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Management of the Israeli Coastal Sand Resources

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by

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Management of the Israeli Coastal Sand Resources
Summary and Conclusions in Hebrew

ניהול משאבי החול בחוף הישראלי
תמצית ומסקנות

אברהם גוליק ודב ס. רוזן

דו"ח זה מציג את התהליכים הטבעיים הפועלים בחוף הישראלי של הים התיכון ומעריך את השפעת האדם על החוף. מטרתו לתת למערכת התכנון הלאומי קוים מנחים, המבוססים על ממצאים מדעיים, לקביעת מדיניות ממשק החופים. מסקנות הדו"ח והמלצותיו הן:

- במאה העשרים הוצאו מהמערכת החופית כ-20 ממ"ק חול. כמחצית הכמות נכרתה לצורכי בנייה וכמחצית נלכדה על ידי מבנים חופיים ושוב אינה משתתפת בתהליך תנועת החול לאורך החוף. כמות זו מהווה כשליש מכמות החול שהובאה לחוף באופן טבעי (הסעה מהדרום ובליית המצוק החופי). לכן מאזן החול החופי נמצא כיום בגירעון. לנוכח התחזיות לצמצום אספקת חול טבעית בעתיד, בשל השפעתו של סכר אסואן והקמת מבנים חופיים בחופי סיני ורצועת עזה, צפויה החמרה במצב החופים אם לא ינקטו צעדי מנע.

- למרות מצב הגירעון במאזן החול החופי, לא נמצאו עדויות לנסיגה כללית של קו החוף בחלקו הדרומי מזיקים ועד לשפיים. לא ידוע אם קיימת נסיגה כזו בקטע החוף שבין שפיים ועתלית, ומומלץ לבצע מעקב רציף אחר מצבו של חוף זה משום שהוא הקטע הפגיע ביותר להרס.

- למרות מציאות כמויות עצומות של סדימנטים (כ-4 מיליארד ממ"ק) על קרקעית הים הרדוד עד לעומק מים של 30 מ', מומלץ לאסור את כרייתם של סדימנטים אלה שכן זו תגרום לדלדול החול בחוף. כ-500 מיליון ממ"ק חול, המכוסה במעטה דק יחסית של בוץ, מצויים על מדף היבשת בעומק מים גדול מ-30 מ' מומלץ לבדוק היתכנות ניצול חול זה.

- כ-12 מיליון ממ"ק חול נלכדו ע"י מבנים חופיים ומרביתה של כמות זו מצויה ליד מבנים גדולים כגון נמלים ותחנות כח. מומלץ לבדוק אפשרות כרייתו של חול זה והשבתו למערכת ההסעה החופית ממנה סולק.

- קצב הסעת החול לאורך החוף מושפע מאד על ידי סערות עזות. סערה כזו, המתחוללת אחת ל-10 שנים או יותר, מסוגלת להסיע במספר ימים כמות חול השווה לזו המוסעת בשנה ממוצעת או שתיים.

- לנוכח לכידת החול הרבה ליד מבנים חופיים מומלץ שהקמת מבנים חדשים תותנה בהעברת חול מצדו האחד של המבנה לצדו האחר, כדי למזער את הנזק להסעה הטבעית. קצב העברת החול צריך להיות זהה לקצב לכידתו, וכיון שזה האחרון הוא בעל שונות גבוהה, יש לבצע ניטור מתמיד של קרקעית הים בסביבת המבנה כדי לוודא העברת חול בכמות נאותה. כמו כן יש להקפיד שהחול המועבר יהיה מקרבת שורש המבנה אשר לידו מצטבר החול הגס שלשפת הים.

- הרעה במצב החופים עלולה להתרחש כתוצאה מהעלייה הצפוייה של פני הים בשל אפקט החממה. מומלץ לבצע מחקר סדימנטולוגי כדי לקבוע את החופים הפגיעים, ולמצוא דרך להגן עליהם באמצעים הנדסיים.

- כדי לבסס ממשק חופים נכון יש להכין תכנית ניטור לאומית לחוף הישראלי, במימון ממשלתי, אשר תכלול בין השאר: א) טיסות צילום אויר, עם תיקון אורתופוטו, לשם מיפוי וקביעת קו המים של כל החוף אחת לשנתיים ולאחר סערות בהן גובה הגל המשמעותי בים עמוק גדול מ-6 מ׳, ב) מיפוי ימי של כל החוף הישראלי עד לעומק מים של 30 מ׳ אחת לכמה שנים, ו ג) ניטור מתמשך של רוחות, גלים, זרמים ומפלס פני הים במספר תחנות שיספיק לכסות את כל החוף של ישראל.

- יש לרכז את כל הנתונים על מצב החופים, כולל נתוני הניטור השוטף, במסגרת "מרכז מידע אוקיאנוגרפי לאומי" שיופעל בדומה למרכזים הקיימים ברחבי העולם. המרכז יארגן, יתעד, ויפיץ את המידע באופן שוטף.

Management of the Israeli Coastal Sand Resources

Abraham Golik and Dov S. Rosen

Executive Summary

This report presents the natural processes active along the Mediterranean coast of Israel, extending between Ziqim in the South to Haifa in the North, and assesses man impact on the coast. The purpose of this report is to provide the national planning authority scientifically based guidelines for formulating a coastal and sand management policy in Israel.

The evaluation of the present sedimentological conditions along the coast is based on the integration of three methods of analysis: (a) comparisons of aerial photographs depicting changes of waterline and beach bluff or lower cliff line during the past 4-5 decades, (b) seabed volumetric changes determined from depth differential charts of redundant surveys, and (c) longshore sediment transport assessment using wave data.

The analysis of waterline changes in three sites, remote from coastal structures or other anthropogenic influence, did not reveal any constant trend of coast erosion, but more a fluctuating pattern, closely linked with the occurrence of extreme storms. These sites are located between Ziqim and Shefaiim, implying that at least from Shefaiim southward no general coastal erosion has occurred. It is not known whether overall coastal erosion occurs north of Shefaiim. Local impacts due to coastal structures are usually represented by the trapping of sand to the south and erosion to the north of the structures. North of Hadera this trend is reversed. Entrapment occurs north of the structures and erosion is apparent on their southern side.

The analysis of bathymetric changes which occurred in the areas studied shows that sand accumulation occurred in the area south of the structures. It implies that the long-term net littoral sediment transport in the study region is directed northwards. This complies with most of the results of the shoreline analysis as well as the results of the sediment transport rate derived by computation of the wave energy flux. This analysis also shows that sand entrapment near coastal structures is a stochastic process. The volume of sand deposited during a severe storm, occurring once in 10 years or more, which lasts only a few days, may be equivalent to the volume deposited in one or more "normal" years.

The long-term mean rate of the net longshore sand transport, is assessed to be some 400,000 m^3/year at Gaza going northward, decreasing to about 100,000 m^3/year at Haifa, still northward. On the other hand, for the period 04/94-03/99 the approximate yearly averages were: at Gaza 400,000 m^3/year northward, at Ashdod 188,000 m^3/year northward at Hadera 26,000 m^3/year northward and 100,000 m^3/year southward at Haifa.

Due to the shift in the orientation of the coast as well as the shift in the direction of incident waves along the coast, there may be periods of reversal in net transport confined to shallow waters (0-3 m depths) in the region north of Shefaiim.

In very general terms, the net input of sand from the south by longshore sand transport is 400,000 m^3/year and input from the coastal cliff erosion about 200,000 m^3/year. The sand loss to Haifa Bay is 100,000 m^3/year, leaving 500,000 m^3/year unaccounted for. The reduction in longshore sand transport volumes between any two adjacent sites means that there should be a long-term coastal accretion growing northward along the coast. As this is not the case, it means that the volumetric difference is transported offshore, or onshore or to both offshore and onshore. Since sand on the sea bottom is confined to water depths less than 30 m, one must pursue the other options. Hence, even though we can not quantitatively prove it, by circumstantial evidence we conclude that a significant part of the cross-shore net transport is blown to the land by wind. The other part is transported outside the surf zone.

Records show that prior to 1964, some 10 million m^3 of sand were mined from the beach for building purposes. In addition, 12 million m^3 of sand were trapped behind coastal structures. The long-term (20th century) mean of anthropogenic sand removal from the Israeli coast stands therefore on 220,000 m^3/year, which is more than a third of the annual input to that coastal system, resulting in a negative coastal sand balance. This, with the forecasted reduction of sand input from the south due to the effect of Aswan Dam, and coastal structures built on the coasts of Sinai and Gaza, put the Israeli coast and its sand resources in a precarious situation.

Despite the huge sediment quantities (~ 4 billion m^3) estimated to be present on the inner continental shelf (in water depths less than 30 m) it is recommended that mining in that area should be prohibited as it will deplete the beach sand. Exploitation of some 500 million m^3 of sand, found under a relatively thin cover of silt and clay at water depths greater than 30 m should be examined. The building of coastal constructions should be forbidden unless proper steps are taken to ensure: (a) bypassing the natural longshore sand transport for the entire lifetime of the structure, and (b) prevention of reflection-induced erosion to neighboring beaches.

The rate of sand bypassing should be determined by the rate of sand entrapment next to a structure. This rate is highly variable and therefore continuous monitoring of the seabed in the vicinity of the structure should be carried out. Also, bypassing should be carried out from the root of the structure to ensure bypassing of coarse sand.

In view of the large volume of sand already trapped in the vicinity of major structures, utilization of this sand should be taken into consideration. This sand should be used for artificial nourishment of deteriorating beaches, complemented by proper means to prevent or minimize quick removal of the nourished sand.

The forecasted sea level rise due to the greenhouse effect is expected to further deteriorate the condition of the beaches as well as increase cliff erosion. The locations of cliffs sited in coastal sectors critically sensitive to sea-level rise should be determined by an adequate sedimentological study, and prevention means for the future must be considered, such as low reflection sea-walls and cliff\dune buried sea-walls.

Finally, to enable reliable information and correct decision-making acts, the government must routinely conduct a permanent and extensive coastal monitoring program. This program should include mapping the waterline, by means of aerial photography and orthophoto rectification of the entire coast every two years, and next to major coastal structures every year. In addition, aerial photography should be conducted in years with storms exceeding 6 m deep water characteristic wave height. Bathymetric charting of the entire coast should be carried out every several years and next to major or new structures every year. Environmental factors (sea level, wind, waves, and currents) should be monitored continuously at sufficient sites for proper coverage of the whole coast.

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1. INTRODUCTION

Israel has both a high population density and a high rate of population growth, coupled with a relatively high rate of economic growth. This manifests itself in intense development pressures in the coastal zone, where the main centers of economic and commercial activity of the country are located. The coastal zone is under development pressures from urbanization, tourism, ports and activities associated with marine transport, oil refining and electricity production, recreation and beach use, marinas for small craft, wastewater outlets, fishing and mariculture, and, until prohibited some 30 years ago, sand mining.

The impact of anthropomorphic activity on the coastal zone is clearly noticeable, in particular, adjacent to coastal structures which caused changes in the waterline position: accretion on one side of the structure and erosion on its other side. But beyond these changes, which are local, recent archaeological findings indicate that the coastal sand balance of Israel suffers from a significant deficit. Hershkovitz and Galili (1990) and Galili *et al.*, (1993) report on remains of a Neolithic village found at a water depth of 8 m off Atlit in which human skeletons were found exposed on the sea bottom (Figure 1). These skeletons could not have remained intact, exposed to the wave energy, had they not been covered and protected for thousands of years by a thick layer of sand. This layer of sand has disappeared and no sand replaced it. This indicates a deficit in the coastal sand balance. Another example is a merchant boat that ran aground 2,000 years ago on the beach of Ma'agan Michael (for geographical locations see Figure 2) and was recently exposed with all its merchandise on it, in excellent shape (Linder, 1992). Again, this boat could not have survived for 2,000 years in the surf zone without a sand cover to protect it, and this sand has disappeared.

Golik (1997a) estimates that during the 20th century, some 20 million m^3 of sand was removed from the coastal zone by mining and entrapment of sand behind coastal structures. It is estimated that this quantity is equivalent to the natural influx of sand to the Israeli coast during some 50 years.

The anthropogenic and natural impact on the Israeli coast will only increase in the future. The expansion of Ashdod Port is already underway and that of Haifa Port is in the stages of approval. A feasibility study for the construction of artificial islands in the offshore of Israel is underway. Several marine farming ventures have already gained success offshore Elat in the Gulf of Aqaba and a few have recently begun in the Mediterranean, offshore Israel. If these too turn out to be successful, there is no doubt that this activity will catch momentum. Field surveys for laying a gas pipeline and a communication cable on the Israeli continental shelf are already under way. There is no doubt that the construction of the Gaza fishing port, the planned construction of the Gaza Port, installations for desalination and other "small" structures, will have their effect on the coast, as will the predicted global sea level rise and climate change.

It is quite obvious that in order to accommodate all these activities in some harmony with nature, two things are required. First, a sound understanding of the natural processes which govern and shape the coastal zone, and a sustainable integrated coastal management program which would guide and control concerted human activity along the coastal zone acting with nature rather than against it.

The most urgent problems that the management of the Israeli coastal zone is facing, in regard to coastal resources and hazards are:

a) The deficit in sand balance - Although early warnings concerning the development of a deficit in sand balance along the Israeli coastline were already noted in the '60s (see the Zifzif Commission, 1964), it was only recently recognized as a problem of a national importance. This occurred when it was realized that: (*i*) reserves of sand on land for the building industry will suffice for only 2-3 more years; (*ii*) the expansion of the ports of Haifa and Ashdod requires some 12 million m^3 of fill material; (*iii*) that if the plans for construction of artificial islands materialize, a 40-50 million m^3 per 2 km^2 island will be required and that (*iv*) an unknown but significant quantity of sand will be required to nourish deteriorating bathing beaches;

b) The deterioration of the coastal cliff - The erosion of the coastal cliff of Israel is a natural phenomenon and there is evidence that this process has been going on at least since sea level reached its present stand some 2,000 years ago. However, there are clear indications that the erosion of the coastal cliff has been intensified in the last century due to human intervention, mostly building, irrigation and heavy vehicle traffic on top of the cliff. As the top of the cliff has a high real estate value, the conflict between economic pressure to build on top of the cliff on one hand, and the desire to protect the cliff and reduce its erosion, on the other hand, is quite obvious;

c) The changes in the configuration of the Israeli coastline – Almost every coastal structure built on the beach causes changes in the configuration of the waterline. These changes could be accretion on one side of the structure and erosion on its other side, or the creation of spits or tombolos behind detached breakwaters. Some of these changes improve the coastline while others damage it. A sustainable integrated coastal zone management program must relate to this phenomenon.

Many studies on the coastal processes and relating issues in Israel have been carried out during the past 40 years. An excellent review of these was recently prepared by Almagor *et al.* (1998b) and will not be repeated here. The purposes of this study were to gather existing information on the coastal processes along the Israeli coastline, to generate new information on some issues, and on the basis of these to propose guidelines, for sand management in the coastal zone. This study is based on five tasks:

a) Evaluation of changes in the waterline position which occurred during the last 50 years, by comparing old aerial photographs to recent ones;
b) Estimation of the volume of sediment eroded, or accumulated, on the seabed in the vicinity of coastal structures;
c) Estimation of the longshore sediment transport rate along the Israeli coastline as derived from wave energy flux, sand characteristics and beach profile.
d) Estimation of the sand reserves on the Israeli continental shelf;

2. GEOMORPHOLOGICAL SETTING

The Israeli coastline is located on the southeastern corner of the Mediterranean Sea. Extending along some 180 km from Ziqim in the south to Rosh HaNiqra in the north, it gently curves from N 35 E at Ziqim to N 20 E in its central part to N 10 E at Rosh HaNiqra (Figure 3). It is generally a smooth coastline, with the exception of Mt. Carmel, which protrudes into the sea thus forming Haifa Bay. Most of the coastline consists of a coastal cliff which ranges from low bluff mostly in the south to a pronounced cliff which is almost continuous between Herzliya and Givat Olga reaching up to 40 m in height. The cliff is built of alternating layers of kurkar (a local term for eolianite sandstone) and red-brown sandy loam called Hamra.

Large areas of the Israeli coastal plain are covered by sand dunes, mostly in the south. South of Tel Aviv, these dunes penetrate landward to a distance of 5 to 10 km from the shore. North of Tel Aviv, dunes are restricted to river outlets to the sea, where breaches in the coastal cliff allow sand penetration landward. Two exceptions are the Hadera and Haifa Bay areas where extensive dune fields are found.

The Israeli beaches are relatively narrow. Between Ziqim and Tel Aviv, as well as between Givat Olga and Rosh HaNiqra they range in width between 20 to 50 m with the exception of river outlets where they may reach up to 200-300 m in width. In the central part of the coast, between Tel Aviv and Givat Olga, the beaches are only a few meters wide and sometimes non-existent.

Beach rock is present in most of the beaches. It consists of consolidated sand, kurkar fragments and shells. The beach rock is located on the beach at the water level and forms abrasional platforms which provide some protection for the beach from waves. In some places, small tombolos are formed behind the beach rock. Partially submerged kurkar ridges also cause formation of tombolos, lagoons and small bays a few scores of meters in size.

Two sedimentological provinces are recognized along the Israeli beaches: south of Akko, the beaches consist of fine to medium-sized quartz grains with small quantities of carbonates; north of Akko, the sand is biogenic, of local source, with some reworked kurkar or limestone fragments. The source of the quartz sand is the Nile River as shown by Pomerancblum (1966) using heavy mineral analyses. The sand grain size decreases from 0.3 mm on Ziqim beach to 0.2 mm north of Tel Aviv to 0.18 mm in the vicinity of Haifa.

The orientation of the Israeli continental shelf follows that of the coastline, gradually changing from south-west in the south to north-south in the north. Its width (defined by the 100 m depth contour) also changes gradually from some 20 km off Ziqim to 10 km off Haifa. From the beach to a water depth of approximately 30 m, the sea floor slope is 0.5-1° and from there to a water depth of about 80 m with a slope of only 10' to 20'.

The continental shelf is generally smooth. Two major morphological features found on it are the Akhziv Canyon found a few km south of the Israeli-Lebanese border and the protrusion of Mt. Carmel which is locally called the "Carmel Nose". In this area, the shelf is shallower and the shelf break begins at 60 m only. Other irregularities on the continental shelf are submerged kurkar hills which crop out of the surrounding sediment. Their relief is a few meters although some of them reach above sea level to form small islets.

3. CHARACTERIZATION OF THE MARINE ENVIRONMENT

3.1 General

A summary of environmental characteristics of the Mediterranean coast of Israel is presented below to give the reader the necessary background. These refer to the climatic characteristics of the parameters responsible directly and indirectly for the transport of sand, namely the sea-level, the waves, the wind and the currents.

3.2 Sea levels and tides

The tidal (astronomic) range on the Mediterranean coast of Israel is characteristic of the low-tide range of the Eastern-Mediterranean basin.

The tide usually varies between 0.40m during spring tides and 0.15m during neap tides. The tide contribution exhibits the usual semi-diurnal periodicity (twice a day highs and lows) and fortnight (14 days) periodicity.

Extreme sea levels may occur in combination with extreme meteorological conditions. However these may differ from site to site along the coast of Israel, particularly in the Haifa bay due to the shadowing effect of Mount Carmel Cape protrusion into the sea-body. During spring and particularly in November – December months, offshore directed easterly winds occur at Haifa inducing lower sea-levels in Haifa Port and Bay area, while that effect is not detected at other locations further south along the Israeli coast.

Low sea-levels occur in winter during February-March months, while high sea-levels occur in August-September, with a second maximum in December.

Extreme sea levels may occur in combination with extreme meteorological conditions. Based on 30 years of data, the following average return periods were assessed (Rosen, 1998a):

Average Return Period [years]	Low Sea Level [m]	High Sea Level [m]
1	-0.41	0.60
50	-0.79	1.00
100	-0.90	1.06

The above values however, do not include the expected sea-level rise due to the "greenhouse effect", for which the assessed global value for 2100 is 0.5 m for the "most probable" scenario.

3.3 Waves

Wave measurements in Israel started in 1957 at Ashdod using visual observations and developed through to instrumental measurements of wave height and period since the late 70's and to full instrumental directional measurements in the 80's using pressure gage arrays in shallow water, to directional wave buoys at Ashdod and Haifa and directional pressure and current gage at Hadera at the beginning of the 90's.

Rosen (1998a,b) indicated that the old non-instrumental directional wave data gathered before the new equipment has been installed at Hadera in December 1991 (in 27m water depth), at Ashdod in April 1992 (in 24m water depth) and at Haifa in late November 1993 (also in 24m water depth) do not provide sufficient accuracy in regards to the directions, and hence are unsuitable for use in longshore sediment transport assessments.

Directional wave distribution in an average year:

The higher wave conditions approaching the Mediterranean coast of Israel are induced by cyclones passing in the Mediterranean from west to east, especially when these became stationary for a few days in the region of Cyprus. All moderate and higher sea states come from WSW to NNW through W. About 66% of all waves approach from W trough WNW directions. The highest sea states approach from W direction, but storm development occurs by veering from WSW to NW trough W directions. Along the coast from south to north, a counter clockwise shift in the simultaneous incident deep water wave direction is found, due to the relative position of the storm cells. A shift of up to 20 degrees was found between Ashdod and Haifa in low sea-states, while in high sea-states this angular shift reduces to only a few degrees. A graphic description of this phenomenon is explained in Figure 4. In very moderate years westerly storms may be absent.

Average Year Deep Water Characteristic Waves :

low sea states (less than 1 m) occur about 50% of the time, **moderate** sea states (between 1 m and 2 m) occur about 25% of the time, **strong** sea states (between 2 m and 4 m) occur some 20% of the time and **high** sea states (above 4 m) occur about 5% of the time. A characteristic seasonal wave height distribution is shown in Figure 5.

Peak wave periods range between 3 and 15 seconds. During high sea states they range usually between 10 and 13 seconds, and very high sea states have peak periods between 12 and 15 seconds.

Extreme Sea States and Average Return Periods:

Average Return Period	years	2	5	10	15	20	50	100
Deep Water Characteristic Wave Height	meter	5.15	6.15	6.80	7.15	7.40	8.20	8.70

3.4 Winds

Statistics of extreme wind distribution are presented in Figure 6. Rosen (1998a) indicated also that the offshore wind climate shows stronger winds than those measured at shore. The following data describe the general coastal wind climatic characteristics at the Mediterranean coast of Israel:

Average Year Intensity Distribution:

light winds (less than 10 knots)	~ 81.4 percent of time
fresh winds (11 to 21 knots)	18.3 percent of time
strong winds (22 to 33 knots)	1.2 percent of time
winds above 33 knots	< 0.1 percent of time

Average Year Directional Distribution:

77% of the **fresh** winds blow from directions W to N through NW.

77% of the **strong** winds blow from directions SW to W trough WSW.

Average Seasonal Distribution:

94% of the **strong** winds occur between November and March, and

60% of the **strong** winds occur in January and February.

3.5 Currents

Tidal Currents:

Tidal currents in this region are in general weak, in the order of about 5 cm/second.

General Circulation:

In this region, the general circulation, is due mainly to the geostrophic current and shelf waves and is oriented counter clockwise most of the time. The currents in most cases have low speeds of about 10 cm/sec flowing parallel to the coast northward more than 70% of the time. The vertical distribution is almost uniform in winter, but decays towards the bottom in summer. The speed decreases towards the shore. In certain instances, currents of about 2 knots were measured.

Wave Induced Currents:

These currents prevail and are predominant within the surf zone. Longshore currents are induced by waves approaching obliquely to the contour lines, and flow parallel to the shore line. Rip currents are generated by perpendicular waves or edge waves, and flow from the shore offshore, almost perpendicular to shore line to a distance of up to about 3 times the surf zone width, within which they decay completely. The former may attain during storms speeds of 4 knots and even more. The latter may also attain 1 to 2 knots, but also in calmer sea states (Bowman et al., 1988a,b, 1992).

Analysis of the correlation between current speeds, against waves and land based winds shows that they were correlated, the correlation coefficient becoming higher during high sea-states, especially between relatively strong current speeds and high waves. Levine (1996) found a varying correlation with the wind during storms, explained by him as being due to the quick change of wind direction and speed during storms, leading to stronger current speeds at the beginning of the storms and weaker later. This was explained by Rosen (1998a) to be due to the changing track of the winds and waves, which at the beginning of the storms being SW-ly to W-ly directed, generate wave induced northward longshore currents in the same direction with the predominant northward current direction strengthening the shallow currents, while later, during the stage of storm decay the locally generated wind waves (sea) change to NW-ly, inducing an opposite longshore current which would reduce the total current speed. The characteristic current statistics on the coast of Israel are presented in Figure 6.

4. CHANGES IN WATERLINE POSITION

4.1 General

The sedimentological balance of a coastline affects the waterline position: a deficit in sand balance would cause beach erosion, shifting of the waterline landward and/or steepening of the beach cross-shore profile. A surplus in sand balance would result in accretion, shifting of the waterline seaward and/or moderation of the beach profile. Therefore, investigation into the history of the waterline position should provide an indication with regard to the condition of the sedimentological balance along the coast.

Contrasting rectified old aerial photographs of the coast to new ones may help in detecting changes in the waterline position. As the waterline shift is rather slow, one needs aerial photographs covering long periods of time in order to detect these changes. Although aerial photographs of the Israeli coastline were taken as early as the beginning of this century, only those taken from 1945 onward could be used for our purposes due to difficulties in analyzing the photographs as discussed below.

Studies in the change of the waterline position along sections of the Mediterranean coast of Israel, by analyzing aerial photographs, have already been carried out in the past. Striem (1963) analyzed the waterline of Atlit, Vajda (1980) and Rosen (1990, 1992) the coast between Hadera and Sdot-Yam, Shoshany (1991) the waterline of Ashqelon near the Rutenberg Power Plant, Shoshany et al. (1996) the waterlines of Netanya and Gaza, Golik et al. (1996a,b) the waterline of Ashdod on both sides of Ashdod Port, Rosen (1998) the waterline between Palmakhim and Bet Yanai and Zviely (in press) the waterline of Herzliya. Most of these were carried out in the vicinity of coastal structures, where changes in waterline position was local, rather large and rapid. It is, however, of interest to find out whether the deficit in the coastal sand budget has caused erosion of the entire Israeli Mediterranean waterline. Therefore, beach sections which were remote from any coastal structure, were selected for analysis in this study. The beaches which were selected are Ziqim, Palmakhim and Atlit-Haifa. In the analysis of the waterline position, results of other studies were also incorporated.

4.2 Methodology

Coastline mapping by means of historical aerial photography is a difficult task due to two typical problems. The first concerns data quality that varies greatly with respect to acquisition equipment, methods of photography and storage. Some of the photographs may be reproduced only from contact prints as a result of the lack of negatives or diapositives. Inaccuracies due to object displacement, geometrical film/paper distortions, resolution limitations and low contrast are compounded where the quality of the photographs has deteriorated. The second problem relates to coastal zone complexity and dynamics, at the beginning, due to the wide range of components (dry sand, wet sand, waves, foam, beach rock, etc.) and their mixtures, and afterwards, due to the fast rate of change in their spatial distribution. The momentary, daily, seasonal and annual displacements of the waterline add to the difficulty of differentiating the component of long-term changes from the total changes detected.

In order to achieve the accuracy necessary for determining long-term coastal changes, the methodology utilized here is based on the following three key elements:

a) Selection of the time of year which is most suitable for monitoring the waterline: During autumn (mid September to mid November) the level of wave energy along the Israeli coast is at its lowest, reaching a minimum in October (Rosen, 1982; Goldsmith and Sofer, 1983; Carmel *et al.*, 1985). As a result, during this season, the beach profile reaches its most pronounced summer profile characterized by maximum beach width, the berm is at its highest level and the beach face is at its steepest condition. Hence, the selection of this period for determination of waterline position has two advantages: the first concerns relative calm sea condition, which implies that the weekly/diurnal fluctuations of the waterline position will be of a low magnitude. The second advantage is that horizontal displacements of the waterline are of minimal magnitude when the beach face is at its steepest condition. This will decrease the inaccuracies due to momentary changes in its position. Accordingly, a search was conducted for all aerial photographs that were taken during autumn in the aerial photograph archives of the Survey of Israel. Photographs selected for this study were from the period of 1945-1995. Most of these were taken after 1955, during autumn (end of August to mid November) but one sortie, from January 1945 covering a section of the Haifa-Atlit coast, was included in order to expand the time range covered by the study.

b) Selection of the waterline type: Dolan *et al.* (1978), Smith and Zarillo (1990) and Shoshany and Degani (1992) argued that the line, which separates the wet part of the beach from the dry one, provides the most suitable element for monitoring waterline position using aerial photographs. They claim that this line (referred to here as the D/W line) is seen clearly and sharply in the photograph. In addition, this line does not fluctuate momentarily as the waterline does. Therefore, the D/W line was used in this study as the waterline.

c) Application of digital image processing methods: A detailed description of these methods, used to eliminate distortions in the photographs and relate one photograph to the one it is compared with, is detailed in Shoshany and Degani

(1992) and Shoshany *et al.* (1996). It will suffice to say here that the photographs are converted from analog/photographic form into a digital format by scanning. The D/W line, which is represented by brightness contrast between the dry and wet sand, is accentuated by enhancing the brightness contrast. This enables the operator to trace the D/W line on the photograph with greater ease. It is estimated that the error involved in determination of the waterline position on a certain photograph is about 10 m.

The method described above was used in the analysis of coastal sections used for this study - Ziqim, Palmakhim and Atlit-Haifa. The same method was also employed in the studies of Golik *et al.* (1996a), Golik *et al.* (1999b) and Shoshany *et al.* (1996) mentioned below. Correction of distortions of the aerial photographs was carried out also in the studies of Rosen (1998) and Zviely (in press), but the waterline was determined as a line running through the middle of the swash zone. Furthermore, these researchers made corrections for the wave-induced setup, tide and wind assuming a certain slope of the beach. Therefore, when results obtained by the two methods are compared to each other, the absolute waterline position may differ, but relative changes in the waterline position during the same period of time should be the same.

4.3 Changes in Waterline Position Along the Israeli Coast

2.3.1 *Ziqim*

Aerial photographs from 4 sorties, conducted in autumn 1958, 1971, 1980 and 1989, along a 1 km stretch of coastline in the vicinity of Ziqim were used for the analysis. Figure 7 shows the positions of the waterline of the northern section of this stretch at these dates. Figure 8 presents, at 10 meters intervals, the distance of the 1958 waterline from each of the succeeding dates. In this graph, the X axis represents the North-South coordinates of the old Israeli grid system and the Y axis is the distance, in meters, of each sampled point from that of 1958. Negative values indicate retreat of the waterline (an eastward shift) and positive values indicate accretion (a westward shift). It can be seen that most of the fluctuations are within ± 10 m with a few points of differences up to 20 m. Figure 9 presents the means and standard deviations of these differences in meters. It shows that during the period of 1958-1989 the largest difference in the mean waterline position, detected for this beach, is 8 m between 1980 and 1989.

4.3.2 *Ashdod*

Changes in the waterline of Ashdod, both south and north of Ashdod Port for a distance of some 4 km from the port, were studied by Golik *et al.* (1996a, b). It was found that during the lifetime of the port since its construction in 1960, the beach south of the port has accreted by more than 100 m. This accretion gradually tapered off at a distance of 2.5 km from the port. North of the port, the waterline did not change its position. Golik *et al.* (1996a, b) explain that the intensive sand mining that took place on this beach prior to the port construction left this beach rocky, devoid of sand and therefore no erosion took place there after construction of the port. The waterline changes that occurred in the vicinity of Ashdod Port clearly indicate that net longshore sand transport there is from south northward.

4.3.3 *Palmakhim*

Analysis of the Palmakhim coastline is based on 5 aerial photography sorties which were carried out during autumn 1956, 1964, 1971, 1980, and 1990 along a 1 km stretch of coastline. The changes that took place during this period with respect to the position of this waterline are presented in Figure 10 as the distances of the means and standard deviations of the waterline position of 1956 from those of the succeeding dates. It is apparent that the largest difference of waterline position, 8.9 m, occurred between 1964 and 1990.

Rosen (1998) conducted a similar study on this coast, almost on the same beach stretch, covering a 1 km coast length. His study was directed more into determining the impact of the strongest storms known during the period of 1958-1998, namely November 1964, January 1968 and February 1992. His results showed very similar patterns to those obtained in the present study. The range of waterline fluctuations was between 5 and 10 m and did not seem to indicate any clear erosional trend over the years. They were related to stormy and calm years. The impact of Ashdod Port was also not visible as one would have expected if the long-term bypassing is considered negligible as concluded by Dearnaley (1996) and estimated by Baird and Associates (1996).

4.3.4 *Bat-Yam*

A coast length of 1km was studied by Rosen (1998) at Bat Yam using 7 flights on 06.08.1966, 02.10.1971, 06.11.1976, 13.09.1986, 21.06.1991, 05.09.1992 and 09.11.1997. With regard to the waterline in the southern sector, only four flights were available. Changes in the waterline position of this coast were up to 40 m but with no specific trend. At some sections of that coast, a waterline retreat of 30 m occurred after the storm of 1992 but not all along the coast.

4.3.5 *Tel-Aviv: Yafo Harbour to Sheraton Hotel*

A series of detached breakwaters were built along this 3 km long coastal section. Rosen(1998) provides a detailed description of the waterline changes on the basis of the analysis of 9 aerial flights conducted between 1958 and 1997. It shows waterline changes which resulted from tombolos formation following the construction of the detached breakwater. Rosen (1998) concludes that the coastal enclosure has become stable since 1976 after accumulating sand which widened the waterline by about 70 m with some sediment exchange during high storms by trapping it and releasing it during milder wave climate years. The same is true with respect to the Sheraton and Hilton breakwaters.

4.3.6 *Tel-Baruch*

This coastal sector was investigated by Rosen (1998) using aerial photographs taken in 6 aerial flights between 1960 and 1997. Changes in waterline position which are related to the detached breakwater were found. For our study, the interesting findings were those in the coastal section further north to the Tel Baruch detached breakwater where no significant changes were found between 1960 and 1971. In 1973, the waterline advanced (westward) by 6 to 8 m and an additional 8 m in 1976. The situation in 1991 returned back to that of 1971, followed by very minor changes in 1992 trough 1997. Hence this section of the coast may be considered stable.

4.3.7 *Herzliya*

The Herzliya marina complex which includes the marina as well as three detached breakwaters north of it, was constructed between 1990 and 1992. Zviely (in press) used a series of aerial photographs taken between 1965 and 1997 to analyze waterline changes there. The photographs cover a 4,250 m long section of the coast, to a distance of 2,500 m north of the marina's lee breakwater and 1,000 m south of its main breakwater. It was found that prior to construction of the marina, the waterline was not stable, fluctuating on the average between 12 to 16 m landward during 1965-1979 and between 15 to 25 m seaward during 1979-1990.

After construction of the marina, the waterline in the study area did not behave uniformly and Zviely divided the waterline into two groups. One group consisted of the beaches, which are in the range of 1,000-2,500 m north of the lee breakwater and 500-1000 m south of the main breakwater. In this group, a mean waterline retreat with a magnitude of 12-15 m was observed. The second group consists of the beaches, which are at the back of the three detached breakwaters and some 500 m south of the main breakwater. The breakwaters induced formation of tombolos behind them, and therefore beach accretion there was large - 53 m on the average. However, the accretion that took place south of the main breakwater was rather modest - 15 m.

4.3.8 *Shefaiim*

A 1 km long beach stretch in this sector was studied by Rosen (1998). The position of the waterline in 1964 was used as a reference. As may be seen in Figure 11, the waterline of 1968 was found to be relatively advanced to that of 1964 by some 4 to 8 m. Furthermore, in 1991 the waterline state retreated back to the 1964 position or even further back in the northern part of the coast, but in 1992 the waterline advanced the coast to the state of 1968 in the south or even further more by some 5m in the northern part. However, the waterline in 1997 retreated some 3 m in the southern part to some 10 m in the northern part, indicating a clear erosion process. The fluctuations in the waterline position of this sector of the coast are within the detection limits of the analysis and the waterline may be considered as a stable one.

4.3.9 *Netanya*

Two detached, shore-parallel breakwaters which were built off Netanya in 1969-1970, formed two tombolos behind them. Shoshany *et al.* (1996) analyzed aerial photographs that were taken of the waterline to a distance of 1,400 m south and north of the tombolos. Of 7 aerial photography sorties taken between 1955 and 1990, 3 were conducted before formation of the tombolos (1955, 1961, 1964) and 4 (1976, 1982, 1984, 1990) after their formation. Results show that after formation of the tombolos a 20 m accretion occurred north of the tombolos whereas south of them the waterline underwent erosion of some 10 m. The interpretation of Shoshany *et al.* (1996) of these findings is that the tombolos act as obstacles to the longshore littoral drift and changes in the waterline position indicate a southward sand flow at Netanya. However, Rosen (1998) reports that contrasting photographs taken in 1991, 1992 and 1997 from that area shows a reversal in the above mentioned trend. The waterline accreted by some 10 m between 1991 and 1992 south of the tombolos and then remained unchanged until 1997, whereas north of the tombolos, an erosion of 15 m, and at places even 30 m, occurred between 1991 and 1992 and stabilization from then until 1997.

4.3.10 *Atlit (Hof HaCarmel - Megadim)*

Waterline changes along the 10 km coastline between Hof HaCarmel and Megadim were analyzed using aerial photographs taken in 10 sorties between 1945 and 1995. For the purpose of analysis, this coast was divided into 6 sections. Figure 12 shows the geographical extension of these sections and the position of the waterline at each of the dates for which aerial photographs were available. Not all of the sections were covered by the same aerial photographs. The oldest sortie, from 1945, covered only sections 1-3 but not sections 4-6 for which the oldest sortie was 1956.

In section 1, a detached, shore-parallel breakwater was built during 1968-1969 at a distance of some 200 m off shore. Figure 13 shows that prior to breakwater construction between 1945 and 1963, this beach experienced a slight accretion. However, by 1970, approximately two years after construction of the breakwater, a tombolo had already been formed behind it. This tombolo continued to develop after

1970, but it can be seen that accretion took place on its northern side whereas the waterline on the southern side remained stable.

Figure 14 shows the change in the mean waterline position with time, relative to the mean of 1945 and 1956, in section 2, which is to the south of the Hof HaCarmel tombolo. One may easily distinguish the difference between the two periods of waterline development. In the first, between 1945 and 1963, the waterline is relatively stable, but in the second, after the construction of the breakwater between 1970 and 1976, the waterline retreated close to 30 m on the average and remained so until 1995.

Figure 15 shows the change in the mean position of the waterline with time for sections 3-6. It can be seen that in all of them a drastic retreat ranging in magnitude between 34 and 48 m occurred between 1956 and the early 60's (1961 for section 3, 1963 for sections 4-6). From then on, accretion of the beach took place. The magnitude of this accretion was 37 m between 1963 and 1984 in section 3, whereas for sections 4-6 it ranged between 16 and 24 m during the period of 1963-1966. After this period of fast recovery, the position of the waterline in the various sections fluctuated back and forth by a few meters but it never regained the position it had in 1956.

4.3.11 *Qishon Harbor - Qiryat Yam*

Aerial photographs, taken on 8 dates between 1945 and 1995 of the coastline between the main breakwater of the Qishon Harbor and Qiryat Yam were used by Golik *et al.* (1999b) for investigation of changes in the waterline position there. This 10 km coast was divided into 6 sections (see Figure 16). The mean and standard deviation of the difference in position of the waterline between 1956 and the succeeding years, in each of the six sections, are shown in Figure 17. It can be seen that between 1956 and 1970, a sharp retreat of up to 25 m of the waterline occurred in sections 1-4. A continuous advance followed this retreat between 1970 and 1990 with stabilization or a slight advance from that time until 1995. The advance of the waterline after 1970 was as much as 35 m. In the two southern sections (5&6), the retreat continued until 1990 and at that point, the waterline began to advance.

4.4 Analysis of Results

The analysis of waterline behavior during the last few decades by means of aerial photographs was carried out for three purposes. The first, to examine if during that period, in which human intervention in the coastal zone was very intensive, an overall, significant change in the position of the Israeli waterline has occurred; The second, to gather evidence on the direction of sediment flow along the Israeli coast; The third, to examine the rehabilitation rate of beaches that suffered damages from beach mining.

4.4.1 *Overall Position of the Israeli Waterline.*

In order to obtain a picture on the overall behavior of the Israeli waterline during the last few decades, the analysis of aerial photographs must be carried out on beaches which are remote from coastal structures in order to eliminate local effects of the structure. The only stretches of coastline, which are, to some extent, remote from anthropogenic activity, are those of Ziqim, Palmakhim and Shefaiim. Even these are not too far away from sites of coastal structures. Ziqim is only 11 km north of the breakwaters of Gaza and 7 km south of the cooling basin of the Rutenberg power plant. Palmakhim beach is 13 km north of Ashdod Port and Shefaiim is 5 km north of Herzliya marina and 12 km south of the breakwaters of Netanya. At least part of the Atlit Coast that was analyzed is also remote from a coastal structure, but there beach sand mining in the past has interfered with the natural processes on the beach. The rest of the beach sections for which the behavior of the waterline was studied by means of aerial photographs were affected by human activity.

The results obtained from Ziqim, Palmakhim and Shefaiim show that the changes in waterline position at these sites, during the last 4-5 decades, are smaller than the detection limit (10 m). Furthermore, the changes which were detected did not show a continuous trend with time, but fluctuated between beach accretion and erosion. These findings lead to the conclusion that at least in the southern part of the Israeli Coast, a general significant erosion or accretion of the waterline did not take place during the last 4-5 decades.

4.4.2 *Changes in Waterline Position as Indicator of Longshore Transport Direction*

The waterline shift in the vicinity of coastal structures, whether detected by analysis of a series of aerial photographs, or by systematic long-term observations in the field, may serve as an indicator to the direction and intensity of the prevailing and predominant longshore sand transport. It must, however, be stressed that in most cases the interference of a coastal structure in the sand transport is restricted to the inshore zone* and will therefore indicate in most cases the flow direction in that zone.

On the basis of the findings in the vicinity of coastal structures, the Israeli coastline can be divided into three: southern, central and northern parts. All the coastal structures in the southern part, the cooling basin of the Rutenberg power plant near Ashqelon, the Ashqelon marina, the Ashdod marina and Ashdod Port exhibit a significant and consistent beach accretion on the southern side of the structure and beach erosion on the northern side. Figure 18 is an aerial photograph of the boat anchorage of the Elat-Ashqelon Oil Pipeline Co. south of Ashqelon. This photograph was taken in 1978, some 6 years after the anchorage construction was completed and prior to the construction of the cooling basin of the Rutenberg power plant in that location. The picture clearly shows the massive accumulation of sand south of the anchorage and the erosion that took place north of it. This process has continued after the construction of the basin. Figure 19, taken from Golik *et al.* (1996a), shows the accretion that took place south of the main breakwater of the Port of Ashdod between 1958 and 1992. It shows not only the magnitude of the accretion, more than 100 m near the breakwater and tapering off at a distance of 2.5 km, but that it was consistent in time. Although quantitative information concerning erosion and accretion next to the marinas of Ashqelon and Ashdod is not available, there is no doubt that the pattern described above exists also there. One therefore may conclude that the net longshore sand flow in the surf zone in the southern part of the Israeli Coast is northward.

In the central part of the coastline, between Tel Aviv and Netanya, the waterline changes in the vicinity of coastal structures are not as dramatic. The series of the

* *Defined as the zone of the beach profile extending seaward from the foreshore to just beyond the breaker zone.*

symmetrical tombolos formed behind the offshore breakwaters in Tel Aviv cannot be indicative as to the longshore direction of the sand flow because this complex is a closed system. The waterline changes that occurred in the vicinity of the Herzliya marina complex after its construction indicate that the net longshore sand transport in the surf zone is from south northward. However, the magnitude of waterline changes which occurred after construction are in the same order of magnitude observed there, under natural conditions, prior to construction. The northward rate of net longshore sand transport at Herzliya must therefore be rather low. The findings at Netanya indicate that the direction of longshore transport there fluctuates between northward and southward. The longshore sand transport in the central part of the Israeli Coast must therefore be in both directions with probably low net flow northward.

The pattern of accretion/erosion next to coastal structures in the northern part of the Israeli Coast shows a net southward sand transport. Beach accretion occurred on the northern side of the cooling basin of the Hadera power plant as soon as its construction started and continued until the beach regained new steady-state conditions. Although the accretion there according to the second author is due mainly to the local near-closed cell conditions, the accretion of the beach along about 1.5km of coast is an indisputable fact and at least part of the accretion is attributed to southward sand transport. Figure 20 shows the beach accretion which occurred north of the basin. In a similar way, a small groin, located a few km south of Hof HaCarmel in Haifa shows accretion on its northern side and erosion to its south (Figure 21). The magnitude of these changes is rather small but they are consistent. The asymmetric development of the Hof HaCarmel tombolo in Haifa, expansion of its northern side vs. stability of its southern one (Figure 13) and the retreat of the waterline south of the tombolo following its formation (Figure 14), are further evidence to a net southward sand flow in the surf zone in this area.

The inference that can be made regarding waterline behavior next to coastal structures is that the littoral drift along the Israeli coast is directed northward, with a decreasing intensity, from Ziqim to Herzliya. In the vicinity of Netanya, the flow direction is reversed and between Hadera and Haifa it is southward. It must be understood that this pattern is general and changes from year to year fluctuates in accordance with the wave climate. This is clearly demonstrated in Netanya, where shift in waterline position indicated southward sand flow until 1991 and northward transport later.

4.4.3 *Rehabilitation of Damaged Beaches*

Analysis of waterline position by means of aerial photographs may provide information regarding rehabilitation processes of damaged beaches. A case study is the southern section of the Hof HaCarmel-Megadim Coast. In that coast, two sites were used in the past for sand quarrying: Kfar Samir (also called Tira) which is found in section 3 of this study and Megadim beach which corresponds to sections 5 and 6 (see Figure 12). In 1963 only, 155,000 m^3 were quarried from the beach of Kfar Samir and 140,000 m^3 from Megadim (Zifzif Commission, 1964, p.11). Between 1958 and 1963, the quantity of sand which was mined from Kfar Samir was 324,500 m^3 and between 1957 and 1963 760,000 m^3 were mined from Megadim (Zifzif Commission, 1964, Annex 1). In actuality, the quantity of sand which was mined might have been larger as according to testimony of the mining company, mining took place near Megadim as early as 1951 (Zifzif Commission, 1964, Annex 3, p. 4).

Undoubtedly, this massive sand mining from the beach has caused the more than 40 m retreat of the waterline between 1956 and 1963 as evidenced by the analysis of the aerial photographs (Figure 15). In 1964, the government prohibited sand mining from the beach. It is not known when mining actually ceased in the area of our study but its effect is noticed in the waterline migration seaward after 1963. From the data we have at hand, it is impossible to determine whether the rehabilitation process of the beach is still going on or not, but until now, the waterline has not returned to its 1956 position.

The rehabilitation rate of the beaches in Haifa Bay between the Qishon Harbor and Qiryat Yam was faster than that of the Haifa-Atlit coast. Golik *et al.* (1999b) suggest that the waterline retreat, which occurred between 1956 and 1970 near Qiryat Yam, was a result of beach sand mining, which was carried out there for the construction of Qiryat Yam and its neighboring towns. However, once the mining stopped, rehabilitation of the beaches was fast, consistent and even surpassed the waterline of 1945-56.

5. SAND ACCUMULATION / EROSION ON THE SEABED

5.1 General

Redundant topographic and bathymetric surveys may provide quantitative information regarding erosional or depositional processes on the seabed and beach face. Subtraction of a chart from another, which was surveyed earlier, will result in a depth differential map that would indicate if such processes took place during the period between the two surveys. However, this method is susceptible to large errors as even a small depth difference between any two surveys, when multiplied by a large area, will result in a large volume. In this manner, an error in a depth reading of only 10 cm when multiplied by an area of 1 km^2 will result in an error of 100,000 m^3. Therefore, this method is appropriate in areas where a depth change between surveys was large. This will occur where the natural processes, which hold the seabed in steady-state conditions, have been disturbed, e.g. near man-made structures.

Volumetric analysis of seabed changes in the vicinity of a coastal structure may yield information as to the direction of the natural flow of sediment on the sea bottom and a semi-quantitative estimate of its rate and the amount of sand trapped by the structure. Although many coastal structures were built during the last 50 years along the Israeli coastline, very little monitoring of their effect on the seabed was carried out. As a matter of fact, the only cases where repetitive sea bottom surveys in the vicinity of a coastal structure were used for volumetric analysis of seabed changes are the Rutenberg power plant south of Ashqelon performed in the framework of the present study, the Port of Ashdod (Golik *et al.*; 1996a,b), coastal structures between Bat Yam and Netanya (Rosen, 1998) and the Port of Haifa (Golik *et al.*; 1999b).

5.2 Methodology

The bathymetric charts which were used for the analysis of the Rutenberg power plant were obtained from the archives of the Israel Electrical Co., for the ports of Ashdod and Haifa from the Israel Port and Railway Authority and for the structures in the central coast from various sources (see Rosen, 1998, Table 4). The dates of these million m^3 between 1985 and 1995 (Golik *et al.*; 1996b). It was shown that most of the sand entrapment, which occurred after 1985, must have been caused by a combination of an extremely severe storm, which occurred in February 1992, with the flooding of the nearby Lakhish River that occurred at the same time. On the basis of differential maps and volumetric calculations, it is roughly estimated that about half of the natural longshore sand transport bypasses the port.

In a follow up study regarding sand by-passing implications at Ashdod port, Chesher and Dearnley (1999) studied also the bathymetric changes which occurred since 1995 in the Ashdod port area, including also the new Ashdod "Blue Marina" built some 2 km south of the port. Contrasting bathymetric maps of 1995, 1997 and 1998 they assessed the volumes eroded or deposited in various areas of the Ashdod coast. Rosen (1999b) analyzed their results and summarized them in table 2. The immediate impact of the construction of the Ashdod marina can be clearly seen. It caused accretion south of the marina, redistribution of the sediments north to and further sand trapping by the existing Ashdod Port.

Table 2. Sedimentologic changes at Ashdod shore between 1995 and 1998

Coast sector	Change period	Above 0.0m	Between 0m and -5m	Between -5 and -10m	Between -10m and -15m	Cumulative to -15m
South to Blue Marina	1997 - 1995	284,000	137,000	-2,000	35,000	[a] 454,000
	1998 - 1997	-56,000	-21,000	-20,000	-91,000	-188,000
	1998 - 1995	228,000	116,000	-22,000	-56,000	266,000
Between the marina and the port main breakwater head	1997 - 1995	50,000	21,000	342,000	-33,000	[b] 380,000
	1998 - 1997	-16,000	-98,000	-127,000	-32,000	-273,000
	1998 - 1995	34,000	-77,000	215,000	-65,000	107,000
Between Ashdod port and Eshkol cooling basin	1997 - 1995	-57,000	-31,000	55,000	-171,000	[c] -204,000
	1998 - 1997	42,000	88,000	12,000	50,000	192,000
	1998 - 1995	-15,000	57,000	67,000	-121,000	-12,000
From Eshkol cooling basin to 1km north to the cooling basin	1997 - 1995	-8,000	-60,000	-14,000	-44,000	-126,000
	1998 - 1997	11,000	46,000	4,000	-28,000	[d] 33,000
	1998 - 1995	3,000	-14,000	-10,000	-72,000	-93,000
North beyond the 1km from Eshkol basin	1997 - 1995	28,000	-49,000	-133,000	-180,000	-334,000
	1998 - 1997	-21,000	60,000	-48,000	-97,000	-106,000
	1998 - 1995	7,000	11,000	-181,000	-277,000	-440,000
South to the port						373,000
North to the port						-545,000

a Including 70,000 m^3 dredged in the marina between 10/96 and 02/97 and 42,000 m^3 dredged between 06/97 and 09/97 in the entrance to Ashdod port.
b Including 30,000 m^3 due to dredging in the marina between 10/96 and 02/97, excluding 126,411 m^3 deposited in deep water
c Including 26,810 m^3 dredged in the Ashdod port entrance
d Including 7,500 m^3 dredged in the Eshkol cooling basin in spring 1998

5.3.4 *Bat Yam to Netanya*

In an assessment of the sedimentological state of the central part of the Israeli coast, Rosen (1998) prepared a series of depth differential maps for various sites between Bat Yam and Netanya. He also computed the volume change, deposition and erosion, for each differential map. The results are given in Table 3.

Table 3. Volumetric changes on the seabed assessed by differential mapping at various sites on the central part of the Israeli Coast. From Rosen (1998).

Map area coverage	Period	No. of years	Accretion m^3	Erosion m^3	Residual m^3
Bat-Yam to Yafo	10/1986 - 11/1962	24	343,000	-735,000	-392,000
	11/1997 - 10/1986	11	1,565,000	-335,000	1,230,000
	11/1997 - 11/1962	35	2,225,000	-3,600,000	-1,375,000
Yarkon River Mouth	08/1994 - 11.1962	32	320,000	-1,280,000	-960,000
	11/1997 - 08/1994	3	1,350,000	-50,000	1,300,000
Atarim to Herzliya	11.1997 - 11.1962	35	7,250,000	-2,815,000	4,435,000
Herzliya Marina	05.1991 - 11.1989	2	860,000	-10,000	850,000
	11.1997 - 05.1991	6	835,000	-2,600,000	-1,765,000
	11.1997 - 11.1989	8	1,480,000	-165,000	1,315,000
Netanya	11.1997 - 06.1996	1	1,840,000	-105,000	1,735,000

It can be seen that the residual volume (deposition - erosion) at each of the sites fluctuates from positive to negative. However, as mentioned by Rosen (1998), some of the maps suffered in their accuracy so the figures presented were given only as indicative trends rather than quantitative ones.

5.3.4 *Haifa Port*

In a study aimed at investigating the sediment dynamics in Haifa Bay, Golik *et al.* (1999b) computed sea bottom changes that took place in front of the main breakwater of Haifa Port. The study was based on 12 bathymetric charts which were surveyed between 1928 (prior to the construction of the port) and 1997. Depth differential maps showed that sand entrapment in front of the main breakwater occurred as soon as the construction of the latter has started. The trapped sand spread along the breakwater from its root to its head (from west to east). Volumetric computations of depth changes show that 4 million m^3 of sand accumulated in front of the main breakwater by 1997 (Figure 32). This is not the total volume of sand that was trapped by the breakwater during its lifetime as some 1.3 million m^3 of sand was dredged from that area in 1961-62 and another 0.6 million m^3 of sand was dredged from the port entrance. A rough estimate of the very long-term mean rate of sediment flow into Haifa Bay must therefore be greater than 85,000 m^3/year because an unknown quantity of sand has probably bypassed the breakwater and dredged from its vicinity during that period.

5.4 Analysis of Results

Examination of the depth differential maps shows that next to the coastal structures in the south, the Rutenberg cooling basin and Ashdod Port, deposition was consistent and on the southern side of the structure. Sand deposition south of the Elat-Ashqelon boat anchorage started as early as it was constructed and continued, on the same side, after the cooling basin of the Rutenberg power plant was built in that area. Golik *et al.* (1996a) show on a series of depth differential maps, a continuous deposition south of Ashdod Port since its construction in 1964. There are not enough redundant depth surveys in the central part of the Israeli coast to state unequivocally that a similar consistent pattern of deposition occurs there. Nevertheless, the impression is that there too, coastal structures caused deposition on their southern side and erosion on their northern side. In Haifa, deposition in front of the main breakwater of the port was also consistent. It was already noticed at the early stages of construction of the breakwater and continued at least until 1994.

The results obtained at Rutenberg and Ashdod Port show the role that storms play in depositing sand next to coastal structures. In February 1992, a severe storm attacked the Israeli coast. Deep water characteristic wave height measured off Hadera (Rosen, 1993) reached up to 7 m during that storm. The effect of this storm on sand entrapment by the cooling basin can be seen in Table 3. More than a third of the sand volume deposited next to the basin during its more than 12 years of existence, took place during the 7-months period in which the storm occurred. Had there been more frequent depth surveys to allow narrower bracketing of the storm period, the effect of the storm on sand trapping next to a coastal structure, would be more dramatic. Golik *et al.* (1996a,b) estimate that close to half of the sediment volume which was deposited south of Ashdod Port by 1995, were trapped there by the three storms which occurred in December 1991, February 1992 and December 1992. Therefore, most of the effect of a coastal structure on sand entrapment occurs during severe storms.

6. LONGSHORE TRANSPORT ASSESSMENT VIA WAVE DATA

6.1 General

Another method utilized to determine the longshore sand transport is that using wave energy flux considerations combined to sediment, beach profile properties and various sediment transport formulas and models.. This method was applied also in the present study, as complementary to the other methods used .

6.2 Review of previous studies

We review these not in the chronological way but in regards to the sites/ areas investigated and their relevance for the present study, starting from Gaza as the southward boundary along the Mediterranean coast of Israel up to Haifa. A summary of the estimates of longshore net sediment transports at various sites is presented in Table 4.

6.2.1 *Gaza coast*

A number of sediment transport assessments were performed for the Gaza coast. The first was the assessment conducted by Migniot and Manoujan (1975), in regards to the design of the Hadera cooling basin. Using the LCHF sediment transport formula, with a coefficient calibrated based on Tunisian beaches (Migniot, 1985 - personal

Table. 4 - Summary of net yearly longshore sediment transport assessments

Place	Author(s) and year	Formula or Model	Volume at site (m^3/year* 10^3)
Nile Delta	Hammad –1979		400 to 3,200
Bardawil	Inman and Harris-1980		300 to 800
Gaza	Migniot-1975	LCHF	400
	PortConsult-1987		400
	Delft Hydraulics-1994	UNIBEST	350
	Bosboom (D.H.)-1996	Delft2DMOR	360
Ashqelon	Vajda and Finkelstein-1984	CERC	675
	Verner-1986		675
	PortConsult-1987		270
	Jensen-1990		250
	Delft Hydraulics-1994		300
Ashdod	Kaiser Engineers-1965	CERC	1,060
	Dornhelm-1972		250
	Migniot-1973	LCHF	215
	Finkelstein-1980	CAMERI	560
	Migniot and Manoujan-1983	LCHF	255
	Rosen-1985	CERC+Komar	350
	Vajda et al.-1988	Bijker without currents	700
	Vajda et al.-1988	Bijker with currents	1,880
	Delft Hydraulics-1994	UNIBEST	180
	Golik et al.-1996	Bijker with currents	350
	Nairn and Baird-1996	COSMOS (Ashdod wave data 04/92-03/93)	300
	Nairn and Baird-1996	COSMOS (Ashdod wave data 04/93-03/95)	-570
	Dearnley-1996	BEACHPLAN	153
	Dearnley-1996	PISCES	120 to 290
Tel-Aviv	Migniot-1966, Migniot and Manoujan-1968	LCHF	85 to 130
	Vajda-1972		150
	Enosh-1996		120 to 156
Herzliya	Nairn and Baird-1996	COSMOS (Asdod wave data 1958-94)	600
	Nairn and Baird-1996	COSMOS (Haifa wave data 1994-95)	650
	Nairn and Baird-1996	COSMOS (Ashdod wave data 04/93-03/95)	-400
Hadera	Migniot-1974	LCHF	100 to 150
Haifa -Dado	Carmel et al. -1985	CERC	110±100
Haifa -Dado	HR Wallingford-1996	Baillard	100
Haifa -Dado	Kit and Perlin-1999	CERC based	80
Haifa -Dado	Jorgensen and Mangor-1999	Fredsoe	36
Haifa -Dado	Toms and van Holland-1999	Bijker	-55

communication), and wave data derived from the visually observed wave data at Ashdod, they assessed the following yearly average sediment transports:

At Gaza - 400,000 m^3/year, at Ashdod - 215,000 m^3/year and at Hadera - 100,000 to 150,000 m^3/year.

Another assessment was performed by PortConsult for a fishing port at Gaza (1987), which estimated the following volumes:

Site	Northward	Southward	Net
	m^3/year	m^3/year	m^3/year
Gaza	400,000	-40,000	360,000
Ashqelon	567,000 ±128,000	-301,000±55,000	270,000

According to verbal information the assessment was based on visually derived wave data from Ashdod and Ashqelon and wind data from Gaza.

Finally, in regards with a major port requested by the Palestinian Authority to be built at Gaza, Delft Hydraulics conducted two studies, first (Delft Hydraulics, 1994) using UNIBEST model (one-line model) and later (Bosboom, 1996) with the Delft 2D-MOR model. The wave data were hindcasted wave data from wind data as well as some Ashdod wave data. The following assessments were obtained using Bijker formula:

Site	Northward	Southward	Net
	m^3/year	m^3/year	m^3/year
Gaza (UNIBEST)	510,000	-160,000	350,000
Gaza (Delft2DMOR)	455,000	-95,000	360,000
Ashqelon	-	-	300,000
Ashdod	-	-	180,000

They also have shown that for Gaza, using various formulas the following results were obtained and selected Bijker formula as the most reasonable one:

Formula	Baillard	Bijker	Van Rijn
	m^3/year	m^3/year	m^3/year
Net yearly at Gaza	170,000	-350,000	540,000

It should also be mentioned that in using the Delft-2D-MOR model, the values above were obtained with the Fredsoe bottom stress model (Fredsoe, 1992) which was considered to provide more reliable results, while using the Bijker (1967) bottom stress model about 40% lower values were obtained.

6.2.2 *Ashqelon coast*

For the Rutenberg cooling basing sedimentological assessments were performed by Finkelstein and Vajda (1982) and by Vajda and Finkelstein (1984). The assessments were performed using a number of formulae and Ashdod wave data (1958-1981) and their statistics (all visually observed wave directions). The following values were assessed:

Formula	Northward	Southward (-)	Net
	m^3/year	m^3/year	m^3/year
Engelund-Hansen	4,000,000	-300,000	3,700,000
CERC	2,000,000	-150,000	1,800,000
SWANBY	1,100,000	-90,000	1,010,000
Bijker (no currents)	950,000	-75,000	875,000
CAMERI	740,000	-65,000	675,000
LCHF	400,000	-35,000	365,000

They concluded that the situation in 1980-82 is a new sedimentological equilibrium state, which led to various changes on the beach and bottom within 1km on each side of the boat anchorage of Katza. The total volume trapped was estimated at 200,000 m^3 with some 40,000 m^3 eroded north of Katza. Based on a physical sedimentological model, it was estimated that as a result of the construction of the cooling basin, a yearly maintenance dredging of 10,000 m^3 will be needed, as well as an initial 60,000 m^3 dredging. It was estimated that a new equilibrium state will be reached within 5 years from the construction of the cooling basin, leading to an additional deposit of 170,000 m^3 to the south of the cooling basin and some 50,000 m^3 erosion in the shallow water north to the cooling basin.

Verner (1986) presented an assessment of the longshore transport at the site of the Ashqelon marina coast as follows

Northward	Southward	Net
m^3/year	m^3/year	m^3/year
740,000	-65,000	675,000

Another assessment of the sediment transport at Ashqelon was performed by Jensen (1990), in regards with the design of the Ashqelon marina. Based on Delft Hydraulics (1994) their assessment was of a net transport northward of about 250,000m^3, with negligible southward transport. The assessment was based on the visual wave data from Ashdod (1958-75).

6.2.3 *Ashdod coast*

Marine Advisers (1965) presented the first assessment on sediment transport at Ashdod Port on the basis measured wave data. According to their assessment, using

CERC formula, the following values were estimated:

Formula	Northward	Southward	Net
	m^3/year	m^3/year	m^3/year
CERC	1,490,000	-420,000	1,060,000

Finkelstein (1980) investigated the sedimentological process near Ashdod Port as part of a study related to the calibration of a sedimentological model for that port. Considering wave energy, he concluded that the natural longshore sediment transport along that coast is 700,000 m^3/year from south northward and 140,000 m^3/year southward leaving a net flow northward of 560,000 m^3/year.

Migniot and Manoujan (1983), conducted a sedimentological model study for the expansion of Ashdod port. Using all wave data gathered at Ashdod until then they assessed, using the LCHF formula, the following yearly average transports:

Formula	Northward	Southward	Net
	m^3/year	m^3/year	m^3/year
LCHF	300,000	- 45,000	255,000

However, they concluded that since the construction of the existing port, almost no sediment has bypassed it, except for a very minor fraction of very fine sand, bringing the by-passed volume to about 15% of the original (~40,000m^3).

On the basis of wave energy flux calculations, Rosen (1985) assessed the sediment transport at Ashdod employing the wave data gathered at Ashdod between 1957 and 1984. Using the CERC formula combined with the profile distribution of the longshore current, according to Komar (1977), he found a mean yearly transport capacity of about 413,000 m^3 northward versus some 58,000 m^3 southward with a net yearly mean transport capacity of some 350,000 m^3. The distribution perpendicular to the shoreline indicated almost zero net transport near the shoreline, with largest net quantities between -2 m and -5 m depth contour lines. The *yearly long-term average* longshore sediment transport south of the port estimated by Rosen (1985) in that study was of about 450,000 m^3 to the north, about 100,000 m^3 to the south leaving a net transport capacity of about 350,000 m^3. A new volumetric transport assessment

(Golik et al., 1996) was based on Bijker formula and 3 years of reliable directional wave data (04/92-03/95) and including general currents contribution to the longshore sediment transport, as well as on another 35 years of wave data with less reliable directions (1958-1992).

A successive sedimentological study related to the expansion of Ashdod port was conducted by Dearnaley (1996), using two numerical sedimentological models, one of the one-line type (BEACHPLAN) and the other two-dimensional (PISCES). For the present port conditions, the sediment transport volumes determined by Dearnaley (1996) were as follows:

MODEL TYPE FOR LONGSHORE TRANSPORT	SITE	BEACHPLAN	PISCES
Yearly Average Net Northward (1992-1995)	open beach	153,000 m^3	
Sensitivity Range of Yearly Average Net Northward	5km South of the port	120,900 m^3 to 290,500 m^3	
Yearly Average Net Northward (1992-1995)	South to port	105,000 m^3	132,000 m^3
Yearly Average Net Northward (1992-1995)	North of port	35,500 m^3	61,000 m^3
Sensitivity Range of Yearly Average Net Northward	North of Eshkol basin	33,800 m^3	26,600 m^3 to 42,900 m^3

These numbers indicate the assessment of the modelers that Ashdod port by-passes lower rates of only about 30% of the net transport on the open beach south to the port. However, it did not include assessment for major sand by-passing events during high storms such as those of 1992-1993, as was did Golik et al. (1996). It should be also mentioned that the assessment of sediment transport was based on the longshore transport derived using Baillard formula, which, as indicated by Delft Hydraulics (1994) leads to lower values than using the Bijker formula. It is obvious that if lower sediment rates bypass the port, a larger deficit would appear to the northern coast.

6.2.4 *Tel-Aviv coast*

Migniot (1966) and Migniot and Manoujan (1968) conducted a study in regards to the Reading power station cooling water basin. Using LCHF formula and visually observed wave data from Ashdod and from Tel-Aviv, they assessed the following transport rates at Tel-Aviv:

Transport	Northward	Southward	Net
Formula	m^3/year	m^3/year	m^3/year
LCHF	110,000 to 150,000	20,000 to 25,000	85,000 to 130,000

Another sedimentological study was conducted by Vajda (1972), in regards to the detached breakwaters system at Atarim coast in Tel-Aviv. He based his initial assessment on the study of Reading mentioned above, but upon re-analysis of the data he assessed a net northward yearly transport at Tel-Aviv shore of about 150,000 m^3 (p.19). He also mentions that the estimated detached breakwater system will trap more than 500,000m^3 of sand.

In a later study for a marina city at the site of the Tel-Aviv harbour, Vajda (1973) presented the following sediment transport estimates using various formulas as well as another result from a report by LCHF as follows:

Transport Formula	Northward m^3/year	Southward m^3/year	Net m^3/year
Bijker (b=5)	590,000	111,000	130,000
Bijker (b=1)	118,000	22,000	96,000
Eagleson	440,000	106,000	334,000
Caldwell (K=1.3-1.9)	575,000	97,000	478,000
Caldwell (K=1.0-1.9)	442,000	97,000	345,000
CERC	805,000	155,000	650,000
LCHF report	166,500	21,000	145,000

Another longshore sediment transport assessment based on LCHF formula is presented by ENOSH Environmental Systems (1995) for the Tel-Aviv coast at the Yarkon sector at Tel-Aviv, in regards with an environmental impact assessment for a marina project in the Yarkon river estuary. The assessment is given without specifying on what wave data the assessment was based. The following values are presented by ENOSH for a moderate year:

Transport Formula	Northward m^3/year	Southward m^3/year	Net m^3/year
LCHF	180,000	60,000	120,000

They mention that for extremely stormy years the assessment will be affected by about 20%, which means that in very stormy years the northward transport would increase by 20% or be about 206,000 m^3, leading to a net transport in that case of 156,000m^3 . However, this sentence is not based on any further data.

6.2.5 *Herzliya coast*

A number of sedimentological studies were performed in regards with the construction of marina Herzliya and its impact on the adjacent coast. The report of the original physical sedimentological model study with movable bed (using ebonite as artificial sand) was not available to us. Since after the construction of the marina significant erosion occurred north to the sector protected by the three detached breakwaters in spite of the forecasted stabilization of the coast, its absence don't seem very important, except as a warning regarding model forecasts.

Baird and Associates (1996), conducted an analysis of the beach erosion on the Herzliya coast north to the marina and its 3 detached breakwaters. They analyzed aerial photographs, bathymetric charts and performed sediment transport assessments at the Herzliya coast based on a two dimensional sedimentological model.

Using wave data from Ashdod for a number of time periods and from Haifa for a two year period, they reached to the following longshore transport assessments at Herzliya coast, using a perpendicular to coast orientation of 284 degrees (as indeed is the case):

Transport Via COSMOS model	Northward m^3/year	Southward m^3/year	Net m^3/year
via Ashdod 1958-94 daily wave maxima	1,750,000	-1,150,000	600,000
Via Ashdod wave data 04/1992-03/1993	1,200,000	-1,200,000	0
Via Ashdod wave data 04/1993-03/1995	550,000	-950,000	- 400,000
Haifa 1994 and 1995 3 hourly wave data	1,000,000	-350,000	650,000

Using the Haifa wave data for 1994 and 1995 and assuming a general constant current of 0.2 m/s, they estimated the contribution of the general circulation to be an additional rate of 6,000 m^3/year in the range of depths between 12 and 24m. They concluded that the annual northward and southward longshore transport components are now in the range of 300,000 to 900,000 m^3/year, or less, and that longshore sand transport in a single major storm event could be as high as 100,000 m^3. Furthermore, they concluded that the bypassing of sand at Ashdod port is up to 10% of the south to north transport south of the Ashdod port, but at Herzliya marina it reached (in 1996) 30% of the pre-marina transport rate. These authors seem that did not attribute importance or were not aware of the low reliability of the old visually observed wave directions at Ashdod prior to April 1992, and the corresponding impact on their conclusions. They were apparently also not aware of the extremely stormy winter of 1991-1992.

A new study conducted again by the same authors (Baird W.F. & Associates Coastal Engineers Ltd., 1998). They re-analized the old data together with new data and presented an updated assessment of the longshore sediment transport at Herzliya coast. Their new assessment is summarized in Table 5 taken from Rosen (1999c) who reviewed their report.

Table 5. New sand transport assessment at Herzliya by Baird Associates (1998)

Position	Period	Northward yearly transport (m^3/m)	Southward yearly transport (m^3/m)	Net yearly transport (m^3/m)
Section 2	04/92-12/97	460,000	-600,000	-140,000 (southward)
	12/95-12/97	500,000	-600,000	-100,000 (southward)
Section 3	04/92-12/97	300,000	-340,000	-40,000 (southward)
	12/95-12/97	270,000	-380,000	-110,000 (southward)
Section 4	04/92-12/97	160,000	Not provided	Not provided
	12/95-12/97	120,000	Not provided	Not provided

Rosen(1999b) in reviewing the above report evaluated for the same coast a long term yearly average longshore net transport of 175,000 m^3 northward. Another study using the directional wave data from Haifa, Ashdod and Hadera was performed by Toms and van Holland (1999) in relation to islands development off the coast of Tel Aviv and Herzliya. The study, conducted using the Delft 3D/2Dh numerical sedimentological model assessed an average yearly transport northward of about 30,000m^3 at Appolonia, some 3km north of Herzliya marina for the period 04/1994-03/1998 (average of 4 sedimentological years). At Bat-Yam for the same period a net northward transport of some 60,000 m^3/year was assessed.

6.2.6 *Hadera coast*

A number of sedimentological studies were carried out for the coast of Hadera in relation to the construction of the cooling water basin of the Orot Rabin power station, its offshore coal unloading terminal there and coastal changes south and north of the cooling basin (see location on inner head page).

Migniot (1974) conducted a physical sedimentological model with movable bed with artificial sand (Bakelite specific density 1.4 gr/cm^3). His forecast were of accretion south to the cooling basin and erosion north to it. He estimated a yearly average net northward directed longshore transport of between 100,000 to 150,000 m^3.

Finkelstein and Vajda (1979) conducted also a physical sedimentological model with movable bed with artificial sand (ebonite-specific density 1.8 gr/cm^3) in regards to an alternative of an offshore terminal based of a shore parallel breakwater in 22m water depth, 1km long. During the calibration phase, they obtained accretion north of the cooling basin lee breakwater and no erosion south of the cooling basin. The construction of the detached breakwater 1km long induced the creation of a large sand spit which could endanger the entrance to the basin by heavy silting. Their estimated yearly average net northward directed longshore transport was based on a new wave climate assessed by Rosen & Vajda (1977), which led to a value of 100,000 m^3/year.

A sediment transport using radioactive tracers was conducted by Sauzay et al. (1974), which indicated that the sediment transport was mainly to the north. Another field study was conducted by Golik et al. (1986), who monitored the spreading of coal particles falling at the coal unloading terminal (in water depth of about 22 to 24m). The results showed a clear northward transport, with some spreading towards to shore, but not closer than about -10m contour line.

A sand trap test was carried off Hadera at a water depth of about 28m by the IEC. A large pit (a few meters) was dredged there, and after a few months, it was found filled completely, indicating that sediment transport occurs also at such water depths.

6.2.7 *Haifa coast*

Carmel et al., 1985, used wave data gathered using a directional wave pressures array off Dado beach at the southern coast of Haifa and presented an assessment of about 110,000 ± 100,000 m3/year. This was due to the fact that the position of Haifa coast relative to the incoming major storms is almost perpendicular (Az 5^0 versus Az 270^0 of the westerly storms) leading to variations in transports from year to year according to the wave climate fluctuations. In recent years two sedimentological model studies were carried out at Haifa coast. The first dealed with the plans for a large marina at Shikmona and Bat-Galim coast, the latter with the expansion of Haifa port. Chesher

(1996) and Chesher and Dearnaley (1997) presented the results of numerical modeling assessments using a small sample of measured wave data from Haifa and 10 years of hindcasted wave data using the UK Meteorological Office Wave model. The later data were found later to be unreliable, but the Wavec data at Haifa were used with a one line model (BEACHPLAN) as well as with a numerical 2D model (PISCES) to assess the sediment transports on the Haifa coast. Their result obtained with the one line model and the Baillard formula for the Dado beach at Haifa south gave a net northward yearly transport of close to 100,000 m^3.

In a research conducted by Perlin and Kit (1999) used the wave data between 1994 and 1998 and a new formulation derived from the CERC formula and provided assessments of longshore transports at Ashdod and Haifa. At Haifa, a net northward yearly transport for the above period of about 85,000 m^3 was presented.

In a more recent study, Jorgensen and Mangor (1999) provided an additional assessment for the same coast using the same data from the Haifa Wavec buoy. Their averaged assessment , obtained with their one line LITPACK model and Fredsoe formula for the period of sedimentological years 04/94-03/96 and 04/97-03/98 gave a net northward transport of 36,000 m^3/year.

Finally, Toms and van Holland using the Haifa wave data for the whole period of 04/94-03/98 assessed a southward average transport of -55,000m3/year for that period, using their UNIBEST model and Bijker formula. Hence, for Haifa contrasting results were obtained by different studies. The reasons for these differences will be discussed later, after presentation of the new longshore transport assessment obtained in the present study.

6.2.8 *General studies*

Goldsmith and Golik (1980), applying wave refraction to the whole coast, studied the sediment transport pattern along the coast assuming a constant wave approach angle in deep water for all the coast. By analyses of the contributions of various theoretical wave directions and periods, and the refracted wave directions relative the coast orientation along the cell, they concluded that the Nile Littoral Cell can be divided in three sectors: a sector south to Rafah where a continuos net northward longshore transport exists, a sector between Rafah and Haifa with longshore transport depending on incoming wave direction leading to shifting net transport to north or to south, and