CNR Short-Term Mobility Program 2017
Final report

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Title of the programme: Morphological evolution of ephemeral channels under changing climate
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Objectives

The general aim of the visit was to contribute to understanding the factors that control the geomorphic evolution of channels and fans undergoing incision under changing climate and land use and the influence of such evolution on sediment connectivity at different spatial scales. The ephemeral streams draining into the Dead Sea provide an optimal context to achieve this objective. Specific objectives are the recognition of sediment (dis)connectivity at the interface between hillslope and channels and along the channels, and the evaluation of the role of flash floods of different intensity in determining channel changes.

Background

The water surface of the Dead Sea has been falling at an astounding rate; in the last decade, it has surpassed 1.1 m/yr. This fast withdrawal induces convexity in the longitudinal profile of stream channels (Bowman et al., 2007), and results in the very rapid incision of previously stable alluvial channels (Storz-Peretz et al., 2011). Dead Seal lowering is causing devastating effects previously unknown to mankind at these rates. These include the formation of hundreds of sinkholes each year (Yechieli et al., 2006) and the incision of channels, causing widespread road instability and infrastructure damages. Channel incision, moreover, is changing the processes of sediment transfer from hillslopes to channels and along the channels. Several research groups in Israel (GeoFluv at the Ben Gurion University, the Israel Geological Survey, and the Hebrew University of Jerusalem) have been studying this phenomenon, normally occurring at much slower rates. The international and interdisciplinary DESERVE project for environmental research in the Dead Sea region (Kottmeier et al., 2016) also merits to be reminded.

General morphometric settings of drainage basins and flow processes

Primary data on drainage basin and alluvial fan (drainage area, maximum elevation in the basin, fan apex elevation, fan slope) permit comparing the alluvial fans of the Dead Sea with other geographical regions.

The plot of fan slope versus basin ruggedness is a well-known tool to identify the control of basin topography and resulting fan slope on the type of flow process, with regard to the basic differentiation between debris flow fans and fluvial fans (i.e. fans built by water floods with bedload). Basin ruggedness is usually expressed by the Melton ruggedness number *R*:

$$R = \frac{(H_{max} - H_{min})/1000}{A^{0.5}}$$

where *A* is drainage basin area (km^2), H_{max} and H_{min} are maximum and minimum basin elevation (m), respectively.
Figure 1 shows this plot from the paper by Bertrand et al. (2013), which includes data from many previous works in different geographical under humid-temperate and Mediterranean climates.
The main morphometric parameters of a few drainage draining into the Dead Sea, including Nahal David and Nahal Qedem, currently under study by the Geomorphology and Fluvial Research Group of the Ben Gurion University of the Negev, are reported in Table 1; the location of three out of the four basins is shown in figure 2; the fourth basin (Nahal Darga) is located approximately 6.5 km north of Qedem.

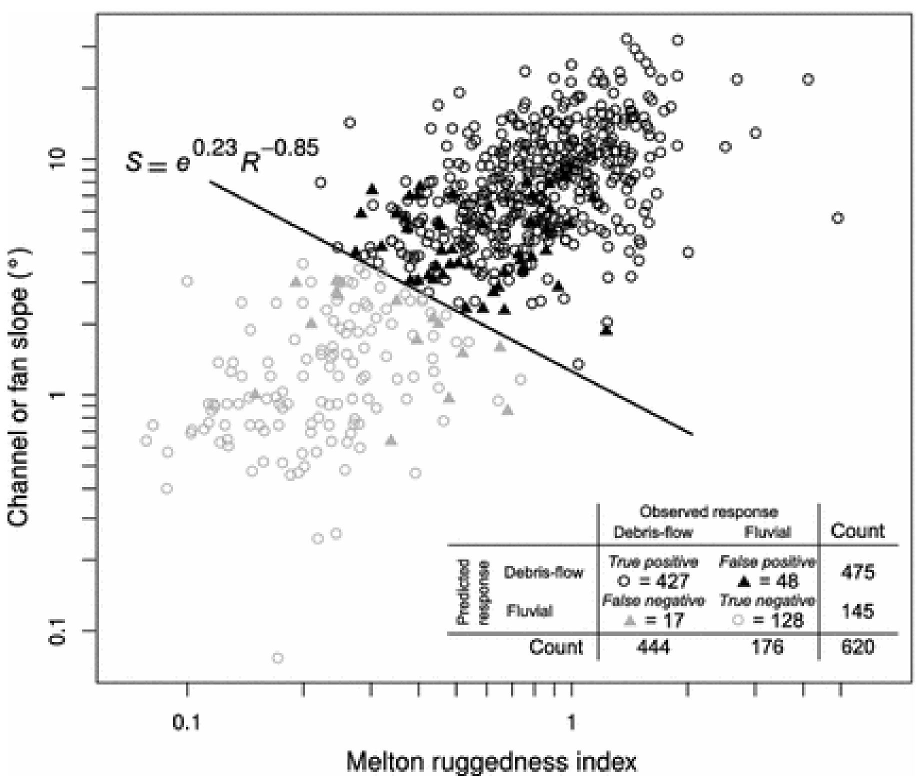

Figure 1. Plot of fan slope versus basin ruggedness from Bertrand et al. (2013). The equation reported in the plot, obtained by means of linear discriminant analysis on a sample of 620 drainage basins, describes the line that separates bedload fans from debris-flow fans (*R*: Melton ruggedness number, *S*: fan slope).

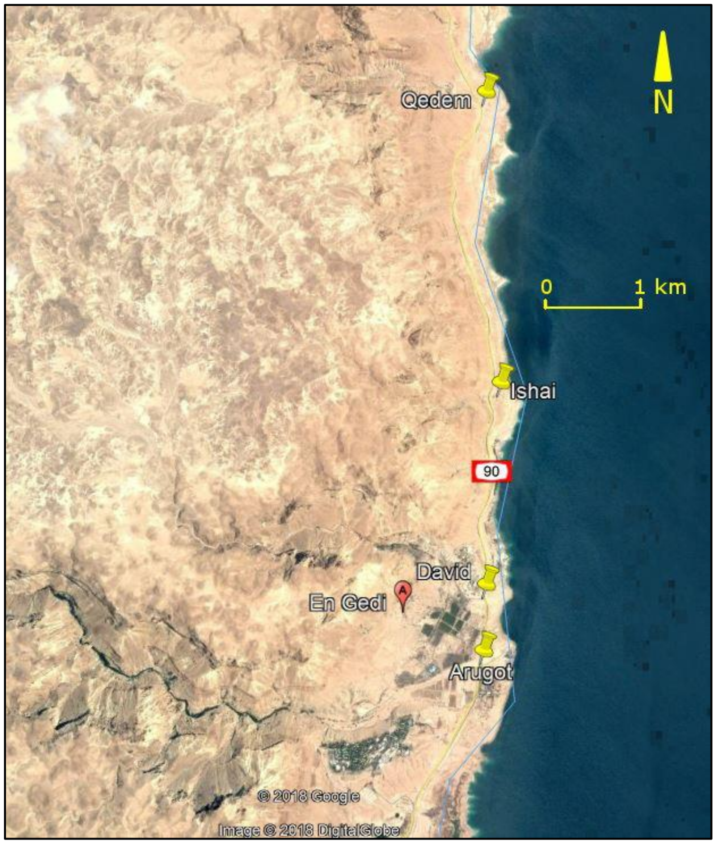

Figure 2. Location of the studied basins.

Table 1. Main morphometric parameters of a sample of drainage basins of the Dead Sea (Storz-Peretz, personal information)

Basin	Darga	Qedem	Ishai	David
Drainage area (km^2)	237	12	2	17
Max elevation (m)	640	438	-197	383
Fan apex elevation (m)	-360	-370	-350	-370
Melton number (m/m)	0.065	0.233	0.108	0.183
Fan slope (°)	1.6	3	12.6	4.1

The low values of the Melton ruggedness number are consistent with the observed alluvial fans genesis from water floods from bedload. Except Ishai, also the values of fan slope are compatible with fans formation by bedload. In the case of Nahal Qedem (3°, cf. the figure 6 of Storz-Peretz et al., 2011) and Nahal David, the slope of the relict fan surface is also coherent with the deposition of coarse bedload from this type of basins. The low slope of the fan of Nahal Darga is consistent with the large area and low ruggedness of this catchment, which fully lies in the domain of bedload basin-fan systems. These results, although obtained for a small sample of drainage basins that includes only bedload fans, could be viewed as a confirmation for the empirical threshold proposed by Bertrand et al. (2013) for discriminating bedload fans from debris-flow fans based on simple geomorphometric parameters. The consistency between the flow process observed and the geomorphometric threshold of figure 1 is a preliminary indication of the suitability of this threshold also for basins of arid and semi-arid regions, which were not included in the sample by Bertrand et al. (2013, page 501). It could also be noted that the steep slope of the incising Qedem distal channel (5.5° in 2004, as reported in figure 6 of Storz-Peretz et al., 2011), is rather unusual for a bedload alluvial fan and, according to the equation reported in figure 1, falls among the values typical of debris flows, whereas the highest value of channel slope in Nahal David (5.5°, as reported in Bowman et al., 2007, Table 1) attains but not exceeds the critical threshold reported in table 1. In Nahal Darga, even the highest values of channel slope affected by Dead Sea level lowering (1.5°, Bowman et al., 2007, Table 1) remain well below the critical threshold. The sediment deposition processes on Ishai alluvial fan, which features a very steep slope, could deserve further investigation.

Implications for sediment connectivity

Channel bed lowering causes the decoupling of the fan surface (referred to as relict fan surface) from the active channel undergoing incision. In the incised fans of the study region along the Dead Sea, most of the fan area is thus inactive and no more involved in sediment transport and deposition processes. Channel incision, however, induces instability in the channel banks, which act as sediment sources for the active channel.

A human influence on sediment connectivity on the studied fans deserves to be mentioned. The National Road 90 crosses the alluvial fans in the study area: bridges and fords act as base level for the upper (western) part of the fans, whereas the Dead Sea represents the base level for the lower (eastern) part. As a consequence, channel bed lowering is limited to the lower part of the fan, whereas the upper part, although providing water and sediment to the downstream part, is artificially decoupled from the incision process. It is worth mentioning that active incision of the lower part of the fan tends to undermine the stability of the road and has required the construction of protection structures.

More implications of the interaction between channel processes and sediment connectivity arise from the discussion on the role of sinkholes, which is reported in the next section of this report.

Sinkholes and channel processes

Sinkholes are widespread in the region around the Dead Sea and are associated, similarly to channel incision, to the lowering of lake level (Yechieli et al., 2006). When sinkholes occur within channels, they have a major impact on the morphological evolution of the channels themselves and with longitudinal sediment connectivity. Depending on the site in which they occur, sinkholes can accelerate or hamper channel bed incision. Sinkholes adjacent to the outlet of channels to the Dead Sea can accelerate the effect of lake lowering by enhancing the convexity of the channel profile and increasing the slope of the terminal front. If located in an upstream part of the channel on the fan, sinkholes act as sinks that decouple the distal part of the channel, prone to incision caused by lake level lowering, from the upstream drainage basin. As a consequence, flood flows cannot act in the distal part of the channel, whose incision is stopped until the sinkhole is filled with sediment transported from upstream. The time required for this process depends on the size of the sinkhole(s) and the frequency and intensity of bedload-transporting floods.

A sinkhole located approximately 120 meters downstream of the National Road 90 (observed during the field visit of 8 February 2018) has caused temporary deactivation of the distal part of Nahal David, which was expected to be the most active one as it is in contact with the lowering Dead Sea. The

absence of an active channel of Nahal David near the shoreline (three annual cycles of annual lake lowering are visible and undisturbed) confirms the absence of geomorphological activity in the last years.
Another outstanding example of a sinkhole interacting with channel process on an alluvial fan is provided by Nahal Ze'elim, approximately 15 km south of En Gedi. Nahal Ze'elim has built a large, flat alluvial fan featuring two mail channels; in the northern channel, a very large sinkhole has caused the collapse of a section of the channel bed. As a consequence, the channel is now dammed by the downstream wall of the sinkhole (Fig. 3).

Figure 3. The collapse of the channel in the northern branch of Nahal Ze'elim (the photo was taken on 8 February 2018).

Two different scenarios could be hypothesized for the evolution of this channel reach of Ze'elim:
- further collapses along the edge of the sinkhole (there is evidence of instability along the edges of the cavity);
- filling of the cavity by the sediment transported during floods and restart of the incision process driven by regional base level lowering.

Both the processes mentioned above are likely to occur: their relative magnitude and frequency will determine the evolution of the distal part of northern Ze'elim fan in the next years.

Post-flood field observations

A flood occurred in several channels of the Dead Sea in the early morning of 17 February 2018. I participated in post-flood observations carried out on February 20, aimed at assessing the basic flood variables and evaluating the geomorphological impact of this event.
The following activities were carried out:

- topographic survey of the cross sections instrumented with level loggers and measurement of longitudinal channel slope in both Nahal David and Nahal Qedem;
- download of water level data from the pressure transducer sensor installed in Nahal David.
- measurement of surface particle size of the channel bed at the sites instrumented with level loggers in Nahal David and Nahal Qedem (transect-by-number technique);
- UAV survey of the distal part of the channel of Nahal David (downstream of the National Road 90): digital pictures were taken for the implementation of a high-resolution digital terrain model by means of Structure from Motion photogrammetry.

Time constraints did not permit to perform the UAV survey on the Nahal Qedem. The download of water level data in Nahal Qedem was postponed because of the need of removing the sediment that had filled the pipe in which the sensor is installed.

The sites of two out of the 20 targets used as benchmarks for comparing different UAV surveys in Nahal David (both in the distal part of the active channel) showed changes caused by the flood. One site was not recovered (no. 7), whereas the other (no. 9), corresponding to a large boulder, appeared to have been tilted.

Field observations in the Nahal David downstream of the National Road 90 evidenced major morphological changes caused by the flood. A striking impact of the flood was the filling of the sinkhole in the Nahal David (mentioned in the previous section "Sinkholes and channel processes") by the sediment transported by the stream. A new sinkhole, much smaller than the one observed on 8 February 2018, has formed approximately at the same site (Fig. 4). This sinkhole involves fresh sediment and marks a discontinuity in the channel bed reshaped by the flood (Fig. 4), indicating that it derives from a new collapse, occurred after the filling of the previous cavity.

Fig. 4. The new sinkhole formed in the Nahal David after the flood of 17 February 2018 (at two different zooms).

Baseflow was present in the Nahal David at the time of the observations (late morning of 17 February) until the National Road 90. At the site of the water level logger, bedload transport was occurring; the transported material was mostly very fine and fine gravel, up to medium gravel. No flow was present in Nahad Qedem.

Flow processes and boulders transport – comparison with other climatic conditions

The observations on steep fans of the Dead Sea, like Qedem, suggest investigating similarities and differences with fans of the same lithology (dolostone and limestone) under a different climate. This comparison could be proposed for some fans in the Dolomites (eastern Italian Alps). Actually, the differences prevail on the similarities. The fans at the outlet of steep basins of the Dolomites often display a contribution of debris flows in their formation, at least for basin areas up to 10 – 15 km^2, and could be classified as "mixed" (their formation is due to both debris flows and water floods with bedload, of course including all intermediate processes). Moreover, no channel incision caused by regional base level lowering is observed in the fans of the Dolomites, which are stable or show moderate aggradation. The similarities regard the widespread presence of boulders in the channels and the possible mechanism for their displacement.

The mechanism proposed by Storz-Peretz et al. (2011) for the mobilization of coarse boulders (undercutting and subsequent rolling of the clast) could be active also in Dolomites alluvial fans. In the case of very large boulders, likely transported and deposited on the fan surface by extreme debris flows, the formation of scour-holes is not sufficient to trigger the rolling mechanism, especially if the fan slope is relatively low, but can cause the tilting of the boulders, as it is shown in figure 5.

Figure 5. A very large boulder on the surface of an alluvial fan in the Dolomites. Recent tilting is indicated by the trees of the top of the boulder.

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Seminar

In the frame of my visit at the Ben Gurion University of the Negev, I was invited to give a seminar at the Department of Geography and Environmental Development on 14 January 2018. The abstract of the seminar, entitled “Documentation and analysis of flash floods and their geomorphic effects in the Mediterranean” is reported below.

The Mediterranean region is often affected by heavy precipitation events causing flash floods, debris flows and other types of landslides, as well as severe morphological channel changes. The study of flash floods provides a unique opportunity for assessing the hydrological response of catchments to extreme rainfall forcing and observing their geomorphic impacts. Flash floods, however, develop at space and time scales that conventional measurement networks of rain and river discharges are not able to sample effectively. In order to overcome this problem, an event-based approach to flood documentation that includes radar-rainfall estimation, post-flood indirect peak flow estimates in ungauged cross sections, flood simulations from a hydrological model, and assessment of geomorphic processes associated to the flood has been devised. The seminar describes this integrated strategy to documentation and analysis of flash floods and presents the results achieved through the study of several floods that occurred in Mediterranean regions (mostly in Italy) in recent years.

Other activities

The visit at the Ben Gurion University has permitted to come into contact, especially thank to field visits, with a range of research activities carried on by the Geomorphology and Fluvial Research Group. The most significant visits are reported below.

- Post-flood observations and sampling of bedload deposited in the bottom traps at the experimental station of Eshtemoa, instrumented for water and sediment transport monitoring.
- Visit at the hydraulic laboratory of the Zuckerberg Institute of Water Research of the Ben Gurion University, located in Sede Boqer.
- Visit of a site instrumented for the monitoring of runoff and eroded sediment on hillslopes reclaimed after exploitation for phosphates production (three experimental plots in the reclaimed area and two on a natural slope).
- Visit of an oil-polluted site in the Evrona natural protected area, near Eilat, and participation in a pre-experiment aimed at testing the response of a shallow ephemeral low-slope channel to runoff. The runoff was created by means of artificial supply of water from a tank. The characteristics of the

resulting channelized flow were measured: water discharge was estimated by salt dilution and suspended and bedload samples were collected.

On 4 February 2018, I visited the Laboratory of Hydrometeorology, directed by Prof. Efrat Morin, of the Hebrew University of Jerusalem (Department of Earth Sciences). The visit included an overview of the researches of the Laboratory of Hydrometeorology and a short presentation of the activities of the Hydrogeomorphology Research Group of CNR IRPI, with focus on post-flood documentation, sediment connectivity and hydrological monitoring in headwater rocky basins.

Acknowledgements

I wish to thank Prof. Jonathan B. Laronne for hosting me at his Department, and the staff and research students of the Geomorphology and Fluvial Research Group for their help and useful discussions during my visit.