected channel; (b) a drastic decrease in sediment concentration in the channel flows (especially due to the deactivation of the badlands), promoting channel incision; (c) a reduction in the magnitude (peak discharge and volume) and frequency of the flows.

CONCLUSION

The effects on the channel system of the rapid development characterizing many parts of the semiarid zone worldwide are often very significant. In some cases the processes associated with these effects stimulate erosion and produce an increase in flood volume and frequency. In others, judicious management of land use coupled with conservation procedures may result in less runoff, a decline in peak discharges, and in reduced soil erosion and sediment yield.

Understanding the implications of planned changes within a catchment is difficult, because of the complexity of the systems involved. It is, however, vital to document some of these systems in order to be able to base planning decisions on sound information. The present study is unique in that it examines the causes and effects involved in the context of a relatively very detailed set of data referring to an entire catchment much larger than a single plot or field, and over a relatively long period of time.

Minimizing grazing and introducing land use practices which conserve water and soil caused a decrease in annual flow volumes. Peak discharges became more moderate and sediment routed to the channels declined. Riparian vegetation has reappeared, gradually establishing itself on bars, banks and flood plains. The multi-channel, wide, braided channels underwent a transition, through bar stabilization, towards single thread, quasimeandering narrow channels substantially entrenched below their previous beds.

Nahal Hoga, located as it is within the semiarid/Mediterranean transition, exhibits a very high sensitivity to changes in land use and management. The short time interval needed for these changes to be felt -a few years - compensates the researcher for the relative imprecision of some of the parameters considered, e.g. the low accuracy of the old hydrometric records, the inherent rainfall variability, and the excessive susceptibility to erosion of the catchment soils.

Land use and management in the semiarid/Mediterranean transition zone can determine, as far as flooding, soil erosion, and sediment yield are concerned, whether a particular catchment will "belong" to the Mediterranean realm or "behave" as a typical semiarid prototype. Thus, human-induced desertification processes in the semiarid zone may be prevented and are, indeed, reversible.

Acknowledgements We are very indebted to Sigalit Oz for her devoted work on the GIS evaluation. We are also grateful to the Research Department of the Nature Reserves Authority, Jerusalem, for letting us use their GIS facilities. Dr D. Gavish located for us the series of the 1917 aerial photographs. Many of our associates at the then Dept. of

Physical Geography helped in the field. The work reported was undertaken within the framework of project C12-090 of the US-Israel Cooperative Development Research Program (US Agency for International Development) entitled "The response of fluvial systems to large scale land use changes".

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