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LONG TERM REMEDIAL MEASURES OF SEDIMENTOLOGICAL IMPACT DUE TO COASTAL DEVELOPMENTS ON THE SOUTH EASTERN MEDITERRANEAN COAST

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Abstract

Coastal developments in the 20th century in the South-eastern Mediterranean coast have already induced sedimentological impacts, expressed as coastal erosion, silting of marinas and other protected areas, and cliff retreat. New development activities are underway or planned for implementation in the near future. The forecasted future sea-level rise (already apparently detected in the last decade in the Eastern Mediterranean) and storm statistics change due to global warming, as well as future diminishing of longshore sand transport in the Nile cell, add to the increased sensitivity of coastal development in this region.

This paper presents a review of the various projects underway or due to be implemented in the next few years, discusses in an integrated manner the outcome of various field and model studies on the sedimentological impacts of these developments, and presents a series of remedial measures which would have to be implemented to achieve a sustainable integrated coastal zone development in this region.

Among the remedial measures discussed are sand bypassing and coastal nourishment, cliff and coastal protection by submerged ("Beachsaver Reef"™) and protruding detached "respiring" rubble mound breakwaters, the "WaveTrap Island" concept developed by the author and utilisation of long-term coast stabilisation using large scale crenulated beaches at artificial peninsulas derived from initial artificial islands development.

1. INTRODUCTION

This paper attempts to summarize the knowledge gathered from a number of sedimentological field and model studies carried out on the coast of Israel, in the Southeastern part of the Mediterranean sea for a number of coastal developments (Fig.1), particularly in the last decade and discusses long term remedial measures of

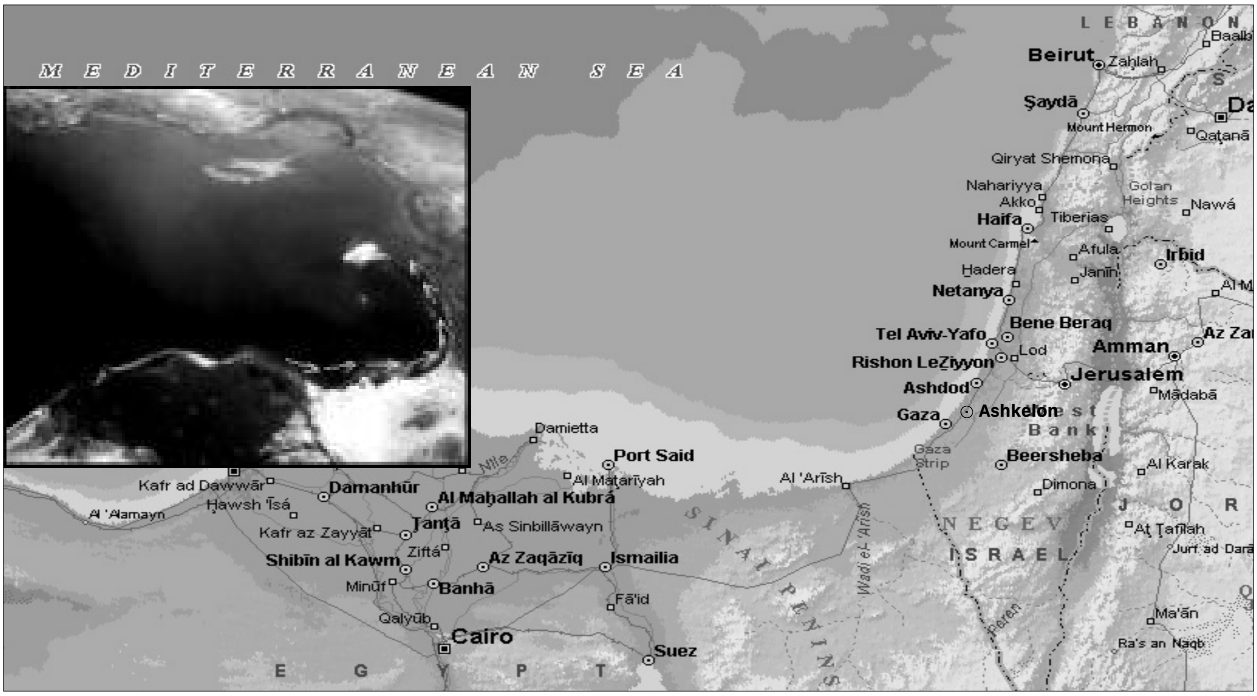

Figure 1: Location of the Israeli coast in the Nile littoral cell and in the Eastern Mediterranean

sedimentological impact due to coastal developments on the South-eastern Mediterranean coast.

2. REVIEW OF THE COAST STATE

2.1 Sedimentological Processes

Reports published by the national "Israel 2020" committee and by other bodies, indicate that Israel is progressing rapidly towards becoming within the next 20 to 30 years the most densely populated country in the world, in its coastal region, where most of its population concentrates.

This implies immediately the need for additional land for various uses such as: housing for residential and commercial activities; offices, hotels, green areas and beaches for recreation, sport and tourism; ports, airports and roads for people and goods transportation; and land remote from residential areas for industrial activities, energy production, chemicals and waste storage and treatment.

With the absence of other land resources in the coastal region for these activities, it is obvious that the answer is considered to be in the form of land reclamation from the sea. Such solution has already been adopted by a number of countries, of which the two most prominent examples are Japan and The Netherlands. The former expanded its land resources by creating more than 86 artificial islands, while the latter did it by peninsular expansion of most of its coast into the sea.

In order to enable major marine land reclamation in the coastal zone it is therefore of utmost importance to identify and assess the feasibility of various reclamation schemes and their environmental impact, in particular in regards to the short and long-term morphological and sedimentological impacts such a development may induce to the coastal region, and especially to the beaches and nearshore areas. Associated with such developments comes the need for identification and proper implementation of long term remedial measures against potential negative impacts, such as beach width shrinking, and cliff retreat due to coastal erosion.

In the last decade, there is increasing evidence that the coastal region of Israel is facing a mild but progressive erosion. Among the facts backing this evidence, one may mention ancient (Neolithic) human skeletons discovered in perfect condition in the late 1980's as well as a few years ago on the sea bottom off Atlith, at about 6m water depth, a 2000 years old merchant wood ship found also in the late 1980's in shallow water (~2.5 m water depth) almost undamaged, with much of its goods onboard and many antiques recently discovered in the shallow water off Ashkelon. All these were found in good condition, and could not have survived the destructive power of the sea-waves and currents, would they not have been covered until recently by a protective, thick layer of sand which is no longer there.

In former studies (Golik *et al*. 1997) it was indicated that two major anthropological activities were identified to be the major factors responsible for the existing situation:

- Sand quarrying from the beaches for concrete preparation and filling of land and road developments, which fortunately was formally stopped by law in 1965;
- Man-made coastal structures obstructing the net longshore sand transport brought to the Israeli coasts along the coast of the Sinai peninsula, itself fed mainly from the Nile Delta.

Due to population growth rate and to rapid industrial development mentioned above, such constructions are estimated to increase soon in size and number, by new port developments and expansions at the Nile Delta coast, at Gaza and Ashdod, new marinas and other coastal and marine structures, including future artificial islands and/or artificial peninsulas.

The coastal face extending from Egypt's Nile Delta to Haifa Bay in the Northern part of the Israeli coast (Fig. 1), belongs to a large sedimentary unit, named the "Nile Littoral Cell". This is due to the fact that the majority of the sediments covering its coasts were initially transported via the Nile River to the Nile delta, as indicated by the large content of "nilotic" (quartz material) sand, versus the low content of local biogenic (carbonate material) sand, produced by shells and some local river outflows. Hence, it is obvious that any developments in this cell would be influenced by their predecessors upstream the longshore sediment transport flow and would be influencing the coast downstream that flow.

According to Egyptian coastal studies (Fanos *et al.* 1997), within the period starting from the construction of the Low Aswan Dam in 1903 until 1965, when the High Aswan Dam was completed, the Nile Delta retreated some 5 km (in 60 years). However, since then and until 1995 (in 30 years), another 5 km of the delta coast has been removed to the sea by accelerated erosion (doubled), induced by the almost cessation of Nile quartz sediment supply to the Nile delta since 1965.

Hence, the future of the existing Nile littoral-cell coast, and in particular the Israeli coast, are threatened not only by the existing erosion due to past sand mining and last century coastal constructions and by new coastal and marine developments mentioned above (if proper remediation steps will not be taken), but also by the cessation of Nile sediment supply. The impact of sediment supply by the Nile River is however estimated not to be significant in this century, because the eroding Nile delta coast is still supplying sand to the Sinai coast, that itself is still rich with sand, which may be transported by the combined natural action of wind, waves and currents to feed the northern part of the Nile cell.

A. Golik (personal communication) pointed out that as long as the sand bars enclosing the Bardawil lagoon do remain relatively stable, it means that sand is still fed to the system from the Nile delta. However, this warning sign may dim in the future, when, according to new Egyptian plans and engineering implementations (Herbich *et al.* 1998), the sandy bar coast would be protected by a series of hard structures (breakwaters).

Unfortunately, in addition to this "far" future impact, one might expect an additional impact due to a probably more rapid future phenomenon also of anthropological origin, which may become significant in the 21 century. We refer to the forecasted world wide sea-level rise and climate change induced by global atmospheric warming via the so-called “green-house effect”.

The forecasted worldwide average sea-level rise (McCarthy *et al*. 2001), assuming a most probable development scenario, is of 32 cm in year 2050 and 89 cm in year 2100. However, it is agreed by most experts that this rise will not be constant over the whole globe. Due to tectonic movements as well as other factors, there may be regions where the rise will be smaller or higher than the average. Secondly, if climate change occurs, it may lead to shift in wind directions and strengths, leading to shift in prevailing wave directions and heights. The major and stronger storms will remain however those inducing waves coming from the West, as this directional sector is the one with the longest fetch for the Israeli coast.

So far, there is only circumstantial evidence of relative sea-level rise in the last 100 years on the Mediterranean coast of Israel. Based on long-term measurements at Marseilles, comparable to a number of other places on the globe, there seems that a consensus exists within the scientific community that global sea-level has risen about 18 cm over the last 100 years, with a global range of 10 sea-level station 80 maintained by IOLR at Hadera (midway between Tel Aviv and Haifa) as also from satellite altimetry (Fenoglio-Marc 2001) seems to indicate a probable acceleration of sea-level rise over the last 10 years in the Eastern Mediterranean significantly larger (>10 mm/year) than the past sea-level trends of 1.0-1.8 mm/year.

These results may, on the other hand represent just a multi-annual sea-level fluctuation and the available data is not sufficient for a robust conclusion. Assuming that the South-eastern Mediterranean coasts will face an accelerated sea-level rise, its long-term impact would be even more significant than that of the future lack of external (Nile driven) sand supply. So far no systematic quantifying study of the meaning and extent of this possible impact to the Israeli coast has been conducted, but is expected to be carried out in the near future, as recommended also by the Intergovernmental Panel for Climate Change of the IOC to the UN member nations and performed already by many countries.

2.2 Review of major coastal developments

A list of the coastal structures built along the Nile Littoral Cell starting from Bardawil lagoon on the Sinai coast and ending at Haifa is presented in this section. The listing of the construction of the major structures includes also a description of the resulting sedimentological changes in their neighborhood. The growth pattern of the coastal structures and their resulting morphological changes at the coast are expected to enable a better understanding of the past coastal processes, leading to an integrated sustainable coastal zone planning and development.

2.2.1 Historic retrospective

Before reviewing the developments in the last half century, we need to remember that a number of ancient coastal developments were built in this area, of which few have been active until the last centuries, and two are still active today. Their historic presence enabled geologists and archeolo-

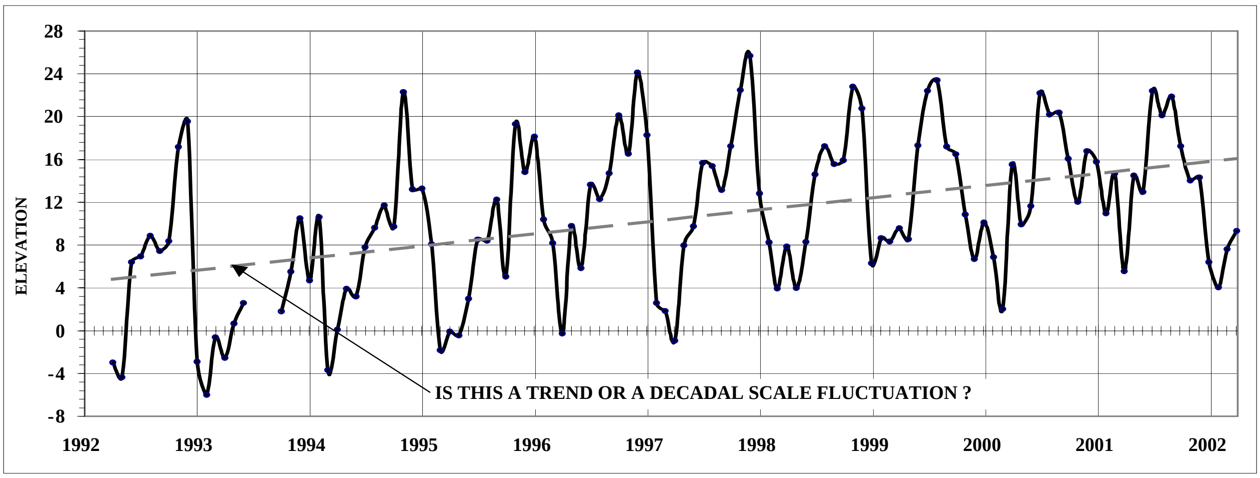

Figure 2. Monthly mean sea level variation at Hadera GLOSS station no. 80 between 1992 and 2002

gists to learn about the sea-level in the last few thousand years in this region and to draw conclusions regarding the very long-term stability of the coast in respect to accretion or erosion processes. We will refer here only to the most relevant site: King Herod's Caesaria Maritima, now Caesarea anchorage.

The harbour site at Caesarea, 10km north of Hadera was a wisely designed and built coastal development carried out some 2,000 years ago (20 BC). It was built by Roman engineers at the site of an existing small anchorage belonging to the remnants of the previous Straton Tower city and harbour. It was skillfully made with various coastal engineering features, which even nowadays are considered by some as novel and indicative of thorough coastal engineering knowledge. Among these one may mention the construction of its breakwaters by caissons filled with sand and topped with pozzolana (an ancient version of cement), a submerged breakwater (prokumatia) in front of the main breakwater to break large waves, openings with gates in the southern part of the main breakwater for water quality maintenance, port flushing and water depth preservation against silting at the entrance. Nowadays the major part of the main breakwater as well as of the lee breakwater are sunken, at the head at about 5m water depth. (Raban 1989) assumed that the breakwaters sank into the sea due to a tectonic fault, which however left intact the land-based part of the harbour. Raban considers the sinking to have occurred gradually, while other researchers estimated a more abrupt sinking. Some later efforts were made to repair the harbour, but it did not return to its previous dimensions. According to archeological findings and historic documentation (Flavius ~78AC, Raban 1989), the harbour coast (Mart and Perecman 1996), north and near to the port was eroded, leading to damage of part of the High Level Aqueduct built by Herod's engineers. This erosion however is quite local. As a matter of fact, both the aqueduct and the port were covered by a thick layer of sand until they were uncovered at the beginning of the 1950's. The coast at the Caesarea port appears to be at about the same location it was some 2,000 years ago, as confirmed by the aqueduct remains on the coast of Caesarea. (Flemming 1978) advocated this fact because most of the ancient coastal structures at the coast (except Caesarea's breakwaters) are found at about the elevation that one would build such constructions for the present sea-level. This fact may indicate a very long-term coast stability, which seems to have started diminishing in the last half of the 20th century. According to Flemming, the mean sea-level, for some period prior to the 3rd century BC, was higher than that of nowadays by about 1.2 to 1.3m. (Galili and Inbar 1987) estimated that the sea-level some 2000 years ago was about the same as the present one, with the rise and fall that occurred since then. However, they reached the conclusion that the sinking of the area north to Caesaria (and hence also that of the Caesaria breakwaters) must have occurred at more than 10000 BC, hence indicating that also the sinking of the Caesaria breakwaters must have been due to other reasons (e.g. destruction due to lack of maintenance).

2.2.2. Coastal engineering in the 20th century

The Mediterranean coast of Israel started to receive coastal developments well before the declaration of the Independence of the State of Israel, in 1948. The immigration and growth of the Jewish settlement prior to the establishment of the State of Israel, and in particular after that event, imposed fast civil engineering works development (housing, roads, etc.), for which the sand material lying on the beaches was used as basic construction material. Only in the 1964 beach sand mining was recognized as damaging to the coast and has been forbidden by law since 1965. It is not known exactly how much sand was mined from the beaches, but (Nir 1976) as well as (Golik 1997) arrived to estimates of about 10 million cubic meters of sand for the period 1948-1965, making use mainly of the records of the Zif-Zif Committee which investigated this mining in 1964.

Among the coastal developments which were carried out during the 20th century we can distinguish four major types: (a) commercial ports and fishing harbours, (b) cooling basins for power stations, marinas and anchorages, (c) offshore marine terminals, (d) detached breakwaters, groins and sea-walls. These are described below:

a. <u>Ports</u>

On the Sinai coast a temporary harbour was constructed in the mid 1970's at El Kals at the northern tip of the Bardawil sand bar by sinking an old ship (A. Golik, personal communication), inducing immediate erosion on the eastern beaches of El-Arish, causing palm trees on the beach to collapse into the sea. Between 1977 and 1978 the local Egyptian authorities built a small craft harbour eastward to the eastern bank of the El-Arish river. This led to significant accumulation on the upstream side, west of the harbour, just in summer 1978, and erosion to the coast east to the harbour. A series of groins were built on the downstream coast to diminish the impact, with little success. This was also the situation in summer 1991 (A. Khafagy 1991-personal communication). Further eastwards, during 1997 a fishing port was built off Gaza coast, extending with its breakwater head to a water depth of about 5.5m. Significant sedimentation resulted to the south of the harbour and correspondingly erosion on the coast downstream to the harbour occurred.

Obviously, in the early 20th century only small structures were built on the Israeli coast. During

1928-1933 the port of Haifa was built by the British army in Haifa Bay. The new main breakwater started trapping sand almost immediately, as shown by recent studies (Golik *et al.* 1999). The British army also rebuilt the ancient Jaffa harbour in 1933 to about its present state, making window openings in the main breakwater body at about sea-level for water flushing and maintenance of the entrance depth. This however did not affect significantly the sediment transport in the area, except for some sediment trapping within the harbour, which was dredged since then from time to time. A new small harbour at Tel-Aviv was built in 1936 south to the Yarkon river mouth. The harbour was built inside the shoreline, with two jetties perpendicular to the coast, extending about 100m into the sea to a water depth of about –2.5m at its southern head and a shorter distance reaching –2.0m at its northern head. This harbour has been suffering of continuous silting, requesting frequent dredging.

The first major (and largest) coastal structure built on the coast of Israel has been the modern deep water port at Ashdod, located some 30 km south of Tel-Aviv. It is one of the few deep water ports in the world which have been constructed on a straight sandy beach backed by sandy dunes. The main breakwater root is located about 200 m north of the mouth of Lakhish River. It was built between 1960 and 1965. The length of the main breakwater was 2,200 m and that of the lee breakwater 900 m. The head of the main breakwater was at 15 m water depth, and the entrance of the port was 13 m deep when it was built. The port penetrated from the shore seaward to a distance of about 1,000 m. In 1986 parts of the port and the entrance channel were deepened to 14 and 15 m water depth, respectively. About 1,350,000 m^3 of sand were dredged then and dumped into the sea over an area of about one km^2 at a distance of about 2-km west of the head of the main breakwater, in water depths between -30m and -35 m contour lines. Additional dredging was performed in the port and in the entrance channel in 1993. A study conducted in 1995 by the author and his colleagues (Golik et al. 1996) showed that during 30 years of operation the port induced trapping of about 4.5 million m^3 of sand at its upstream coast side, along about 2.5 km. No erosion was detected on the near downstream rocky coast, as it has been eroded by sand mining prior to the port construction. Nowadays, the port is being expanded and its main breakwater is being extended by 1000 m to reach within a few years a water depth at the new main breakwater head of about -22m. The construction of a temporary marine construction equipment service port and new wharves protected by a sea-wall started last year.Sedimentological mathematical model studies (1line and 2D) conducted by HRWallingford for the assessment of the port expansion, indicated almost complete longshore sediment transport blocking and a net yearly average transport rate ranging between 120,000 to 180,000 m^3 based on high quality directional wave data but of only a few years. Larger values have been estimated there by a number of researchers, including the author (Golik and Rosen 1997). To compensate for the trapped sand and future port expansion impact, the port authority agreed to bypass yearly 180,000m^3 of sand for the period 2001-2005 and at least 120,000 m3 afterwards. The first sand bypassing operation was performed using a dredger last year.

In 1977 the main breakwater of Haifa port has also been extended, and this port is presently in the last phases of planning and permitting before starting its further expansion and deepening, probably this fall. A sedimentological impact study was carried out by IOLR in cooperation with Danish Hydraulics and Environment. To derive input data for the calibration and verification of the sedimentological models run at DHI (1-line LITPACK and 2-D MIKE 21) a series of field studies were carried out by IOLR. They included comparison of waterline position changes during 1945-1997, differential bathymetric maps, sand granulometric analyses and meteomarine data gathering and analyses (waves, currents, sea-level, wind). The major outcome of the field study resulted from the differential maps of the surroundings of the port. It showed that during 69 years since the port construction, about 5.3 million m3 of sand have accumulated in the bay near the existing main breakwater, while another 0.7 million m^3 have bypassed the breakwater (based on the model results) and fed the beaches of the bay. The study also showed that the majority of the sand is of Nilotic source, being of quartz type. This would correspond to an average net yearly transport of about 87,000m^3. Such an yearly averaged value misleads proper understanding of the coastal processes, as a major part of the above 6 million m^3 of sand were transported in a small number of rare strong W-ly storm events.

b. <u>Cooling basins, marinas and anchorages</u>

A small cooling basin for the Reading power station was built north to the mouth of Yarkon River at Tel-Aviv in 1938, with its breakwaters entrance in about –2.5m depth. Later on, it was expanded by extension of the breakwaters to -4m in 1951, and again the cooling basin was expanded in 1969 to its present size, reaching now a water depth of –5.5m at the entrance. Since 1948 additional coastal structures were built at Zikim, Ashdod, Hadera and Haifa to serve as sediment settling basins for sea water cooling of the local power stations. At the last 3 sites the sedimentological impacts of the plans were investigated at the Laboratoire Centrale d'Hydraulique de France (LCHF). Eshkol cooling basin, located north to the present Ashdod port, was built between 1956 and 1958. In 1974-75 the cooling basin was expanded, having today a 640 m long main breakwater and 310 m lee breakwater, and penetrating seaward to a distance of 300 m from the shoreline to a water depth of -4 m.

Construction of the Tel-Aviv Marina was performed between September 1970 and fall 1972. Its entrance is at –5m water depth. Since its construction it requires periodic dredging of its entrance, almost every year.

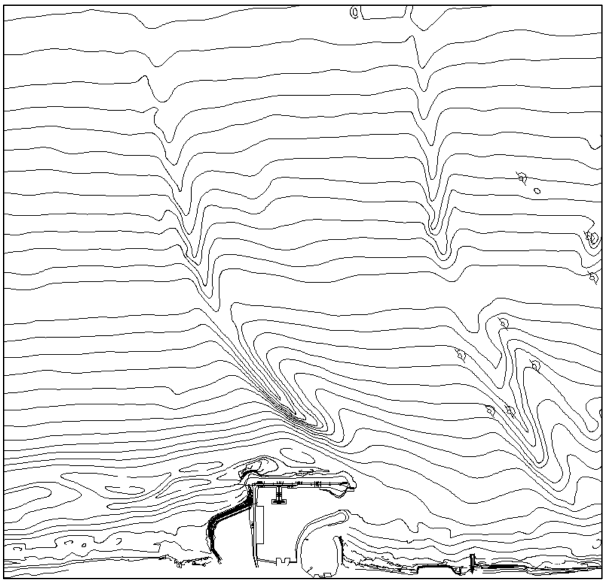

Figure 3. Underwater canyons at Rutenberg cooling basin and oil service harbour

Between fall 1973 and summer 1974 a small service anchorage was built at Zikim (10km south to Ashkelon) for the Eilat-Ashkelon oil pipe-line, with its entrance in -3m water depth. Its design was based on sedimentological physical model studies carried at LCHF. To protect it against silting, two groins were built, one north of the harbour, only 80m long, in 1974, and another one 160m long to the south, in 1975. Sedimentological changes at the beach resulted almost immediately.

The erosion to the north was so significant that the beach rock was exposed, and to prevent further beach erosion a rubble mound low coverage was placed there. As a result of the severe local erosion which occurred, numerous antique remnants were discovered at the neighboring park cliff base and cliff face. During 1987-1988, the cooling basin of the Rutenberg power station was built (Fig. 3) as a new main breakwater and groin, 350m to the south of the root of the main breakwater of the service harbour, in the shape of the Greek Γ letter, covering the main breakwater of the service harbour, reaching a water depth of about -7m at the toe of the head. In 1989 a storm event induced damage to about half of the main breakwater, leading to its re-armoring. A study conducted by the author (Rosen 1990) detected the development of an underwater "canyon" which induced wave focusing and damage to the breakwater. The author estimated that this unique canyon development was due to vortex shedding scouring initiated by the presence of large pipelines on the sea bottom, which afterwards moved away from the pipelines and deepened due to the local directional wave conditions. A recent study by comparing successive bathymetric maps (Golik and Rosen 1999) showed that the canyon stabilized, but that it performs as a sediment trap, accumulating on its flanks a volume of about 1.2 million m^3 during a period of about 14 years.

During mid 1978 to mid 1980 the cooling basin of the Orot Rabin electric power station was built on the northern bank of the Hadera river, (some 50 km north of Tel-Aviv). Its main breakwater reaches a water depth of -6m at the head, protruding some 600m into the sea, and its lee breakwater is remote 700m northward from the root of the main breakwater. Since the construction of the breakwaters, no significant changes were detected on the beaches south to the cooling basin, but a significant accretion occurred on the beach north to the lee breakwater for a distance of about 1.5 km, and erosion some 2 to 2.5 km further north. The accretion (Rosen 1990, 1992) has been attributed mainly to special local conditions which are predominant there (closed sedimentary cell), while the erosion was attributed to local coastal developments lacking coastal engineering involvment.

A very large marina was constructed between 1991 and spring 1992 at Herzliya coast, some 4km south of the ancient Apollonia harbour site. The main breakwater was completely built in 1991. Three detached breakwaters were built north to the marina in parallel with its construction. The marina main breakwater extends at the head about 800m into the sea, to a water depth of -6m, while the lee breakwater extends about 425m from the coast. The lengths of detached breakwaters decrease from 150m to 100m northward, and they were built at about 200m from the original waterline, in about 3m water depth. Following the completion of the marina and of the detached breakwaters, beach erosion of up to 25m occurred north to them along about 3km of coast.

Another marina as well as 3 new detached breakwaters to the north of it, were built at Ashkelon, north to the Dlila beach, where 3 detached breakwaters were built in the late 1980's. The new development took place between 1992 and 1994, and resulted in sedimentation behind the detached breakwaters and significant erosion on about 3km of coast north to them. Finally, during 1996 and 1997 the Ashdod marina was built south to Ashdod port, with its main breakwater head at –5m water depth. It already trapped a significant amount of sand south to the marina, and is encountering significant sedimentation in its entrance, requiring frequent dredging operations.

c. Offshore marine terminals

An offshore coal unloading terminal was built at Hadera during 1998-1980. It is a 300 long, west east oriented open type structure on piles, extending from –22m to –26m depth. It is connected to the coast by a 1.8 km long trestle on piles. No sedimentological impact has been observed on neighboring beaches. A local trench developed between the piles supporting the wharf, reaching a scouring depth of about 2m. Sedimentological studies conducted prior and after its construction showed that the sediment transport is confined mainly longshore and northward, parallel to the contour lines. Field monitoring of coal spilled during unloading operations, did not find any coal on the neighboring beaches, although it was found up to a water depth contour line of 14m. A radioactive traced sand study run prior to the construction gave the same results.

An identical coal unloading terminal was built recently just south to the Rutenberg power station cooling basin, south of Ashkelon. Again, no significant sedimentological impacts have been identified there so far.

d. Detached breakwaters, groins and sea-walls

To keep the two channels connecting the Bardawil lagoon enclosure on the Sinai coast with the sea open against silting, groins were built on the sand bar during the 1970's, as the lagoon has considerable economic value for the Egyptian fishing industry (Nir 1982). The result was sand accumulation on the western side of these groins. (Inman and Harris 1970) estimated the net eastward sediment transport at the western channel to be of between 300,000 and 800,000 m^3/year.

A first T-shape detached breakwater was built in Israel at Tel-Baruch (Tel Aviv) in 1964. It is 200m long, almost shore parallel with a connecting groin remote about 100m from the previous waterline, away 500m north to Reading cooling basin. It reached a mature tombolo within only 2.5 years after its construction (Nir 1976) trapping in its tombolo sand body about 15,000 m^3.

Two T-shape shore parallel breakwaters, each 200m long, with a shore connecting groin (also about 200m long) were built in Tel Aviv south to Tel Aviv harbour between September 1967 and May 1969 without any model studies. Until October 1969 about 100,000m^3 of sand accumulated in behind them, while the erosion between the two units was estimated to 5,000m^3 of sand.

A pair of detached breakwaters were built at Netanya starting with the southern one in 1969, followed by the northern one in 1970 (Nir 1976). Both were built using construction groins, which were removed afterwards. The breakwaters reached mature tombolos within 4 years from their construction. The length of the southern one is 240m at about 215m from the waterline, while the length of the northern one is 210m, at about 200m from the waterline. Subsequently, a small groin (100m) was built about 250m north of the northern breakwater centerline. The estimated amount of sand trapped by the two breakwaters was 72,000 m^3 (Nir 1976). 38,000 m^3 were trapped by the southern one and 34,000 m^3 by the other. A number of studies used this site to claim the presence of a nodal longshore sand transport in this sector (Spar 1977, Shoshany *et al.* 1996). They studied the sedimentological and waterline position changes since their construction and concluded that the coast north to the northern breakwater has accreted, while south of the southern breakwater the coast has eroded. A new study (Rosen, 1997) agreed only partially with this evolution, as the opposite occurred after a large storm in 1992. The author found that during mild years northerly waves induce a net longshore transport up to about Herzliya, but the long-term longshore net transport is northward, controlled by less frequent but large westerly storms.

A detached, shore-parallel breakwater was built in 1968-1969 at Hof Hacarmel at Haifa southern coast 200 m off shore. Prior to the construction of the breakwater, between 1945 and 1963, this beach experienced a slight accretion. However, by 1970, 2 years after its construction, a tombolo developed behind it. The tombolo continued to grow after 1970, but the accretion took place mainly on its northern half whereas the waterline on the southern part remained quite stable.

Between 1973 and 1977 a series of 7 detached breakwaters and two groins, creating a closed system were built on the Atarim beach, south to the Gordon marina on the Tel-Aviv shore. Except for the first and fourth breakwaters, all the others were built further remote from the shore, in a water depth of about -3.5m, at about 200 m from the coast. The scheme was built at a rate of about 2 breakwaters per year, ending the construction of the scheme in 1977. The construction was according to the results of a distorted physical movable bed model study carried out at the Technion coastal laboratory in Haifa. So far the field results fitted extremely well the model forecasted sedimentological development. Later, 3 systems of series of 3 detached breakwaters were built at the Ashkelon Dlila beach in 1984, and north to the Herzliya (1991) and Ashkelon (1993) marinas. All induced sand accretion behind them, but also erosion to the downstream coast for a few kilometers, as well as generation of rip currents near their heads. The latter led to many drownings of bathers since then.

2.2.3 Studies for future coastal developments

Given the situation described above one can understand the heavy present burden on the coastal zone. It should be also mentioned that about a third of the Israeli coastal length of only 197 km is occupied by various industrial, energy, transportation and military uses, leading to a high public sensitivity for the state of the beaches left for public access. The forecasted population growth combined with the world wide known desire of more than 70% of the people to live near the coast led obviously to serious considerations of land reclamation from the sea, either as seaward land expansions or as artificial islands.

a. Gaza commercial port

On Gaza coast, eastward a few kilometers to the fishing harbour a large commercial port, with its entrance at –12 m water depth is planned to be constructed. For its design, various studies were carried out by Delft Hydraulics Laboratory, including sedimentological numerical modeling. The outcome (Bosboom, 1996) estimated a net yearly average sediment transport of 350,000 m^3 directed northeast, towards the Israeli coast. The present author, in a separate study based on reliable directional wave data assessed a net yearly average value of 400,000 m^3 (same direction).

b. Artificial islands

Following a cooperative agreement between Israel and The Netherlands, a joint study has been carried out for the sedimentological impact assessment of artificial islands on the Israeli coast. The study combined extensive field meteo-marine data gathering and analyses (waves, sea-level, currents, wind, sediments, geo-morphology, fill material sources survey, etc.) by the IOLR, sedimentological modeling (1 line UNIBEST and 2-D DELFT3D) by Delft Hydraulics Laboratory within a testing program agreed and supervised by IOLR, and with investigation of fill material sources in cooperation with Dutch companies. Of various island shapes desk-studied, two were selected as the most appropriate: a tear-drop shape for residential, industrial or environmental uses and a rectangular shore parallel shape for an offshore airport. Tear-drop island sizes of 1000, 2000 and 5000 dunams at various distances from the shore, at different locations and in different arrangements (single, 3 units) were investigated.

The 2.8km by 0.8km rectangular shape (Fig. 4) was too studied for 3 distances from the coast The modeling included investigation of relatively long term effects (30 years) and extreme storm conditions impacts on the central coast of Israel from Palmachim to Bet Yanai. The field survey included comparison of waterline and cliff positions derived from rectified aerial photographs over the previous 40 years. The waterline positions were all brought to the same datum and coordinate system, including corrections for wave set-up and tide. A sector of about 50km of coast was covered, including 2 sectors remote from coastal structures and 5 sectors including coastal structures. When available, differential bathymetric charts were also produced. Major findings were (Rosen, 2000):

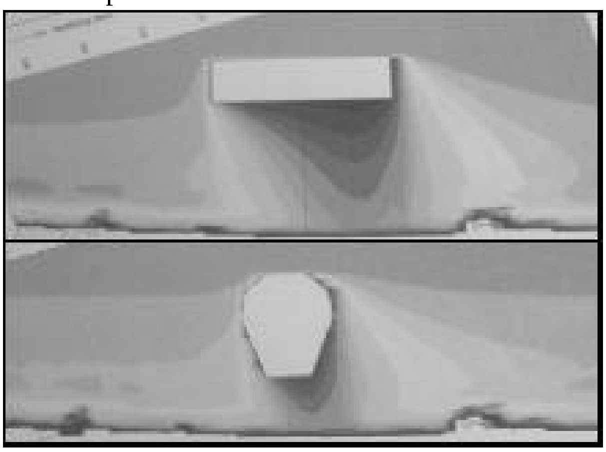

Figure 4. Tear-drop (2000) vs rectangular islands wave diffraction pattern from (Toms *et al.* 1998).

The simultaneous wave direction along the Israeli coast is changing. For local sea waves differences up to 25 deg. were measured between Ashdod and Haifa, while during severe westerly storms the difference was less than 5 degrees.

Wind induced currents are the major longshore contributor to wave suspended sediment transport beyond the surf zone.

The further the island is from the shore (at least for the investigated dimensions) the longer is the coast affected by it in the long term. An island closer to shore would induce a stronger but local concentrated sedimentological impact, making easier, cheaper and more effective sedimentological impact remediation.

A 2000 dunams island is more economical and of similar impact relative to the 1000 dunams one.

Construction of artificial islands induces longshore sand transport blocking, trapping it between the island and the beach as sand spits and starvation of beaches downstream of the islands. This can be remediated by initial artificial sand nourishment there as well as in the island shadowed area and periodic sand bypassing after the island construction during its whole life time.

Floating islands or open structure islands on pile would induce a similar sedimentological impact in the long run.

The rate of sand bypassing should be identical to its rate of trapping on the upstream net longshore transport side. As this changes in time, continuous monitoring of the meteo-marine environment must be performed, including gathering of wave, wind, current and sea-level data and bi-yearly surveys of the bathymetry and aerial ortho-photo beach and cliff surveys. In addition to these, surveys after severe storm events with average return periods above 10 years should be also performed. Differential maps would provide reliable guidance to the amounts of sand and where to be bypassed. Utilization of modern multi-beam survey equipment can speed the mapping by almost and order of magnitude in time.

To prevent visual obstruction of the horizon at sea, it is possible to construct low elevation islands using S-shaped breakwaters and submerged wide rubble mound blankets, breaking the waves away from the protecting breakwater.

Engineering and economical feasibility for the construction of artificial islands were confirmed.

c. CAMP Israel

A study on the management of the Israeli coastal sand resources was conducted (Golik *et al.,* 1999). It combined the outcome of the islands study with new field data gathered in the southern part of the Israeli coast as well as in the sector Hadera trough Haifa. Major results were:

Beach erosion started along the coastline, due to beach sand mining, long before the construction of the Ashdod port. Anthropogenic activities disturbed the natural balance between the supply (Nile Delta) and removal (to coastal dunes and the open sea) of coastal sand.

In the last century, about 20 million m^3 of sand (equivalent to about 50 years of natural supply) were removed from the general coastal reservoir due to mining and entrapment behind coastal structures. The negative coastal sand budget has already affected the near-shore area but hasn't yet cause significant general retreat of the coastline.

Reassessment of the net longshore sand transport rate using Bijker formula and 7 years of reliable directional wave data at Haifa, Hadera and Ashdod (Rosen 2000) showed that while for short term periods of mild years the net longshore transport is always northward in the sector southward to Shefaiim. It may be shift to southward in that between Shefaiim and Haifa, but the true long term net yearly average longshore transport is northward along the whole coast length, gradually decreasing from about 400,000 m^3 at Gaza to less than 100,000m^3 at Haifa. The actual yearly sediment transports may significantly fluctuate from the average values, depending on the occurrence of strong storms on the one hand and the availability of sand on the sea-bottom.

The reduction in net long-term longshore sand transport along the coast means that the volumetric difference is transported offshore, or onshore or both offshore and onshore. As the sandy band is confined to water depths less than 30m, one must pursue another answer. Budget assessment indicated that a portion of the net longshore sand transport is washed to the dunes, a small one to the offshore, and a significant part most probably just lays on the bottom undetected due to sea-level rise and sounding accuracy.

In the future the state of the coast might deteriorate further due to global climate change (sea-level rise and changes in the storm regime).

d. Land extensions (peninsulas)

The author has prepared preliminary plans for a new "turquise" (blue-green) marina at Bat-Yam, using novel concepts such as minimization of sand sedimentation by proper breakwaters layout, shallow artificial beaches within the marina body returning to the public the length of original beach but with improved bathing conditions as well as utilization of the Beachsaver reef patented submerged breakwater units for preservation of nourished beaches. Another option included implementation of respiring detached breakwater structure capable of diminishing the presence and strength of the rip currents at breakwater heads to reduce drowning risks.

Another development plan (Shapiro and Rosen, 1999) proposed a new jet-foils ferries port and land reclamation just south of Jaffa fishing harbour. It also includes new artificial recreation beaches as for Bat-Yam. The port and reclamation area would first use for the construction of the first phase of airport island off Tel Baruch. The layout of the main breakwater was shaped to facilitate natural sand by-passing.

3. LONG TERM ICZ DEVELOPMENT AND NEW REMEDIAL MEANS

The situation presented as well as the future development plans must of course integrate to a sustainable coastal zone development. It needs to consider the reduction of future sand availability from the Nile delta and Sinai coast, erosion by sea level rise and the already lack of sand sources for construction purposes. The implementation of remedial measures such as sand bypassing and coastal nourishment, needs to prevent washing of the beach nourished sand offshore. A solution to this can be utilization of the Beachsaver reef, which uses holes in the precast concrete submerged breakwater to induce vertical transport of offshore transported sand in the water column, to return to the beach with each new coming wave.

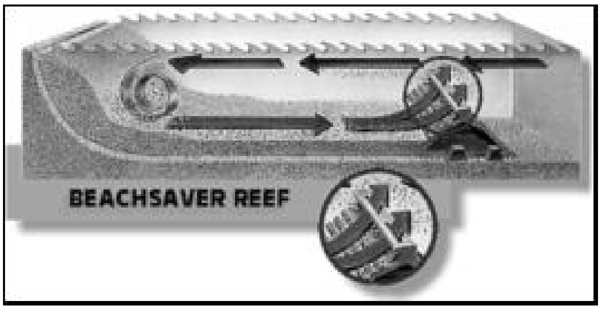

Figure 5 Visualization of Beachsaver reef concept

Another remedial measure in the case of artificial island planning is the "WaveTrap©" island concept developed by the author. It is based on the fact that the sedimentation in the shadow area is due to a radiation stress induced longshore gradient between the upstream and downstream sides of the island. Using the wave stem effect, by which waves approaching a wall at less than 10 degrees are not reflected but trapped along the wall face, the author devised a multi faceted island shape which for the same island area, is about half wide at the shore side than the tear-drop island shape, preserving about the same wave energy on both island sides, and thus reducing the strength of the radiation stresses gradient. It was not tested by numerical or physical models so far, but consultation with a number of known experts confirmed the principles of the proposed shape (Fig.6).

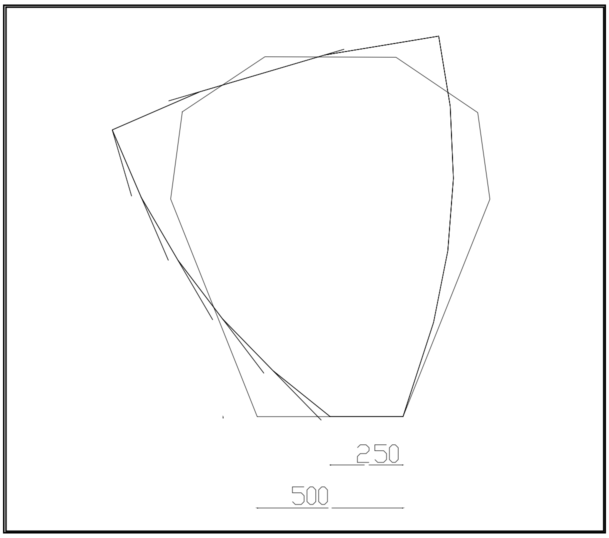

Figure 6. “WaveTrap” vs tear-drop islands

Finally, the reduction of future sand availability led the author to suggest a very long term plan of reshaping of the Israeli coast as crenulated beaches between artificial peninsulas (initially as detached breakwaters about 2.5 km offshore, each 6km long, spaced at about 15km from each other. The area behind each would be artificially filled to the shape of a wide tombolo, such as between each two units a crenulated beach would be created. It is well known that in crenulated beaches there is only local sediment transport, so the beaches will fluctuate around an equilibrium state. Unfortunately, even though the scheme is economically feasible per m^2 cost, the total volumes needed for each pair are about 300 million m^3 hence unrealistic. The artificial islands however, have the potential of becoming in the long run, if decided to fill the area behind them, just crenulated beaches between headlands. Of course, one would have in this case to start construction from the end of the Nile cell (Haifa coast) in order to prevent erosion to northerly downstream beaches. It is considered that this concept may be suitable for other coasts elsewhere.

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