Israel Oceanographic & Limnological Research
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חקר ימים ואגמים לישראל
המכון הלאומי לאוקיאנוגרפיה

RESEARCH ON COASTAL CLIFFS AND BEACH EROSION IN ISRAEL

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PROGRESS REPORT

Report IOLR H56/2009

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Submitted to

Mr. Bertram COHN

NORTH AMERICAN FRIENDS OF IOLR

EXECUTIVE SUMMARY

OBJECTIVES

The objectives of this research study are to improve our scientific understanding of the factors affecting the coastal cliffs and beach erosion along the Mediterranean coast of Israel, particularly the future onshore-offshore and alongshore dynamics of waves, currents, sea level rise and sediment transport processes. The progress of the study carried out so far is presented in this progress report.

The author and the staff of the Department of Marine Geology and Coastal Processes wish to express our appreciation and thank Mr. Bertram Cohn of North American Friends of IOLR for the funding support provided.

RESULTS

Main results obtained so far are presented in tables and graphs. They show assessments of the maximum runup of the waves during extreme storm conditions, of the extreme waves and sea levels for return average periods of up to 100 years, results of erosion-accretion balance for the study coast during 1997-2004 period, examples of differential maps of the beach and cliff at Apolonia and near Marina Herzliya between 2002 and 2003 as well as the waterline position changes between 1997 and 2004, and examples of the numerical wave and sedimentological modeling simulations and their outcomes for the study sector – the central sector of the Mediterranean coast of Israel.

PRELIMINARY CONCLUSIONS

The work presented in this report is an ongoing study on the coastal erosion at the beach and coastal cliff of a typical coastal sector at the Mediterranean coast of Israel. It contains both sectors with anthropogenic impact as well as sectors remote from coastal structures.

The investigation method used is a combination of various methods of study of the coastal processes inducing erosion, including in situ long term monitoring of meteo-marine climate and analysis of the morphological changes measured using differential maps and shifts of the waterline position, as well as numerical modeling of the coastal processes.

Preliminary results indicate sectors of higher sensitivity to coastal erosion and sea level rise due to climate change impact.

Continuation of the monitoring of the meteomarine environment as well as the performance of aerial photography and mapping of the coastal zone (beach and cliff) is considered very important for the proper integrated coastal management of the Mediterranean coast of Israel. These however depend to a great extent to the availability of funding which would enable these activities.

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1. INTRODUCTION

This progress report presents a concise outline of the progress achieved so far in the research study on coastal cliffs and beach erosion in Israel by IOLR. Only thanks to the generous donation of funding support by the American Friends of IOLR Association to this on-going research it was possible to carry out a number of important tasks of the study, which undoubtedly could not have been carried out otherwise due to lack of sufficient funding, and which have an important outcome contribution to the decision making national process for a sustainable, environmentally conscious coastal cliffs and beaches management of the Mediterranean coast of Israel. Consequently, **the Department of Marine Geology and Coastal Processes staff and the author express our gratitude to Mr. Bertram Cohn of the North American Friends of IOLR for the funding support provided**.

The main objectives of the research study on coastal cliffs and beach erosion on the Mediterranean coast of Israel have been defined as :

(a) To monitor qualitatively and quantitatively the present and future coastal changes,

(b) To improve the scientific understanding on the present and particularly the future onshore-offshore and longshore dynamics of waves, currents, sea level rise and sediment transport processes in view of anthropogenic growing loading and forecasted climate change,

(c) To enable to provide national decision making authorities and public stakeholders improved advice on the best feasible mitigation and/or protective means against the foreseen beach and coastal cliffs erosion, for a sustainable integrated coastal zone management.

2. BACKGROUND

Reports published by the national "Israel 2020" committee and by other bodies, indicate that Israel is progressing rapidly towards becoming within the next 10 to 20 years one of the most densely populated countries in the world, at its coastal region, where the majority 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 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 150 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 development may induce to the coastal zone, 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 and coastal cliff retreat due to coastal erosion and even temporary beach width shrinking, inducing also coastal groundwater salinization.

Since the 1980's, increasing evidence has been acquired that the coastal region of Israel is faces progressive erosion. Among the facts backing this evidence, one may mention ancient (Neolithic) human skeletons discovered in perfect condition 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 (Rosen, 1992; 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 shore of the Sinai peninsula, itself fed mainly from the Nile Delta.

Figure 1. Location of the Israeli coast in the Nile littoral cell and in the South-Eastern Mediterranean

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 about 5 km (in 62 years). However, from 1965 until 1995 (in 30 years), about another 5 km of the delta coast were removed by accelerated erosion (doubled), induced by the cessation of Nile quartz sediment supply to the Nile delta after 1965. Hence, the future of the existing Nile littoral-cell coast, and in particular the Israeli coast, seems to be threatened not only by the local causes 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 the 21 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. Unfortunately, to this "far" future impact, one might expect an additional impact due to a more rapid phenomenon also of anthropological origin, which is expected to become increasingly significant in this century and further in the next centuries. 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 assessed by IPCC (McCarthy *et al*. 2001) assuming a business as usual scenario, was of 32 cm in year 2050 and 89 cm in year 2100. A more recent IPCC assessment (IPCC 2007) reduced the forecasted rise by 2100 to only 59cm, excluding however from its assessment the additional contribution of ice caps melting. An updated assessment of the global sea level rise is expected by the end of 2009, including ice cap melting and based on improved climate modeling outcomes. However, a significantly higher sea level rise was assessed by other scientists (Rahmstorf, 2006), reaching 1.4m by 2100, but other scientists (Woodworth, 2009) claimed they were not able to reproduce that assessment.

In addition to climate warming effect, there is a group of scientists claiming that presently the world is encountering not only global warming effect, but also a global dimming effect. This dimming effect refers to the claimed impact of increased global dust pollution, induced by industrial and aerial traffic. This is claimed to be leading to an increased reflection of the solar radiation by brighter clouds, which temporarily is masking/diminishing the global warming effects. According to the global dimming scientists (???, 20??; ???, 20??), by 2030's, the increased global warming will overcome the global dimming and then an accelerated global warming and correspondingly an accelerated global sea level rise will occur.

Furthermore, it is agreed by most experts that the sea level rise will not be the same 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 global average. Secondly, climate change may lead to a shift in the local/regional wind directions and wind speeds statistical distributions, leading to a shift in prevailing and predominant wave directions and heights. If such a change would occur, it may lead to shifts in the local/regional net sediment transport balance, leading to a shifting in the accretional and erosional features of the impacted coastal sectors.

Another forecasted effect of the climate change is an increase of the frequency of meteo-marine extreme events and their spatial and temporal statistics. For the Mediterranean coast of Israel however, the predominant and strongest storms will remain however those inducing waves coming from the West direction interval, as this directional sector is the one with the longest wind fetch for the Israeli coast.

The sea level rise has been also monitored by IOLR on the Israeli coast using its monitoing station at Hadera, serving as one of the Global Sea Level Observing System (GLOSS) of IOC/UNESCO major observing stations (Fig. 2).

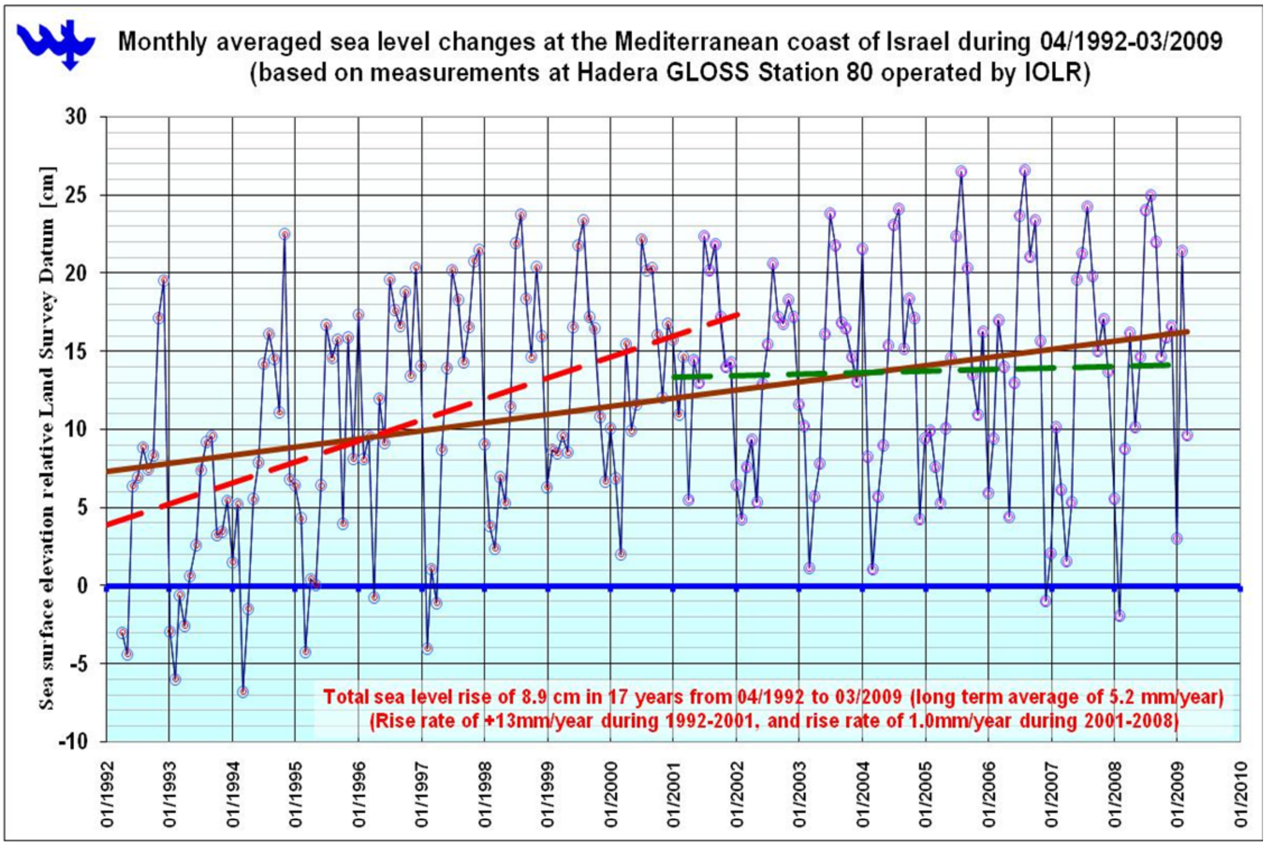


Figure 2. – Long term sea level rise observed on the Mediterranean coast of Israel in the last 17 years

In the last decade the Mediterranean coast of Israel encountered severe erosion at a significant number of places along the coast, some of them in key locations such as damage to antique sites (Ashkelon park – Figures 3 and 4), at popular beaches (eg. North to Hertzliya Marina development (Fig. 4), endangering of housing and hotels located on eroding coastal cliffs (Ashkelon, Netanya, Bet-Yanai - Fig. 5) or severe denuding of the Zamir beach at Haifa (Fig. 6).

Figure 3. Severe erosion at Ashkelon park reached ancient fortress wall, damaging this ancient site.

Figure 4. Detail of the damaged ancient wall at Ashkelon park.

Figure 5. Coastal erosion protection using geotextile tubes filled with sand at northern Ashkelon coast.

Figure 6. Failure of the geotextile tubes protection, probably due to their impermeable rubber cover.

Figure 7. Severe coastal and cliff erosion north of Apolonia ancient fortress, at Herzliya

Figure 8. Collapse of Apolonia fortress wall due to severe beach and cliff erosion

Figure 9. Beach and cliff erosion at Shefaim-Gaash coast endangers residents on cliff top.

Figure 10. Coastal and cliff erosion at HaSharon sector, north of Netanya.

Figure 11. Erosion of beach sand at Haifa Zamir beach, (see eroded beach grass and sand layer).

Figure 12. Severe depletion of beach sand at Haifa Dado beach, (see missing sand below walkway.

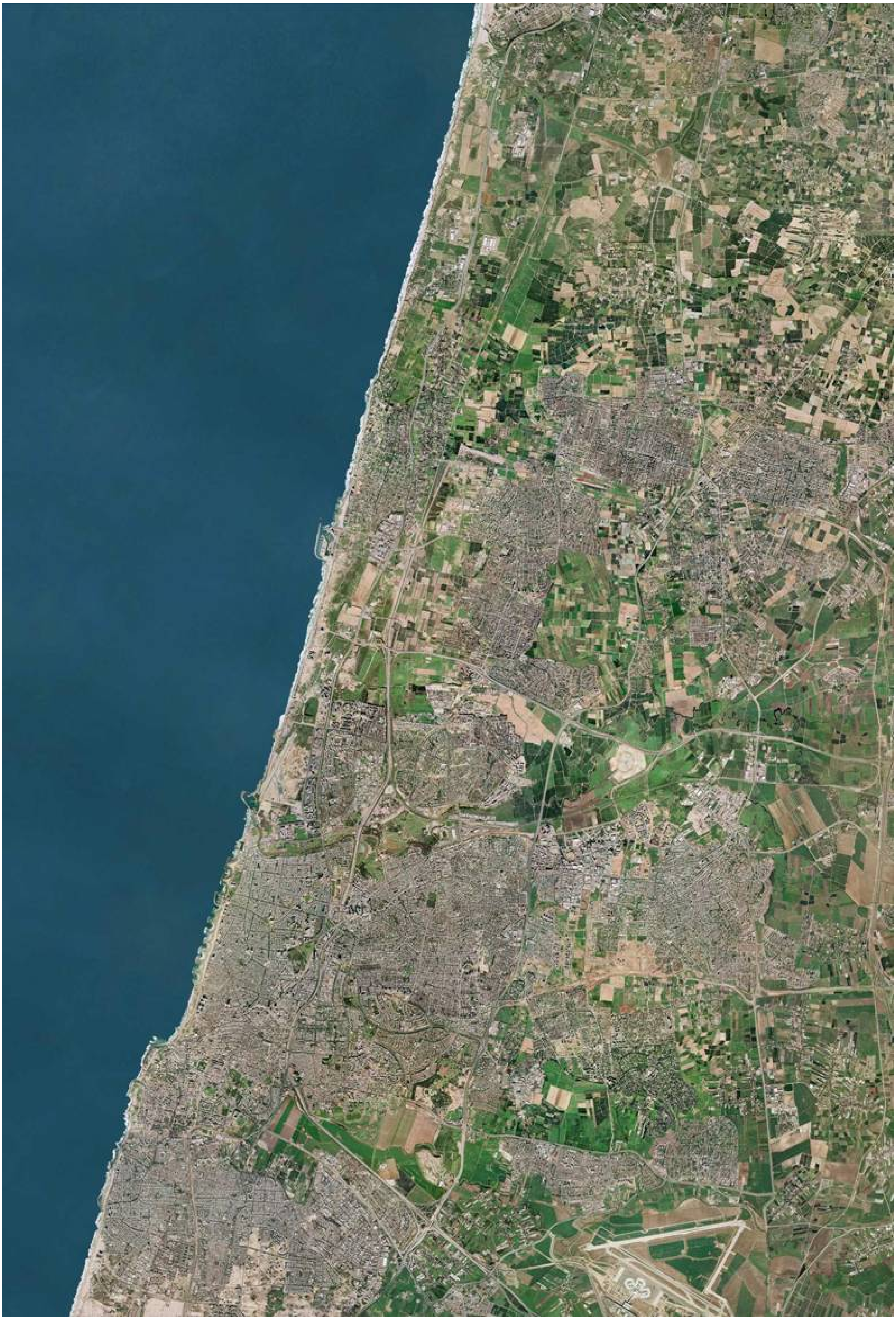


Figure 13. Coastal sector from Yarkon river to Poleg river , the study sector, centered at Herzliya

3. OBJECTIVES AND SCOPE OF RESEARCH PROGRAM

The objectives of this research proposal is to improve our scientific understanding of the factors affecting the coastal cliffs and beach erosion along the Mediterranean coast of Israel, particularly the future onshore-offshore and alongshore dynamics of waves, currents, sea level rise and sediment transport processes.

The scope and program of the proposed study includes the following activities:

- **a.** Gathering of existing and new data regarding the meteo-marine and physical state (including new essential measurements on sea and land) of a typical coastal sector of the Israeli coast (Figure 11), analysis of the data and derivation of statistical and morphological characterization of the existing state.
- **b.** Modeling of the coastal processes under various future wave, wind, and sea level climate scenarios (including recent past and present state for calibration and validation) to assess possible implications of hazards due to global warming (e.g. sea level rise, meteo-marine climate change) and availability of sand resources from the south (Sinai and Nile delta) and earthquake induced tsunamis for the stability of the shore zone (underwater, on beach and cliff stability).
- **c.** Assess future scenarios for the nearshore, beach and the coastal cliff, for a time horizon of up to 100 years.
- **d.** Transform the resulting scenarios into maps of areas likely to be exposed to significant erosion and damage due to the various hazards identified.
- **e.** Identify alternative feasible measures which may be used for the mitigation of damage from coastal erosion and assess their likely impact by new modeling including simulation of the effects of these measures.
- **f.** Select the optimum feasible alternative.

4. IMPLEMENTATION TASKS AND THEIR STATUS

The detailed complementary implementation tasks considered necessary to achieve the scope of the research are listed below, together with their accomplishment status at reporting time:

- a. Use existing old maps and aerial photographs to derive past bathymetric and topographic maps. This task has been completed and serves as part of the basic information regarding the intensity, extent and impact of past sedimentological processes on the Israeli coast versus the coastal development and storm waves history.

b. Carry two bathymetric and topographic surveys for two consecutive autumns, to map and quantify recent spatial and temporal volumetric changes of the sea bottom, beach and cliff. The bathymetric surveys had to be carried out using IOLR's marine survey vessels while the very shallow sector and dry land areas had to be surveyed by aerial photogrametry.

c. We have carried out so far 2 bathymetric surveys and a total number of 5 aerial photography mapping of the beach and cliff sector along 30 km of coastline at a scale of 1:500 (high resolution) in autumns of 1997, 2002, 2003, 2004 and 2005. The data gathered have been processed for preparation of differential bathymetric and differential topographic charts of the coastal zone covering a coastal length of about 30km, from Poleg river estuary in the north to the beach at the border between Rishon LeZion and Bat-Yam. The processing of the differential maps is in the last stages of analysis.

d. Carry out a sediment thickness survey by performing a number of sub-bottom profiles of the coastal sector, perpendicular to the shoreline using IOLR's CHIRP sub-bottom profiler and water jetting prickings in the shallow and beach parts. This task has been only partially implemented for a coastal sector along some 5 km of coast at Herzliya. The information acquired indicated that the sand layer on the beach face and shallow sea bottom is relatively thin, making the beach and coast very sensitive to sand erosion and beach denuding due to lack of natural nourishment induced by coastal structures sand trapping, by deficit in sand budget due to the old beach sand mining and by the impact of present sea level rise.

e. Derive a spatial and temporal quantification of sedimentological changes by computing differential maps and tabulating erosion and accretion in the various parts of the investigated coast. So far this has been finished only for one period investigated, between 2002 and 2003. (As mentioned in item 2 above, the processing of the other yearly data will be soon completed, enabling to quantify for the first time at the Israeli coast volumetric changes of beach and cliff erosion (or accretion very locally).

f. Determine changes in the corrected position of the waterline in past and in the new surveys, after correction of the contributions of wind and wave induced super-elevation of the waterline, tide and sea level rise, and common reference to same datum (Israel and survey datum). The rectified aerial potographies were used to depict the instantaneous positions of the waterline along the coastal sector listed above. Then they were all adjusted to a common reference elevation of the sea level equivalent the Israel Land Survey Datum, by computing the vertical adjustment necessary due to the instantaneous tide, wind surge and wave induced superelevation, and the necessary horizontal shifting of the position of the depicted waterline based on the slope of the local foreshore.

g. Monitoring of meteo-marine climate (sea level, currents, waves, wind) during the study period and integrate all in the long term data bank available at IOLR. The meteomarine data (see next item) were gathered at the Hadera IOLR GLOSS Station 80, which has been equipped thanks to the funding with a new Teledyne RDInstruments Acoustic Doppler Current Profiler directional wave gauge of the Monitor type (600 KHZ) transmitting data in near real time to a logging computer located on the coal unloading pier, from where the data are transmitted hourly to IOLR.

h. Analyze the sedimentological changes relative the meteo-marine climate and extreme events which occurred in the same period covered by the differential maps. The analysis of the sedimentological changes of the cliff and dry beach for the period 2002-2003 has been already completed. Those during 2003-2004 and 2004-2005 are presently being analysed and will be finished in December 2009. Bathymetric changes on the sea bottom have not been analysed after 2005, because there are no new bathymetric surveys at this coast sector.

i. Set-up, calibrate and validate hydrodynamic (waves, currents, runup) and sedimentological models available at IOLR for the study region. A SWAN hydrodynamic wave model has been setup and performed for the coastal sector from Poleg to BatYam. In addition a two dimensional sedimentological model SBEACH has been run for the same coastal sector.

j. Formulate scenarios for a time horizon of 100 years of sea level rise, wave, wind and currents climate change as well as for a tsunami event with a high risk of encounter in this time period. Scenarios of raising sea level and storm strength were selected based on forecast of future climate change induced impact for simulations using these models.

k. Run the models for the a/m scenarios to determine expected sedimentological coastal changes. The SWAN and SBEACH models have been run for the various scenarios for the coastal sector described above, producing outcomes of the erosion induced by various simulated present state and future forecasts. Additional runs are planned using a more sophisticate model to investigate further three dimensional effects inducing erosion.

l. Based on the outcome of the models and survey of worldwide experience analyze and select up to 3 most potentially feasible alternative solutions for mitigation/protection from the erosion impacts obtained in 10 and rerun the models. This was only partially performed.

m. Rank the alternatives investigated based on the simulations outcomes and select the optimum feasible alternative. This activity has only started but needs further input from a/m tasks before completion.

n. Submit final detailed report. This will be accomplished in 2010.

5. RESULTS

Main results obtained so far are presented in the following tables and graphs.

In table 1 is presented the assessment of the maximum runup of the waves during extreme storm conditions as a function of the average return period, expressed in years. This is a direct indication of the range of cliff elevations expected to be impacted directly during extreme storm conditions.

Table 1 – Maximum wave runup during extreme sea states at the Mediterranean coast of Israel

Average return period [years]	Elevation of maximum runup on the coastal cliff relative Israel land survey datum [m]
2	4.09
10	4.85
20	5.51
50	7.39
100	8.34

The same data are also presented in Figure 14, together with the data of extreme deepwater significant wave heights, estimated sea level rise, extreme tide highs and lows for various average return periods. The abscissa is given on logarithmic scaling.

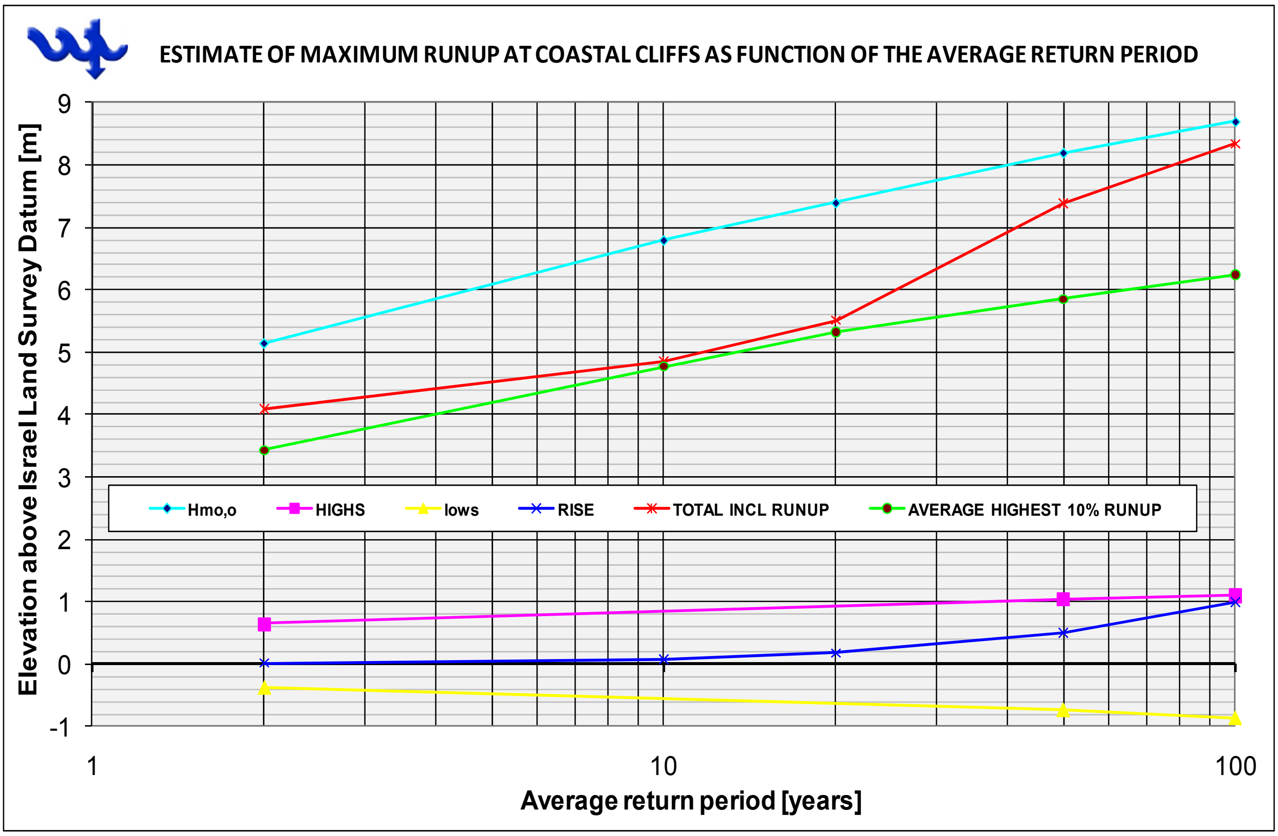


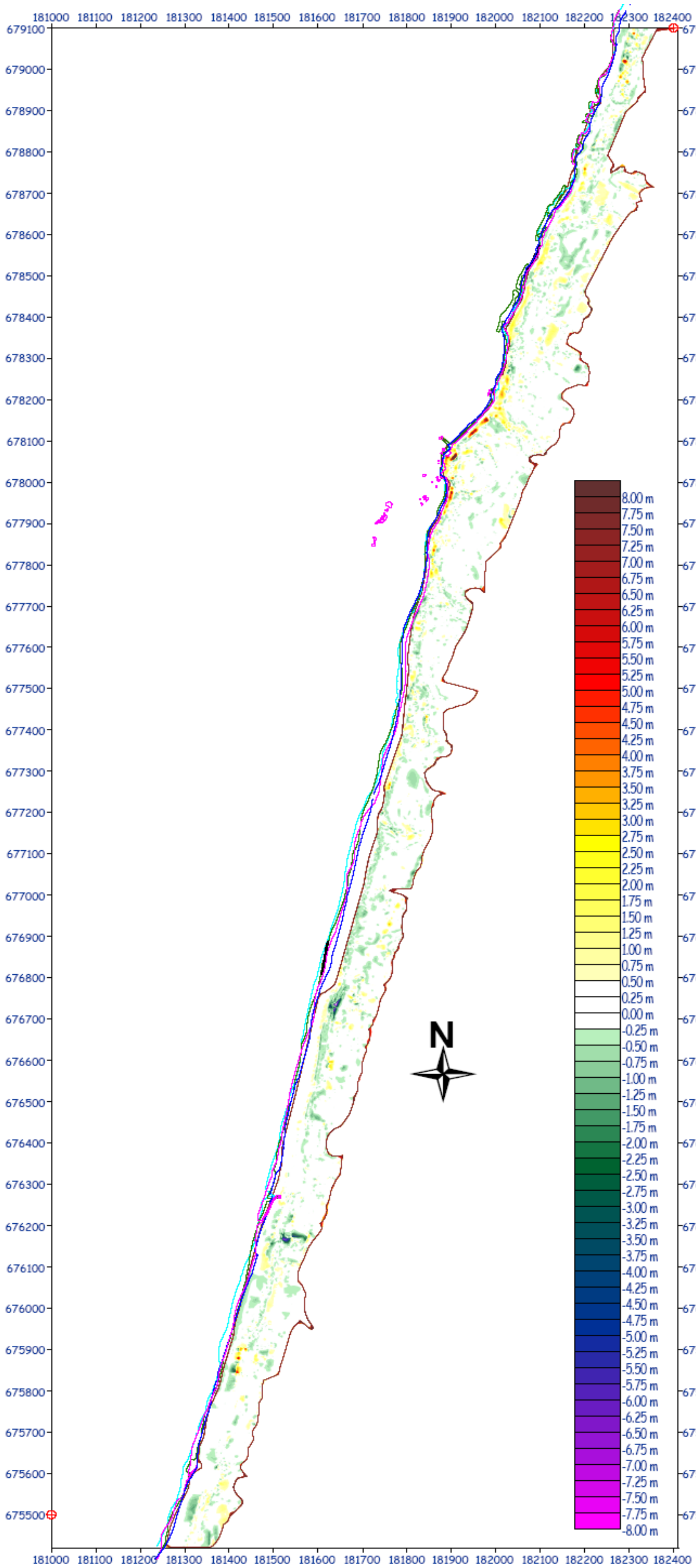
Figure 14. Maxima of waves and sea levels at Mediterranean coast of Israel

In Table 2 are presented the volumetric results of the differential maps during the two bathymetric surveys made in 1997 and in 2004. The show a cumulative erosion of the coast of about 1.5 million cubic meters over a period of 7 years period, or about 215,000 m^3/year.

Table 2 – Results of erosion-accretion balance for the study coast during 1997-2004 period

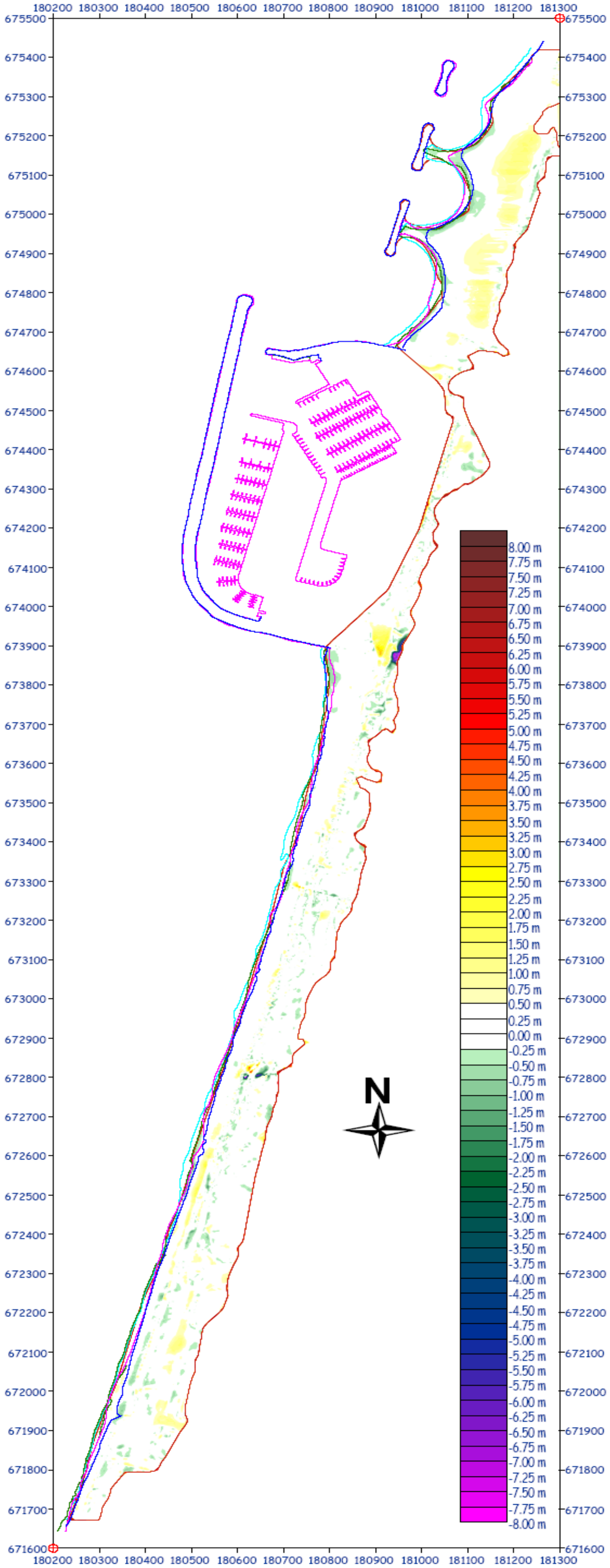
Sector Description	Coastal Sector No.	South Latitude (m)N	North Latitude (m)N	Elevations range (m)	Erosion Volume (m^3)	Deposit Volume (m^3)	Differential Volume (m^3)
From Poleg river mouth 1.25km southward	26S	686,750	688,000	-3 - +3	-231,995	48,751	-183,244
1.25 km to 2.5 km south of Poleg river mouth	25S	685,500	686,750	-3 - +3	-241,012	184,819	-56,193
2.5km to 3.75km south of Poleg river mouth	24S	684,250	685,500	-3 - +3	-324,475	123,869	-200,606
North Gaash coast	23S	683,000	684,250	-3 - +3	-222,545	137,828	-84,718
South Gaash coast	22S	681,750	683,000	-3 - +3	-111,745	120,168	8,422
Shefaiim towards Gaash coast	21S	680,500	681,750	-3 - +3	-213,861	192,819	-21,042
Kfar Shmariyahu towards Shefaiim coast	20S	679,250	680,500	-3 - +3	-135,509	341,120	205,611
Nof-Yam coast	19S	678,000	679,250	-3 - +3	-113,332	154,176	40,845
Herzliya Sidna Ali till Apolonia and northward	18S	676,750	678,000	-3 - +3	-125,154	186,558	61,405
Herzliya Hasharon beach towards Sidna-Ali	17S	675,500	676,750	-3 - +3	-116,090	194,429	78,338
Herzliya middle of main breakwater till after 3rd detached breakwater	16S	674,250	675,500	-3 - +3	-178,660	96,279	-82,380
South to Herzliya marina till mid of marina main breakwater	15S	673,000	674,250	-3 - +3	-108,007	150,317	42,310
Herzliya south border almost until Hezliya marina	14S	671,750	673,000	-3 - +3	-85,076	101,800	16,724
Tel-Aviv Sea and Sun coast to Herzliya south border	13S	670,500	671,750	-3 - +3	-69,325	107,266	37,942
Tel-Aviv south to Tel Baruch breakwater to north of the breakwater	12S	669,250	670,500	-3 - +3	-128,755	85,551	-43,204
Tel-Aviv Reading basin and northward towards Tel Baruch	11S	668,000	669,250	-3 - +3	-273,780	70,223	-203,557
Tel-Aviv Sheraton breakwater to Yarkon river mouth	10S	666,750	668,000	-3 - +3	-211,834	64,148	-147,686
Tel-Aviv Atarim, Gordon marina, Hilton detached breakwater	9S	665,500	666,750	-3 - +3	-342,181	156,142	-186,039
Tel-Aviv Atarim coast - southern 5 detached breakwaters zone	8S	664,250	665,500	-3 - +3	-272,559	111,129	-161,430
Tel-Aviv Manshia (Charles Klor coast) to Atarim South Breakwater	7S	663,000	664,250	-3 - +3	-176,422	159,739	-16,683
South of Jaffa Harbour to North of Jaffa Harbour	6S	661,750	663,000	-3 - +3	-557,373	144,995	-412,377
North Bat-Yam to Ageami in Jaffa	5S	660,500	661,750	-3 - +3	-123,662	92,591	-31,072
Bat-Yam North to Sela Pool	4S	659,250	660,500	-3 - +3	-163,933	73,159	-90,774
South Bat-Yam to Sela Pool	3S	658,000	659,250	-3 - +3	-249,197	123,825	-125,373
South Bat-Yam	2S	656,750	658,000	-3 - +3	-135,281	144,327	9,046
Border Bat-Yam with Rishon Le Zion	1S	655,500	656,750	-3 - +3	-69,325	107,266	37,942
From Border Rishon LeZion with Bat-Yam until Poleg River	TOTAL	**655,500**	**688,000**		**-4,981,090**	**3,473,296**	**-1,507,794**

In Figures 15 and 16 are shown results of differential maps of the beach and cliff at Apolonia and near Marina Herzliya between 2002 and 2003. The waterline changes are based on rectified positions of the waterline taken by aerial photographies in fall 1997 (blue line), fall 2002 (light blue line), fall 2003 (green line) and fall 2004 (magenta line).



BEACH SECTOR 3 : 675420N - 679100N			
From	To	Diff. Area	Diff. Volume
m	m	m^2	m^3
-9.50	-9.25	7	-9
-9.25	-9.00	7	-11
-9.00	-8.75	7	-13
-8.75	-8.50	7	-15
-8.50	-8.25	7	-16
-8.25	-8.00	8	-18
-7.75	-7.50	10	-23
-7.50	-7.25	14	-26
-7.25	-7.00	18	-30
-7.00	-6.75	20	-35
-6.75	-6.50	23	-40
-6.50	-6.25	23	-46
-6.25	-6.00	25	-52
-6.00	-5.75	30	-58
-5.75	-5.50	37	-67
-5.50	-5.25	40	-76
-5.25	-5.00	46	-87
-5.00	-4.75	58	-100
-4.75	-4.50	69	-116
-4.50	-4.25	68	-133
-4.25	-4.00	81	-151
-4.00	-3.75	95	-173
-3.75	-3.50	104	-198
-3.50	-3.25	121	-226
-3.25	-3.00	143	-259
-3.00	-2.75	175	-298
-2.75	-2.50	213	-347
-2.50	-2.25	299	-410
-2.25	-2.00	414	-499
-2.00	-1.75	589	-624
-1.75	-1.50	810	-800
-1.50	-1.25	1,375	-1,060
-1.25	-1.00	2,706	-1,557
-1.00	-0.75	6,175	-2,597
-0.75	-0.50	15,791	-5,207
-0.50	-0.25	44,421	-12,008
Erosion volume [m^3]			-27,384
-0.25	0.00	177,192	-35,799
0.00	0.25	153,099	32,242
0.25	0.50	38,439	12,634
0.50	0.75	15,635	6,399
0.75	1.00	7,439	3,605
1.00	1.25	3,815	2,247
1.25	1.50	2,300	1,500
1.50	1.75	1,431	1,046
1.75	2.00	908	756
2.00	2.25	571	575
2.25	2.50	430	452
2.50	2.75	329	358
2.75	3.00	267	282
3.00	3.25	201	223
3.25	3.50	168	178
3.50	3.75	121	142
3.75	4.00	91	115
4.00	4.25	64	96
4.25	4.50	54	82
4.50	4.75	46	69
4.75	5.00	39	58
5.00	5.25	32	49
5.25	5.50	28	42
5.50	5.75	23	36
5.75	6.00	19	30
6.00	6.25	19	26
6.25	6.50	15	21
6.50	6.75	11	18
6.75	7.00	9	16
7.00	7.25	7	14
7.25	7.50	6	12
7.50	7.75	5	11
7.75	8.00	4	9
8.00	8.25	4	8
8.25	8.50	3	8
8.50	8.75	3	7
8.75	9.00	3	6
9.00	9.25	3	5
9.25	9.50	3	5
9.50	9.75	3	4
9.75	10.00	3	3
Deposition volume [m^3]			31,148
Net Sand Volume [m3]			3,764
Net Sand Volume1 [m3]			3,138

Figure 15 – Volumetric and waterline changes between fall 2002 and fall 2003 off Apolonia coast



BEACH SECTOR 4 : 671600N - 675500N			
From	To	Diff. Area	Diff. Volume
m	m	m^2	m^3
-10.00	-9.75	1	-1
-9.75	-9.50	1	-1
-9.50	-9.25	1	-1
-9.25	-9.00	1	-2
-9.00	-8.75	1	-2
-8.75	-8.50	2	-2
-8.50	-8.25	2	-3
-8.25	-8.00	3	-3
-8.00	-7.75	10	-5
-7.75	-7.50	20	-8
-7.50	-7.25	49	-17
-7.25	-7.00	66	-31
-7.00	-6.75	88	-52
-6.75	-6.50	65	-72
-6.50	-6.25	45	-88
-6.25	-6.00	35	-98
-6.00	-5.75	33	-108
-5.75	-5.50	33	-117
-5.50	-5.25	46	-126
-5.25	-5.00	83	-144
-5.00	-4.75	78	-166
-4.75	-4.50	62	-184
-4.50	-4.25	66	-201
-4.25	-4.00	64	-219
-4.00	-3.75	52	-233
-3.75	-3.50	51	-247
-3.50	-3.25	50	-261
-3.25	-3.00	53	-275
-3.00	-2.75	56	-289
-2.75	-2.50	67	-305
-2.50	-2.25	73	-324
-2.25	-2.00	100	-345
-2.00	-1.75	154	-377
-1.75	-1.50	293	-432
-1.50	-1.25	524	-540
-1.25	-1.00	937	-722
-1.00	-0.75	2,783	-1,143
-0.75	-0.50	11,467	-2,773
-0.50	-0.25	35,654	-8,154
Erosion volume [m^3]			**-18,072**
-0.25	0.00	148,827	-27,198
0.00	0.25	192,811	48,040
0.25	0.50	61,773	19,154
0.50	0.75	26,030	9,033
0.75	1.00	12,873	4,386
1.00	1.25	7,166	1,963
1.25	1.50	2,496	775
1.50	1.75	853	415
1.75	2.00	482	247
2.00	2.25	189	167
2.25	2.50	147	128
2.50	2.75	148	90
2.75	3.00	150	55
3.00	3.25	69	24
3.25	3.50	16	15
3.50	3.75	12	12
3.75	4.00	9	9
4.00	4.25	7	7
4.25	4.50	7	5
4.50	4.75	4	4
4.75	5.00	3	3
5.00	5.25	2	2
5.25	5.50	2	2
5.50	5.75	2	1
5.75	6.00	1	1
6.00	6.25	1	0
6.25	6.50	1	0
6.50	6.75	0	0
6.75	7.00	0	0
Deposition volume [m^3]			**36,496**
Net Sand Volume [m3]			**18,424**
Net Sand Volume1 [m3]			**7,425**

Figure 16 – Volumetric and waterline changes between fall 2002 and fall 2003 off Herzliya coast

An example of the bathymetry and topography of the study coastal sector (right side) and the resulting wave height transformation on this coast (left side) for an extreme sea state with an average return period of 100 years computed using SWAN wave transformation program is shown in Figure 17.

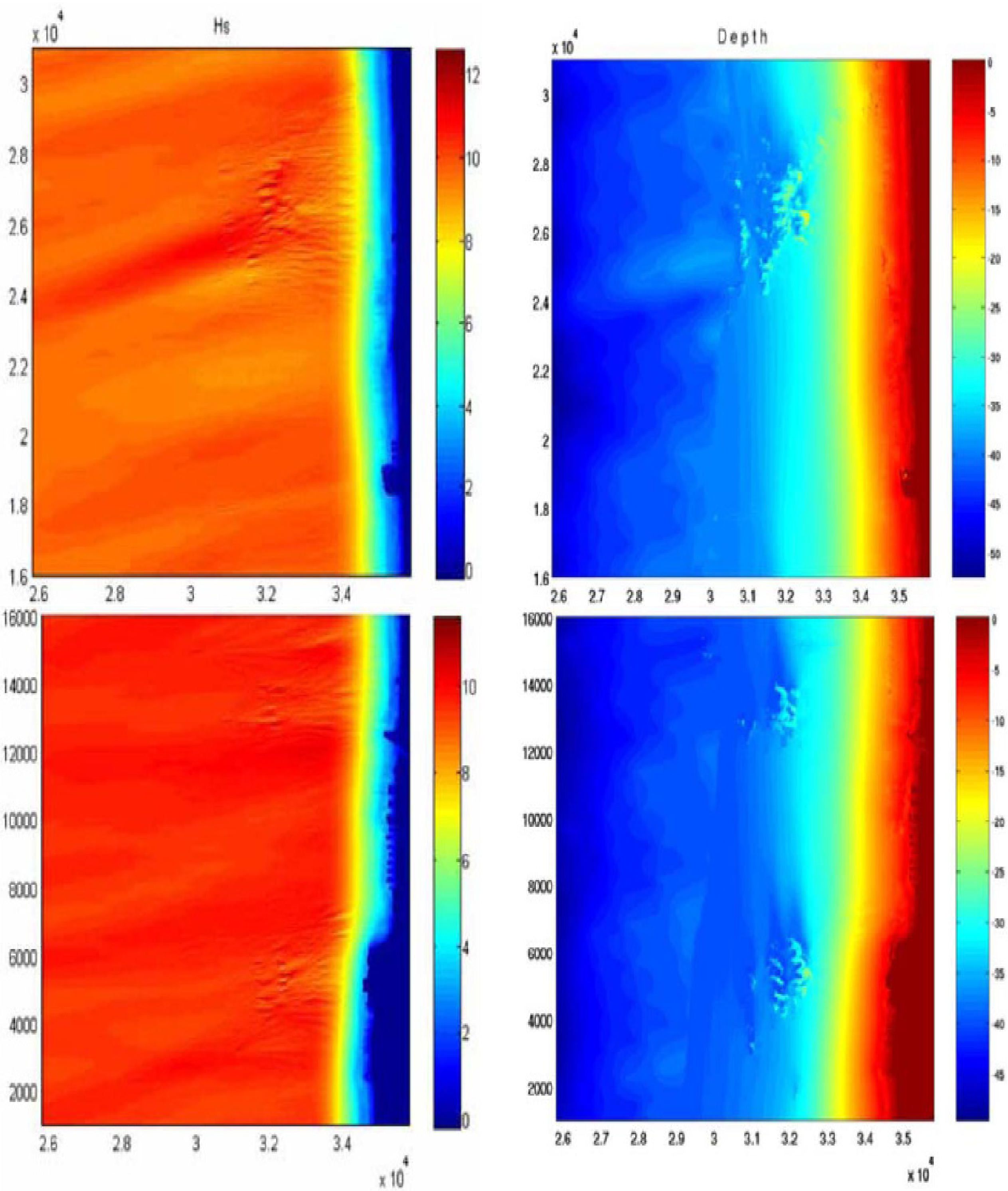


Figure 17. Bathymetry and wave height transformation on coastal sector for Hs,o=8.7m

The corresponding wave induced setup on the coast for the case in Figure 17 is shown in Figure 18, as planar map on its right side, and as 3-dimensional map on its left side.

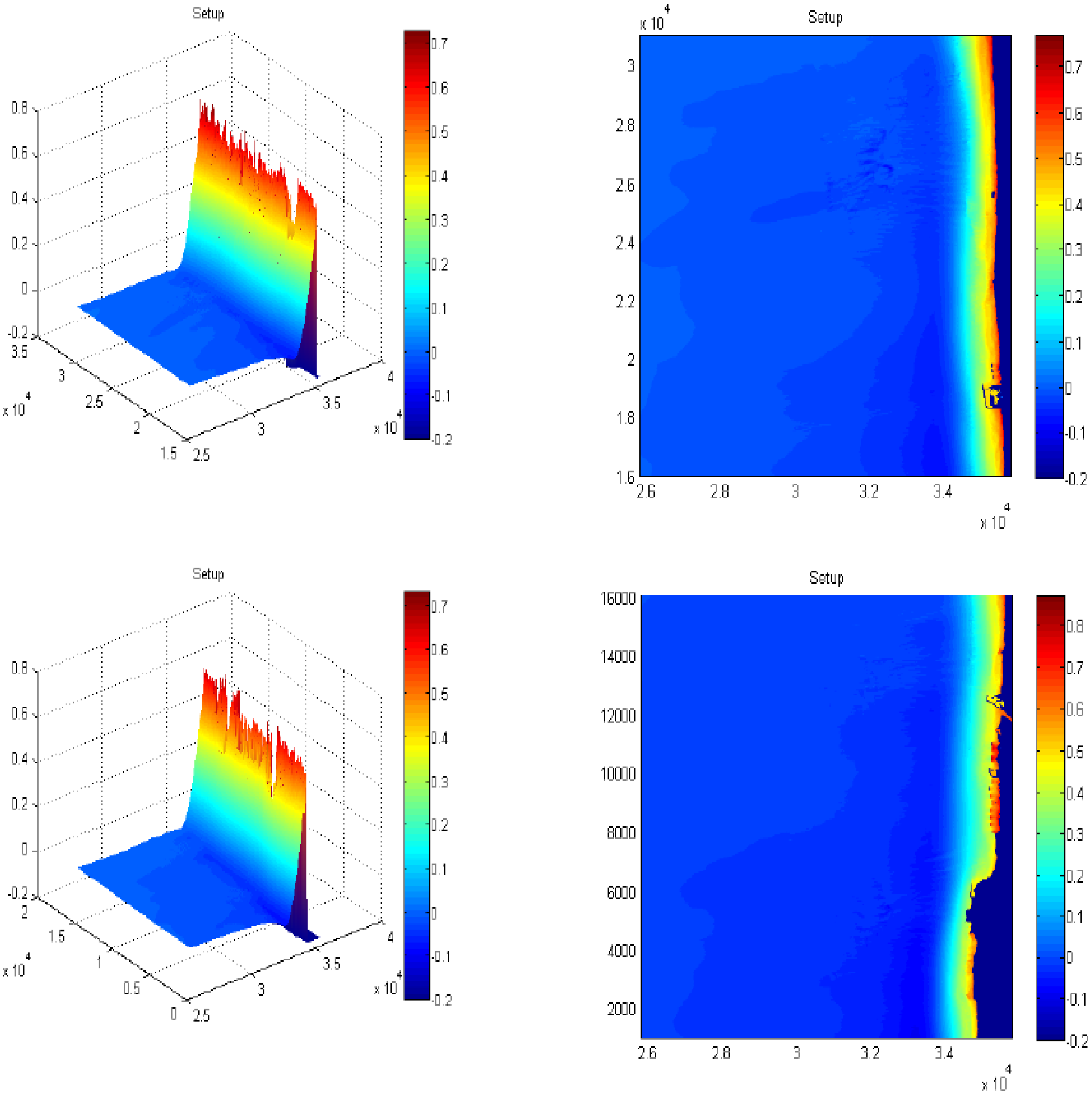


Figure 18 – Wave induced setup in surf zone up to waterline during waves shown in Fig.15

A comparison of modeling simulations using the SWAN hydrodynamic wave model for various extreme sea states attacking the coastal sector for present and for future sea level rise conditions, generating wave induced superelevation at the waterline is shown in Figure 19.

Results of the SBEACH modeling of the beach and cliff profile erosion at cross shore sections equally spaced every 1 km along the coast for various present and future extreme sea states are shown in Table 3 shown in Figures 20 through 22.

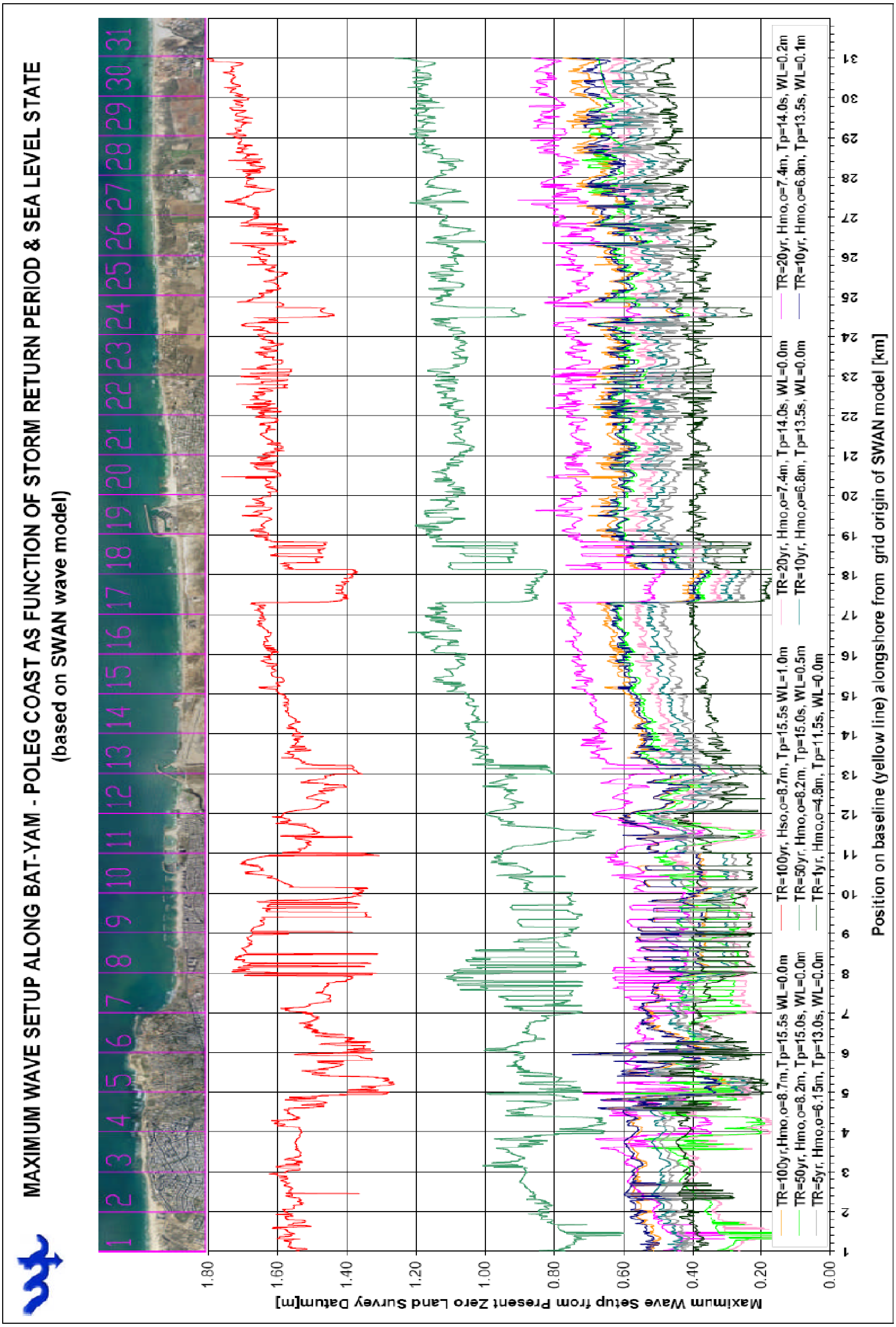


Figure 19 – Comparison of wave induced superelevation for various conditions

Averaged profiles	Present sea level at +0.0m		New Sea level with 0 at +1.0m , profile comparison at -1.0m		Present sea level at +0.0m		New Sea level with 0 at +0.5m , profile comparison at -0.5m		Present sea level at +0.0m		New Sea level with 0 at +0.2m , profile comparison at -0.2m		Present sea level at +0.0m	
	Storm 100yr, z0,central		Storm 100yr, z0,central		Storm 50yr, z0,central		Storm 50yr, z0,central		Storm 20yr, z0,central		Storm 20yr, z0,central		Storm 1yr, z0,central	
	Volume Change [m³/m]	Water line shift from present 0 position [m]	Volume Change [m³/m]	Water line shift from present 0 position [m]	Volume Change [m³/m]	Water line shift from present 0 position [m]	Volume Change [m³/m]	Water line shift from present 0 position [m]	Volume Change [m³/m]	Water line shift from present 0 position [m]	Volume Change [m³/m]	Water line shift from present 0 position [m]	Volume Change [m³/m]	Water line shift from present 0 position [m]
0	-6.4	-3.1	-30.3	-1.9	-5.8	-3.1	-17.3	-6.1	-3.6	-3.3	-7.5	-7.0	-3.3	-4.4
1	-6.1	-5.9	-25.0	3.3	-3.6	-2.2	-14.5	0.1	-4.3	0.0	-2.4	-9.9	-3.9	-1.4
2	-6.7	-9.4	-35.4	-0.8	-5.6	-10.1	-20.6	-11.6	-3.7	-9.8	-8.8	-14.3	-2.9	-11.7
3	-6.1	3.7	-19.3	1.0	-5.5	3.2	-11.8	3.3	-3.0	1.5	-5.8	0.0	-2.7	0.2
4	-15.7	11.1	-26.4	0.5	-7.1	7.4	-18.0	31.4	0.5	2.4	-3.8	2.9	-4.0	-0.7
5	-170.6	-39.2	-251.7	-4.4	-163.4	-37.6	-211.6	-23.9	-106.7	-30.6	-140.2	-33.4	-95.5	-28.2
6	-26.6	4.0	-63.4	-9.0	-26.7	4.1	-45.1	1.4	-11.7	-0.3	-14.2	-6.3	-4.4	-0.4
7	-4.2	6.4	-24.6	-3.1	-3.5	5.7	-11.2	2.0	-1.6	3.0	-3.8	0.2	-1.0	1.0
8	-2.7	4.6	-45.4	-63.6	-2.2	4.7	-11.4	-17.6	-0.6	4.4	-0.6	1.4	-0.4	3.2
9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	-7.8	-6.1	-34.6	-4.2	-7.0	-6.4	-20.6	-7.6	-3.0	-5.8	-7.6	-9.3	-2.4	-6.4
15	-16.7	-7.7	-46.8	4.9	-18.1	-7.0	-33.5	2.3	-12.4	-7.8	-18.4	-6.3	-10.0	-9.5
16	-12.6	-1.1	-34.7	0.0	-11.5	-1.1	-23.5	2.1	-8.2	-2.3	-12.8	-2.6	-7.1	-3.8
17	-15.0	-1.8	-28.7	15.8	-8.5	-7.5	-22.6	5.8	-8.2	-2.3	-14.5	-3.7	-8.0	-5.7
18	-6.2	-1.6	-26.8	1.1	-5.7	-1.8	-15.7	-4.4	-4.2	-3.2	-7.8	-6.7	-4.1	-4.4
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	-10.9	-9.5	-37.2	-4.0	-11.0	-9.1	-22.3	-6.4	-7.3	-6.9	-11.8	-7.0	-8.0	-7.9
21	-18.6	-6.3	-48.4	11.3	-17.1	-6.9	-31.6	-1.7	-12.7	-7.6	-18.7	-7.6	-10.7	-9.0
22	-23.2	-12.4	-60.2	14.7	-15.9	-10.5	-47.1	-2.4	-10.7	-13.8	-17.7	-19.3	-9.3	-12.9
23	-35.5	9.2	-71.8	24.7	-20.0	2.6	-55.5	8.5	-22.2	2.5	-24.2	-1.7	-14.4	1.9
24	-47.4	-3.3	-88.4	32.8	-50.0	-2.9	-70.9	14.6	-20.4	-5.4	-35.1	-10.2	-12.8	-7.4
25	-35.1	6.8	-73.6	15.4	-31.4	7.7	-51.3	0.5	-16.5	1.0	-22.0	-15.0	-10.6	0.8
26	-9.1	-7.1	-52.7	24.2	-14.5	-3.2	-31.0	0.8	-5.9	-7.9	-11.7	-11.0	-4.3	-10.5
27	-34.4	2.1	-74.6	30.7	-26.7	-1.4	-64.7	20.6	-18.1	-0.6	-26.6	-2.7	-12.2	-2.6
28	-16.7	-18.1	-63.6	18.2	-10.8	-19.1	-44.9	-4.6	-6.4	-17.5	-18.4	-18.6	-4.7	-18.2
29	-25.9	5.4	-71.9	21.6	-26.7	7.3	-48.2	15.0	-11.9	-0.1	-14.6	-4.1	-6.5	-1.6
30	-16.7	1.7	-57.8	27.3	-21.6	2.9	-47.4	15.2	-10.2	1.4	-16.1	-6.5	-5.9	-2.0
31	-10.0	-1.6	-20.4	10.9	-9.6	-2.1	-16.1	3.6	-7.8	-4.7	-11.6	-4.5	-7.1	-0.4
32	0.0	0.0	-13.3	-4.9	0.0	0.0	-3.8	-4.4	0.0	-0.2	-1.2	-3.9	-0.1	-1.0

Table 3-Example of results of erosion volumes and water line retreat obtained with SBEACH

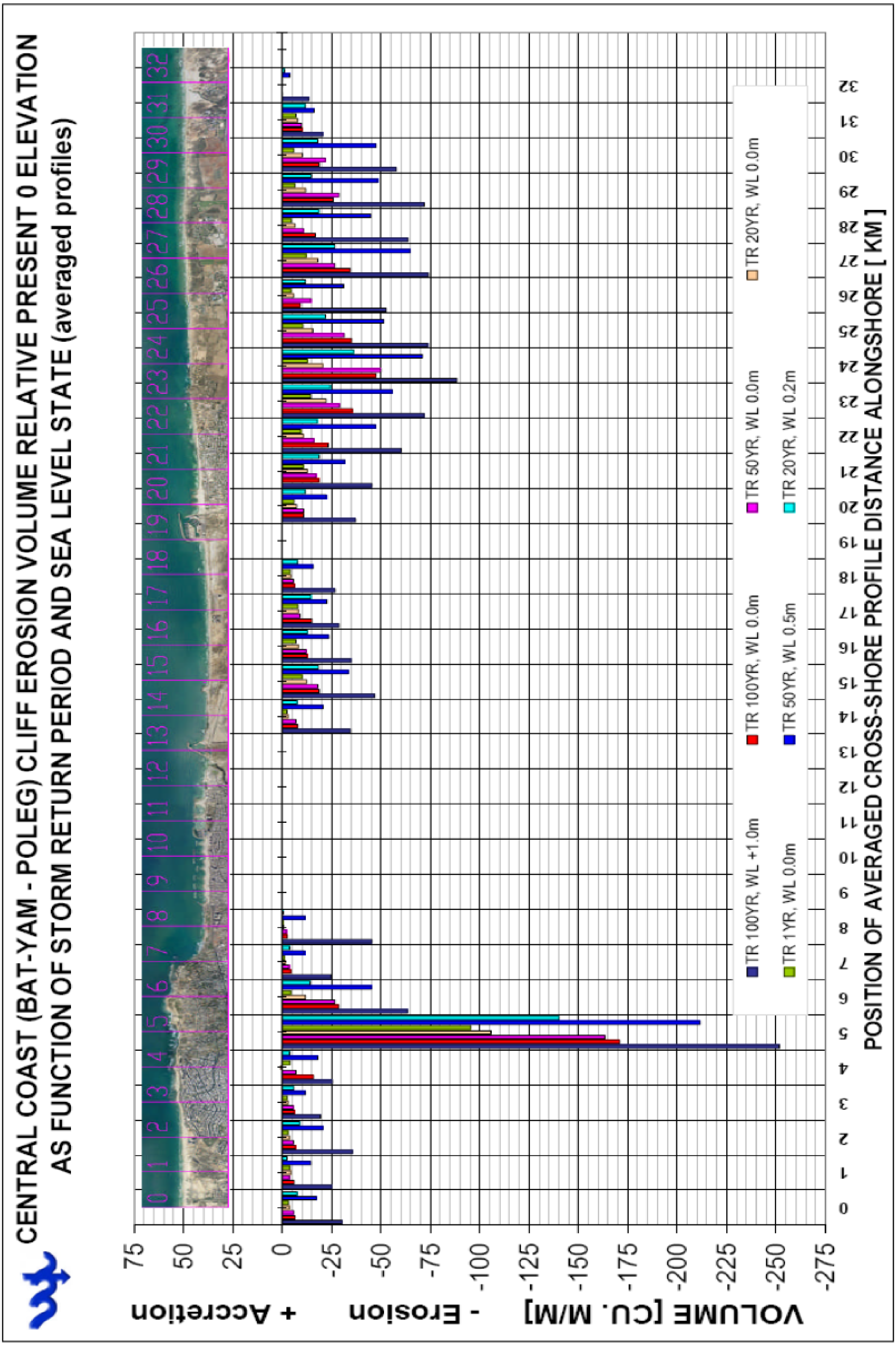


Figure 20. Results of erosion volume estimates for various sea states and sea level rise scenarios

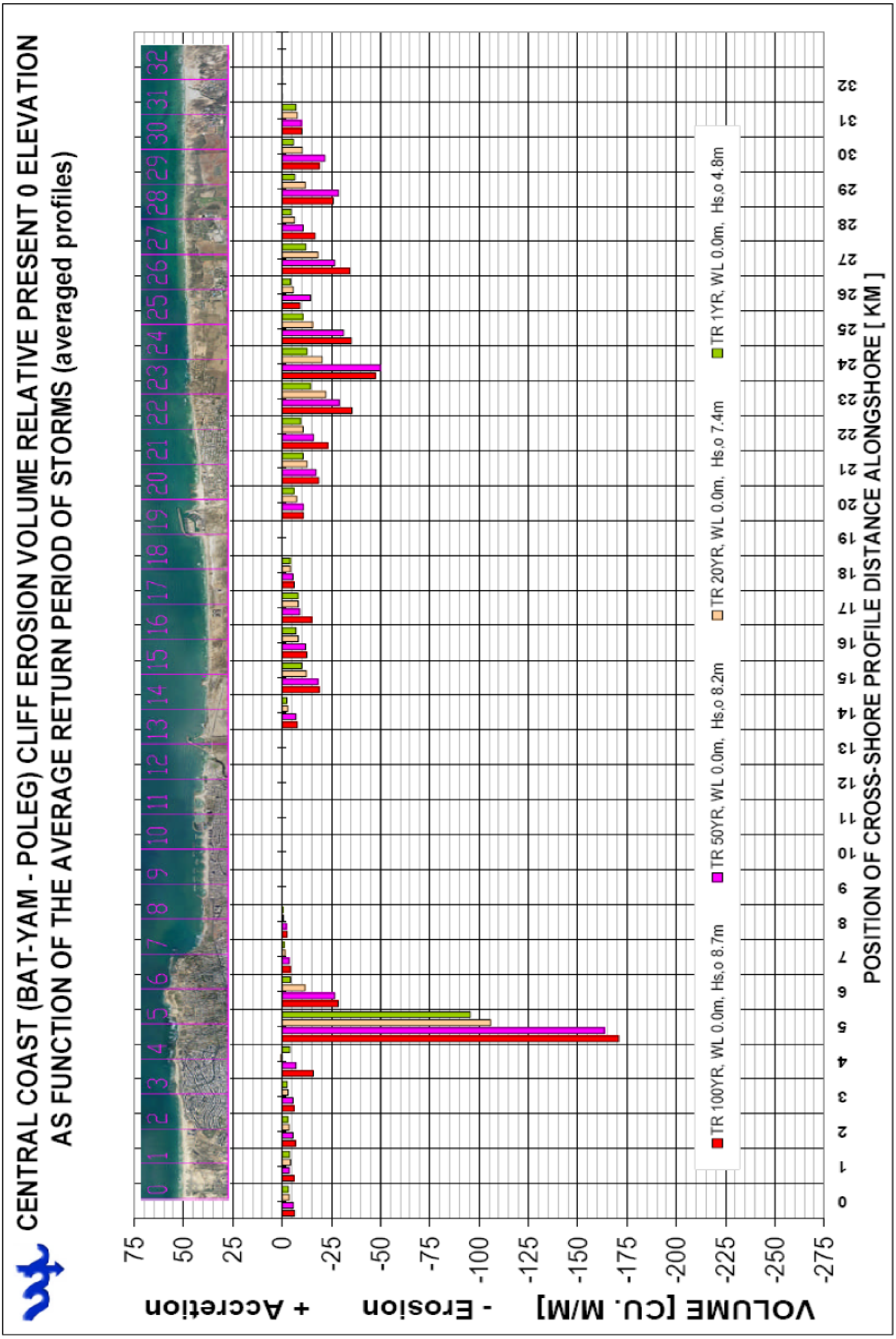


Figure 21. Results of erosion volume estimates for various sea states at present sea level state

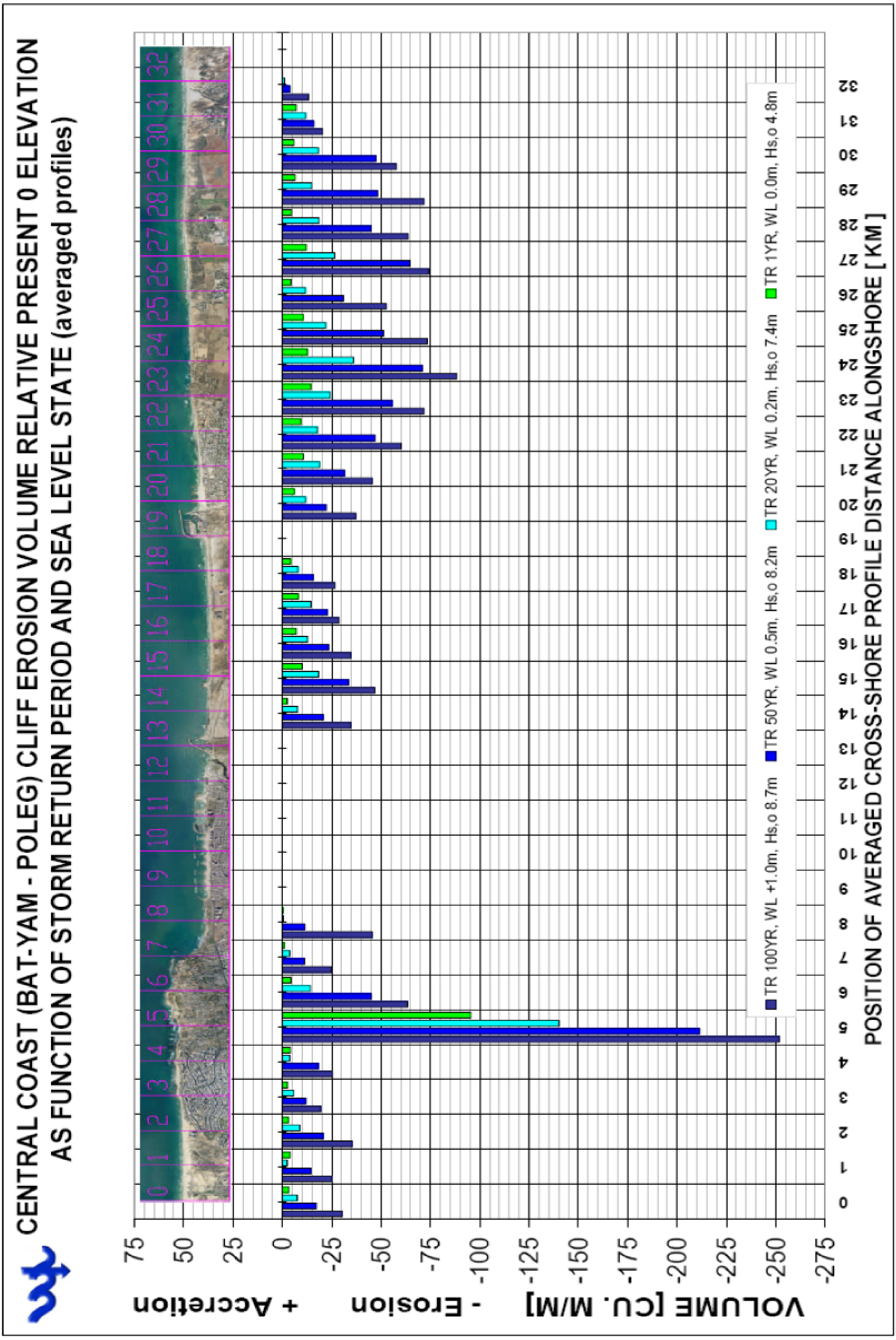


Figure 20. Results of erosion volume estimates for various sea states at future sea level rise states

6. PRELIMINARY CONCLUSIONS

The work presented in this report is an ongoing study on the coastal erosion at the beach and coastal cliff of a typical coastal sector at the Mediterranean coast of Israel. It contains both sectors with anthropogenic impact as well as sectors remote from coastal structures.

The investigation method used is a combination of various methods of study of the coastal processes inducing erosion, including in situ long term monitoring of meteo-marine climate and analysis of the morphological changes measured using differential maps and shifts of the waterline position, as well as numerical modeling of the coastal processes.

Preliminary results indicate sectors of higher sensitivity to coastal erosion and sea level rise due to climate change impact.

Continuation of the monitoring of the meteomarine environment as well as the performance of aerial photography and mapping of the coastal zone (beach and cliff) is considered very important for the proper integrated coastal management of the Mediterranean coast of Israel. These however depend to a great extent to the availability of funding which would enable these activities.

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