# Dynamic morphology of the Na'aman River mouth, Israel

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Abstract: Israeli Mediterranean river mouths are characterized by an extremely dynamic morphology, as they tend to migrate hundreds of meters along the coast. River mouths represent different morphologies caused by different fluvial and coastal conditions, and are also influenced by anthropogenic factors (more so at present than in the past). The Na'aman River mouth is located in the Haifa Bay, the northern end of the Nile littoral cell. Its morphological changes are studied as part of an extensive research on the dynamic morphology of river mouths along the Mediterranean coast of Israel, covering seven rivers, on sandy beaches, affected by natural factors such as topographic setting, river discharge, wave climate, sand availability and vegetation cover. Research methodology comprised the detailed monitoring and mapping by GIS techniques, through data derived from historic aerial photographs, river discharge records, wave measurements and a digital elevation model, incorporated into a homogenous database and subsequently applied in spatial, temporal and statistical analysis. The Na'aman River mouth is extremely spatially dynamic, migrating over 1.5 km in 55 observations covering 60 years from 1945 to 2005. This article reviews the factors influencing the river mouth spatial changes, its temporal morphological patterns and "resetting" events.

Key words: River outlet, aerial photographs, GIS, Mediterranean coast

## 1. INTRODUCTION

The Nile littoral cell shoreline is relatively smooth, it changes direction from east- west to south- north (figure 1). Its coastal morphology is characterized by Kurkar (fossilized dunes) ridges paralleled to the shoreline and dunes mostly adjacent to river mouths. Israeli beaches are relatively narrow, most of them are 20-50 m in width, where as around river mouths their width can reach 200-300 m. In some places the beach width is a few meters wide or almost does not exist at all (Goldsmith and Golik, 1978). Haifa Bay is the most significant morphological feature on the southern Mediterranean coast and it constitutes the northern end of the Nile littoral cell, where Nile sediments are trapped and deposited (Zviely, 2007). North of Haifa Bay, most of the sediments are carbonates from local sources, while south of Haifa Bay sediments are mostly quartzic, transported by the Nile River to the south eastern Mediterranean coast. Sediments stemming from local sources are relatively scarce (Goldsmith and Golik, 1980, Almagor, 2002). Grain sizes decrease from south to north: in shallow waters (depth of up to 5 m) they range from 0.16-0.56 mm near the Nile delta to 0.16 mm in the Haifa Bay. In deeper waters grain sizes are 0.12-0.16 mm regardless of the distance from the Nile delta (Almagor, 2002). Annual tidal range along the Israeli coast is 40 cm.

Israel's Mediterranean coastal rivers drain the mountainous backbone areas in Israel. Both the length of these rivers and drainage areas increase to the south. Most of these rivers are characterized by flood flow during winter and there are order of magnitude differences in their discharge (Nir, 1995). As some of Israel's coastal rivers are ephemeral streams and part of their flow is wastewater, they become local points of pollution through which substantial amounts of pollutants, including heavy metals, nutrients and organic substances are carried into Israel's coastal waters, at several points in the vicinity of river mouths (Herut et al., 2003).

River mouths along the Israeli Mediterranean coast represent different morphologies caused by different fluvial and coastal factors (also influenced by anthropogenic factors, more so at present than in the past). The morphological changes in the Na'aman River mouth were studied as part of an extensive study on the dynamic morphology of seven river mouths along the coast of Israel, all of which flow in sandy beaches, allowing changing fluvial and costal conditions to influence their morphology. As part of this study, the Na'aman River mouth morphology and its natural migrations were mapped and characterized, with emphasis on the factors influencing them (topographic setting, river discharge, wave climate, sand availability and vegetation changes).

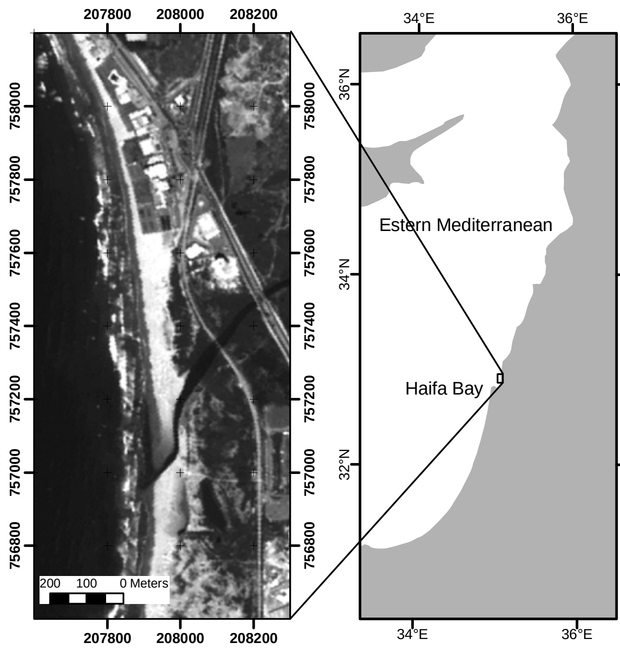



Figure 1: The Na'aman River mouth study area
(SPOT image No. 118-284/0, 25/04/05)

The Na'aman River mouth, located in Haifa Bay, is the northernmost river mouth in this study. The annual net longshore sediment transport into Haifa Bay is estimated to be 80,000 to 90,000 $m^3$ (Perlin and Kit, 1999; Zviely, 2007) .The Na'aman catchment area covers 317 $km^2$, with a mean annual rainfall of 640 mm, and a peak discharge at the Hilazon River gauging station of 88.5 $m^3$/sec (about 175 $m^3$/sec at the mouth) (Israeli Hydrological Service, 2006).

## 2. METHODOLOGY

### 2.1 Generating the database

Time series of aerial photographs were rectified and geo- referenced into the New Israel TM Grid (ArcGIS 9). Geomorphic elements in the vicinity of the river mouths were mapped vectorically, and the derived quantative data together with other data sources were incorporated into a homogenous database.

#### 2.1.1 The mapping process

Mapping accuracy was preset at ±7 m, as river mouth widths are at least twice as wide and their spatial migration along the beach covers hundreds of meters. All consecutive mapping stages were executed in consideration of this level of accuracy. Aerial photographs of the

Na'aman River are available since the 1940's and observations cover all seasons. The photographs were scanned into a TIFF format, producing smaller than 2 m pixel size raster images. The aerial photographs were rectified and geo- referenced into the New Israel TM Grid, using ArcGIS 9. The maximum RMS residual error was smaller than 2 m. The geo-referencing method applied was Affine transformation which was sufficient for achieving the mapping accuracy set, as the research area surrounding each river mouth is a relatively small area and has low topographic elevation. Since the maximum RMS residual error obtained in the geo- referencing process does not necessarily represent the real precision of the geo-referencing output, a vector quality assessment layer mapping major elements in the study area, was prepared. By overlaying this layer on each of the aerial photograph series, the relative accuracy of the process was verified, keeping geo- referencing inaccuracies below ±7 m Morphologic features in the vicinity of the river mouths were mapped for every observation, including river mouth channels, waterlines, vegetation and infrastructures. Figure 2A demonstrates the geomorphologic mapping of observation no. 19910 (Na'aman River mouth 04/99).

2.1.2 Deriving quantitive data from aerial photographs

After all geomorphologic features are mapped; a **Lower most point of no migration (LMP)** is set where the mouth channel begins to mildly migrate. Seaward from this point; another **point of pronounced migration (PPM)** is set where channel migration is more pronounced. **Channel length** is measured by extracting the **centerline** of the river mouth polygon by using ArcGIS. The length of the channel in this research is measured from the **LMP** to either the **end point of a closed mouth (EPCM)** or to the **point of sea and mouth intersection (PSMI)**. By drawing a **straight-line** between the **LMP** and the **EPCM** or **PSMI**, the **general direction of flow** is measured in ArcGIS. **Sinuosity** is calculated by dividing **Channel length** and the corresponding **straight line**. **Straight flow** is marked as a straight line between the **LMP** and **PPM** and from there its direction alters to the mean azimuth between **LMP** and **PPM** azimuth and the perpendicular to **beach azimuth**. **Beach azimuth** is measured between the two farthest **PSMIs**. Figure 2B illustrates the mapping of features such as **LMP, PPM, straight flow, EPCM, PSMI** and **beach azimuth** for the Na'aman River mouth. **Beach width** is calculated relative to a **baseline** set parallel to **beach azimuth**. The **High Waterline**, which is the border between wet and dry sand, was chosen as a shoreline indicator because of its relative stability and minor horizontal displacement relative to that of the **momentary waterline**. **A high waterline** layer for each observation was created by mapping a polygon bordered by the **baseline** to the east and by the **high waterline** to the west. A polygonal **baseline** layer was created dividing the beach to 50 m long polygons. The area between **baseline** and **high waterline** in each polygon

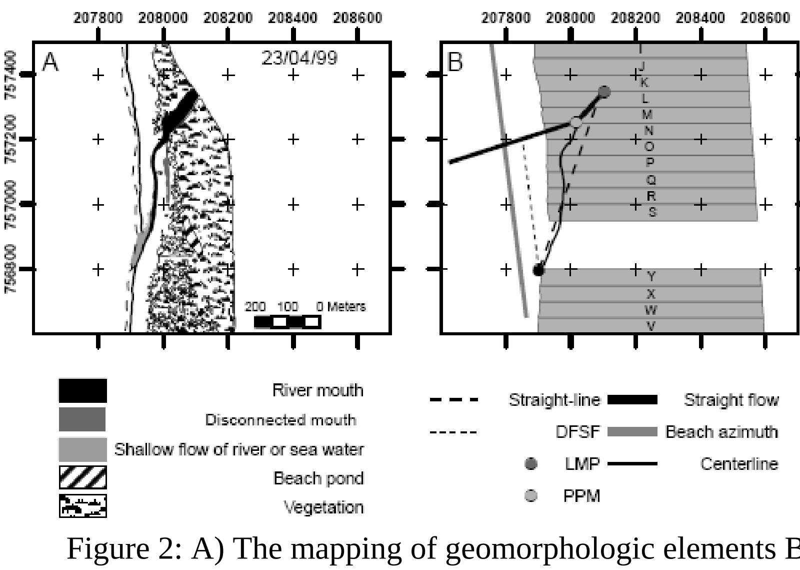
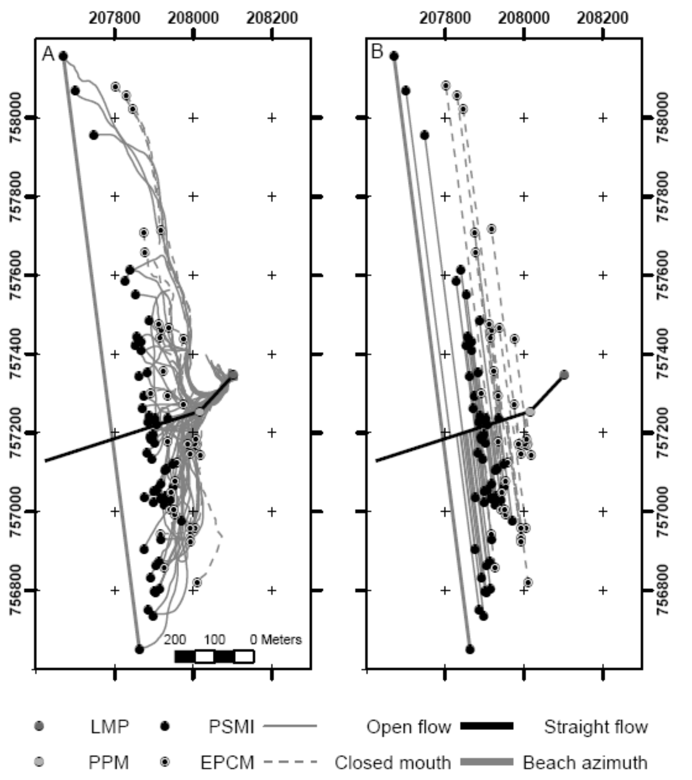



Figure 2: A) The mapping of geomorphologic elements B) Quantative data derived from the mapping process

was obtained by intersecting the polygonal **baseline** layer and the **high-waterline** layer in ArcGIS. Figure 2B illustrates the extraction of **channels length, sinuosity, general direction of flow, beach width** for observation no. 19510 (Na'aman River mouth 04/95).The measurement of the **distance from straight flow (DFSF)** of each **EPCM** or **PSMI** was obtained by pulling a line from each point to the **straight flow** line parallel to beach azimuth and measuring its length (figure 2B).

2.1.3 Other data sources

A) Discharge records are available from the Hilazon River gauging station (No. 7105- sub basin of the Na'aaman drainage area) by the Israeli Hydrological Service. B) Wave measurements are available for 1994-2004. The records are measured in Haifa by CAMERI — The Coastal and Marine Engineering Research Institute. C) Digital Elevation Model by the Survey of Israel is comprised of a regular model of a 50 m point grid and an irregular model mapping typical topographic points and topographic breakpoints such as river channels and ridges. The accuracy of this model is ±2 m.




A) River mouth centerlines B) DFSF

## 3. SPATIAL PATTERNS

Comparing the spatial patterns of the Na'aman River mouth with other rivers along the Israeli coast reveal that the Na'aman River mouth is the most spatially dynamic during the second half of the 20th century. The spatial extent of the Na'aman River mouth as it is mapped from 55 observation spanning 60 years from 1945 until 2005; covers 0.177 km$^2$. River mouth's sinuosity ranges from 1.01 to 3.58 (figure 3A). The river mouth's spatial migration along the shoreline; measured as the distance of the PSMI from straight flow; covers 1.5 km (figure 3B).

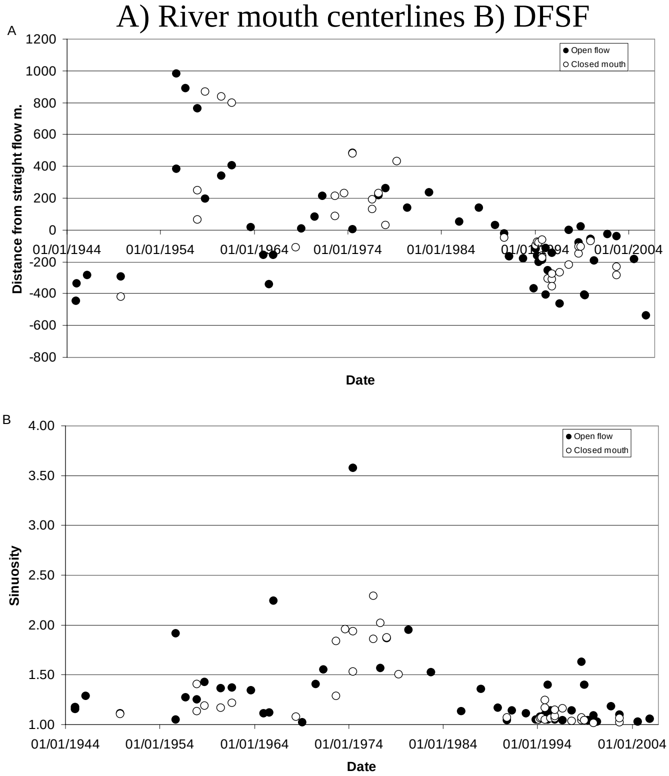



Figure 4: Na'aman River mouth temporal patterns: A) DFSF B) sinuosity

## 4. TEMPORAL PATTERNS

The DFSF, when superimposed on a time axis (figure 4A) show a distinct temporal pattern. The mouth channel is diverted from straight flow at a certain direction during a few years. This allows the establishment of a semi permanent channel on the sandy beach. Extreme geomorphologic events are needed in order to divert or completely erase the existing channel and create a new semi permanent channel. The Sinuosity temporal pattern (figure 4B) show periods of high (over 1.5) and low sinuosity over tens of years. This pattern resembles the DFSF temporal pattern. The resemblance between these two parameters reinforces the claim of flow in semi permanent channels over years.

## 5. INFLUENCING FACTORS

### 5.1 Topographic setting

Along the Israeli Mediterranean coast; the topographic setting of the beach where the river mouth flows, is the most important factor influencing river mouth morphology; it's spatial and temporal patterns. Two main types of river mouth beach topographic settings were identified in this research: A) Elongated strip topography- extremely tight elevation contours, forming a uniform slope along the beach even adjacent to the mouth channel. A narrow sandy strip between the shoreline and the back berm exists (figure 5A). B) Funnel topography- beach slope is not uniform as a funnel shape topographic low adjacent to the river mouth exists. The back berm is either pushed back or not apparent in the immediate vicinity of the mouth (figure 5B). From a comparison of spatial and temporal river mouths parameters made between the two types of topographic settings; a number of differences are apparent. Elongated strip topography mouths have a much larger spatial extent as they tend to migrate along the beach and establish semi permanent channels flowing along the back berm away from the shoreline. This distance from shoreline allows the wide range migration of semi permanent channels over tens of years until a strong "resetting" event erases the current channel forming another. Another spatial characteristic of elongated strip topography mouths is that channel sinuosity sometimes exceeds 1.5 and has a distinct temporal pattern. Funnel topography mouth channels have a much smaller spatial extent, and do not tend to form permanent channels. The mouths channels are temporally more dynamic than that of elongated strip topography mouths, as they migrate within the "funnel" boundaries and do not follow the back berm. The sinuosity of funnel topography channels seldom exceeds 1.5 and do not show a temporal pattern. The topographic setting in the vicinity of the Na'aman River mouth is a distinct elongated strip topography. Both the

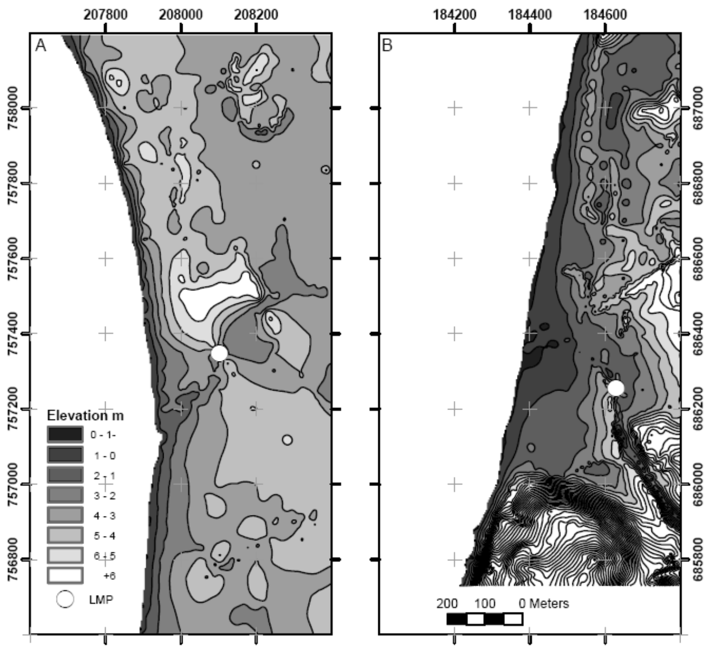



Figure 5: A) Elongated strip topography (Na'aman River mouth) B) Funnel topography (Poleg river mouth)

spatial and temporal patterns of the Na'aman River mouth are typical elongated strip topography patterns.

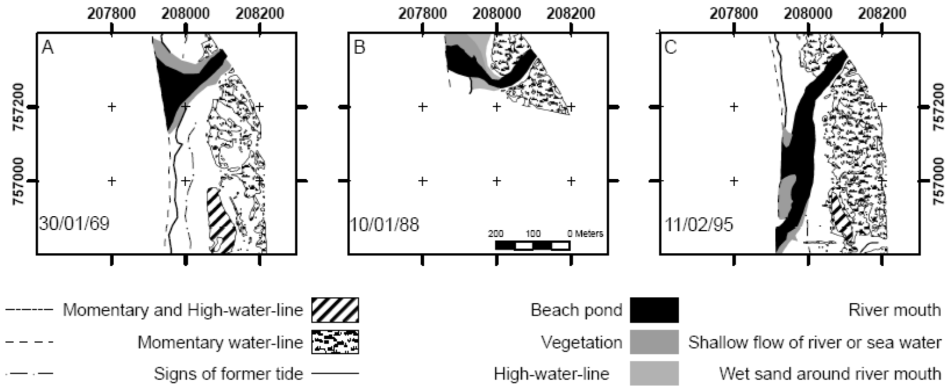



Figure 6: Observations after flood events

## 5.2 River discharge

Three observations in the database document the mouth days after large floods. The first from 30/01/69 (figure 6A), 7 days after a 60 $m^3$/sec flood (1:25 yr) was measured in the Hilazon River gauging station (about 115 $m^3$/sec at the mouth). This flood was a "resetting" event and diverted the mouth channel from south of straight flow to north. The direction of flow in this observation coincides with straight flow as defined. The second observation is from 10/01/88 (figure 6B), 18 days after a 32.7 $m^3$/sec flood (1:5 yr) was measured in the Hilazon River gauging station (about 57 $m^3$/sec at the mouth). It seems like this flood served also as a resetting event but the time passed from the time of flood to the time of the observation does not allow the determination whether during the flood the direction of flow was that of straight flow. The PSMI is diverted some 130 m north of straight flow at the time of observation. The third large flood occurred in 11/02/95 (figure 6C), 3 days after a 41.8 $m^3$/sec flood (1:10 yr) was measured in the Hilazon River gauging station (about 74 $m^3$/sec at the mouth). It is apparent that this flood, larger than the one in 1988, did not "reset" the mouth morphology and did not erase the existing channel but rather broadened it and caused a second breaching channel to the sea. It is possible that because of the relative stability of the existing channel since 1991, and the low sinuosity values

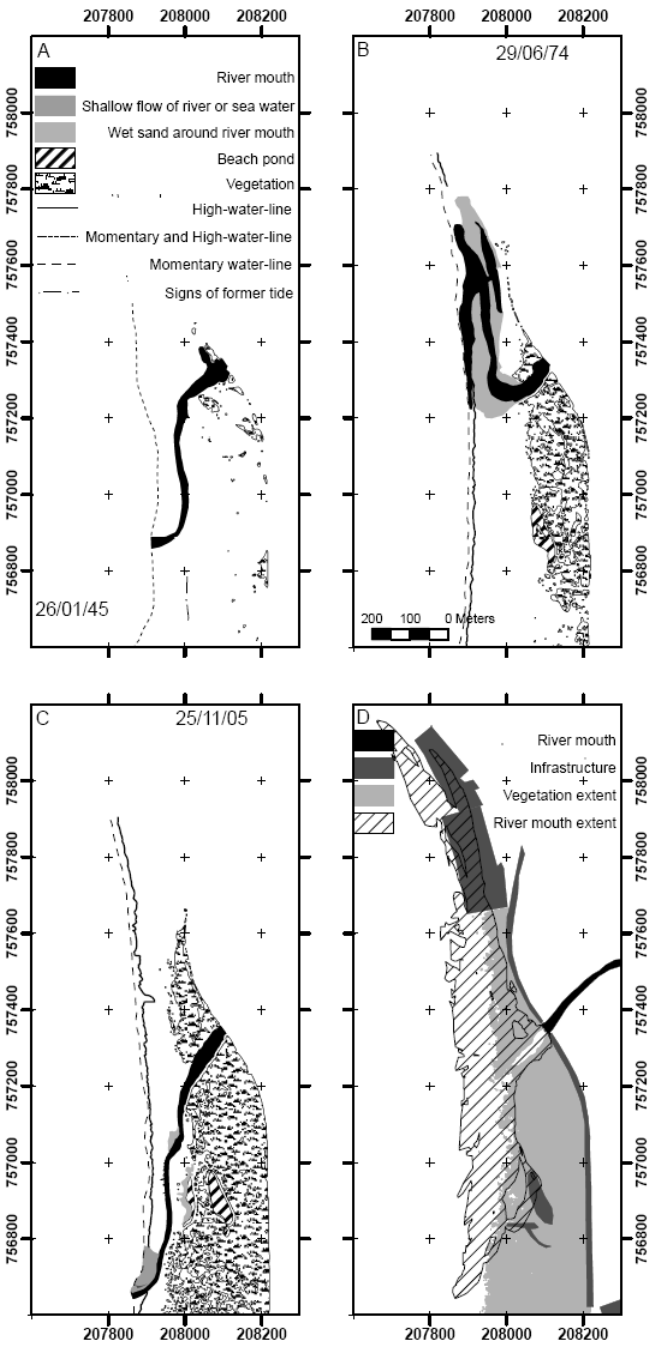



Figure 7: Vegetation densification in the vicinity of Na'aman River mouth

characterizing this semi permanent channel, no coincidence with straight- flow event occurred in this flood.

5.3 Wave action

The Na'aman River mouth is a classic elongated strip topography type mouth. Since the most apparent geomorphologic characteristic of elongated strip topography river mouths is the establishment of semi permanent channels over tens of years, flowing along the back berm of the beach away from the shoreline; wave action may not be able influence the channel course, but only mildly move the point of sea and mouth interaction back and forth. Wave action might be able to determine the direction to which the channel will be diverted after a "resetting" event. This kind of influence occurs on a short period of time and after the channel is established wave action does not seem to play a part in channel diversion. A three hourly wave measurement data for this research is only available since 1994 through 2004. During these years the Na'aman River mouth was stable and no "resetting" event occurred so this question remains open.

5.4 Vegetation cover

A common characteristic of the Israeli landscape is the densification of vegetation cover in sandy coastal areas since the 1950's. The main reason for the thin vegetation cover in the past was overgrazing. Grazing control and regulations since the 1950's caused denser vegetation cover in many places in the coastal plain. Vegetation cover has a restrictive influence on the channel path. It also influences micro- topography on the beach as sand accumulates and fossilizes around it. Vegetation densification on the back berm causes it to fossilize and progress seawards, which leaves a narrower beach for the mouth channel to flow on (relevant in elongated strip topography mouths only). Figure 7 illustrates the progression of vegetation cover in the vicinity of the Na'aman River mouth since 1945 through 2005 (figure 7A-C). In figure 7D the total extent of the Na'aman River mouth from all observations is superimposed on the total vegetation cover extent, and infrastructures exist on the beach today. Current vegetation cover limits the lateral migration of the mouth, which was possible in the past. This is more prominent north to straight flow than south to it. North to straight flow, coastal structures on the beach restrict the migration of the mouth north.

5.5 Beach width

Over 55 observations, high-waterline's average short- term position changed by 80 m Beach width can affect the DFSF, especially on elongated strip topography mouths, where the spatial migration from straight flow is often large. Figure 8 shows the relationship between beach width and DFSF. When beach is extremely narrow (many times during storms) the DFSF shortens. However, as the beach becomes wider, higher DFSFs occur but short distances are apparent as well. Statistically, for a narrowing of 1 m in beach width there's a 5 m shortening in DFSF.

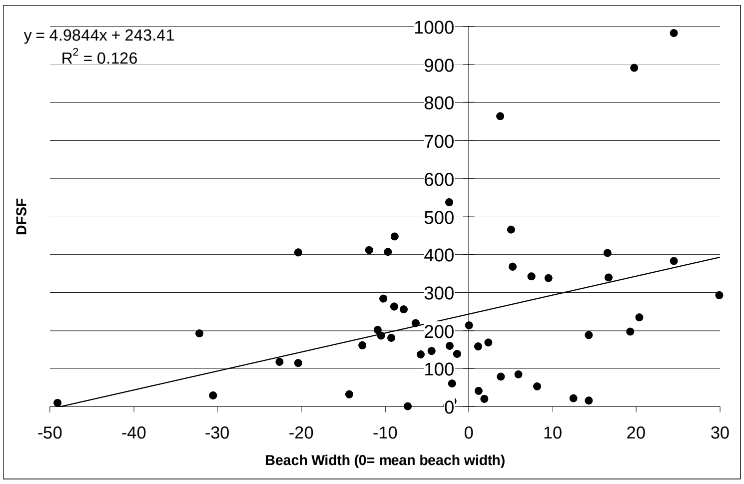



Figure 8: Beach width effect on DFSF

## 6. SUMMERY AND CONCLUSIONS

The Na'aman River mouth is the most spatially dynamic river mouth in this study covering the dynamic morphology of seven river mouths along the Israeli Mediterranean coast in the past 60 years. Its spatial migration extends 1.5 km along the shoreline during 1945-2005. The temporal patterns of the mouth channel migration is less dynamic as it tends to follow the beach's back berm and form semi permanent channels active for a number of years until an extreme resetting event erases that channel and a new one if formed. These spatial and temporal patterns are distinct characteristics of the elongated strip topography of the beach where the mouth flows. Therefore, the topographic setting is the most important factor influencing the morphology of the mouth. Flood events can serve as morphology resetting events, though when sinuosity is low and the channel well established even a 1:10 yr flood would not bring the channel to straight flow and erase the existing semi permanent channel. The effect of wave action on the mouth morphology is not apparent in the available observations. Vegetation densification during the years serves as a restrictive element on the beach and as a micro topography builder. Narrow beach would cause the mouth migration to shorten. On a wide beach, all migration distances are apparent.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