CHAPTER 4:

ANALYSIS OF BEACH MORPHOLOGY AND PREDICTION OF SHORELINE CHANGES

Chapter 4 Analysis of Beach Morphology and Prediction of Shoreline Changes

4.1 Shoreline Change Analysis Based on Historical Maps

4.1.1 Data Source

Search was made during the Study for old maps and charts, which may provide the information on the locations of the shoreline in historical times. A number of charts along the Southern Romanian Black Sea shore dating back to the mid-19th centuries were obtained from the archives of the UK Hydrographic Office. However, they turned out to be based on the coordinate systems that are different from the present standard ones, and reliable comparison of the old and present shoreline positions could not be made. Nevertheless, two sources of information were available fortunately.

One source is the topographic maps surveyed in 1924, which were compared with later topographic maps and the Ikonos satellite images in 2002 for examination of the shoreline position changes. The examination was undertaken by Dr. Stefan Constantinescu for his doctorate dissertation to the University of Bucharest in 2005. The information obtained has been included in the description of shore sectors in **3.5**.

Another source is a series of coastal topographic survey maps from 1960 to 1997, which have been compiled in the report by PROIECT S.A. Topographic surveys were made seven times in 1963, 1976, 1980, 1982, 1990, 1995, and 1997, and the maps were prepared in the scale of 1 on 500 to 1 on 2,000. However, each survey covered some limited parts of the study area only, and any given section of the study area was surveyed a few times only. The shoreline positions were digitized from these topographic maps whatever available, and the shorelines at different years were compared for the position changes of advance or retreat. The exact dates of surveys were not listed on the maps and the survey results of the shoreline positions may have been affected by seasonal variations.

Figures 4.1.1 to 4.1.3 summarize the results of the shoreline change analysis based on the topographic survey maps. The abscissa of the lower figure that shows the coastal topography represents the distance in meters along the meridian with the origin at Midia Port, while the abscissa of the upper figures is the distance with the origin at the left end of the topographic map; e.g., the distance 5000 m in the upper figure of Fig. 4.1.2 corresponds to the meridian distance of 32,000 (27,000 + 5,000) m. The numerals at the right side of each drawing in the upper figures indicate the years of topographic surveys. More diagrams of shoreline change analysis are presented in Annex **E.1.**

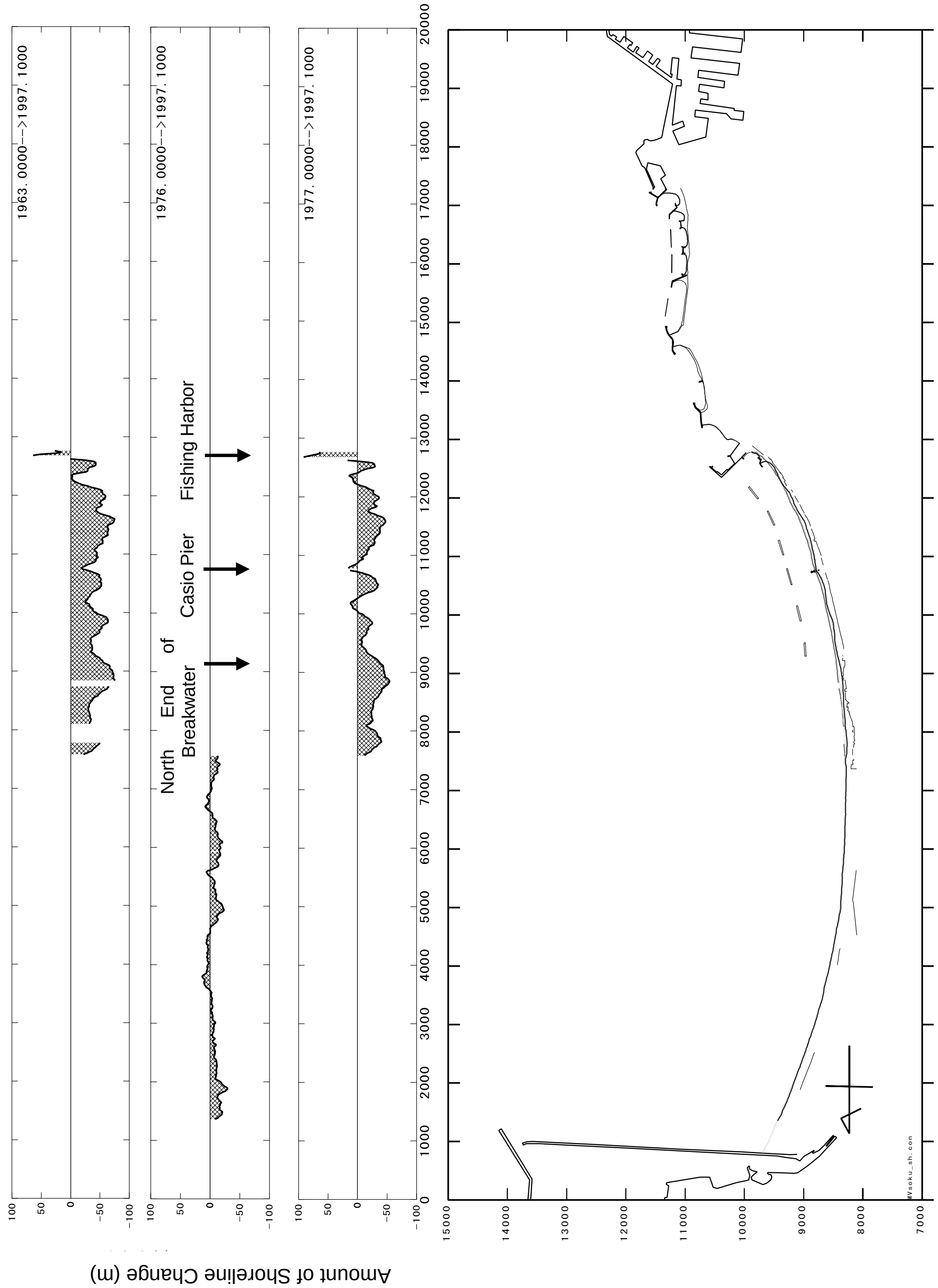

Fig. 4.1.1 Advance or retreat of shoreline in Constanța Sector from Năvodari to Tomis from 1963 to 1997

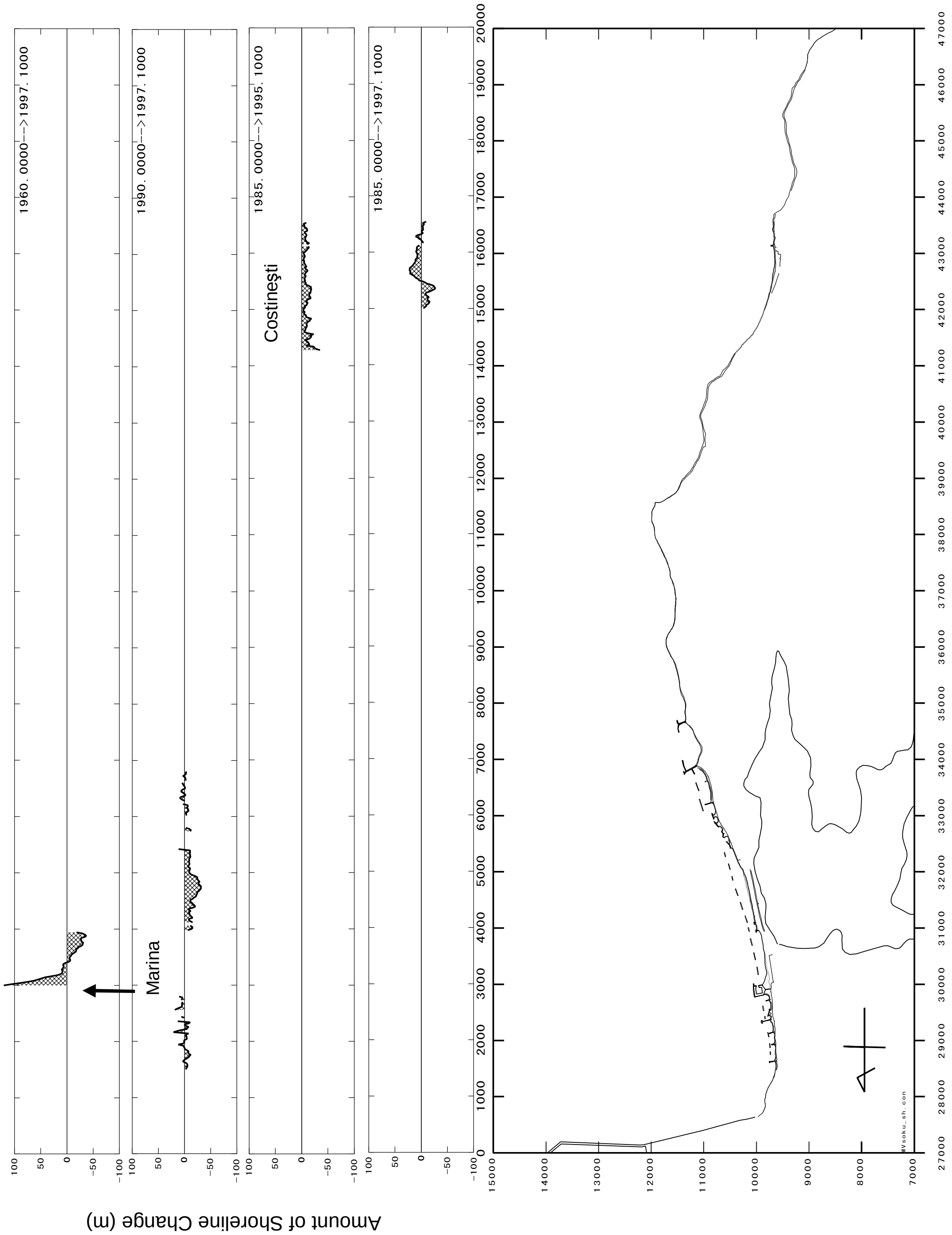

Fig. 4.1.2: Advance or retreat of shoreline in Eforie and Costineşti Sectors from 1960 to 1997

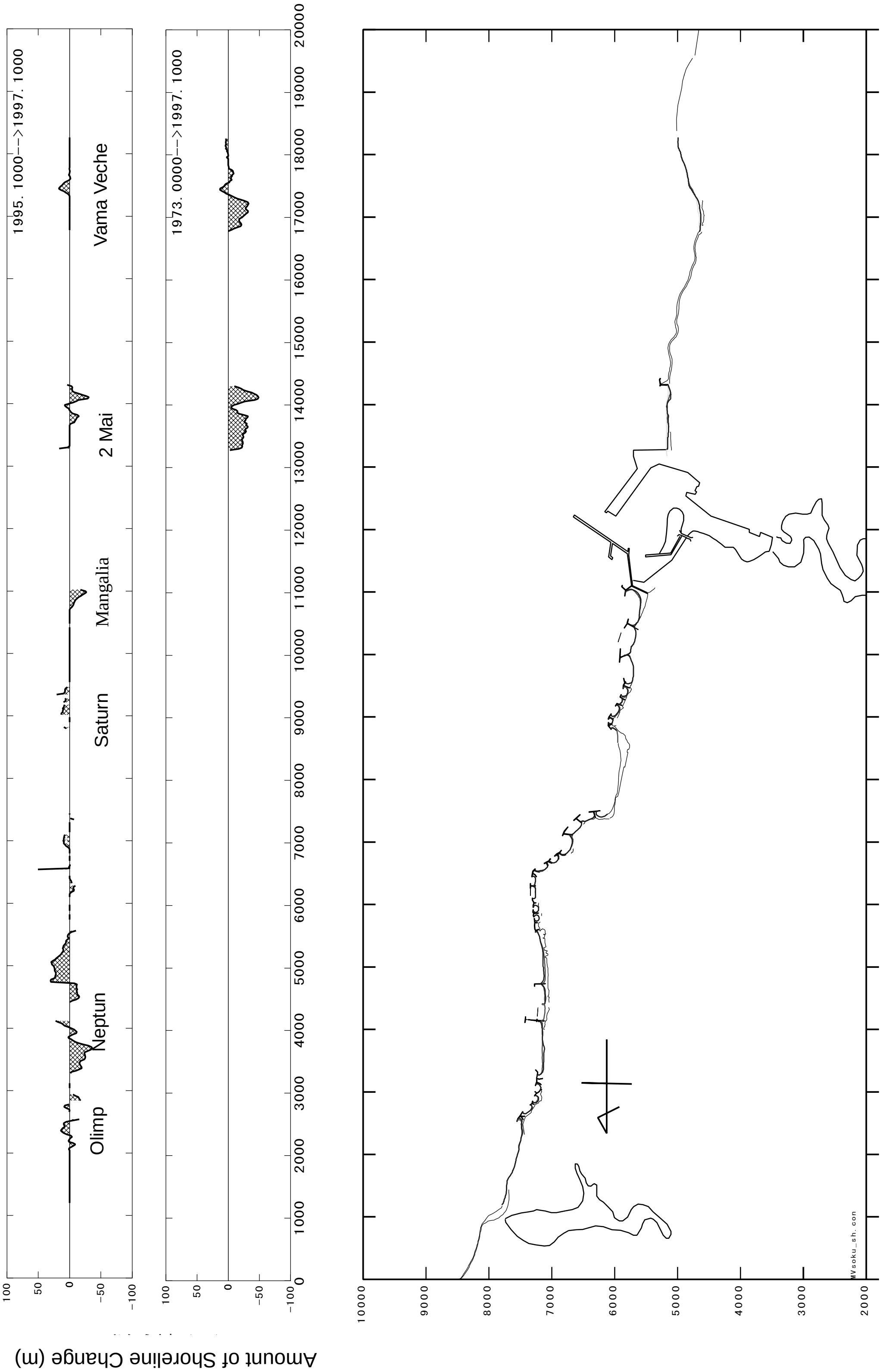

Fig. 4.1.3: Advance or retreat of shoreline in Mangalia Sectors from 1960 to 1997

4.1.2 Shoreline Changes in Constanța Sector

As discussed in **3.6.1**, the long beach of Năvodari and Mamaia was exposed to intensive erosion as the result of the extension of the north breakwater of Midia Port. However, the sub-sectors of Năvodari North and Năvodari South (see **5.2** for the definition and name of sub-sectors) do not show significant changes in the shoreline position. Locally the shoreline retreat registered 30 m at maximum at a few places in the period from 1976 to 1977, but the location around the distance 4000 m shows a slight advance and the average retreat distance is about 10 m.

In the sub-sectors of Mamaia North to South, the locations at the distances 9000 and 12,000 m marked the largest retreat of about 80 m in the period from 1963 to 1997. The shoreline retreat in the locations at the distance 9,500 to 11,000 m was slowed down in the period from 1977 to 1997, because of the wave dissipating function of the six detached breakwaters that were built in 1988 to 1990 and a beach fill project.

4.1.3 Shoreline Changes in Eforie, Tuzla, and Costinești Sectors

In this sector, the influence of the construction of the marina “Yacht Club Europa” in the late 1980s is most significant. Behind the marina, the shoreline advanced by about 120 m until 1997, while at its south the shoreline retreated about 30 m, as shown in Fig. 4.1.2. In the north of the marina, the shoreline position did not change much in the period from 1990 to 1997. In the sub-sector of Eforie Middle at the distance 4,000 to 5,400 m (the meridian distance 31,000 to 32,400 m), the shoreline retreated 30 m at maximum. In the sub-sector of Eforie Sud, the shoreline change is not noticeable because of the presence of shore protection facilities.

Comparison of the shoreline in 1924 and the Ikonos images taken in 2002 is shown in Fig. 4.1.4, which is taken from a PhD dissertation by Constantinescu in 2005[1]. He overlaid the shorelines (in blue lines) appearing in the topographic maps of 1924 on the Ikonos satellite images taken in 2002. The sub-sectors of Eforie Nord, Eforie Middle, and Eforie Sud experienced the shoreline retreat of 30 to 80 m during this period, the amount of which varies from place to place. The local advance of the shoreline around the Yacht Club Europa by about 80 m is clearly observed in Fig. 4.1.4.

The Ikonos image of the area from Cape Tuzla via Costineşti to Schitu is shown in Fig. 4.1.5. During the period of 1924 to 2002, the cliff around Cape Tuzla retreated by 73 m at maximum. The rate of cliff retreat is estimated as about 0.7 m per year on the average. The topographic map of 1924 indicated contours of reef-like configurations between Costineşti and Frenchman’s Gulf around a cape at Hotel Forum. The emerged configurations in 1924 are missing in 2002, having disappeared probably by the abrasive force of wave action.

In the Sector of Costineşti, the shoreline retreated about 10 m on the average in the period from 1985 to 1995, but the southern part (the meridian distance 15,400 to 16,200 m) made advance in the period from 1995 to 1997 by some 30 m and the overall advance was recorded there in the period from 1985 to 1997. The erosive feature in the north and the accretive feature in the south are also visible in Fig. 4.1.5.

[1] Constantinescu, St.: Analiza geomorfologică a ţărmului cu faleză intre Capul Midia şi Vama Veche pe baza modelelor numerice altitudinale, Unpublished PhD thesis, Faculty of Geography, University of Bucharest, 2005.

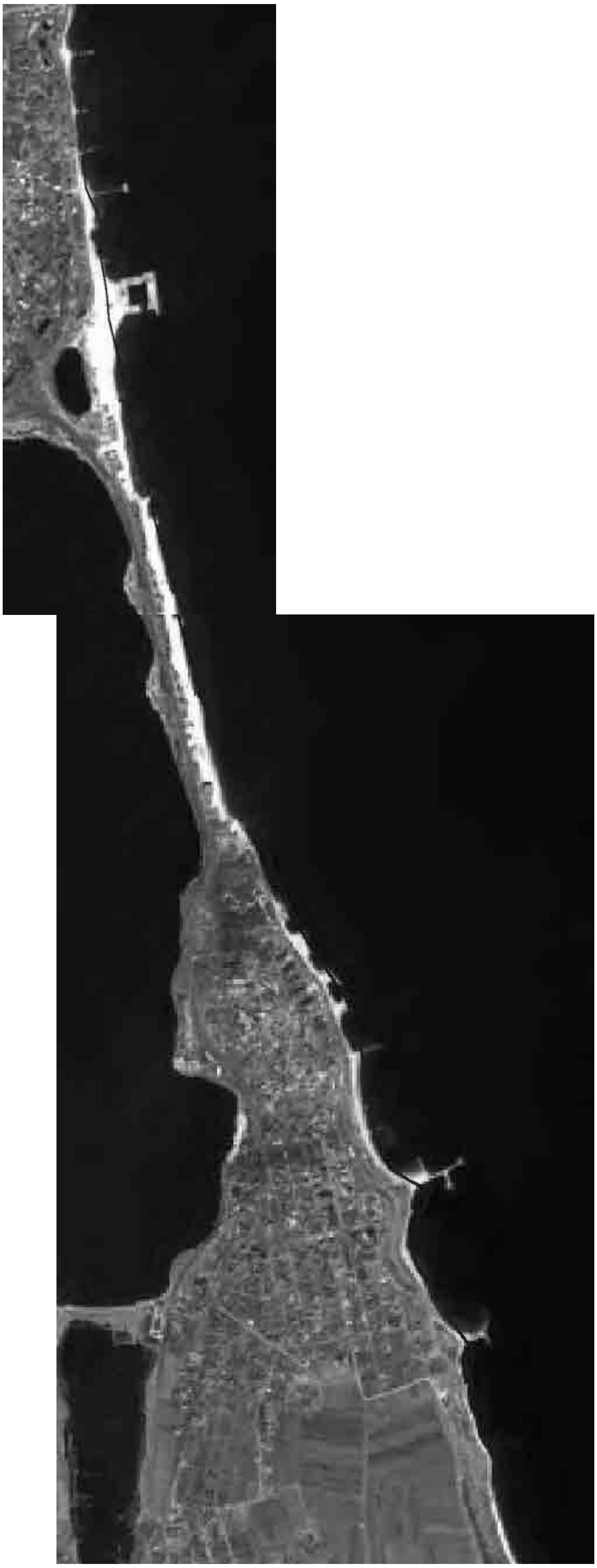

Fig. 4.1.4: Comparison of the shoreline in 1924 (blue line) and the Ikonos image in 2002 for the Eforie Nord to Eforie Sud area

Fig. 4.1.5: Comparison of the shoreline in 1924 (red lines) and the Ikonos image in 2002 for the Tuzla to Schitu area

4.1.4 Shoreline Changes in Mangalia and Limanu Sector

In the sub-sector of Olimp–Venus, only two survey maps in 1995 and 1997 are available. The location at the distance 3,200 to 4,000 m shows a retreat of 30 m at maximum, while the location at the distance 4,800 to 5,300 m shows an advance of 30 m at maximum. The amount of shoreline position change seems too large to occur in only two years. Such changes are judged to reflect the seasonal and/or yearly variations, which can be observed in the diagrams of regression analysis of the shoreline locations listed in Annex **E.2.**

There is no survey data in the sub-sector of Balta Mangalia so that no information can be deduced from the topographic maps. However, the information is deduced from the beach profile survey data as described in **4.2.6.**

For the sub-sectors of 2 Mai and Vama Veche, three topographic survey maps of 1973, 1995, and 1977 are available. Their analysis shows the retreat of the shoreline up to 50 m in the period from 1973 to 1997 for the sub-sector of 2 Mai. The sub-sector of Vama Veche also shows the shoreline retreat up to 30 m in the same period, but the retreat seems to have stopped in the period after 1995 and a narrow area around the distance 17,500 m advanced by nearly 20 m in the period of 1995 to 1997.

A part of the cliff of Limanu does not have a limestone outcrop at its foot, which should be able to withstand wave attacks. In such a place (e.g. in front of military units), the cliff is being intensively eroded by scouring and the shoreline retreat rate exceeds 3 m per year.

4.2 Shoreline Change Analysis Based on Beach Profile Survey

4.2.1 Methodology of Analysis

The data on the temporal changes of shoreline locations was provided by the National Institute for Marine Research and Development (NIMRD), which has the database of the successive beach profile surveys at the 41 benchmarks along the northern unit of the Romanian Black Sea shore from Sulina to Corbu and the 34 benchmarks along the southern unit from Năvodari to Vama Veche. The surveys have been made at least once year and several times at some benchmarks since 1979 for the southern unit. The survey for the northern unit began in 1962 for the northern unit, but the data since 1991 were made available to the Study.

The cross-shore distance between each benchmark and the corresponding shoreline was defined from the database, and a trend analysis has been made for temporal variation of the shoreline distance for all the 41 benchmark data of the northern unit and the 34 data of the southern unit. The result of the trend analysis is shown in a graphical form in Annex **E.2**. The shoreline distance shows a clear trend of linear retreat or advance over years, though seasonal variations appear on the linear trend. The rate of shoreline retreat or advance is defined from the gradient of the straight line of linear trend.

4.2.2 Northern Unit of the Romanian Black Sea Shore

The benchmarks in the northern unit are numbered with the legends of SS-1 to SS-9 for the section from Sulina to Sf. Gheorghe, SZ-1 to SZ-6 for the section from Sakhalin to Zaton, PP-1 to PP-10 from Perisor to North Portița, and PC-1 to PC-16 for the section from Portița to Corbu. Figures 4.2.1 show the result of the shoreline change rates for the 21 selected northern benchmark locations. The rate of change of the shoreline position is plotted for all the benchmark locations in Fig. 4.2.2 against the alongshore distance from Sulina.

The section from Sulina to Sf. Gheorghe is experiencing rapid beach erosion with the maximum rate of –9 m/year except at the locations of SS-1 and SS-2, which are located just south of the long jetties of Sulina Channel and the local clockwise currents are feeding sediment for accretion of beach there.

The beach in the section from Sf. Gheorghe to Zaton is most severely eroded with the maximum rate reaching –19 m/year at SZ-1. This section includes the outer shore of Sakhalin Island, which is gradually moving toward the southwest by wave actions. Only the location SZ-3, which is behind Sakhalin Island, indicates a tendency of slight advance. The section from Perisor to Portița is stable with accretive tendency with the maximum rate of +3 m/year.

The section of Portița to Corbu along Chituc Spit is in the state of beach erosion except the area near Corbu. The largest erosion appears at the middle point of PC-9 with the rate of –9 m/year. The tendency of beach accretion near Corbu is understood as a result of the impoundment effect of the north breakwater of Midia Port.

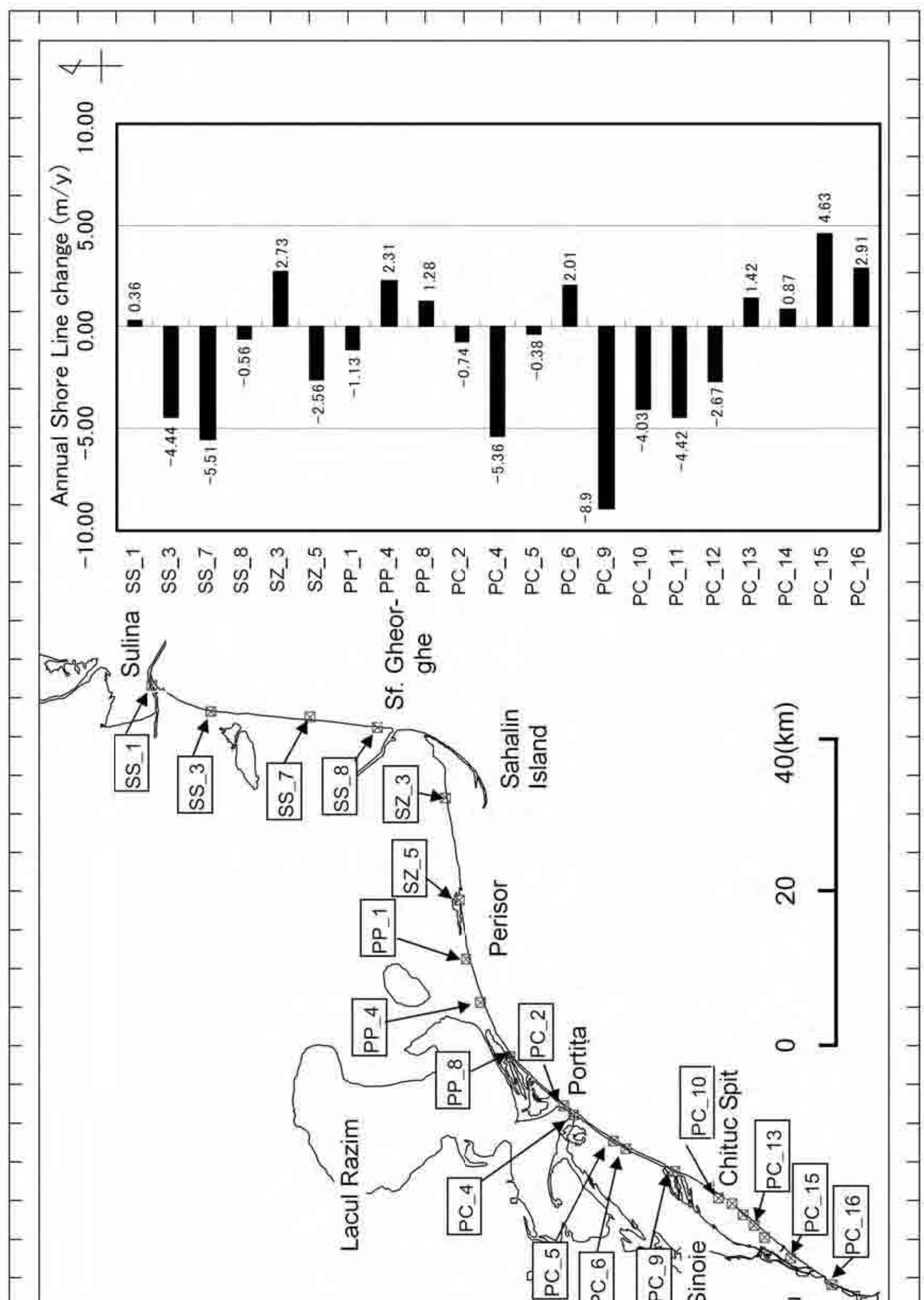

Fig. 4.2.1: Rate of shoreline position changes (1)

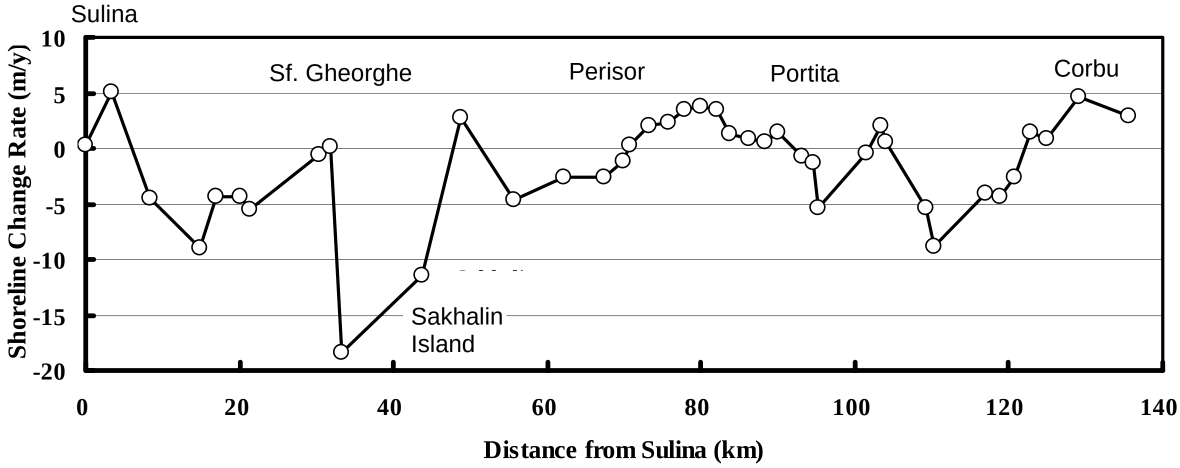

Fig. 4.2.2: Alongshore variation of the rate of shoreline change

4.2.3 Shore Sectors of Năvodari and Mamaia

The benchmark locations in Năvodari and Mamaia are shown in Fig. 4.2.3. Because the data at the benchmarks MM-13, MM-14 and MM-15 indicated abrupt advance of the shoreline in 1989 to 1990 owing to the beach fill operation at that time, the trend analysis was made for the data after 1991. The benchmark MM-7 at the boundary of the sub-sectors Mamaia North and Mamaia South shows a retreat rate of –1.7 m/year. This large retreat is considered as of local nature, because it is located at the northern edge of the shadow zone of the group of detached breakwaters. The shoreline of the three benchmarks MM-13, MM-14, and MM-15 at the southern part of Mamaia South shows the retreat rate of –2 m/year on the average, which presents a serious threat for the beach utilization and demands an urgent countermeasure.

The other sub-sectors of Năvodari and Mamaia do not exhibit significant shoreline changes, indicating general stability as a whole. The sub-sectors of Tomis North and Tomis South are not provided with the benchmarks for beach profile surveys and no information can be deduced from the database of NIMRD.

4.2.4 Shore Sectors of Eforie and Costinești

The benchmark locations in the Eforie and Costineşti Sectors are shown in Fig. 4.2.4. The advance of the shoreline at EF-1 at the rate of +1.5 m/year represents the sand accumulation effect of the marina “Yacht Club Europa,” the construction of which began in 1986. The above rate of shoreline advance is an average value between 1988 and 2004, and the advance rate is large in the period from 1986 to 1993 with a slowdown in recent years as seen in Fig. E.2.16 in Annex **E.2**. The phenomenon of beach accretion behind the marina is a typical tombolo formation.

The shorelines at the locations EF-4 and EF-5 are retreating with the rate of about –1m/year, which is regarded as the adverse effect of tombolo formation behind the marina. The retreat of the shorelines at EF-6 and Ef-7, on the other hand, has been taking place since 1981, when the

[2] Giosan, L., Bokuniewicz, H., Panin, N. and Postolache, I.: Longshore sediment transport pattern along Romanaian Danube Delta Coast, *GEO-ECO-MARINA*, 2/1997, pp. 11-23.

beach profile survey began. Therefore, the cause of the shoreline retreat there must be sought for other than the adverse effect of tombolo formation. One possible cause is considered as the increase of wave actions due to wave reflection from the seawall of the promenade built at the north end of Eforie Sud (see **4.4.5**).

The shoreline of Costineşti maintains almost a constant position, indicating its stable condition, though a range of seasonal variation of up to 40 m was observed.

4.2.5 Shore Sectors of Neptun to Saturn–Mangalia

The benchmark locations in the sub-sectors of Neptune to Saturn–Mangalia and those of the sub-sectors of 2 Mai and Vama Veche are shown in Fig. 4.2.5.

The beach of Olimp is experiencing a rapid shoreline retreat of –1.3 m/year at NN-1, but the other two locations of NN-2 and NN-3 remain as stable.

The shoreline of Balta Mangalia is retreating at the rate of –1.6 and –1.2 m/year at the benchmark SN-1 and SN-2, respectively. However, the natural beach of 800 m long has a sufficient width and can sustain further beach erosion for the while. Because this place is not a favorite site of summer beach visitors, no urgent countermeasures will be required.

The sub-sector of Saturn–Mangalia is composed of three areas. The north area has four small pocket beaches but not suitable for summer ocean bathing because of poor water quality. The center area has no beach. A beach is present at the south area next to the Mangalia breakwater. This beach is being eroded with the rate of –0.7 m/year.

4.2.6 Shore Sectors of 2 Mai to Vama Veche

The benchmarks for beach profile surveys are set at two locations in these shore sectors, one at 2 Mai and another at Vama Veche. The shoreline of the beach of 2 Mai is retreating with the rate of –0.6 m/year. There are many houses just behind the beach, but the beach erosion will not progress rapidly because the beach is a kind of pocket beach between the south breakwater of Mangalia Port and a long jetty for fishing boats.

The shoreline of the beach of Vama Veche is also retreating with the rate of –0.7 m/year, but the beach has a backshore width of about 50 m, which will be able to tolerate a certain amount of erosion in future.

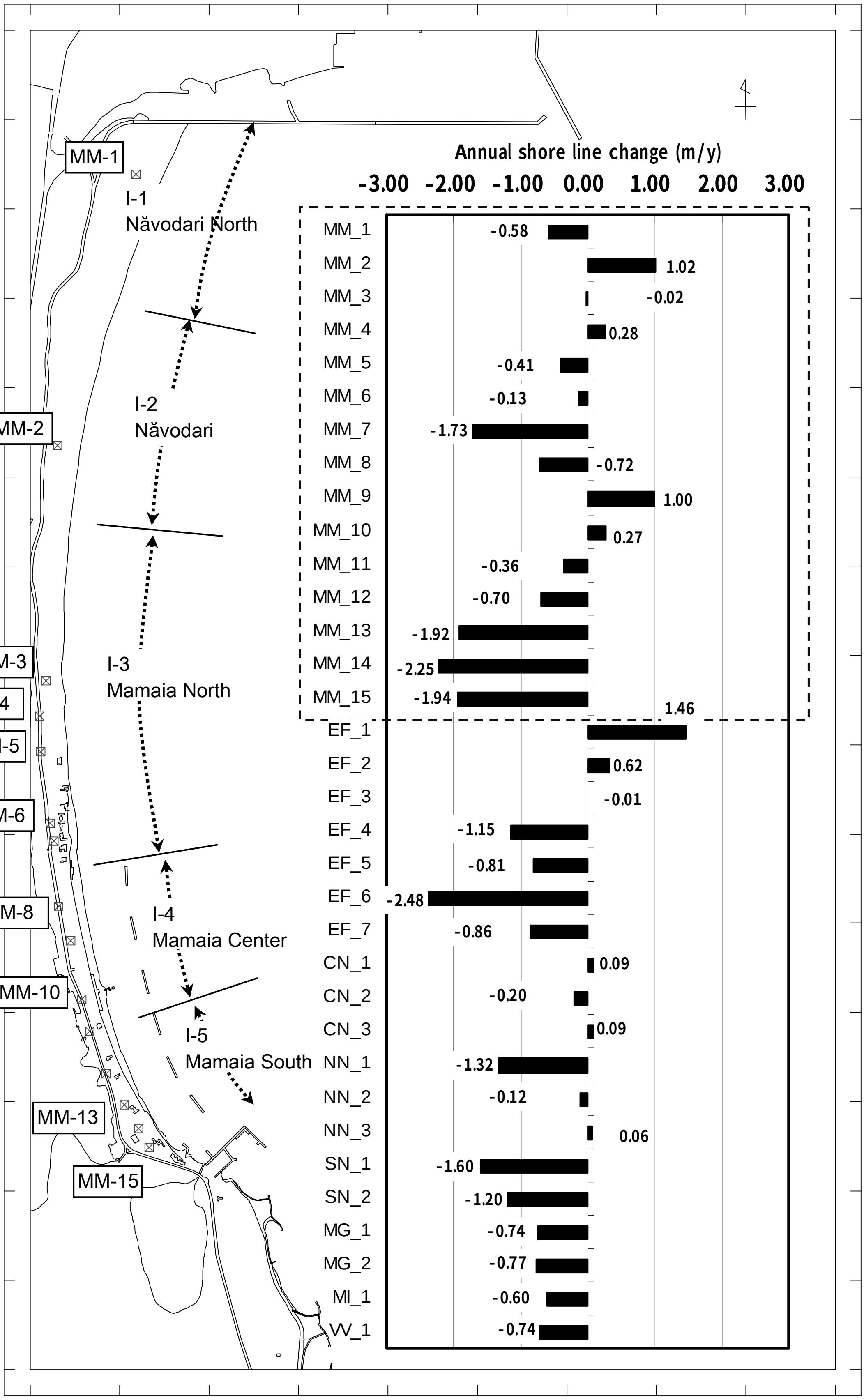

Fig. 4.2.3: Rate of shoreline position changes (2)

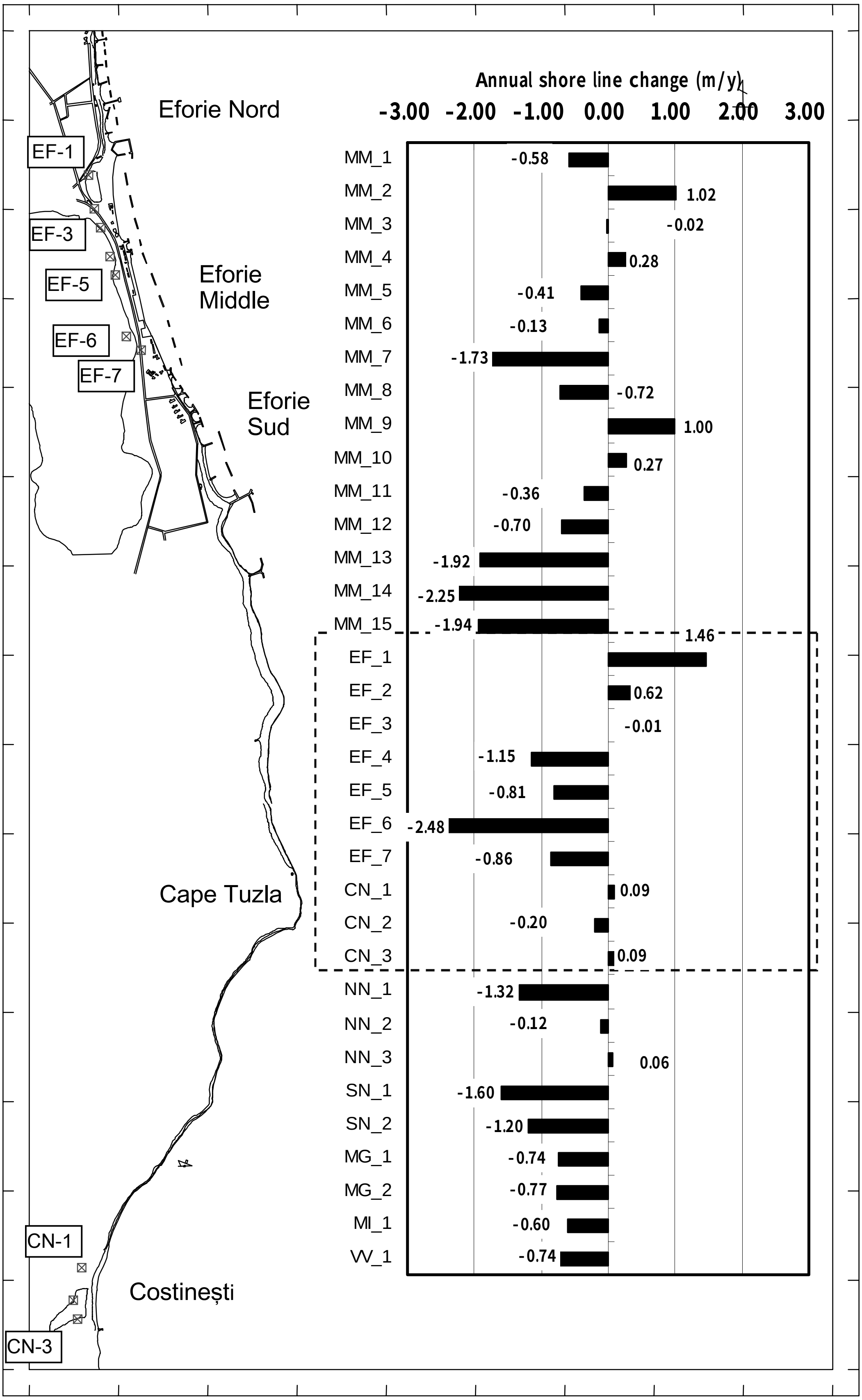

Fig. 4.2.4: Rate of shoreline position changes (3)

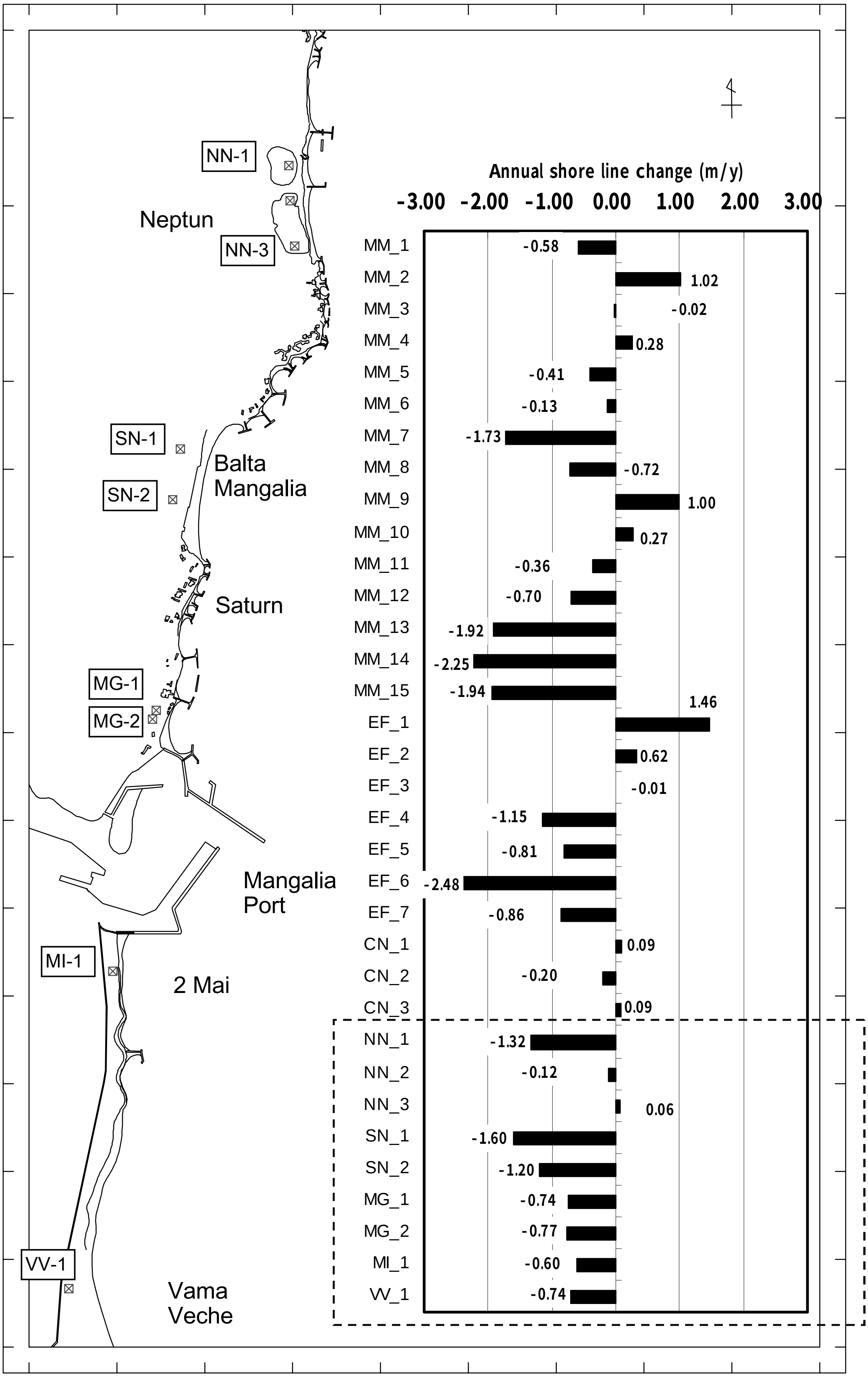

Fig. 4.2.5: Rate of shoreline position changes (4)

4.3 Sediment Sample Analysis

4.3.1 Analysis of Sediment Samples at Foreshore

(1) Alongshore distributions of median diameter and specific density

During the field reconnaissance, sediment samples were taken along the foreshore of the study area. A sample was prepared by digging a sediment mass of about 10 cm in cube around the shoreline, by mixing it well, and by taking about 500 g of sediment into a plastic bag. Thirty samples were taken in the area between Vadu (located at 17 km northeast of Midia Port) and Vama Veche. The samples were subjected for sieve analysis for grain size distribution and specific density measurements in laboratory.

Figures 4.3.1 shows the alongshore distributions of the median diameter d_{50} and the specific density γ. As a general rule along a continuous sandy beach, the grain size gradually decreases from the up-drift side of sediment transport toward the down-drift side. The specific density often becomes smaller toward the down-drift side. Within the present study area, a section from Vadu (Z-1) via Corbu (Z-2) to Midia (Z-3) can be regarded as a continuous beach. In this section, the grain size becomes smaller toward the south and the specific density becomes lighter. Thus it is estimated that the predominant direction of sediment transport is from the north to the south.

The sand grains in Năvodari and Mamaia beaches (A-1 to A-6) are largest at the sampling location A-3 at the northern part of the sub-sector Mamaia North with d_{50} = 0.69 mm; the large grain size reflects a large content of shell fragments at this location. Other locations of this shore sector indicate the median grain size between 0.2 to 0.3 mm. The specific density is relatively lighter in the north than in the south. This pattern of specific density suggests a northward sediment transport as a whole, which is supported by the analysis of alongshore sediment transport rate to be discussed in **4.5.1**.

The sub-sectors of Tomis North and Tomis South (B-1 to B-3) have the grain size larger than those in Năvodari and Mamaia beaches. Especially the sediment at the location B-1 at the north of the sub-sector Tomis North shows a large diameter of d_{50} = 0.96 mm, possibly owing to inclusion of a large content of shell fragments.

The sediment at the Eforie Sector (C-1 to C-7) has the grain size of about 0.4 mm, being larger than that of Năvodari to Mamaia sub-sectors. The sampling location C-5 at the center of this sector exhibits the median diameter of 0.75 mm, being much larger than other locations of this sector. The sediment color of this location also differs from others. Thus, there may be a possibility of the sand having been brought from some other place. The specific density is almost uniform at the value of 2.75 including the sub-sector of Eforie Sud. It is difficult to make an estimate on the pattern of sediment transport from the information of sediment distribution alone. A near-uniformity of sediment characteristics may indicate a rather small rate of net alongshore sediment transport (difference between the northward and southward transport).

The sediment at the sub-sector of Costineşti contains much large amount of shell fragments. The median diameter is 0.69 mm at D-1 and 0.44 mm at D-2, and the specific density is about 2.75.

In the Mangalia Sector (E-1 to E-5 and F-1 to F-3), small pocket beaches protected by short jetties are present and no particular pattern of sediment distribution is observed. The median diameter ranges between 0.4 and 0.7 mm with the specific density around 2.75, except for the sampling location F-2 at the southern part of Balta Mangalia, where the median diameter is small at d_{50} = 0.23 mm and the specific density is slightly light at γ = 2.72. The departure of the sediment characteristics at this location may owe to the complexity of sediment transport process in this area, but the dominant cause could not be identified.

(2) Spatial distributions of sorting coefficient and skewness

Other parameters that describe the sediment characteristics are the sorting coefficient S_0 and the skewness S_k, which are defined by the following formulas:

$$\left.\begin{aligned} S_0 &= \sqrt{d_{75} / d_{25}} \\ S_k &= \frac{d_{75} d_{25}}{d_{50}^2} \end{aligned}\right\} \qquad (4.3.1)$$

where d_{75}, d_{50}, and d_{25} represent the grain diameters at the cumulative ratio of 75%, 50%, and 25%, respectively. The sorting coefficient S_0 is greater than 1 and it is the indicator of the uniformity of grain size distribution; as the value approaches to 1, the grain sizes become nearly uniform with a sharp rise of the cumulative distribution curve. At the beach of well-sorted sediment, the sorting coefficient often takes the value around 1.25.

The skewness S_k indicates the degree of skew of the grain size distribution curve. The skewness of $S_k = 1$ represents a symmetric distribution around the median diameter, while $S_k > 1$ or $S_k < 1$ indicates the distribution is skewed toward the large or small grain size, respectively.

Figure 4.3.2 shows the alongshore distribution of the sorting coefficient and the skewness. The sorting coefficient becomes large at the sampling locations of A-3 and B-2 (Constanța Sector) where the median diameter is large possibly owing to a large content of shell fragments, but the sorting coefficient is distributed around the mean of about S_0 = 1.8 as a whole. At the locations in the Eforie Sector (C-3, C-4, and C-6) and the Olimp–Venus Sector (E-2 and E-3), the sorting coefficient has the value of around 1.25, which corresponds to that of well-sorted beaches.

The skewness is distributed around the value of 1.0 so that the grain size distribution is nearly symmetrical with respect to the median diameter.

(3) Mineral content analysis

In addition to the sieve analysis and the specific density measurements, the fluorescence X-ray analysis has been carried out to investigate the mineral contents of sediment samples. The analysis is made by irradiating X-rays to a sample of sediment and measure the wavelength-wise intensity of secondary X-ray fluorescence. By this method, the quantitative contents of various compounds can be obtained. In the present analysis, the fluorescence intensity of the four compounds of silicon dioxide (SiO_2), calcium oxide (CaO), titanium dioxide (TiO_2), and manganese oxide (MnO) were analyzed. Silicon dioxide constitutes quartz, while calcium oxide represents calcium carbonate, which is the major component of limestone and mollusk shells.

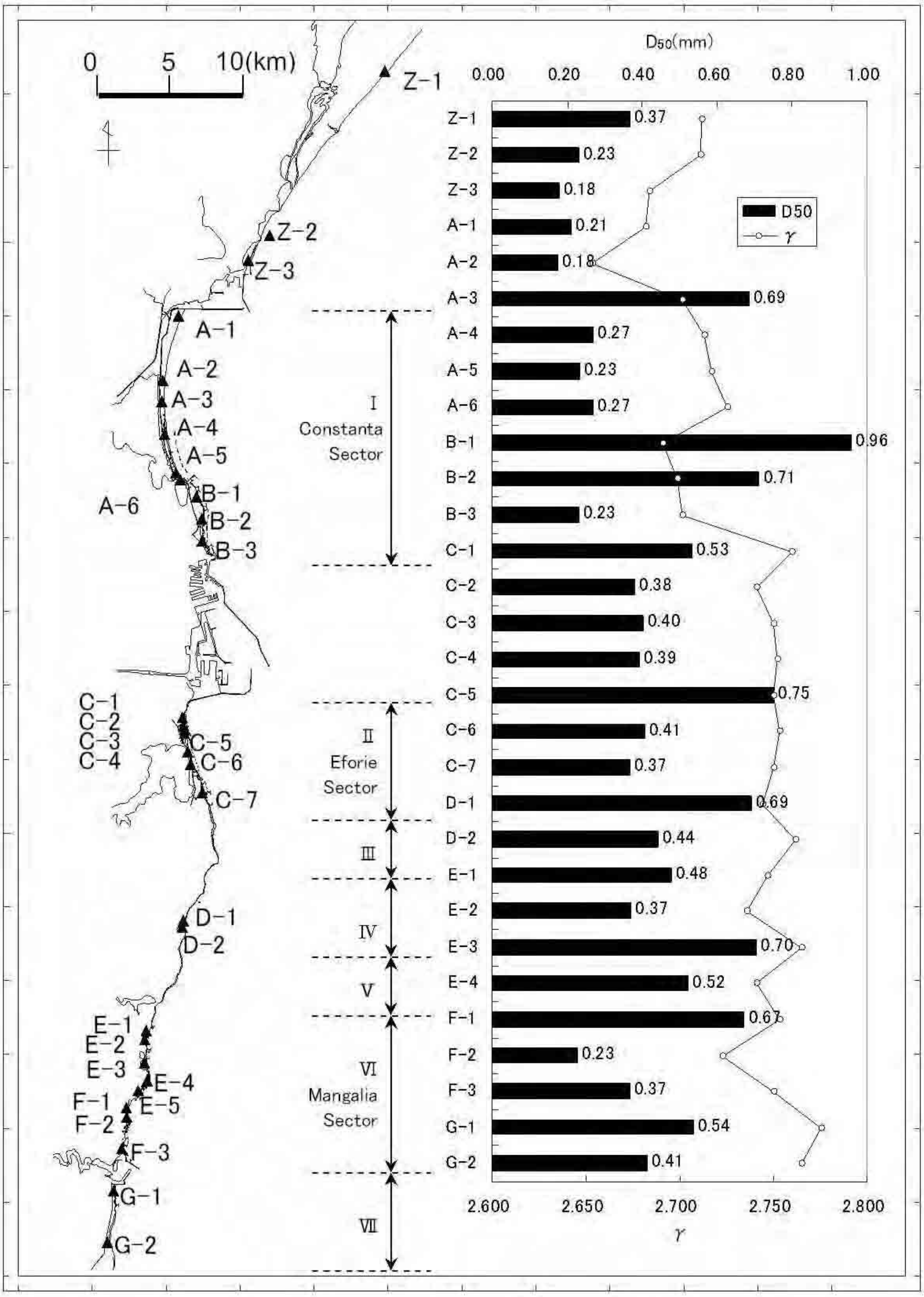

Fig. 4.3.1: Alongshore distributions of median grain size and specific density

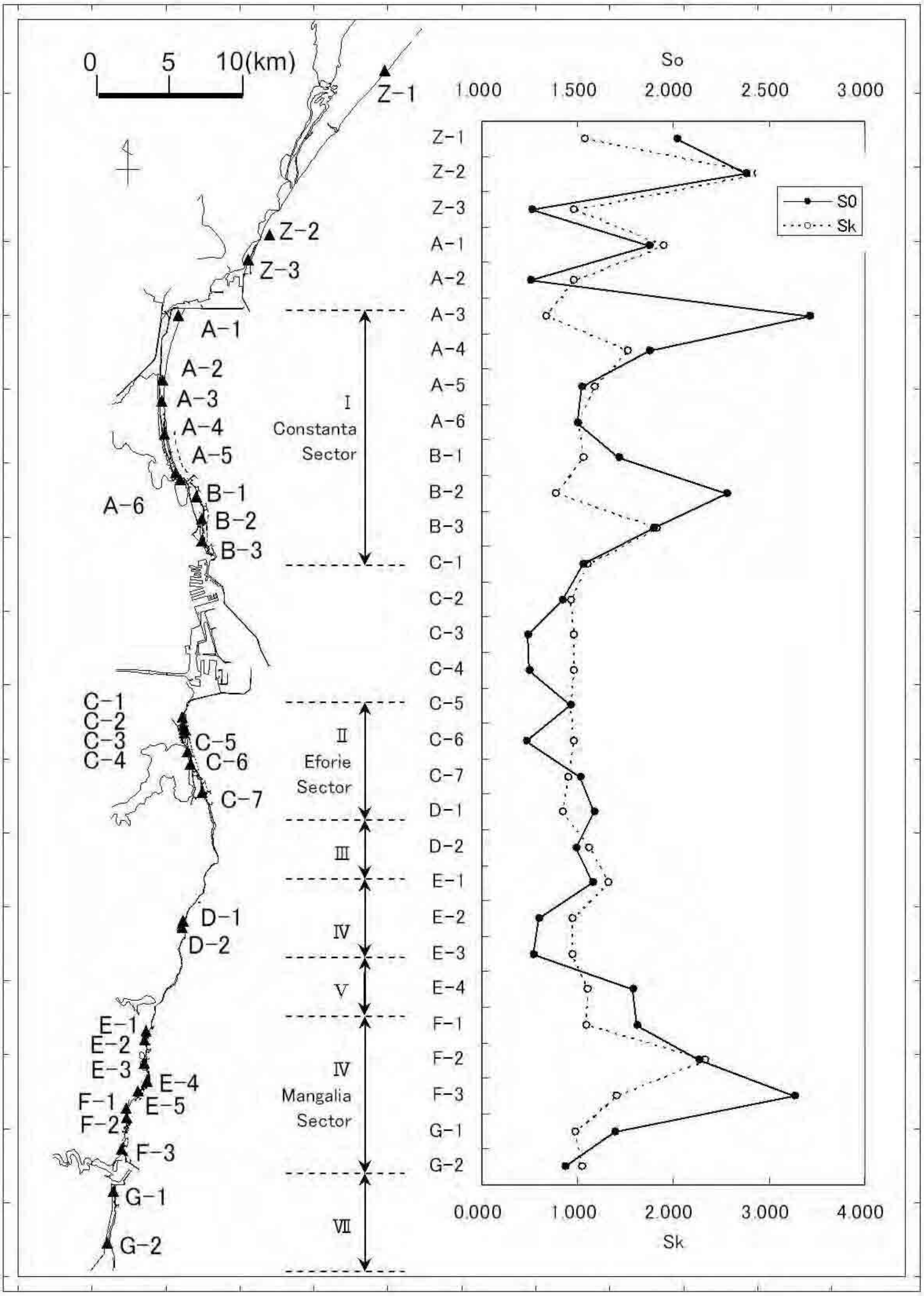

Fig. 4.3.2: Alongshore distributions of sorting coefficient and skewness

Figure 4.3.3 shows the alongshore distribution of the relative contents of SiO_2 and CaO. The sample R3 has been taken from the Danube riverbed around Călarăsi. Silicon dioxide is predominant in the area from Corbu to Tomis including the mainstream of the Danube. In the sectors south of Constanța Port, on the other hand, silicon dioxide is almost absent, while carbon oxide occupies more than 90% of mineral contents. About 25% share of SiO2 at the location F-3 may have an origin from a beach nourishment project executed some years ago, although details of the project are known.

Figure 4.3.4 is the alongshore distributions of the heavy mineral TiO_2 and MnO, which have the origin in the mountain reaches of the Danube. The two minerals appear in the samples in the sectors north of Constanța Port and in the Danube mainstream, but they disappear completely in the sectors south of Constanța Port.

The results of Figs. 4.3.3 and 4.3.4 verify the fact that the southernmost reach of the terrigenous sediment from the Danube is the sub-sector of Tomis South and the terrigenous sediment does not reach the shore south of Constanța Port.

4.3.2 Analysis of Sediment Samples on Seabed

Sediment samples were also taken from the seabed with a grab sampler from a survey boat "Marina" of the Water Directorate Dobrogea – Litoral (DADL) of Apele Romane. The depth of sampling sites varied from 3.8 to 20 m.

Figure 4.3.5 shows the spatial distributions of the median diameter and specific density, while Fig. 4.3.6 is for the skewness and kurtosis. The median diameter of the sediment grains sampled at the east of Midia Port (CC1 and CC2) is about 0.1 mm, which is smaller than those along Mamaia Beach. The sediment grains in the offshore of Eforie (AA2-05 to AA2-20) are 0.1 to 0.2 mm.

At the offshore of Costinești, the sediment grains sampled at the depth of 5 and 10 m are relatively small with the median diameter of 0.1 to 0.2 mm (AA3-5 and AA3-10). On the other hand, the sediment grains sampled at the depth of 20 m (AA3-20) have the median diameter of 0.49 mm, which is almost the same as those at the foreshore. At this location, several trials of sediment sampling were made, but most of the trials hit the rocky seabed and failed to sample the bed material. One successful trial yielded the sample containing a few live shells. Thus it is estimated that the seabed is basically of rock foundation, on top of which a thin layer of shell fragments is spread out.

At the offshore of Vama Veche, the sediment grains with the median diameter of 0.15 mm were obtained (AA4-20). The sampling points BB1 and AA5-1 are located within the harbor of Mangalia Port. At the depth of 5 and 10 mm off Vama Veche, however, the seabed was found to be the rocky foundation.

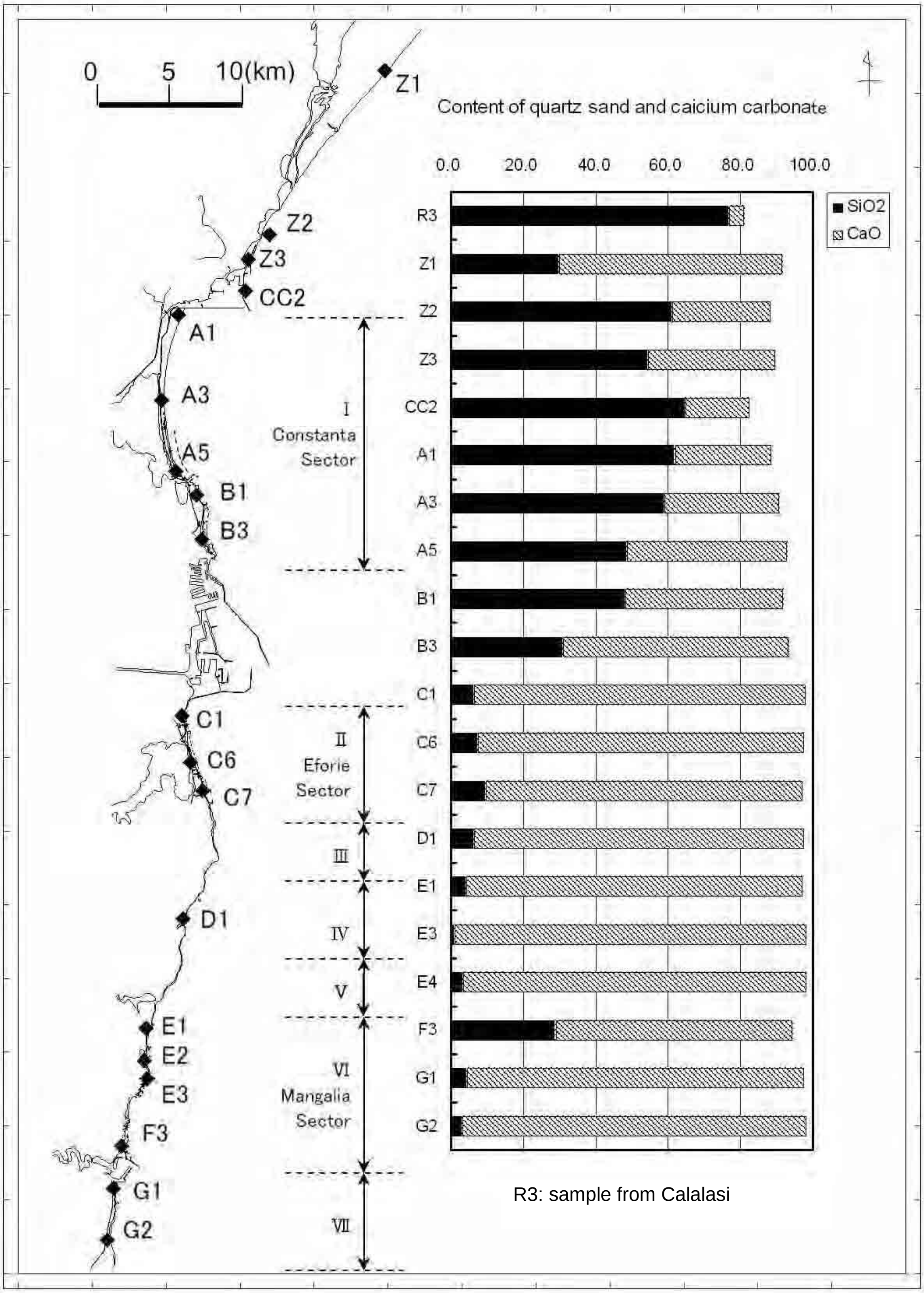

Fig. 4.3.3: Alongshore distributions of mineral contents of SiO_2 and CaO

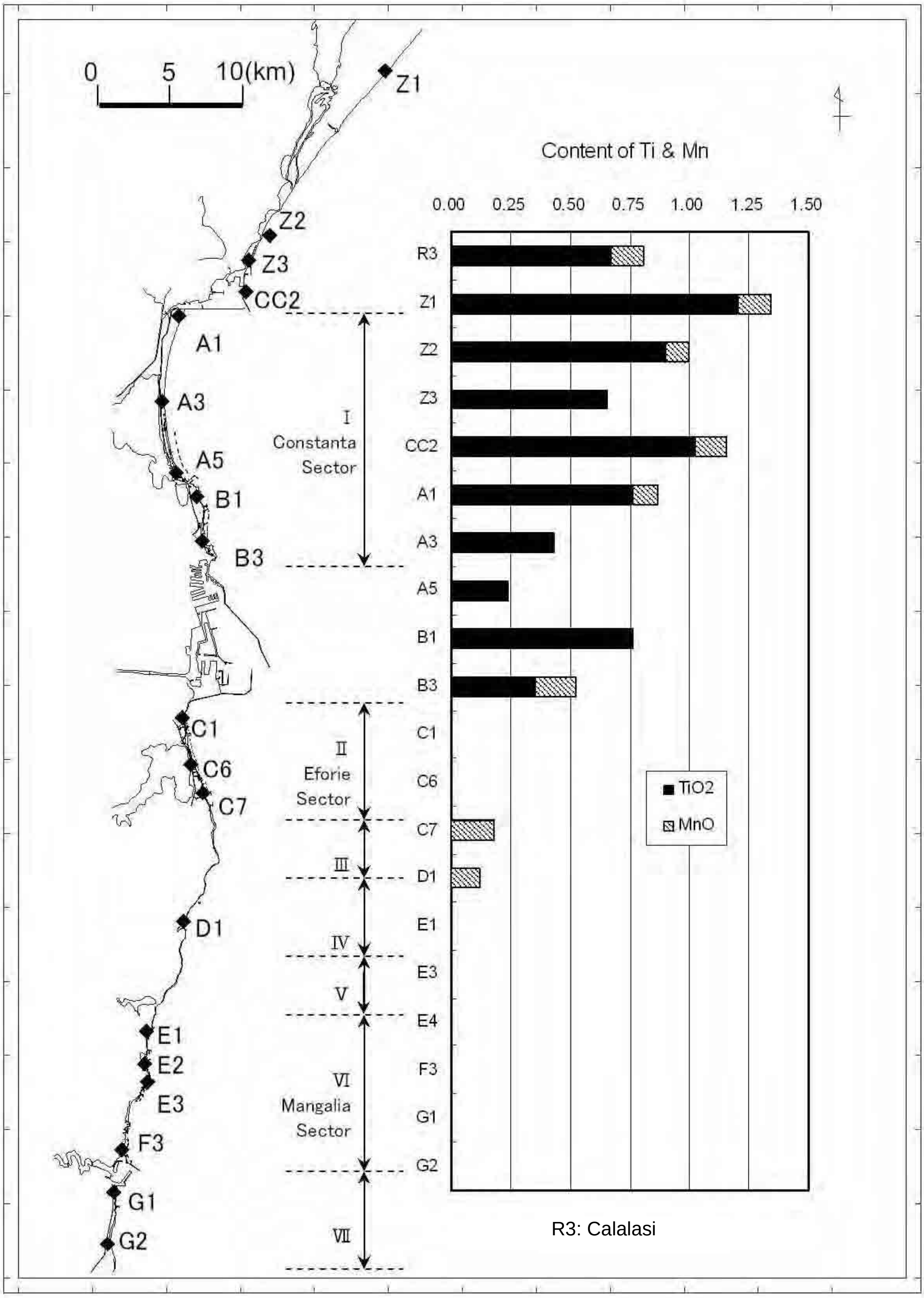

Fig. 4.3.4: Alongshore distributions of mineral contents of TiO_2 and MnO

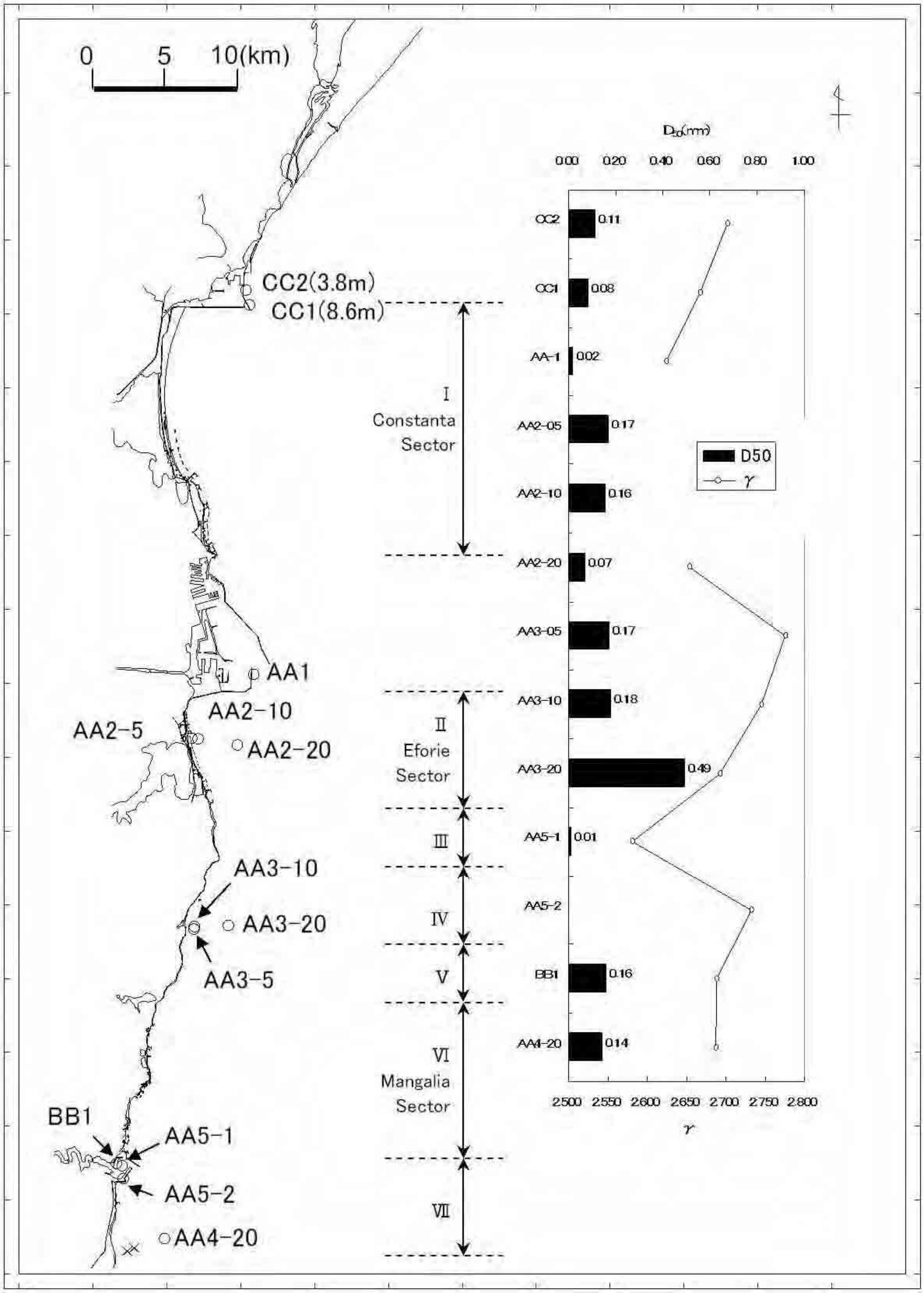

Fig. 4.3.5: Median grain size and specific density of sediment samples from seabed

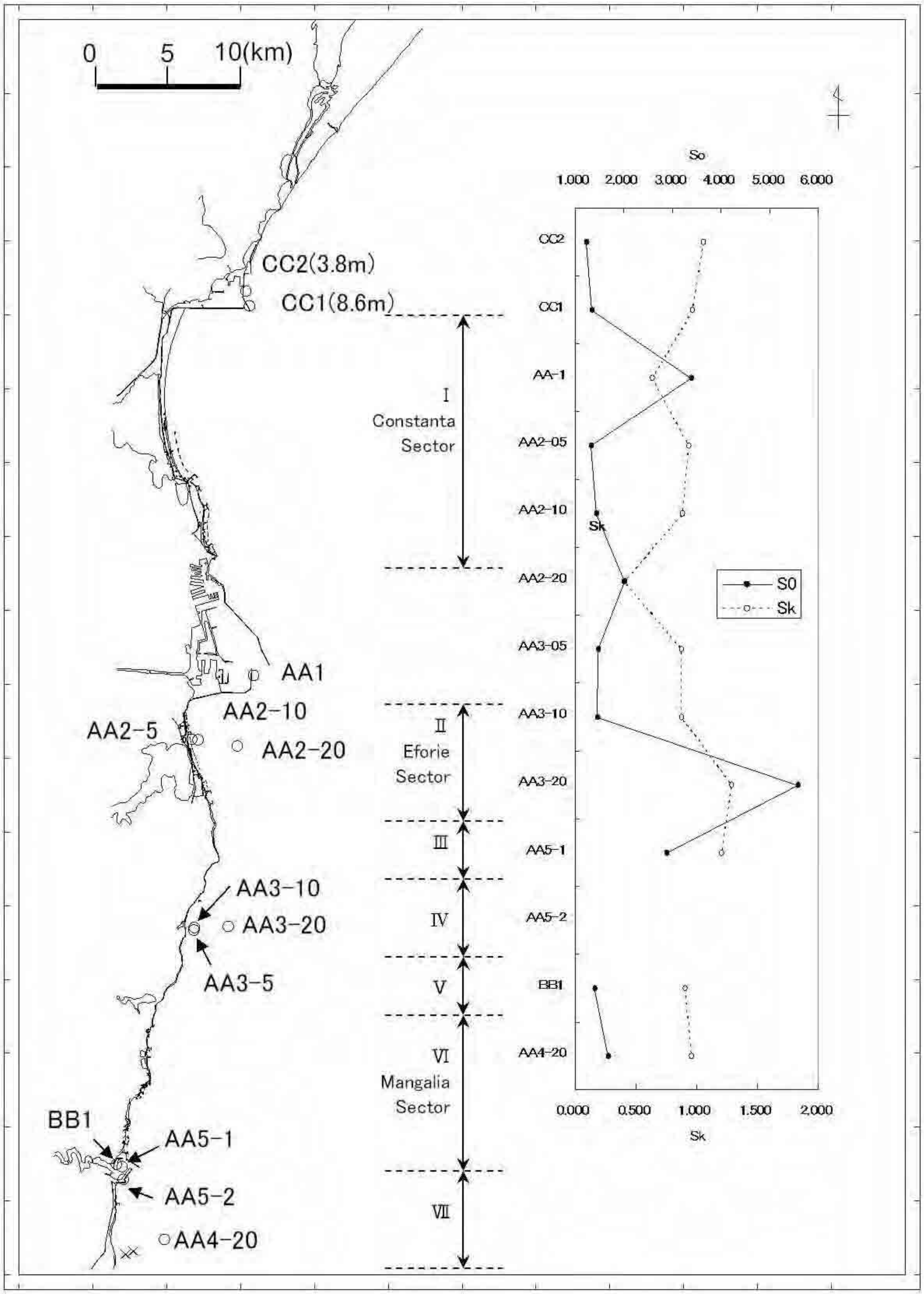

Fig. 4.3.6: Sorting coefficient and skewness of sediment samples from seabed

4.4 Mechanism of Beach Erosion along the Romanian Black Sea shore

4.4.1 Mean Rate of Shoreline Position Changes at Respective Shore Sectors

Two analyses of the shoreline position changes were reported in **4.1.1** and **4.1.2**: the former based on comparison of historical maps and the latter based on beach profile surveys. The results of the estimate of the mean rate of the shoreline position change are summarized in Table 4.4.1. The mean rate of the shoreline position change is inclusive of those due to the mean water level rise of 2.2 mm per year, ranging from –0.08 to –0.18 m per year, as discussed in **3.3** and **4.6**.

The mean rate of the shoreline position change in the northern unit is an approximate estimate, because of large distance between the benchmarks compared with that in the southern unit.

Table 4.4.1: Mean rate of beach erosion in shore sectors

Black Sea shore	Sector Name	Sub-sector name	Mean erosion rate (m/year)	Remarks
Nortern unit	None	Sulina – Sf. Gheorghe	–2.8	[2]
		Sakhalin Island	–10	[2]
		Zato	–2.2	[2]
		Peristor – Portița	+1.7	[2]
		Portița – mid-Chitu	–3.0	[2]
		Corbu	+2.5	[2]
Southern unit	I. Constanța	I-1 Năvodari North	–0.6	[2]
		I-2 Năvodari South	+1.0	[2]
		I-3 Mamaia North	–0.4	[2]
		I-4 Mamaia Center	+0.2	[2]
		I-5 Mamaia South Whole Southern part	 –1.4 –2.0	[2]
		I-6 Tomis North	–0.2	[1]
		I-7 Tomis South	–0.2	[1]
	II. Eforie	II-1 Eforie Nord	+1.5	[2] around the marina
		II-2 Eforie Middle	–0.7	[2]
		II-3 Eforie Sud	–0.6	[1]
	III. Tuzla	III-1 Tuzla North	–0.7	[1]
		III-2 Tuzla South	–0.7	[1]
	IV. Costineşti	IV-0 Costineşti	±0.0	[1] and [2]
	V. 23 August	V-0 Schitu	–0.7?	Probably similar as III
	VI. Mangalia	VI-1 Olimp–Venus	–0.5	[2]
		VI-2 Balta Mangalia	–1.4	[2]
		VI-3 Saturn–Mangalia	–0.8	[2]
	VII. Limanu	VII-1 2 Mai	–0.6	[2]
		VII-2 Limanu	–2.0	[1]
		VII-3 Vama Veche	–0.7	[2]

Note: [1] is based on the analysis of historical maps and [2] is based on the beach profile analysis.

4.4.2 Mechanism of Beach Erosion at the Northern Unit

The Danube Delta has been formed during the late Quaternary period, especially in the Holocene. Large supply of the sediment by the Danube has expanded the deltaic area and helped the growth of several sand spits toward the south. Lake Razim and Lake Sinoie were originally embayments of the Black Sea, but they became lakes by closure of their entrance with growth of barrier beaches.

In 1897, an event of exceptionally high flood took place through the branch of Sf. Gheorghe and it created Sakhalin Island off its mouth.[3] With no further sediment supply from the Sf. Gheorghe, the offshore-side shore of the island is eroded by waves and currents, and the eroded sediment has been transported toward the southwestern tip of the island. The result is a gradual elongation and shift of the island toward the northwest.

Decrease of the sediment discharge of the Danube in the past centuries has caused gradual erosion of sandy shores and barrier beaches. According to the formula by Bondar and Panin[4], the total amount of sediment transport is estimated as 73 million m^3 in the mid-19th century, but it becomes 36 million m^3 around 1990, though annual variation is quite large. Sediment is mostly clay and silt, and the content of fine sand is about 4%. Beach erosion has been accelerated in recent years as discussed in **4.2.2**. The barrier beaches of Lake Razim and Lake Sinoie are being threatened of eventual breaches by erosion.

Beach accretion at some sections of the northern unit is caused by the surplus of the sediment inflow from the east over the outflow to the west of respective sections, which is mainly governed by the orientation of the coastline with respect to the predominant wave direction.

The northern unit of the Romanian Black Sea shore is not included in the scope of the Study. Therefore, no further analysis of the northern unit will be made in the present report.

4.4.3 Mechanism of Beach Erosion at Năvodari – Mamaia Beaches

As described in **3.6.1**, the beaches of Năvodari and Mamaia have suffered from intensive erosion, which is caused by the stoppage of southward sediment movement by the north breakwater of Midia Port. Sediment carried by longshore currents induced by northerly waves was impounded by the breakwater and forced to be dispersed offshore in the southeasterly direction. Some sand and mud managed to detour the breakwater head and deposited in the water of 8 to 12 m deep, as indicated in the bathymetric survey results by the port authority. However, the water was too deep for waves to agitate and bring forth the deposited sediment into motion again. Judging from the records of bathymetric charts, the depth of 5 m seems to be the limit of an impounding structure around which sediment can be transported by wave-induced longshore currents.

The north breakwater of Midia Port exercises the wave sheltering effect to the northern part of the long beach. Waves in the inshore area are high in the south and low in the north. The gradient in the wave height distribution induces the net northward sediment movement when evaluated over a full year. Thus the southern part of Mamaia beach is more eroded than the northern part of Năvodari. The tendency of sediment movement should cause beach accretion at the north end of Năvodari from which the south breakwater of Midia Port extends eastward. However, the latter breakwater of more than 2 km long partially reflects southerly waves and blocks the sand accumulation at the base of the breakwater. Sand must be transported offshore

[3] Panin, N.: On the geomorphologic and geologic evolution of the River Danube – Black Sea interaction zone, GEO-ECO-MARINE, 2/1997, pp. 31-40.
[4] Bondar, C. and Panin, N: The Danube delta hydrologic database and modelling, *GEO-ECO-MARINA*, 5-6/2000-2001, pp. 5-52 (see Table 4).

along the breakwater with the result of slight beach erosion as indicated by the data of the benchmark MM-1 in Fig. 4.2.3. The beach advance at the MM-2 location is an evidence of the northward sediment transport.

The erosive tendency at the MM-7 and MM-8 locations is the result of the local wave condition such that the wave height around MM-9 and MM-10 is lowered by the wave damping produced by the offshore breakwaters compared with the area around MM-7, which is located outside the wave sheltering zone.

The beach fill project executed in 1989 at Mamaia South has been referred to as a failure, because the beach advancement gained by beach fill was lost in a short time. However, a quite large portion of nourished sand has been deposited between the shoreline and the offshore breakwaters. The water depth at the breakwaters was originally 5 m, but nowadays it is about 3 m just behind the breakwaters. The nourished sand was of fine grain sizes around 0.1 mm and it could not maintain the initial beach slope against the incoming wave conditions. The equilibrium beach slope for this grain size seems to be 1:150 to 1:200 based on the bathymetric data of the present beach condition.

4.4.4 Mechanism of Cliff and Beach Erosion at Tomis Sub-sectors

The coast in the northeastern part of Constanța City is made of cliffs and narrow beaches. As described in **3.6.2**, a number of housings have been built at the edge of cliffs and they are susceptible to destruction by collapse of cliffs, which will be the result of geotechnical instability by the rise of water table in the upper soil of cliffs when heavy rain falls on the locality or when a large leakage of water from waste water pipes etc. takes place.

In addition, progress of the erosion of narrow beaches will eventually invites direct attack of waves upon the feet of cliffs. When it happens, the feet of cliffs will be scoured by wave actions and the cliffs will collapse as seen along the Tuzla sector (see **3.6.4**). Although such events will not occur soon, some protective measures need to be taken against the beach erosion and cliff collapse.

4.4.5 Mechanism of Beach Erosion at Eforie Sector

The mechanism of the shoreline changes in the sub-sectors of Eforie Nord and Eforie Middle is a gradual cliff retreat as evidenced in Fig. 4.1.4 and the tombolo formation behind the marina “Yacht Club Europa” as discussed in **3.6.3**.

A rapid retreat of the shoreline around the benchmark locations EF-6 and EF-7 as shown in Fig. 4.2.4 is considered mainly as the result of tombolo formation. It must also have been caused by the increase of wave reflection from the collapsed seawall in front of a sanatorium at the northern part of Eforie Sud. The following process of morphological change of the beach is thought to have taken place:

1) The seawall for the promenade was built in front of the existing cliff by stretching out its frontline into the sea.
2) A narrow, thin beach may have existed at the time of seawall construction, but it must have been washed out by waves running up the beach on stormy conditions.

3) With disappearance of the beach, even medium to low waves began to hit the seawall directly and were reflected, causing erosion of the sediment on the seabed in front of the seawall.
4) Increase of water depth caused the increase of wave reflection by the seawall, and a large-scale erosion of the seabed took place, which induced the collapse of the jetty there.
5) In the sub-sectors of Eforie Middle and Eforie Sud, calculation of alongshore sediment transport based on the wave energy flux throughout a year has indicated the net transport toward the north. With no sediment supply from the south, the beach at the south end of Eforie Middle was forced to retreat: i.e. beach erosion.

The area of resort beaches in Eforie Sud has not been surveyed for beach profile changes, because no benchmarks were established there by the National Institute for Marine Research and Development. As described in **4.1.3**, the area experienced the shoreline retreat of 40 to 80 m in the period between 1924 and 2002. The retreat is similar as the cliff erosion in the Tuzla Sector and is considered as the natural process of coastal geomorphology of the Romanian Black Sea shore. In this area, the shore protection facilities of large and small jetties shown in Fig. 5.2.6 were built in the period of 1956 to 1960 as listed in Table 5.2.1. They must have been effective to prevent further erosion of resort beaches, but at the same time they must have hindered the northward transport of sediment that was needed to maintain the beach in Eforie Middle.

4.4.6 Mechanism of Cliff Erosion at Tuzla and Schitu Sectors

The state of cliff erosion has been described in **3.6.4** and **4.1.3**. Erosion of cliffs is a rather common feature of coastal morphology in the world. Zenkovich[5] states that parts of the east coast of England consisting of unconsolidated Quaternary deposits are receding at an unusually rapid rate averaging between 2.1 and 4.5 m per year. In the United States, Dean[6] cites several estimates of historical erosion rate of the Outer Cape Cod cliffs, which varies from 0.66 to 0.97 m per year. Horikawa[7] refers to Sunamura's work on cliff erosion, who compiled the mean erosion rate of cliffs in Japan, ranging from 0.3 to 2.2 m per year. One of the cliff coasts in Japan, Byobugaura in Chiba Prefecture, has receded more than 2000 m since the twelfth century.

Erosion of cliffs often yields the material for retardation of the erosion of neighboring beaches. Thus, prevention of cliff erosion by means of seawalls and/or revetments at the feet of cliffs may cause erosion of nearby beaches, as exemplified in many places in the world.

4.4.7 Stability of Costinești Beach

The beach of Costineşti has been stable without significant erosion as a whole, although the northern part is erosive and the southern part is accretive, as described in **4.1.3**. The stability of beach owes to a nearly perfect balance between the northward and southward alongshore sediment transport as will be discussed in **4.5.1**. The stability also seems to have been supported by ample production of mollusks in the cliff coasts of Tuzla and Schitu, which yields a large amount of shell fragments for beach sand. Limestone clasts produced from the

5 Zenkovich, V.P. (1962): Process of Coastal Development (English translation edited by J.A. Steers in 1967), Oliver & Boyd, Edinburgh and London, p.164
6 Dean, C. (1999): *Against the Tide*, Columbia Univ. Press, New York, p.18.
7 Horikawa, K. (1978): Coastal Engineering, University of Tokyo Press, pp. 239-242.

feet of erosive cliffs must have also contributed to the stability of Costineşti beach.

4.4.8 Mechanism of Beach Erosion at Mangalia Sector

In this shore sector, the beach in front of Lake Neptun (NN-1) and the beach at Balta Mangalia have been retreating with the rate exceeding –1.2 m/year, as described in **4.2.5**. The cause of the erosion in excess of the natural cliff erosion rate of about 0.6 m/year is not clear, but the protection of low cliff areas in Olimp, Jupiter, Venus, and Saturn with construction of many coastal structures may have hindered free movement of sediment along the shore and caused the erosion of the two natural beaches.

4.4.9 Mechanism of Beach Erosion at Limanu Sector

It was reported that the sub-sector of 2 Mai experienced a rapid retreat of the shoreline with the rate exceeding 2 m/year during the period from 1913 to 1960. It must have been caused by the construction of a breakwater for a fishing harbor (see Fig. 3.6.1), which stopped the southward transport of sediment. Expansion of Mangalia Port with construction of long breakwaters accelerated beach erosion at the sub-sector of 2 Mai. However, the shoreline surveys since 1973 indicate a low rate of the shoreline retreat down to about 0.6 m/year as described in **4.2.6**.

The cause of the erosion of Vama Veche beach is not known at this stage; it may be in pace with the retreat of the cliffs in the north and south as the natural coastal morphological process.

4.5 Prediction of Future Shoreline Changes

4.5.1 Alongshore Sediment Transport Rate

(1) Simulation model for shoreline change prediction

In the present study, shoreline changes are simulated with a model based on the one-line theory, the methodology of which is described in Annex **E.5**. The model has been selected because of its reliability when good field data are available for calibration. The input data are the representative beach profiles, the depth of closure, the wave characteristics (spectrum, height, period, and direction), the proportionality coefficients of the alongshore sediment transport rate formula, and the rate of cross-shore sediment transport rate. The beach profiles and the depth of closure have been determined on the basis of field data and others as described in E.4, and the wave characteristics are discussed in **(2)** below.

The simulation model has been calibrated with past records of the shoreline changes evaluated from the topographic surveys as described in **4.1**. The calibration has assisted selection of the optimum values of the sediment transport coefficients and the cross-shore transport rate as listed in Table E.6.2 in Annex **E.6.2**. The calibration has verified the reliability of the simulation method to be discussed in **4.5.2**. The calibration has also yielded the estimate of the rate of alongshore sediment transport for the entire beaches within the study area from Năvodari to Vama Veche.

(2) Representative waves for simulation

For the shoreline change simulation, the two wave conditions listed in Table 4.5.1 were selected to represent the northerly and southerly waves. The dimensions of the two representative waves were selected by taking the energetic averages of the ECMWF wave data over the period of ten years; refer to Annex **E.6** for details. In execution of numerical simulation, the energy level of the northerly and southerly waves has been varied on the monthly basis so as to introduce seasonal changes of shoreline positions.

Table 4.5.1 Wave conditions for shoreline change simulation

Waves	Northerly waves	Southerly waves
Wave direction	N64.0ºE	N115.2ºE
Wave height, $H_{1/3}$ (m)	1.65	1.11
Wave period, $T_{1/3}$ (s)	6.2	6.2
Directional spreading, s_{max}	25	25

The wave direction is set at the location of the longitude 44.0ºN and the latitude 29.0ºE, where the wave hindcast by ECMWF was given. However, adjustments have been made for the wave direction by taking into account of the bias of ECMWF data due to its deepwater assumption in wave hindcast as discussed in **3.4.1 (4)**. The data of wave direction observed by NIMRD was mainly referred to when the directions of the above representative waves were determined.

The wave transformation from the offshore to the nearshore was computed by solving the energy balance equation. The computation area of 120 km (alongshore) and 65 km (cross-shore) shown in Fig. 4.5.1 was employed for wave transformation analysis.

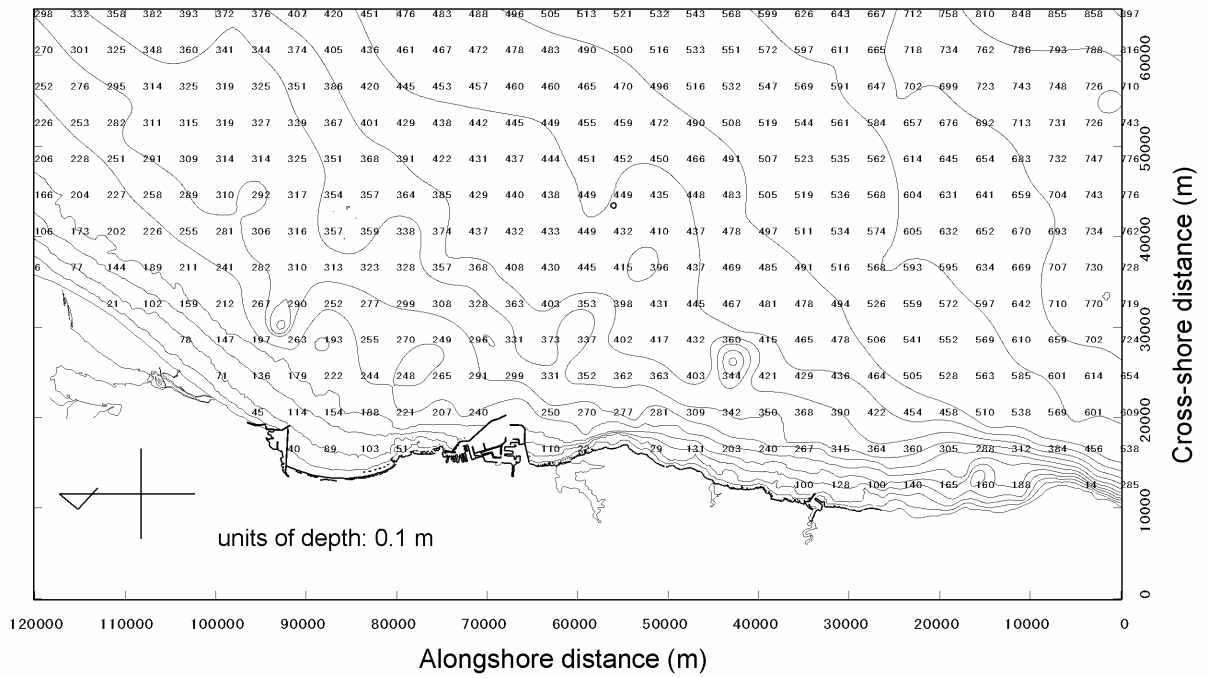

Fig. 4.5.1: Computation area for wave transformation

A small circle at the alongshore distance 57,000 m and the cross-shore distance 43,000 m corresponds to the wave hindcast point. Though the grid points in Fig. 4.5.1 are shown with the spacing of 4,000 m, actual computation was carried out the grid spacing of 250 m in both the alongshore and cross-shore distances.

Examples of the results of wave transformation computation are shown in Figs. 4.5.2 and 4.5.3 for changes of wave directions. Owing to wave refraction effect, the wave directions are gradually deflected toward the lines normal to the depth contours as waves propagate near the shore. Though not shown here, the areas south of the ports of Midia and Constanța have the reduced wave heights owing to wave diffraction effect for the northerly waves.

In the nearshore zones with the water shallower than 4 m or so, detailed wave analyses were made for the coastal sectors with the grid spacing of 20 m by using the regular wave approximation. The analyses yielded the wave height and direction at breaking at every 20 m along the coast, which were input for the sediment transport rate formula with consideration of the presence of breakwaters, jetties and other structures.

The representative waves listed in Table 4.5.1 are the annual averages. Actual computation of wave transformation and sediment transport rate was carried out by multiplying the wave energy of the northerly and southerly waves with their monthly energy ratios in consideration of their occurrence frequency, which are listed in Table E.6.1 of Annex **E.6.1**. Thus, seasonal variations of sediment transport and shoreline changes have been simulated.

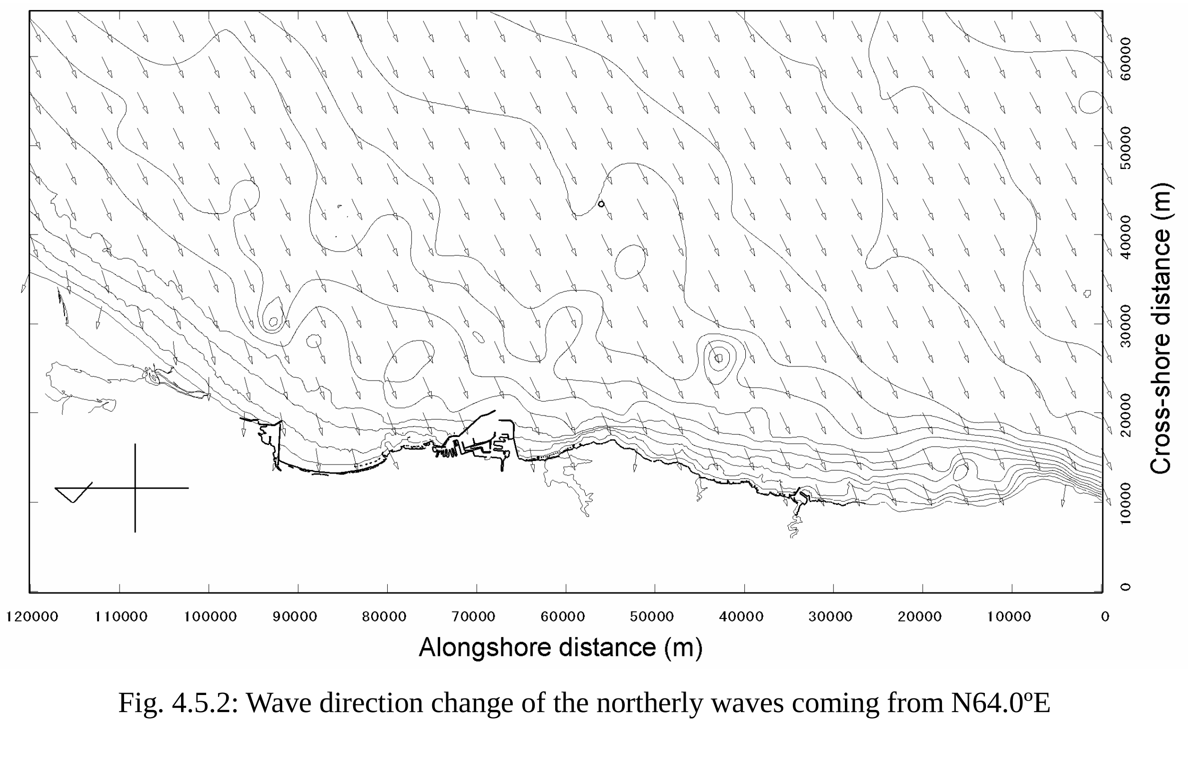

Fig. 4.5.2: Wave direction change of the northerly waves coming from N64.0ºE

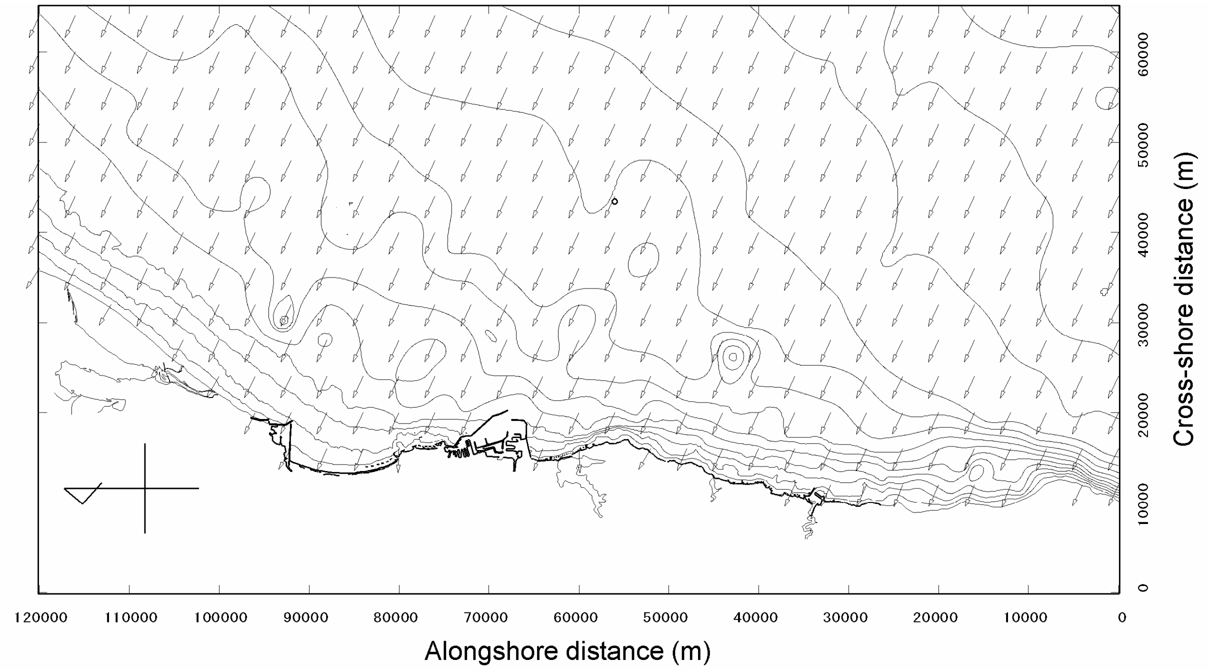

Fig. 4.5.3: Wave direction change of the southerly waves coming from N115.2ºE

(3) Sediment transport rate

The rate of alongshore sediment transport is mainly governed by the incident wave energy and the orientation of the shoreline relative to the wave direction at breaking. The sediment grain size indirectly affects the sediment transport rate through the empirical proportionality constant *K* in such a way that a coast composed of fine sediment has a larger rate than the coast of coarse sediment. Presence of breakwaters, jetties, and other structures also affects the sediment transport by modifying the wave energy reaching to the shoreline.

Reliable estimate of sediment transport rate is only possible by means of field measurement in such a place where alongshore sediment transport is impounded by a jetty or some barriers. Detailed topographic and bathymetric surveys in the area concerned before and after construction of a barrier can indicate the impounded volume of sediment; the mean rate of sediment transport can be deducted from such a data. If the simultaneous wave measurement data is available, the empirical constant value is assessed and the process enriches the database of the constant *K* for the sediment transport rate formula (see Annex **E.5.2** for the formula).

In case of the study area, the topographic survey maps intermittently prepared from 1960 to 1997 and described in **4.1.1** provide the basic data for calibration of the constant *K* and the shoreline simulation model. The rate of alongshore sediment transport is very sensitive to the plan shape of the shoreline, because a slight change causes a significant difference in the shoreline orientation relative to the wave direction at breaking. Except for the coast with extensive sediment transport in one direction such as the coast of Chennai (Madras) in the Southeast India, most of shorelines appear to converge to equilibrium stage after some lapse of time in shoreline simulation. It means that the alongshore sediment transport rate decreases gradually and becomes null at the equilibrium stage. In the following, the results of the calculation of alongshore sediment rate are shown as the mean value of five years, starting from the shoreline geometry in January 2006 and ending in December 2010.

Figure 4.5.4 shows the sediment transport rate in the coast from Năvodari to Tomis Tourist Port. The upper panel is the plan shape of the coast with the initial shoreline in January 2006, the calculated shoreline in December 2010, and the location of seawalls. The middle panel shows the southward and northward sediment transport rates. The net transport rate, which is the difference between the both rates, is indicated with red line. The lower panel is the net transport rate on an enlarged scale. Because presence of breakwaters and jetties causes some decrease in wave energy reaching at the shore, the areas with these structures have large variations in the sediment transport rate in both the southward and northward directions.

In the center of this coast where natural beaches stretch, the northward transport is up to about 160,000 m^3 per year while the southward transport is up to about 140,000 m^3 per year. The difference is about 20,000 m^3 per year in the northward direction. The maximum rate of the net northward transport at 24,000 m^3 per year is observed at the location from 9,000 to 10,000 m, which is behind the northernmost detached breakwater. Around this location, the alongshore gradient of wave height is largest. The significant erosive tendency at the benchmarks MM-7 and MM-8 shown in Fig. 4.2.3 corresponds to the largest net transport rate there. In the center of Tomis sub-sector, the southward and northward sediment transport rates amount to about 260,000 m^3 per year, but they are almost equal in the magnitude and do not produce any net transport.

The alongshore sediment transport rate in the Eforie Sector is shown in Fig. 4.5.5. Two cases of calculation are presented here; one under the present topography with cliffs and seawall and another under an imaginary condition with wide beach areas without presence of cliffs and seawalls. In the former case, the retreat of shoreline is stopped when it reaches the foot of cliff or seawall, while in the latter case the shoreline continues to retreat without limitation of cliff or seawall.

The difference between the two cases is most noticeable in the Agigea area. If unlimited by the existing cliff, beach sand would be transported southward with the rate of 8,000 m^3 per year; the southward transport there is due to the NW–SE orientation of the shoreline even though the northerly waves are much weakened by the wave sheltering effect of the breakwater of Constanța Port. Except for the Agigea area, the net sediment transport is generally northward with the maximum net rate of about 7,000 m^3 per year at Eforie Middle, while the one-directional (northward or southward) alongshore sediment transport rate amounts to about 100,000 m^3 per year. A smaller rate of sediment transport in Eforie than that in Mamaia owes to a smaller value of the constant *K* assigned to this area in recognition of the presence of coarser sediment.

The sediment transport rate around Costinești is shown in Fig. 4.5.6 under the condition of the presence of cliffs. The northward and southward sediment transport rates are both about 100,000 m^3 per year, and they are almost equal so that the net transport is slightly southward with the rate of 60 m^3 per year only. The very small rate of the net sediment transport explains a healthy stability of Costinești beach.

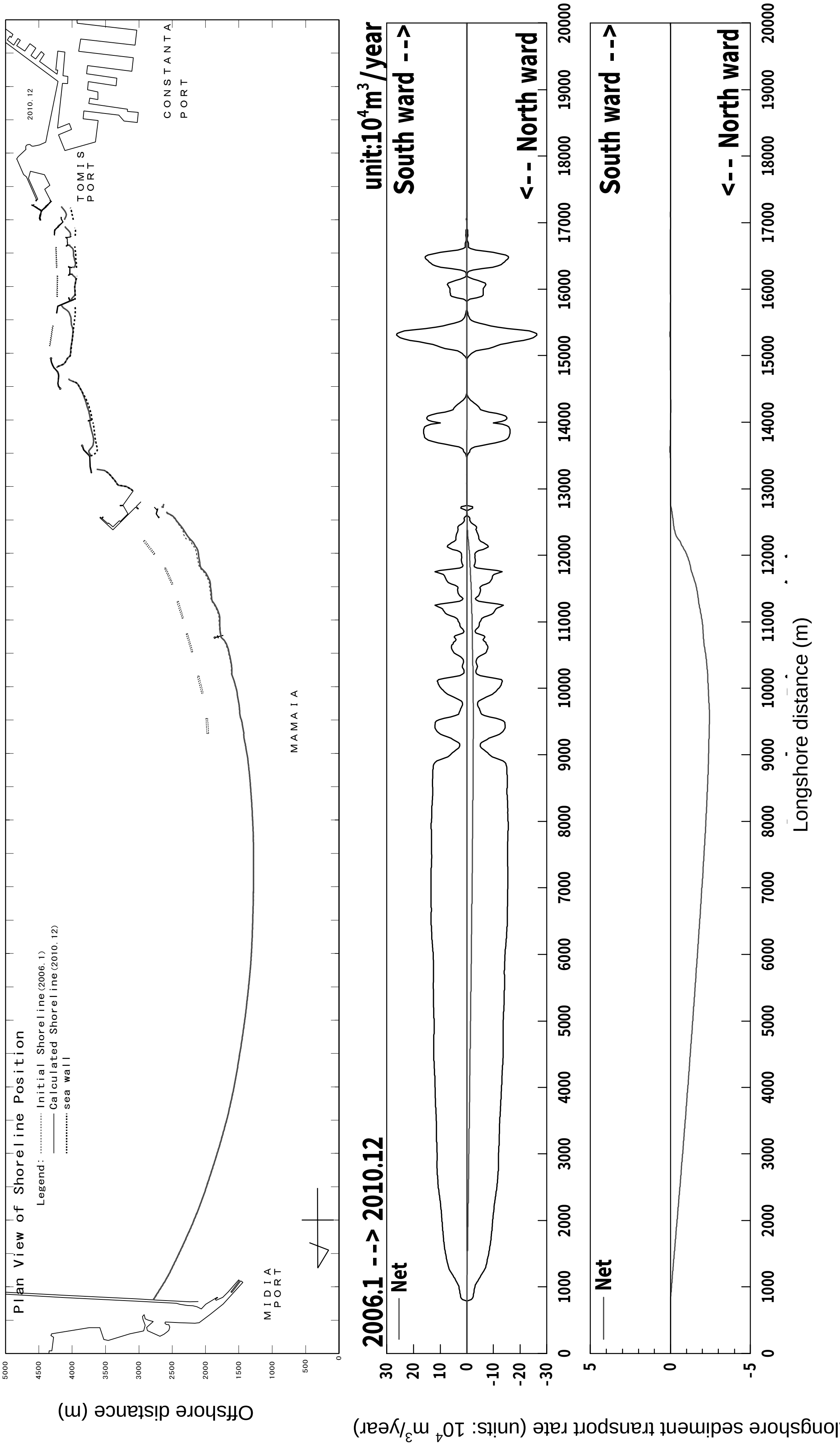

Fig. 4.5.4: Alongshore sediment transport rate in the coast from Năvodari to Tomis

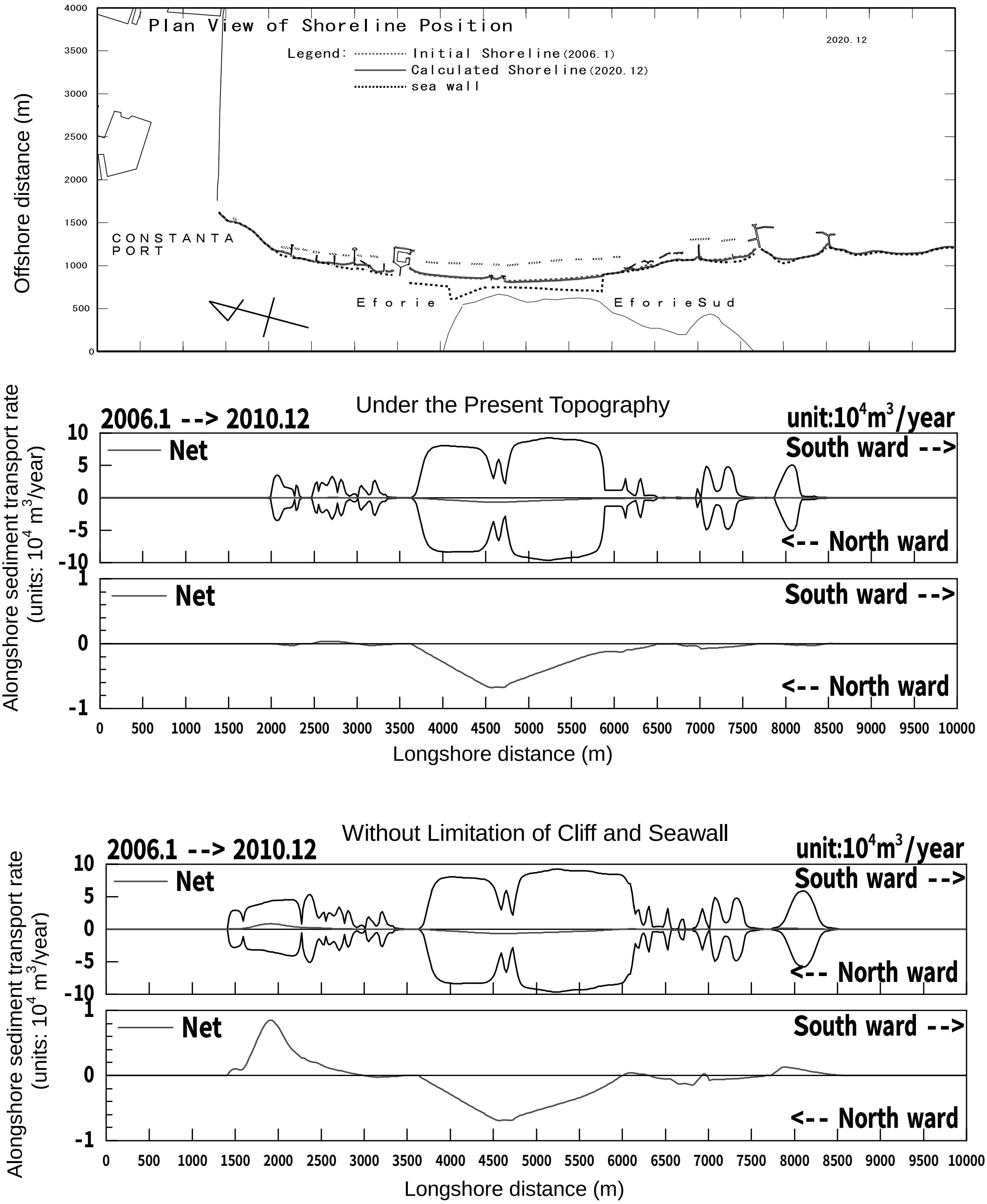

Fig. 4.5.5: Alongshore sediment transport rate in the coast in Eforie Sector with and without cliff and seawall

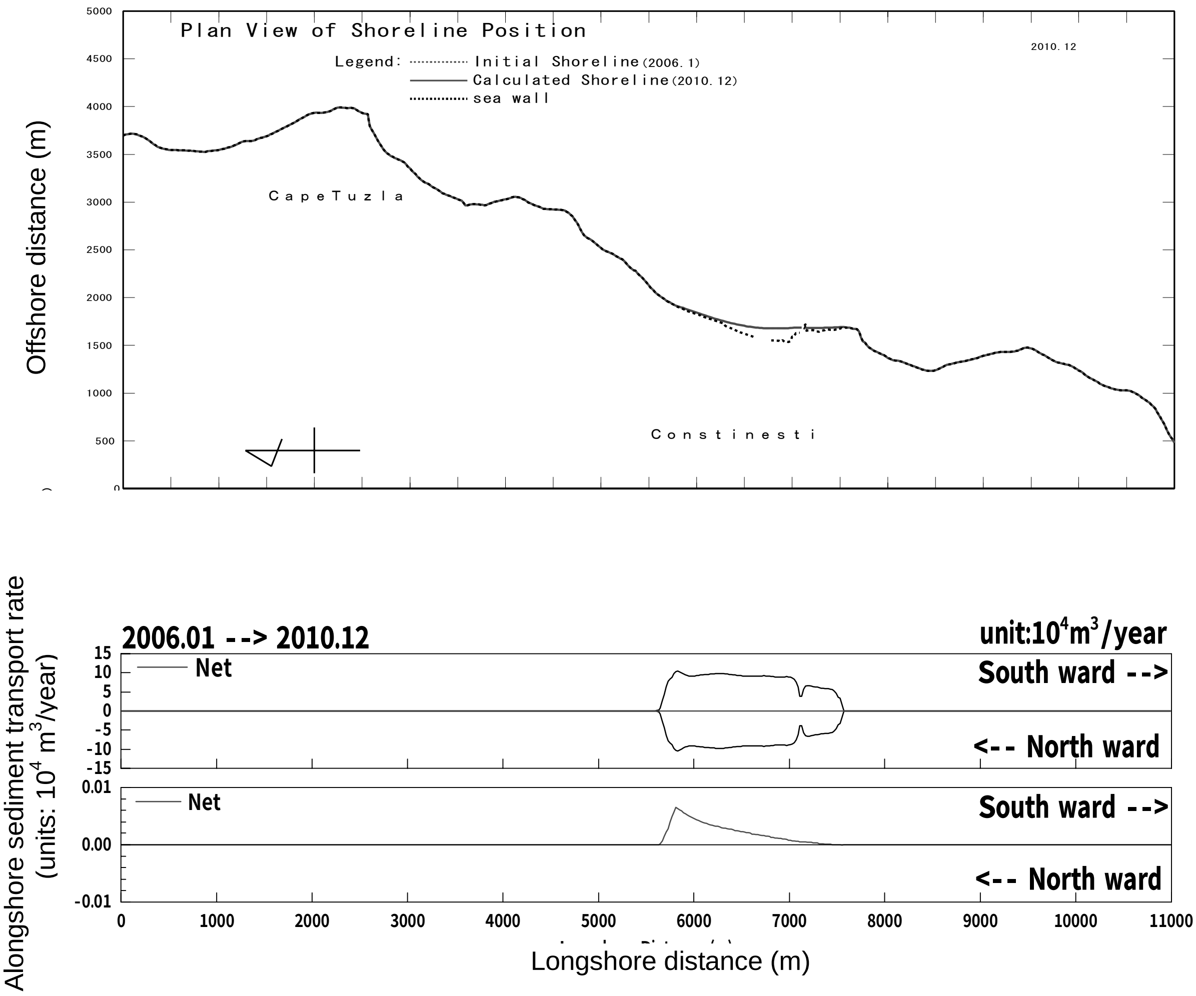

Fig. 4.5.6: Alongshore sediment transport rate in the coast in Tuzla, Costineşti, and Schitu Sectors under presence of cliffs

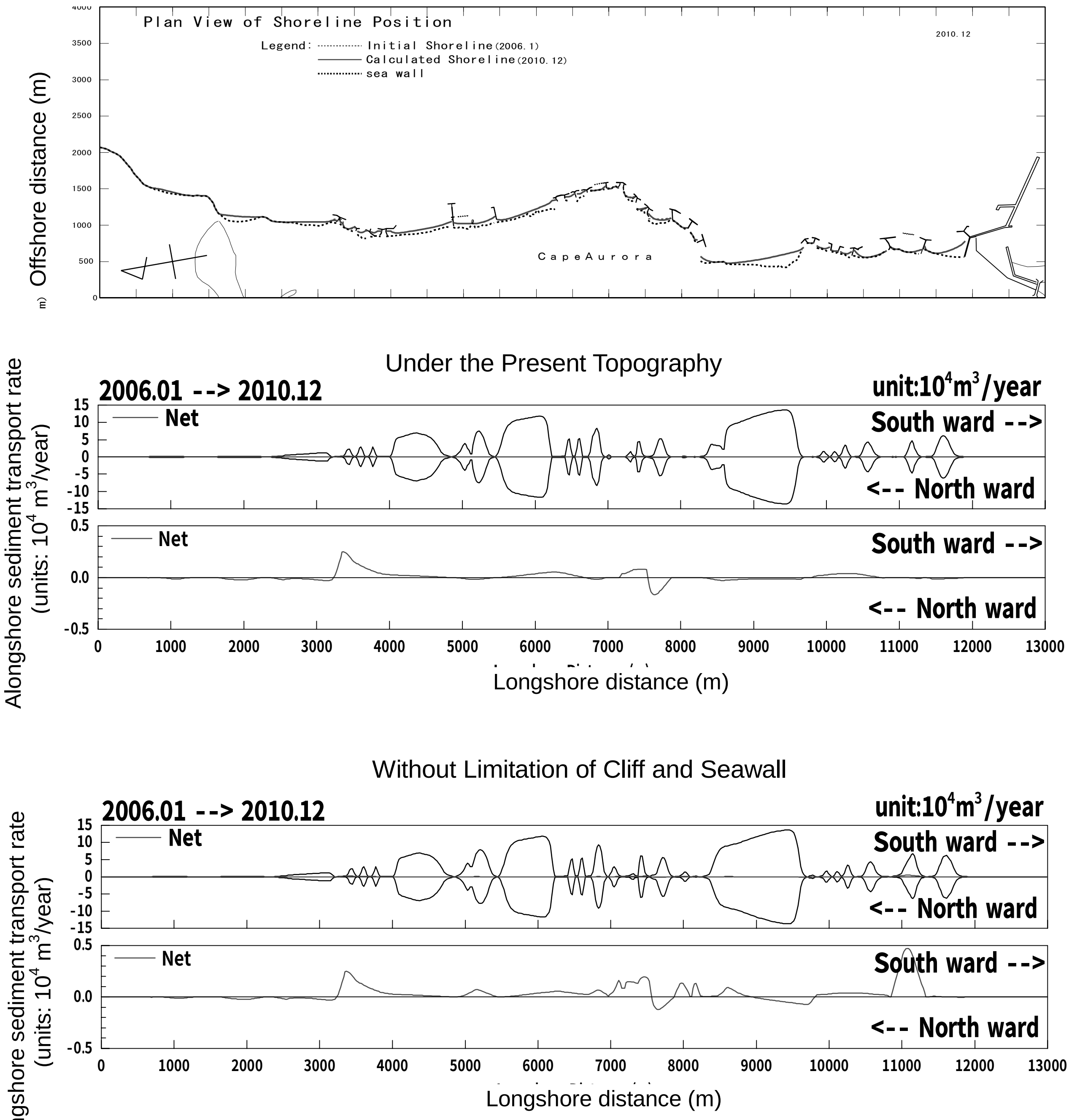

Fig. 4.5.7: Alongshore sediment transport rate in the coast in Mangalia Sector
with and without cliff and seawall

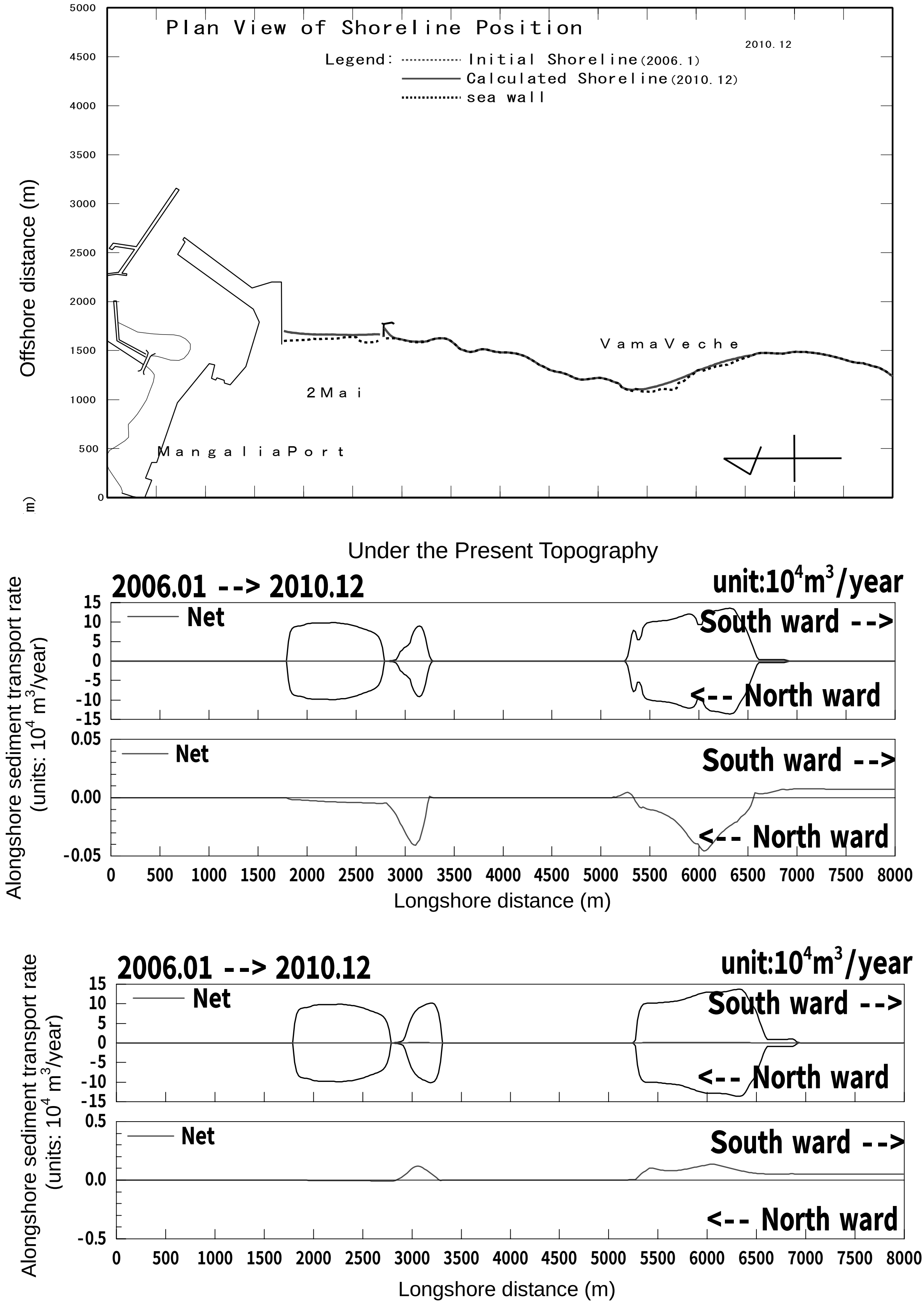

Fig. 4.5.8: Alongshore sediment transport rate in the coast in Limanu Sector
with and without cliff and seawall

The coast of the Mangalia Sector is presented in Fig. 4.5.7. The area has no cliff limiting the retreat of shoreline, but some areas are fronted by seawalls without sandy beaches. The difference between the cases with and without seawalls is largest at the center of Saturn–Mangalia sub-sector, which has no beach. The one-directional sediment transport rate is largest at the Balta Mangalia sub-sector, where the transport rate is about 140,000 m^3 per year in both the northward and southward directions. The largest net transport appears at Olimp with the rate of about 6,000 m^3 per year in the southward direction.

Lastly, Fig. 4.5.8 shows the sediment transport rate in the Limanu Sector, which covers 2 Mai and Vama Veche. The one-directional sediment transport rate amounts up to about 130,000 m^3 per year, but the northward and southward transport rate is almost equal and there is little net transport. If not limited by cliffs, the net transport rate may become 250 m^3 per year southward, but the presence of cliffs limits the net transport to 40 m^3 per year northward.

In conclusion, the alongshore sediment transport rate in the Study area between Năvodari and Vama Veche is estimated to be in the range between 100,000 and 160,000 m^3 per year in both the northward and southward directions, except for the center of Tomis sub-sector. The northward and southward sediment transport rates are almost equal so that the net transport rate becomes small. The maximum net sediment transport rate is about 26,000 m^3 per year (northward) in Mamaia Beach, 7,000 m^3 per year (northward) in Eforie Middle, and 6,000 m^3 per year (southward) in Olimp. However, the net sediment transport is quite small in the Costineşti and Limanu Sectors with the rate of 60 and 40 m^3 per year, respectively.

4.5.2 Verification of Shoreline Change Analysis with the Past Records

A simulation model for the shoreline change needs to be validated through calibration with the past records of the shoreline position changes. Figures 4.5.9 and 4.5.10 present the verification data for the cases of Constanța and Eforie Sectors, respectively. The Mangalia Sector had the past records of 1995 and 1997 only so that a meaningful verification was not feasible. The shorelines of the Costineşti and Limanu Sectors are relatively stable and not fitted for verification.

In Fig. 4.5.9 for the Constanța Sector, the shoreline data in 1976 is taken as the baseline. Then the four survey data in 1980, 1990, 1995, and 1997 are used to identify the changes in the shoreline positions since 1976; the measured shorelines are shown with the dashed black lines. The calculation results of the shoreline positions at the four survey years are indicated with the solid red lines. The amount of shoreline retreat is shown with the hatched blue lines, while the shoreline advance is shown with the shaded red area.

The supply of sand in a beach fill project in 1989 in the southern part of Mamaia is incorporated in the simulation as indicated as the shoreline advance in the second panel for 1976 to 1990. The offshore outflow (loss) of sediment is assessed to be 3.0 m^3 per year for the whole Mamaia Beach from Năvodari North to Mamaia South, and it is incorporated in the simulation throughout the simulation period. However, the offshore outflow was assumed to have ceased in Mamaia Center and Mamaia South after construction of the detached breakwaters in 1988 and 1990.

As seen in the four panels of comparison of the measurement and calculation, the simulation model succeeds in reproducing the past changes of the shoreline position quite well. There is some discrepancy in Năvodari North and Năvodari South, where the calculation yields some advance of shoreline, but the measurement shows only a modest advance or retreat. In this area, the offshore outflow of sediment might have been greater than the assessed value of 3.0 m^3 per year, but further adjustment was not undertaken because of a limited interest for this area from the viewpoint of coastal protection.

For the Eforie Sector, the shoreline data in 1981 is taken as the baseline. Then the three survey data in 1986, 1995, and 1997 are used to identify the shoreline changes. The offshore outflow of sediment is assumed to correspond to the retreat rate of 0.6 m per year for the whole area. A distinct feature of the shoreline change in the Eforie Sector is the formation of the geometry of tombolo behind the Yacht Club Europa, construction of which began in 1986; the shoreline has advanced in its southern side, while the shoreline retreat occurred in Eforie Middle. The calculation is made with the input of its full geometry in the beginning of the year 1986 and thus the calculated shoreline in the upper panel is more advanced than the actual measurement. However, the calculation for 1997 in the lower panel yields almost the same shoreline advances and retreats as those of measurements.

In the northern sides of the Yacht Club Europa and the Eforie Sud sub-sector, the pattern of the measured shoreline changes is complex without consistent trend, and a detailed comparison with calculation is difficult. In these areas, small groins have been installed very close to the shore, and some groins are set askew with small angles to the shoreline. A part of the northern shore lacked sandy beach but was covered by broken rocks. It was difficult to reproduce the influence of such small groins on the along sediment transport with the scale of the present simulation (spacing of 20 m), and the simulation could not bring good agreement with the measured data. Nevertheless, it can be said that the overall tendency supports the reliability of the simulation model for shoreline changes.

It is concluded on the basis of Figs. 4.5.9 and 4.5.10 that the present model of shoreline change calculation is quite reliable and can be effectively employed for the prediction of future changes.

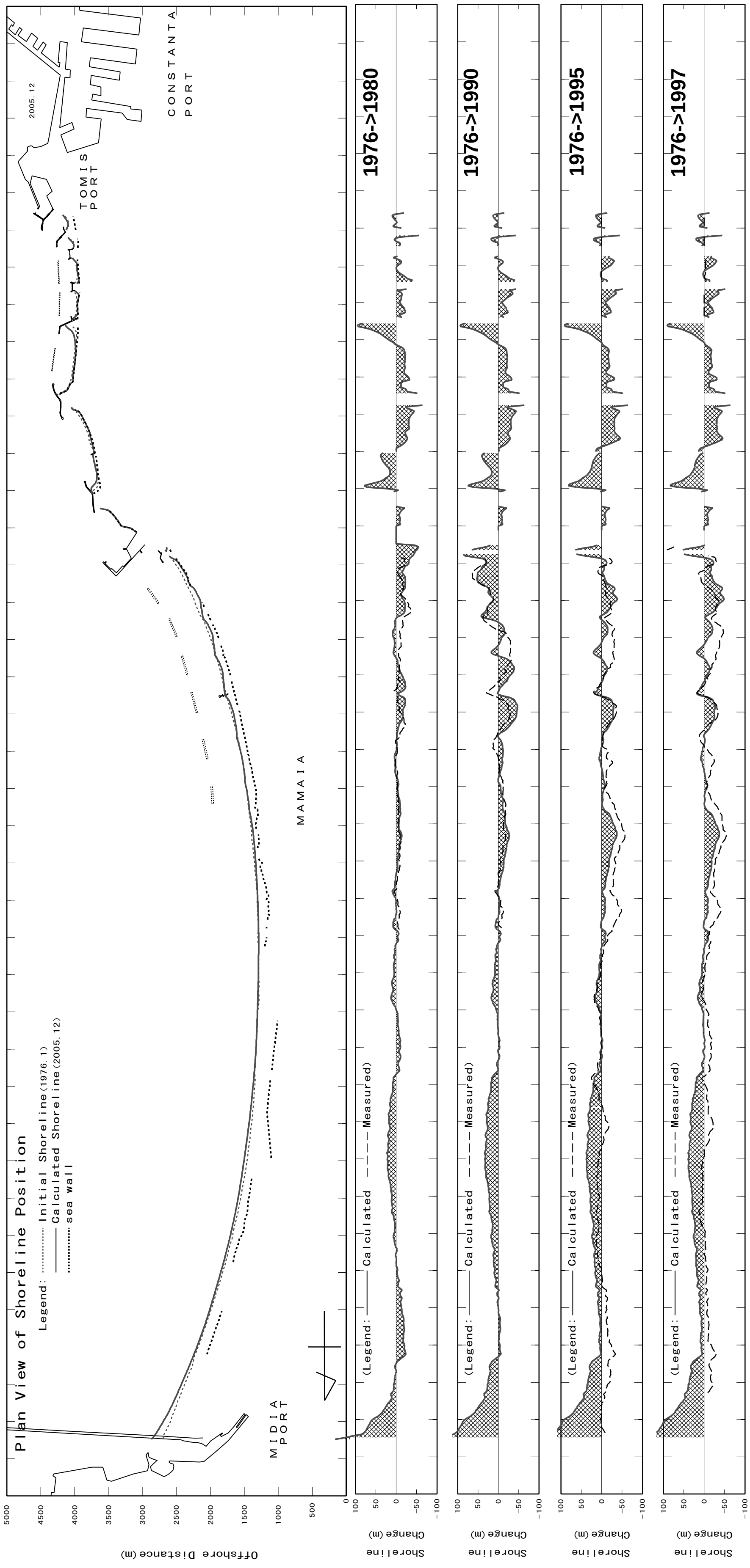

Fig. 4.5.9: Comparison of the measured and calculated shoreline positions in the coast from Năvodari to Tomis from 1976 to 1997

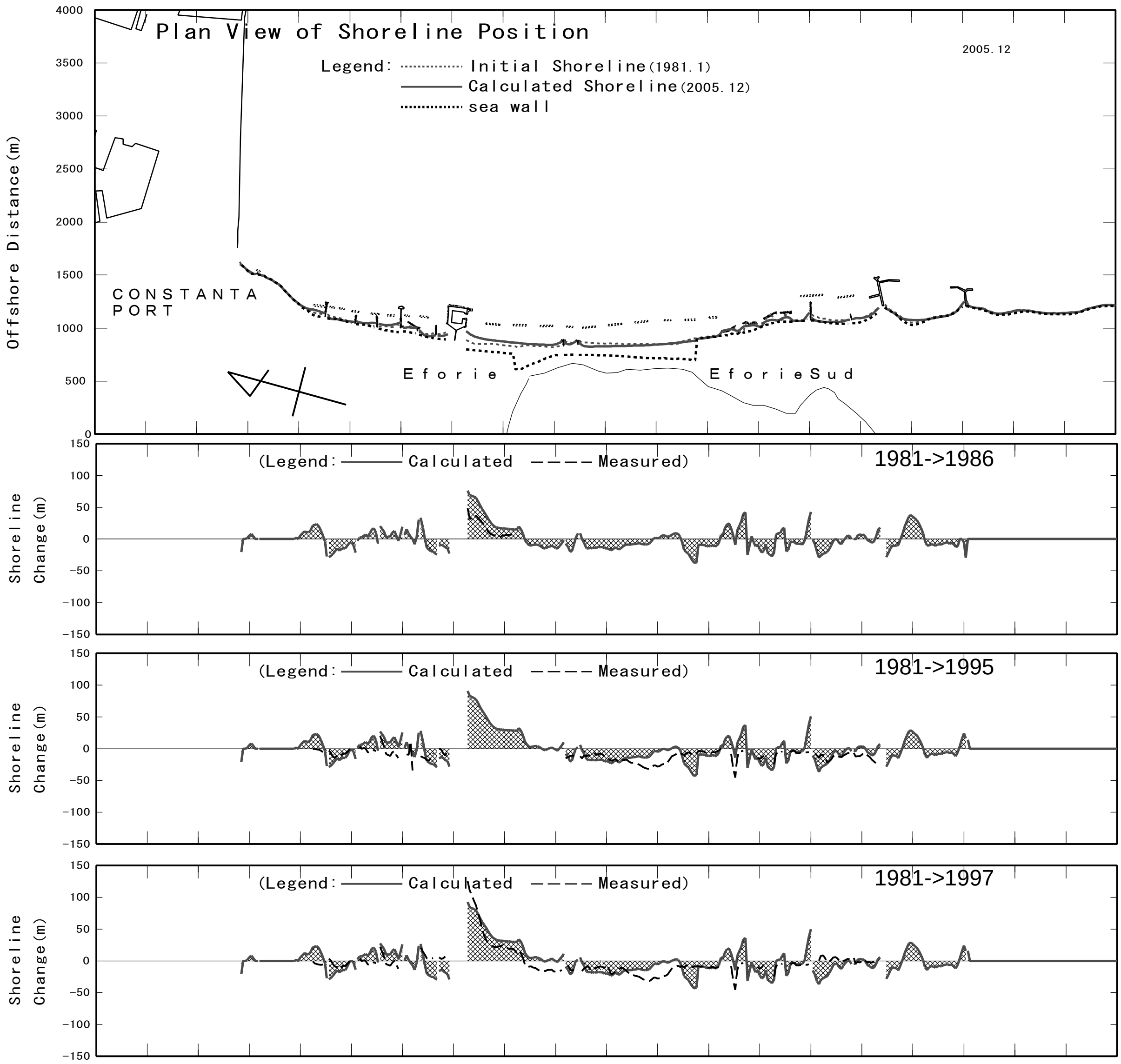

Fig. 4.5.10: Comparison of the measured and calculated shoreline positions in Eforie from 1981 to 1997

4.5.3 Prediction of Future Shoreline Changes with Existing Facilities Only

As concluded in **4.5.2**, the numerical simulation model employed in the Study can reliably predict shoreline position changes with lapse of time. Thus, prediction is made for the future shoreline position and beach width for the whole area under the Study. Calculation is made from the 00:00 hour of the 1st January 2006 with the time step of about one hour in day after day by employing the various ratios of the monthly wave energy to the annual mean wave energy for the northerly and southerly waves (see Table E.6.1 in Annex **E.6** for details). The shoreline shape varies with lapse of time as calculation progress and the alongshore sediment transport rate continues to change because of the change in the shoreline orientation with respect to the wave direction at breaking. Calculation is continued in month after month and in year after year until the target year is reached. In the following, the results of calculation after twenty years that are obtained on the 31st December 2025 are presented as shown in Fig.

4.5.11 to 4.5.15. The results represent the cases with no alteration made on the present shore protection facilities.

Figure 4.5.11 shows the changes of the beach width and shoreline position in twenty years in the Constanța Sectors. The initial shoreline on the 1st January 2006 is a calculated one starting from the topographic survey map of 1976; the calculation results have been presented in Fig. 4.5.9 for comparison of the calculation and measurement. The top panel is the location map, the middle panel shows the beach width from the baseline of backshore, and the bottom panel represents the advance or retreat of the shoreline from the present location. The dotted blue-green lines indicate the shoreline in 2006 and the solid red lines are the shoreline in 2025. The hatched area in blue-green color represents the shoreline retreat. In the area in the longshore distance from 9,500 m to 12,700 m, the shoreline is predicted to retreat by up to **40 m**. Especially in the area in the longshore distance from 11,600 m to 12,600 m, no beach will remain there and some hotels at the beach side may fall down into the sea.

In this prediction, the offshore outflow of sediment or the cross-shore sediment loss is not incorporated. The advance of shoreline of about 20 m in the Năvodari area may be the result of the neglect of cross-shore sediment loss, and the shoreline retreat in the southern Mamaia area may be greater than the prediction in Fig. 4.5.11. In the Tomis area, the change in the shoreline position is slight and the beach width remains almost unchanged.

The case of the Eforie Sector is shown in Fig. 4.5.12. The initial shoreline on the 1st January 2006 is a calculated one starting from the topographic survey map of 1981. In the area south of the Yacht Club Europa, slight shoreline advance and increase of beach width are predicted. In this sector, the overall cross-shore sediment loss equivalent of the shoreline retreat of 0.6 m per year, or shoreline retreat of 12 m in twenty years, is incorporated. However, local unbalance of alongshore sediment transport causes the shoreline retreat of more than **20 m** at some places in Eforie Nord, Eforie Middle and Eforie Sud. There are some sections without shoreline retreat, but the reality is such that the calculated shoreline has reached at the foot of cliff or the seawall and no further beach erosion could not take place. The area north of the Yacht Club Europa is one of such cases, and the scour at the cliff foot will occur after disappearance of the beach there, being followed by cliff collapse.

Figure 4.5.13 shows the calculation result for the Costineşti Sector. As discussed in **4.5.1**, the net alongshore sediment transport rate is only 60 m^3 per year and no appreciable change of shoreline position and beach width is expected.

Calculation results of future shoreline position and beach width of the Mangalia Sector are shown in Fig. 4.5.14. The shoreline retreat of about 12 m represents the effect of cross-shore sediment loss at the rate of 0.6 m per year incorporated in the calculation. The Olimp and Aurora areas exhibit a shoreline retreat more than 20 m, indicating some acceleration of beach erosion there. The areas around Jupiter, Saturn, and others show only a small or no retreat, but it indicates that the predicted shoreline reached the cliff foot or the seawall and no beach will remain there.

Figure 4.5.15 shows the calculation result for the Limanu Sector. The shoreline retreat is mainly due to the cross-shore sediment loss and it is predicted not exceeding 12 m in twenty years in Vama Veche.

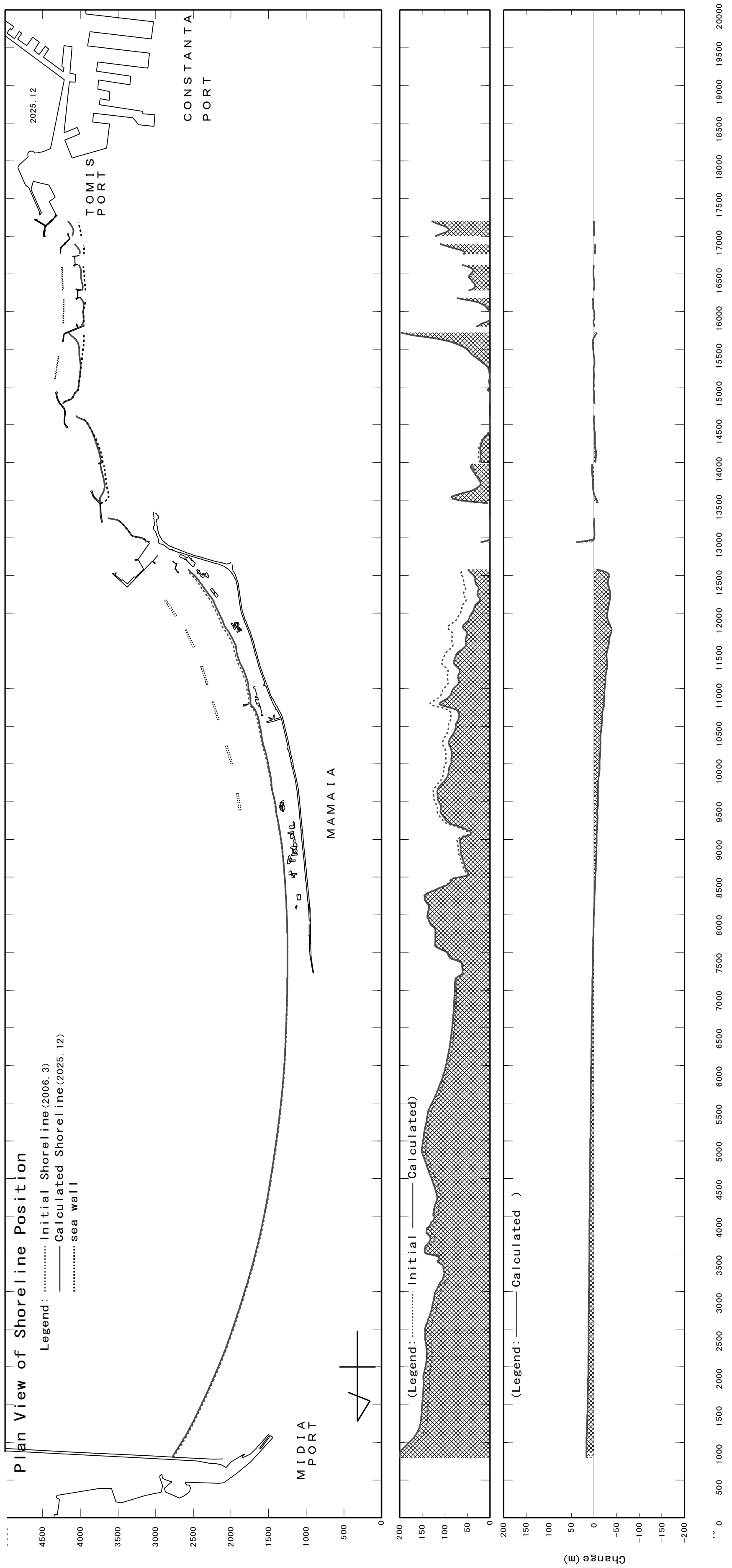

Fig. 4.5.11: Prediction of beach width and shoreline changes between 2006 and 2025 in Constanța Sector

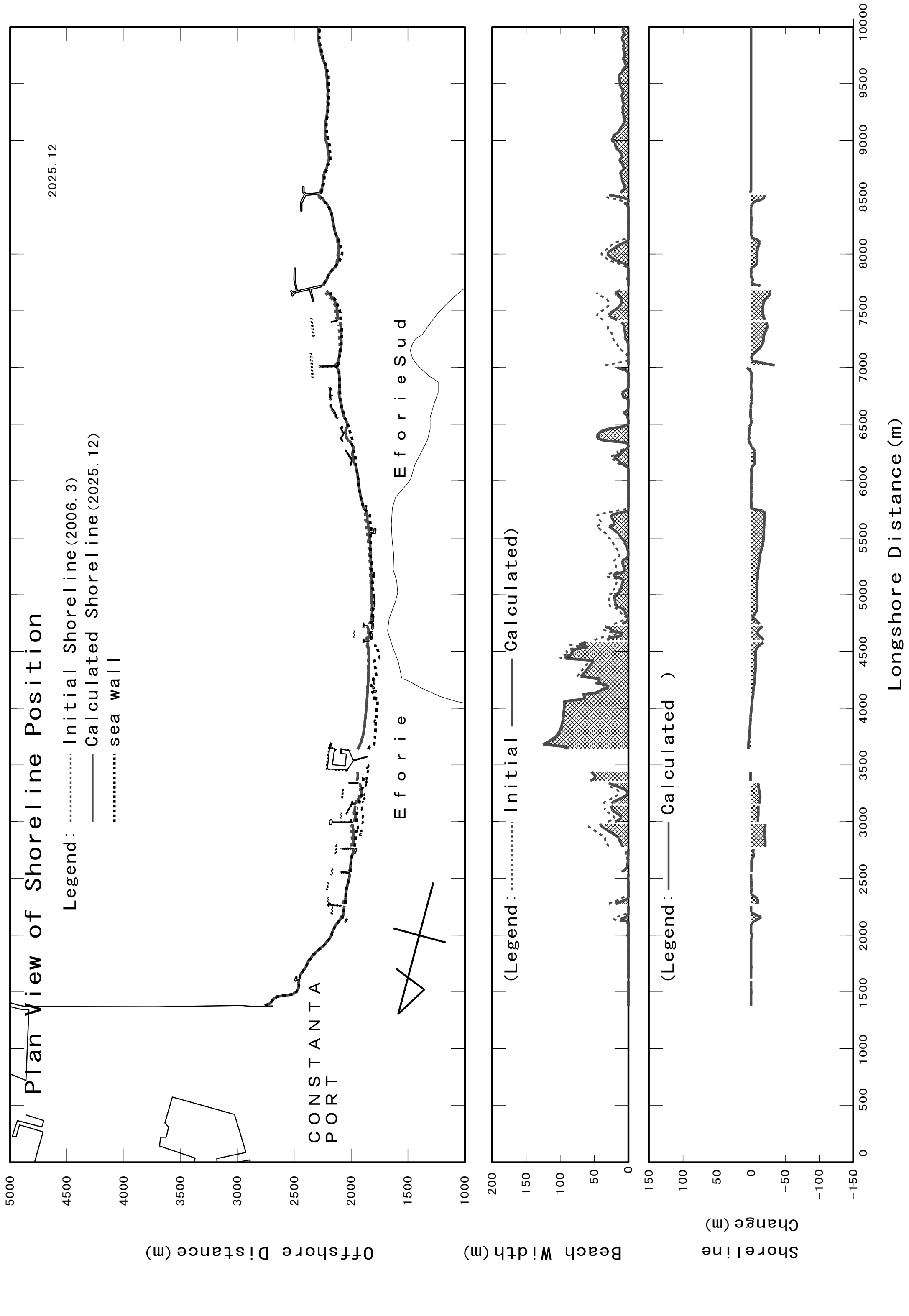

Fig. 4.5.12: Prediction of beach width and shoreline changes between 2006 and 2025 in Eforie Sector

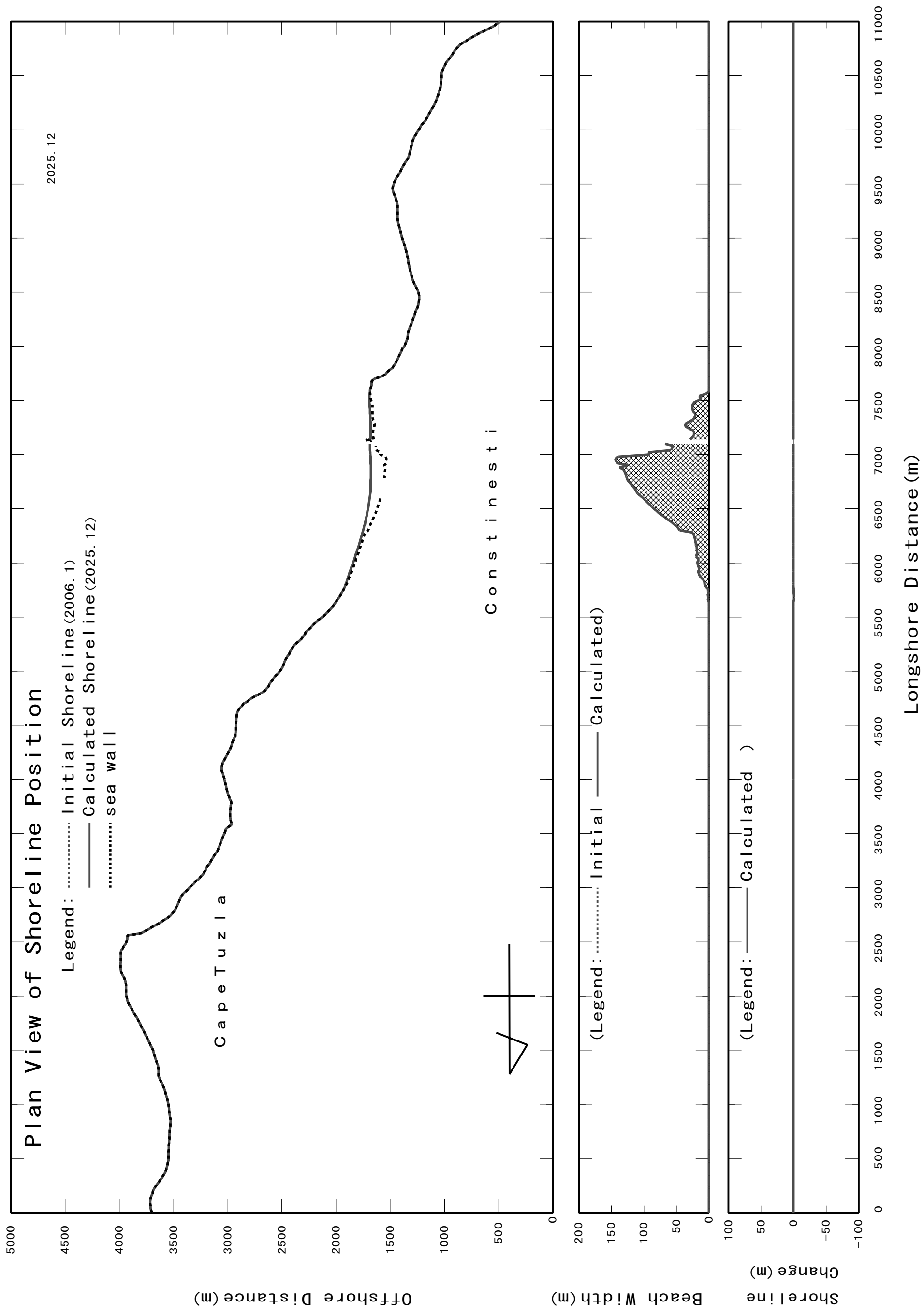

Fig. 4.5.13: Prediction of beach width and shoreline changes between 2006 and 2025 in Costineşti Sector

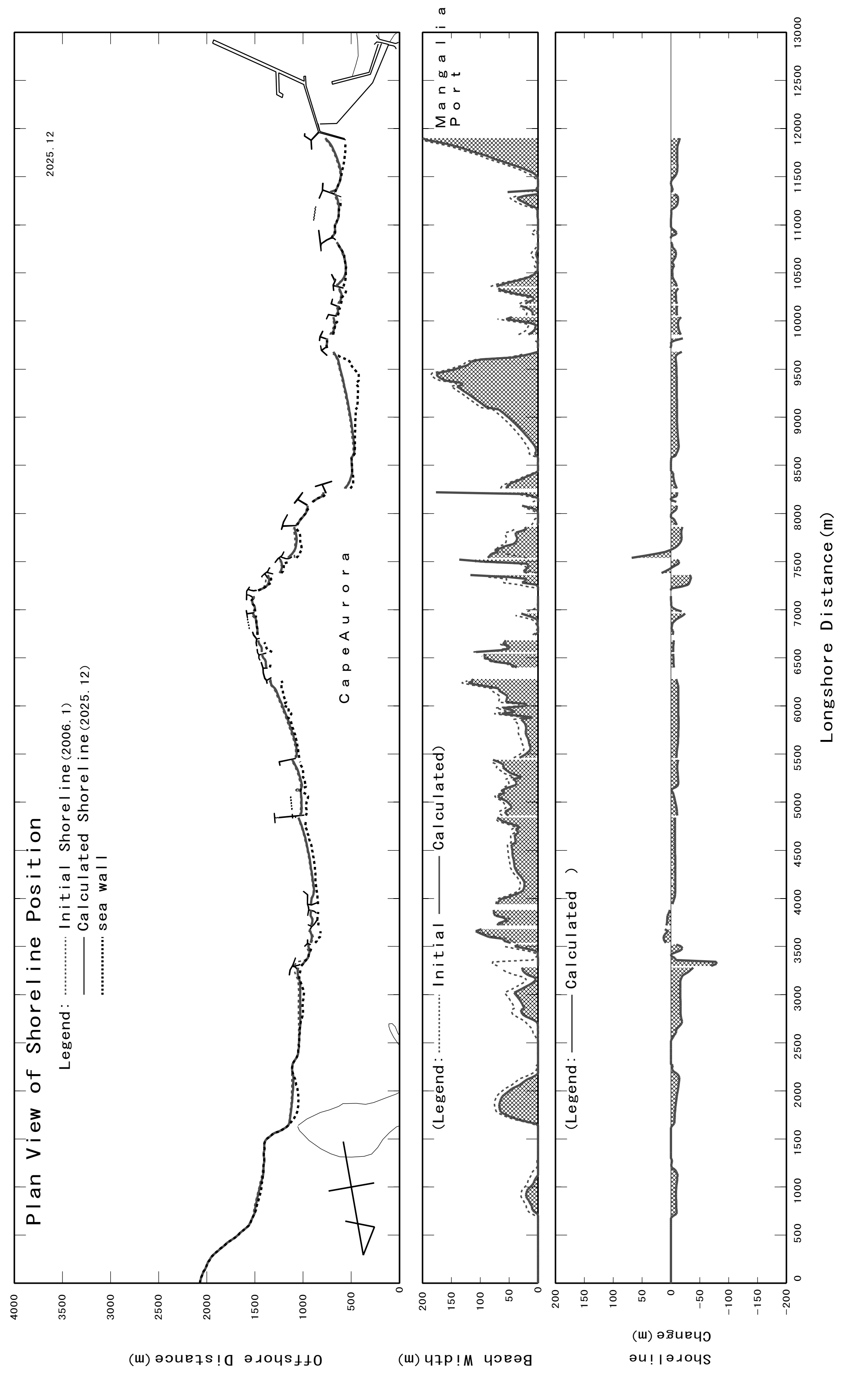

Fig. 4.5.14: Prediction of beach width and shoreline changes between 2006 and 2025 in Mangalia Sector

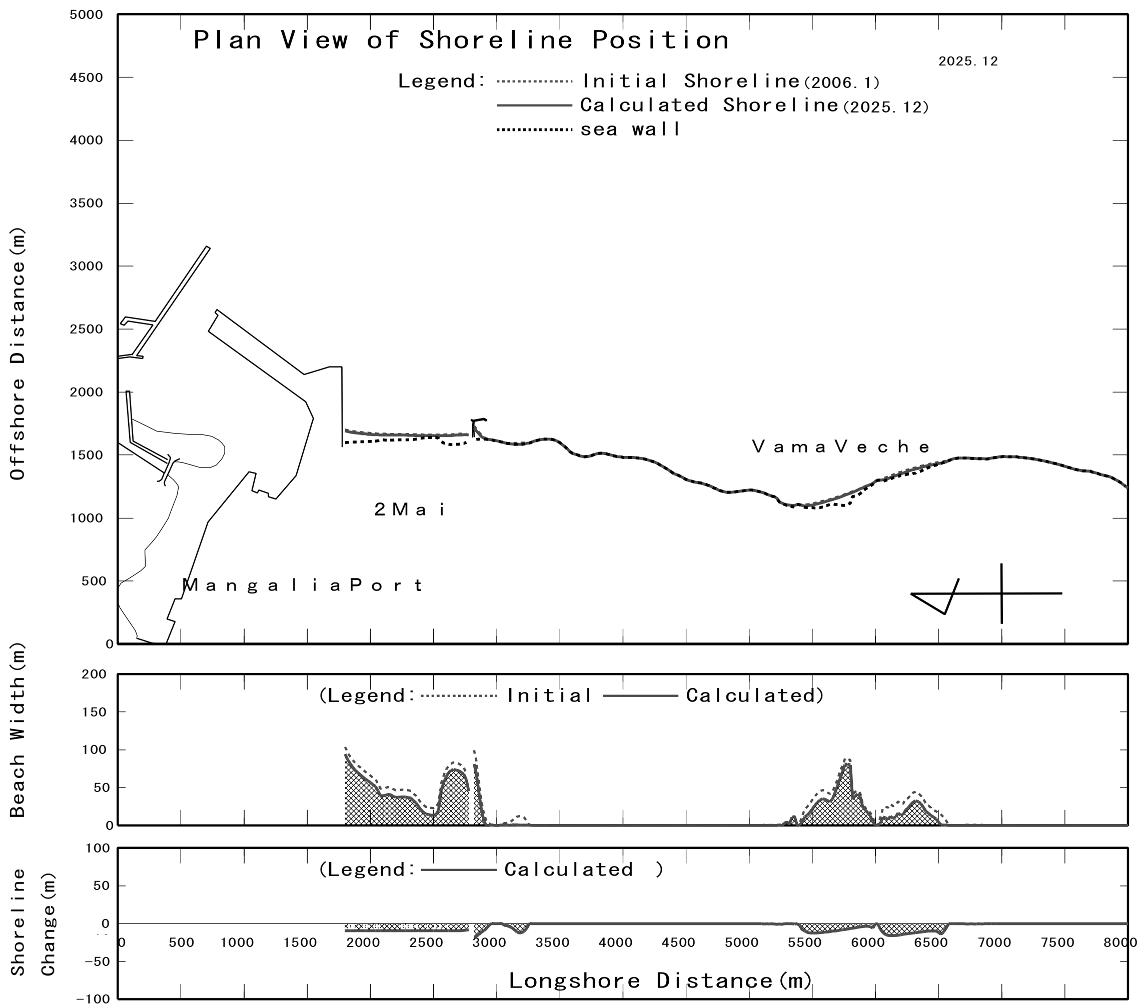

Fig. 4.5.15: Prediction of beach width and shoreline changes between 2006 and 2025 in Limanu Sector

4.6 Influence of Mean Sea Level Rise

Global warming is the well-recognized phenomenon, which causes a rise of the mean sea level. The Working Group I of the Intergovernmental Panel on Climate Change (IPCC) has been working for prediction of global climate change by employing various emission scenarios and revising the predictions from time to time. The report in 2001 states that the global mean sea level is projected to rise by 0.09 to 0.88 m between 1990 and 2100, for the full range of emission scenarios. A wide range is to cover the uncertainty in assessment of various factors involved. The several representative scenarios predict the average rise of 0.31 to 0.49 m by 2100.

As described in 3.3, the annual mean water level in Constanța Port has recorded a rise of 15.4 cm in the period from 1933 to 2003. The rate of sea level rise is 2.2 mm per year. It is not clear whether this is a part of the global mean sea level rise, but it must have contributed to the beach erosion in the Southern Romanian Black Sea shore.

When the sea level rises temporarily by wave setup, low atmospheric pressure, or other causes, the shoreline retreats over the foreshore and the amount of retreat is calculated by multiplying the sea level rise by the foreshore slope. However, when the mean sea level rises gradually over a long time span, the beach will reform itself toward an equilibrium profile under the raised mean sea level. In 1962 Bruun[8] has proposed a formula to estimate the retreat quantity R_∞, which is written as follows:

$$R_\infty = S \frac{L_c}{h_c + z} \quad (4.6.1)$$

where S is the amount of the mean sea level rise, h_c denotes the depth of closure beyond which no significant seabed change by sediment transport takes place, z is the height of backshore, and L_c denotes the horizontal distance between the backshore to the depth of closure.

The information of the depth of closure h_c and the horizontal distance L_c is compiled in Table E.4.3 in Annex **E.4**; the former varies from 7.1 to 9.3 m and the latter is in the range of 355 to 930 m. The backshore height is about 2.3 m in Mamaia Beach (see Table E.7.1) and other beaches have similar heights.

By taking an upper value of 0.5 m for the mean sea level rise by the year 2100, Bruun's formula predicts the estimated amount of beach erosion as listed in Table 4.6.1 for various sub-sectors. The sub-sectors of Năvodari and Mamaia are most susceptible to the mean sea level rise with the shoreline retreat of 40 m, because of the gentle slope of the inshore. The shoreline of the Costineşti Sector is estimated to retreat by 19 m by the sea level rise of 0.5 m. Other areas will have the amount of the shoreline retreat in between.

Table 4.6.1: Estimate of beach erosion by means sea level rise

Sub-sector name	Amount of beach erosion by 50 cm seal level rise (m)	Annual rate of beach erosion by sea level rise of 2.2 mm/year (m/year)
Năvodari – Mamaia	40.0	0.18
Tomis	40.0	0.18
Eforie Nord – Sud	34.4	0.15
Costineşti	19.1	0.08
Olimp – Venus	19.1	0.08
Satrun – Mangalia	30.5	0.13
2 Mai – Vama Veche	26.7	0.12

Table 4.6.1 also lists the annual rate of the shoreline retreat corresponding to the past rate of the mean water level rise of 2.2 mm per year. It ranges from 0.08 to 0.18 m per year. Although it may look small, it is not negligible one in comparison with the measured ones shown in Figs. 4.2.3 to 4.2.5. Therefore, the rise of the mean water level in the Black Sea shore is one of the causes of beach erosion.

The amount of shoreline retreat is proportional to the mean sea level rise, and the shoreline retreat for the mean sea level rise other than 0.5 m can be easily estimated on the data listed in Table 4.6.1. The above amount of shoreline retreat is within the range of shoreline position change by sediment transport. Continuous monitoring of the mean sea level and the shoreline position will make it possible to prepare any countermeasure required.

[8] Bruun, P. (1962): Sea-level rise as a cause of shore erosion, J. Waterways ad Harbor Div., Proc. American Society of Civil Engineers, Vol. 88, pp. 118-130.

CHAPTER 5:

COASTAL PROTECTION PLAN AIMED AT 2020

Chapter 5 Coastal Protection Plan Aimed at 2020

5.1 Integrated Coastal Zone Management in Romania

Integrated Coastal Zone Management (ICZM) is 'a process of administering the use, development, and protection of the coastal zone and its resources towards democratically agreed objectives' (after Post and Lundin 1996)[1]. It is to maintain a balance between protection of valuable ecosystem and development of coast-dependent economies and to provide a mechanism to reduce or resolve conflicts among various stakeholders. It consists of the legal and institutional framework, spanning multiple sectoral activities, various institutions at national, regional, and local levels, and diverse interests of stakeholders. ICZM aims at promoting the sustainable management of coastal zones and should evolve dynamically, continuously, and interactively. The concept of ICZM is quite complex and is difficult to be summarized in a few sentences.

According to Post and Lundin (1996), coastal zone management as a formal governmental activity was first undertaken in the United States in 1972 with the enactment by the U.S. Congress of the Coastal Zone Management Act. The threats of the degradation of natural resources in coastal zones by severe conflicts over coastal space and resource utilization were acutely recognized at the 1992 United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro. The conference recommended drafting of the guidelines on ICZM to minimize conflicts and to provide for optimal sustainable resource use. In response to this recommendation, the "Noordwijk Guidelines" on ICZM were presented at the 1993 World Coast Conference in Noordwijk, the Netherlands, on the basis of which various guidelines and code of practice have been prepared by several international, national, and other institutions.

In 2000 after nearly a decade's effort, the Commission of the European Communities made a proposal for a European Parliament and Council Recommendation concerning the implementation of Integrated Coastal Zone Management in Europe as the document 2000/0227 (COD). The proposal resulted in the Recommendation of the European Parliament and of the Council of 30 May 2002 concerning the implementation of Integrated Coastal Zone Management in Europe (hereinafter referred to as "EU Recommendation"). It consists of seven chapters and set out the basic principles for formulation of national strategy for ICZM by the Member States.

In preparation for Romania's accession into the EU, the Government of Romania has been transposing various legal frameworks and procedures of EU into the Romanian system, including the environment impact assessment (EIA) for which Ministerial Order no. 860/2002 constitutes the basis of environmental permit. As for ICZM, Romanian Government issued the Emergency Ordinance no. 202/2002, which has been modified with addition by Law no. 280/2004. As of January 2004, it is composed of ten chapters and eighty-seven articles; its outline is given in Annex **C.1**. The E.O. 202/2002 stipulates establishment of a national committee of the coastal zone in Article 68 of Chapter 6. The activity of the national committee began in April 2005 and three meetings were held during the year 2005; brief description of the committee meetings is given in Annex **C.2**.

[1] Post, J.C. and Lundin, C.G.. (ed.): *Guidelines for Integrated Coastal Zone Management*, The International Bank for Reconstruction and Development / The World Bank, 1996. p. 5.

Under the E.O. 202/2002, coastal protection against erosion is stipulated as the responsibility of the Ministry of Environment and Water Management. This constitutes the basis of the Study initiated by request of Romanian Government to Japanese Government.

5.2 Division of Study Area into Sub-Sectors

5.2.1 Sectors and Sub-sectors

The study area, which is the southern unit of the Romanian Black Sea shore from Midia to Vama Veche, is divided into seven sectors of the following to facilitate execution of the Study, by taking account of administrative divisions for the purpose of shoreline survey by the Department of Water Dobrogea – Litoral (DADL) of Apele Romane as well as the characteristics of littoral sediment transport:

I.	Constanța Sector	(approximate. linear length of 19.0 km)
II.	Eforie Sector	(approximate. linear length of 7.7 km)
III.	Tuzla Sector	(approximate. linear length of 7.5 km)
IV.	Costineşti Sector	(approximate. linear length of 2.6 km)
V.	23 August Sector	(approximate. linear length of 4.9 km)
VI.	Mangalia Sector	(approximate. linear length of 11.6 km)
VII.	Limanu Sector	(approximate. linear length of 5.9 km)

The seven sectors are further divided into twenty sub-sectors as listed in Table 5.2.1, by taking consideration of the continuity of topographic and beach characteristics from the viewpoint of littoral sediment transport. The zone from Cape Midia to the south breakwater of Midia Port is excluded from the study area because of no beach erosion problem there. The port areas of Constanța and Mangalia are also excluded form the sub-sectors. The total length of the seven sectors is approximately 59 km.

The zone from Cape Midia to the south breakwater of Midia Port is about 7 km long. The area of Constanța Port extends over approximately 11.3 km, and that of Mangalia Port is approximately 2.2 km. With addition of the port areas and the zone in the north of the south breakwater of Midia Port, the total length of the southern unit of the Romanian Black Sea shore becomes approximately 80 km.

The seven sectors and twenty sub-sectors are exhibited in Fig. 5.2.1.

5.2.2 Coastal Sediment Cells in the Study Area

Each of the seven sectors defined in **5.2.1** represents an independent coastal sediment cell in principle. A coastal sediment cell is a boundary defined by littoral processes and zones of sediment convergence and divergence.[2] Thus, measures taken within a specific sediment cell may affect the shore process of the same cell, but they will not impact on adjacent cells.

Because of almost no permanent coastal currents flowing near the seabed in the littoral zone of the study area, littoral processes are dominated by wave actions only. Under the wave

[2] DGENV European Commission (2004): Development of a Guidance Document on Strategic Environment Assessment (SEA) and Coastal Erosion, p.14.

climate described in **3.4**, the threshold depth of water beyond which little sediment movements are induced by waves is judged as 7 to 9 m (see Annex **E.4**).

Table 5.2.1: Sub-sectorial division of the study area

Sector No.	Sub-sec-tor No.	Sub-sector name	Description	Remark	Apprx. Distance (km)
I	I–1	Năvodari North	Năvodari Breakwater – Camping Năvodari	Beach	2.3
	I–2	Năvodari South	Camping Năvodari – Boundary between Năvodari and Constanța	Beach	2.2
	I–3	Mamaia North	Boundary between Năvodari and Constanța – Hotel Rex	Beach	4.1
	I–4	Mamaia Center	Hotel Rex – Hotel Melody	Beach	2.3
	I–5	Mamaia South	Hotel Melody - Pescarie	Beach	2.9
	I–6	Tomis North	Pescarie – Hotel Unirii	Cliff & beach	2.3
	I–7	Tomis South	Hotel Uniruii – Tomis Tourist Port	Cliff & Beach	2.9
II	II–1	Eforie Nord	Agigea Breakwater – Hotel Vraja Mării	Cliff & beach	3.1
	II–2	Eforie Middle	Hotel Vraja Mării – Tabara International	Beach	1.7
	II–3	Eforie Sud	Tabara International – Pescarie Eforie Sud	Beach & cliff	2.9
III	III–1	Tuzla North	Pescarie Efforie Sud – Cape Tuzla	Cliff	4.2
	III–2	Tuzla South	Cape Tuzla – Cherhana	Cliff	3.3
IV	IV–0	Costineşti	Cherhana – Hotel Horum	Beach	2.6
V	V–0	Schitu	Hotel Horum –Pescărie Tatlageac	Cliff	4.9
VI	VI–1	Olimp – Venus	Pescărie Tatlageac – Hotel Silvia	Beach	7.2
	VI–2	Balta Mangalia	Hotel Silvia – Hotel Cerna	Beach	1.9
	VI–3	Saturn – Mangalia	Hotel Cerna – Mangalia North Breakwater	Beach	2.5
VII	VII–1	2 Mai	Mangalia South Jetty – Pescărie 2 Mai	Beach	1.2
	VII–2	Limanu	Pescărie 2 Mai – North Vile Vama Veche	Cliff	2.3
	VII–3	Vama Veche	North Vile Vama Veche – Territorial Boundary	Beach & Cliff	2.4

The breakwaters of the Ports of Midia, Tomis, Constanța, and Mangalia form the boundaries of coastal sediment cells in the study area. The breakwater of the fishing harbor at the junction between the sub-sectors of Mamaia South and Tomis North can also be taken as the boundary of coastal sediment cells, together with the topographic feature of Cape Singol. Cape Aurora also can be taken as the cell boundaries because of its topographic features.

The seven sectors listed in Table 5.2.1 are regarded as independent coastal sediment cells as stated above. As a modification to that statement, the Constanța Sector may be divided into two cells with the boundary at Cape Singol. The Mangalia Sector may be divided into two cells with the boundary at Cape Aurora. Therefore, nine coastal sediment cells of the following are recognized in the Study area:

1) Navodari to Mamaia
2) Tomis North and South
3) Eforie Nord to Eforie Sud
4) Tuzla North and South
5) Costineşti
6) Schitu

7) Olimp to Cape Aurora
8) Cape Aurora to Mangalia
9) 2 Mai to Vama Veche

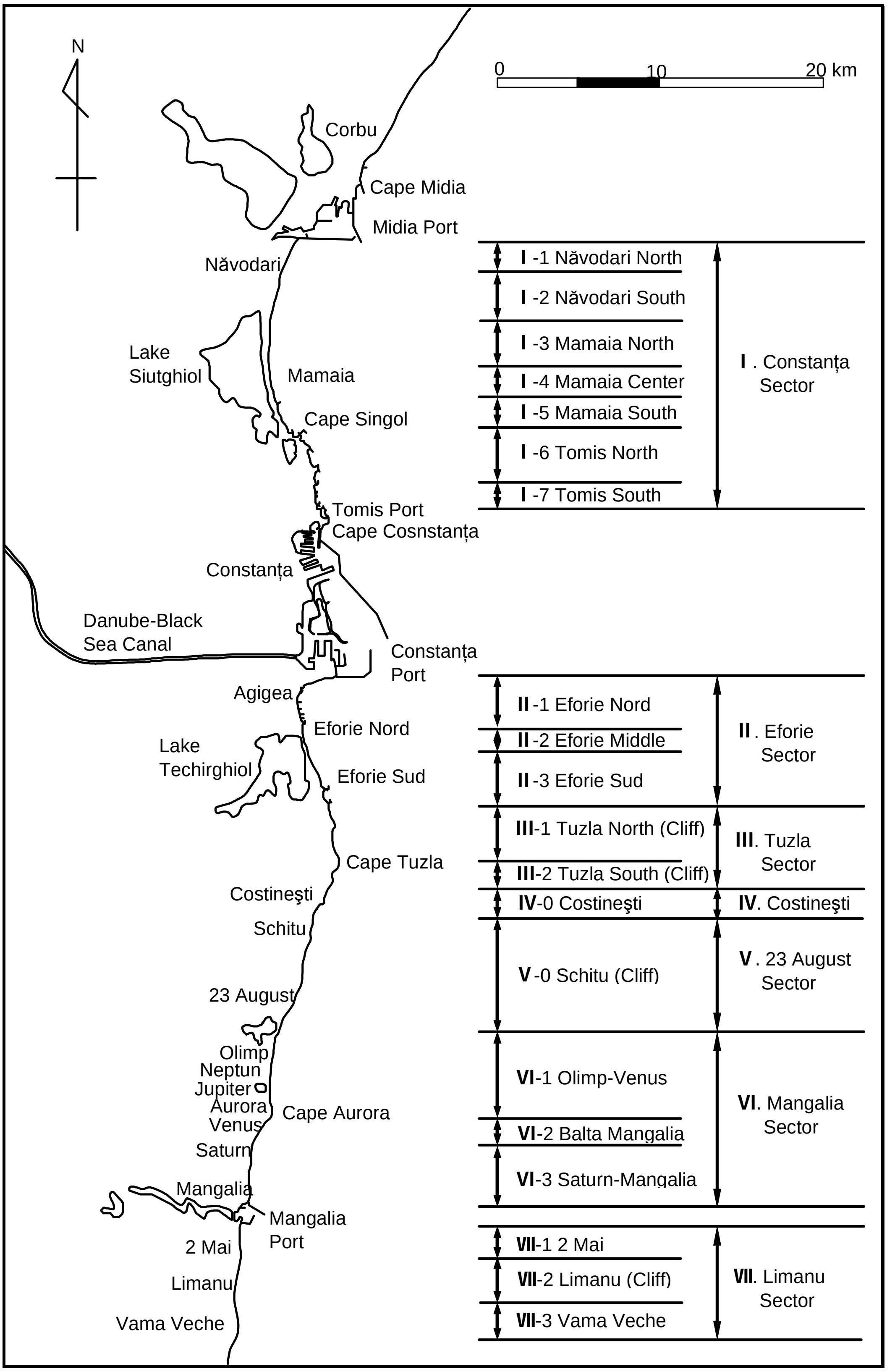

Fig. 5.2.1: Map of sector and sub-sector division of the study area

By definition of a coastal sediment cell, installment of any shore protection measure within a cell will not cause any adverse effect on the adjacent coastal sediment cells. Thus there will be no transboundary effects to the coast of Bulgaria by the coastal protection and rehabilitation projects contemplated in the Study.

5.3 Fundamental Features of Coastal Protection Plan against Erosion

5.3.1 Methodology of Formulating Coastal Protection Plan and Alternative Sites

A coastal protection plan for a score of years or longer, as in the case of the Study, aims to provide a long-term prospective of the most rational measures desired for protection and rehabilitation of the coastal area under consideration. The target area covers a long stretch of the shoreline, being about 80 km in the case of the present study. The area is divided in a number of sub-sectors, and the natural, environmental, and social conditions of these sub-sectors are examined with due consideration of the existing shore protection facilities. Then various plans are drawn up in search of the most rational measures. The actual process of these works is described hereinafter.

Most projects of infrastructure development such as ports, highways, bridges, dams, and others are aimed at developing a single set of infrastructures at the most optimum location. Alternative plans of different sets of infrastructures at several possible sites should be developed, analyzed for functionality and financial and economical soundness, and examined for possible environmental impacts and their mitigation measures. After careful comparison, the optimum solution is selected and a master plan is set forth. The optimum solution thus selected is sometimes called the priority project, though it may refer to the first set of infrastructures to be implemented at the earliest stage. Once a master plan is established, the first stage of facility implementation is undertaken, and after that the expansion projects in the second and later stages are implemented around the zone of the first stage.

Unlike these development projects, a coastal protection plan against erosion does not have any alternative site as a whole, but has to take care of every sub-sector or coastal sediment cell within the study area. Some sub-sector may be found as unnecessary for further protection and rehabilitation after examination of the present condition. Nonetheless, every sub-sector needs diagnosis for the necessity of protection and rehabilitation projects and should be given the appropriate design for the projects. In this sense, alternative plans are drawn up for individual sub-sectors separately, and these alternatives are examined for the most fitted one for individual sub-sectors.

Naturally, urgency and importance of projects differ from a sub-sector to another, and therefore there should be priority in the sequence of project implementation. This is the process of the priority site selection to be discussed in **6.2**. The priority projects referred to in the Study should be understood as the projects to be implemented earliest at the selected sub-sectors without excluding project implementation at other sub-sectors in near future. Therefore, it should be noted that the meaning of the priority projects in a coastal protection plan against beach erosion differs from that used in other infrastructure development projects.

5.3.2 Options for Shore Protection Strategy

When there appears the necessity of coastal protection of a certain coastal unit, there are five options of protection strategy as below[3].

A. Zero-option or "do nothing,"
B. Retreat or setting back the line of defense,
C. Reinforcement of coastal dikes, seawalls etc. at the line of defense,
D. Beach fill without any protective facilities, and
E. Beach fill with appropriate protective facilities.

The selection of the protection strategy depends on the nature of threat to the area behind the shore, the state of coastal utilization, the financial situations, and other factors. The coastal area having a wide beach can adopt the strategy A "do-nothing" until the time when the erosion of beach advances and threatens the properties along the shore. A locality of small population with a wide open space in the back, the strategy B "retreat" is often the best one; if the sea advances toward the land, people are asked to move back to the hinterland. Some areas in the Netherlands can adopt such strategy under the scenario of the global mean sea level rise.

For the densely populated area that is susceptible to the danger of inundation by storm surges, the retreat strategy is unfeasible and people must protect the land by building strong coastal dikes, seawalls and other structures, i.e. the strategy C. Japan has been constructing long lines of seawalls to protect houses, industries etc., which are located just behind the shoreline. The Netherlands also adopts this strategy often, because many parts of their land are located below the mean sea level.

The beach fill strategies of D and E intend to expand the beach width by bringing sand from outside sources. When no facilities are built to attenuate wave energy and/or to retain the nourished sand within the fill area, the capital cost is low, but the filled beach will disappear after the lapse of a certain period. Otherwise, an appreciable quantity of sand needs to be brought from time to time to maintain the beach in good condition. The U.S. prefers this strategy D to the strategy E, probably because of the budgetary system that admits expenditure for maintenance works.

In European countries and Japan, the strategy D is rarely adopted but the strategy E is popular. One reason, especially applicable to Japan, is the reluctance of the national financial authority for subsidy to maintenance works. A public authority prefers a beach protection design with minimum maintenance cost to that with continuous maintenance cost, even though the capital cost of the former is higher than the latter; a local authority can expect a subsidy for the capital cost from the national government but nor for the maintenance.

Usually, the five strategies are not scrutinized for mutual comparison at a given project, because one of them distinguishes itself owing to the local situations, prevailing practice, etc. In case of the Romanian Black Sea shore under the Study, the strategies A "zero-option" or B "retreat" cannot be adopted for the study area as a whole, because there is no room to allow further beach erosion except for a few sub-sectors such as Costineşti and Vama Veche. The strategy C is for the area threatened by the danger of inundation, but the study area does

[3] UK Ministry of Agriculture, Fisheries and Food (2001): "Flood and Coastal Defense Project Appraisal Guidance: Strategic Planning and Appraisal," p. 38.

include such areas and thus the strategy C is not applicable here.

The American preference of the strategy D is supported by the presence of many offshore sand sources for frequent maintenance fill operations. In case of the Romanian Black Sea area, no evidence of such abundant offshore sources of beach fill sand has been found. Difficulty to obtain the funding for coastal protection projects eliminates the possibility of adopting the strategy D in the Study.

Thus remains the strategy E as the only one to be employed for the coastal protection and rehabilitation projects of the Southern Romanian Black Sea shore for the majority of the sub-sectors in the Study area. Then the selection must be made for the best facility arrangement to guarantee the protection of beach and to minimize the necessity of maintenance sand supply.

Two schools of approach exist for protective facility arrangement. The European approach mainly employs single use of low crested structures without groins or jetties. The Japanese approach is to extend long jetties with wide spacing and to install submerged, wide-crested breakwaters between the heads of long jetties in addition to beach fill. Detailed discussions will be given in **5.6**.

5.3.3 Applicability of Financial Analysis of Coastal Protection Plan

Unlike other infrastructure developments that yield yearly revenue, a coastal protection project does not yield any tangible benefit of monetary value. Expansion of beach area will invite an increase of beach visitors, who will spend money for lodging, eating, and many other activities. Managers of hotels, restaurants, and other shops will have the increased sales. Transport industry will also be benefited by the increase of beach visitors. The benefit will eventually be translated into the increased tax revenue etc. However, the project developer which is often a public institution does not receive any direct revenue from the expansion of beach.

Without any tangible revenue, it is impossible to make a financial analysis of a coastal protection plan. Furthermore, a master plan extending over a long time span is not amenable for reliable financial analysis because of many uncertainties in the future. Even if a financial analysis is made, it presents a crude estimate only for comparison among the alternatives. Because there can be no alternatives of the overall coastal protection plan, no financial analysis is meaningful. Financial institutions never negotiate with the owners of master plans over long time spans, and they only discuss on projects for the time span of several years only.

For a coastal protection plan, the economical analysis instead of financial analysis should be undertaken at the stage of feasibility study of individual projects at respective coastal units. In this sense, economical analysis of priority projects will be carried out and presented in Volume 2, Feasibility Study Report.

5.3.4 Flexibility in Implementation of Projects under Coastal Protection Plan

The Study proposes an implementation schedule from 2006 to 2020 and afterwards as described in **5.9.2**. Although the sequence of the order of project implementation at various sub-sectors is listed in Table 5.9.2, the sequence itself can be modified by the judgment of the authority concerned of the Government of Romania. In some of infrastructure development projects, the sequence of facility installation is fixed and a change of sequence is difficult. However, the coastal sub-sectors to be discussed in **5.2** are independent of themselves in the standpoint of sediment transport and beach morphology. If some urgent needs of protection emerge in future for a certain coastal sub-sector, it is quite feasible to implement a project there when the funding for it becomes available.

Securing of the financial resources for executing the coastal protection plan is also the unsolved question. Preferably the Ministry of Environmental and Water Management should conclude negations with the Ministry of Public Finance to establish a special long-term budget commitment for coastal protection. It has been the practice in Japan to have the rolling-budget systems of every five year period for various fields of infrastructure development.

In case the funding becomes difficult, coastal protection projects at respective coastal sub-sectors have to be postponed until the time when the funding becomes available. Such maneuver is permissible unless the state of beach erosion becomes unbearable. Securing funding for a number of coastal protection projects at appropriate timing is the important task of the coastal management unit to be established in the Ministry of Environmental and Water Management.

5.4 Existing Shore Protection Facilities

The conditions of existing shore protection facilities in the study area have been inspected during the field reconnaissance. The facilities have been given the identification numbers as listed in Table 5.4.1 and their locations are shown in Figs. 5.4.1 to 5.4.12; both the table and figures are placed at the end of **5.4**. Photographs of these facilities are listed in Annex **K**. The following is a brief description of the existing shore protection facilities. Headings and sub-headings of the areas are based on the area divisions described in **5.2.1**. For detailed information of their designs, construction period, etc., please refer to Annex **L.12** “Report of IPTANA S.A. on Shore Protection Facilities.”

5.4.1 Constanța Sector

(1) Sub-Sectors I-1 “Năvodari North” to I-4 “Mamaia North”

No shore protection facilities have been built in these sub-sectors.

(2) Sub-Sectors I-4 “Mamaia Center” to I-5 “Mamaia South”

In these sub-sectors, six detached breakwaters and one jetty have been built. The Detached Breakwaters I-B-01 to I-B-06 are located about 500 m offshore of the shoreline, which were built during 1988 to 1990. The Detached Breakwater I-B-01 was built only halfway. The breakwaters are 250 m long and are arranged with the distance of 250 to 300 m in between. They are permeable ones built with randomly placed concrete cube blocks and armored with 20-ton stabilopods. Their crests were designed to have the elevation of +2.0 m above the mean sea level, but the breakwaters have subsided considerably after construction; presently several legs of stabilopods and/or deformed concrete cubes are emerging by 1 m above the mean sea level. Rehabilitation of the breakwaters to the original crest elevation by provision of stabilopods is necessary.

The Jetty I-J-01 is a Z-shaped one (a small lateral branch attached near to the base of an L-shaped jetty). It was built in front of Hotel Parc at the southern end of Mamaia Beach to protect beach there during 1989 to 1991. The sides of the jetty are armored with stabilopods and the crest is protected with concrete slab.

(3) Sub-Sector I-6 "Tomis North"

In this sub-sector, three jetties and one submerged, detached breakwaters have been built. The Jetty I-J-02 is a large Π-shaped one. Its core is made of limestone rubbles and it is armored with 4.5-ton stabilopods in two layers. It seems to have been built rather recently. Most of its extension is well maintained, but the edge of the southern wing has been suffered scattering of stabilopods and rubbles though not of a serious damage.

The Jetty I-J-03 is for support of discharge pipes. It is a straight jetty built with crown concrete slab upon foundation rubbles and discharge pipes are installed on top of it. The offshore end has been protected with a small number of 4.5-ton stabilopods, but they do not provide sufficient protection. Many of foundation rubbles have been sucked out and the concrete slab at the crest has been damaged quite a lot.

The Jetty I-J-04 is a Π-shaped one with the size similar as the Jetty I-J-02. A crown concrete slab of 20 to 30 cm thick is placed on top of foundation rubble stones, and the side slopes are armored with limestone blocks and stabilopods in two layers. The jetty's north wing is severely damaged with loss of rubble stones by scouring, collapse of concrete slabs, and scattering of stabilopods. The remaining portion of concrete slab is susceptible for collapse because of sucking out of foundation rubble stones. On top of the remaining slab of the north wing, there are scattered about ten 4.5-ton stabilopods. The north wind of this jetty requires rehabilitation.

The Submerged Breakwater I-B-07 is listed in the document, but its presence could not be confirmed by visual inspection from a boat. During interview with the Team, researchers of NIMRD suggested a possibility that it had not been constructed.

The retaining wall behind the beach between the Jetties I-J-03 and I-J-04 is in danger of collapse with washing-out of foundation stones. In fact, a portion of it has already been collapsed. It is urgent to rehabilitate the retaining wall.

(4) Sub-Sector I-7 "Tomis South"

In this sub-sector, five jetties and three submerged, detached breakwaters have been built. The Jetty I-J-05 is a Z-shaped one with the structure similar as I-J-01 and others. The crown concrete slab is about 4 m wide. It is well maintained.

The Jetty I-J-6 is a small Π-shaped jetty armored with concrete cubes and limestone rubbles. The tip of its south wing was destroyed by scattering and washing-out of armor stones and foundation rubbles, and breakage of crown concrete slab. The rest of the Jetty I-J-06 is not damaged.

The Jetty I-J-07 is the same type of structure as the Jetty I-J-06 and is maintained in a better condition than the latter. However, the tip of its north wind has been collapsed.

The Jetty I-J-08 is a Z-shaped one with armoring by limestone blocks only: no stabilopods are employed for armoring. Its north wing has been quite damaged by washing-out of foundation rubbles and breakage of crown concrete slab. Armoring by stabilopods will be necessary for its rehabilitation.

The Jetty I-J-09 is a wing jetty attached to the north breakwater of Tomis Tourist Port, which is under its extension works to be completed by 2006. The seaside slope of Jetty I-J-09 is covered with 4.5-ton stabilopods.

The Submerged Breakwaters I-B-08, I-B-09 and I-B-10 are listed in the documents and affirmed of their existence by researchers of NIMRD, even though the Team could not recognize them by visual inspection from a boat. They seem to have subsided greatly or scattered by waves; their structural types are not known.

5.4.2 Eforie Sector

(1) Sub-Section II-1 "Eforie Nord"

In this sub-sector, seven jetties and nine submerged, detached breakwaters have been built. However, the majority of submerged breakwaters could not be recognized by visual inspection from a boat because of the low transparency of the seawater. There is a possibility that they were only planned and never constructed. A marina (yacht harbor) is located in the middle of this sub-section, and beaches are wider in the south of the marina than in the north.

The Jetty II-J-01 is a Y-shaped one at Agigea located in the south of the large south breakwater of Constanța Port. Possibly because of its location sheltered by the large breakwater, the jetty maintains its original shape without armoring by stabilopods, but the crown concrete slab around the base of the jetty is slightly damaged. Its construction period is unknown. The jetties listed below were built during 1956 to 1960.

The Jetties II-J-02, II-J-03, and II-J-04 have the shape of the letter I, having the length of about 65 m. The seaward heads of the jetties are protected by 4.5-ton stabilopods and the trunks are armored with limestone blocks. A few numbers of stabilopods and limestone blocks are transported on top of the concrete slab possibly by wave actions. The Jetties II-J-02 and II-J-03 maintain good conditions including crown concrete slab, but the Jetty II-J-04 has been damaged on the head portion with scattering of stabilopods and armor stones and breakage of concrete slab. This portion requires repair works.

The Jetty II-J-05 is a T-shaped jetty, which is the largest in this sub-sector with the length of about 240 m. The head section of T-shape is about 46 m long. The top of crown concrete slab has the elevation of +1.2m or so, which is higher than other jetties. The head portion is protected with 4.5-ton stabilopods. Armoring of the trunk section with limestone blocks is only up to the middle point from the beach. The rest of the section is suffering from damage on concrete slab. Because many tourists are walking on top of this jetty, damaged concrete slab is hazardous for them. For safety of beach users, repair of crown concrete slab and protection with armoring stones will be necessary.

The Jetty II-J-06 is placed nearly parallel to the shoreline and its crest of about 5 m wide is barely above the mean sea level. Concrete slab on the crest is partially damaged.

The Jetty II-J-07 is the same type as the Jetty II-J-02 with only a partial damage on crown concrete slab. The elevation of crown concrete slab is +0.3 m or so.

The Submerged Breakwaters II-B-01 to II-B-03 could be only discerned from a height of cliff on a day of good visibility, but they were difficult to recognize by visual inspection from a boat. The Team was barely able to see some of submerged stabilopods of the Breakwater II-B-04 from a boat. Thus, it is estimated that these breakwaters were built by placing stabilopods in the sea. Their crests were originally set at +0.5 m and they must have subsided greatly.

The Submerged Breakwater II-B-05 could not be recognized at all. Some stabilopods at the crests of the Submerged Breakwater II-B-06 and II-B-07 can be seen from the shore when waves are relatively high. The Submerged Breakwaters II-B-01 to II-B-07 are located in the north of the marina (named the Yacht Club Europa) and were built during 1981 to 1985.

In the south of the marina, the Submerged Breakwaters II-B-08 and II-B-09 were said to have been built during 1983 to 1985 according to the documents and interview with researchers of NIMRD. However, the Team could not recognize them at all during reconnaissance. They were designed with the crest elevation of +0.5 m by placing stabilopods in situ, but they must have subsided greatly.

(2) Sub-Section II-2 “Eforie Middle”

In this sub-sector, two small jetties and eight submerged, detached breakwaters have been built. The Jetty II-J-08 and II-J-09 are small T-shaped ones, which were built around 1970. They are located around the center of a long beach between the Yacht Club Europa) and Eforie Sud and were intended to prevent beach erosion around them. Both jetties have been severely damaged since then with scattering of armor blocks and rubble stones as well as breakage of crown concrete slab.

Among the eight Submerged Breakwaters II-B-10 to II-B-17, only II-B-11 maintained its crest near to the sea surface; and a rubber boat got nearly aground on the breakwater crest during the Team’s field inspection. The other seven submerged breakwaters could not be recognized neither by aerial inspection from a helicopter or sea inspection from a rubber boat. Nevertheless, the available documents record their designs with the crest elevation of +0.5 m and researchers of NIMRD affirmed their existence.

(3) Sub-Section II-3 “Eforie Sud”

In this sub-sector, eight jetties and two submerged, detached breakwaters have been built. The Jetties II-J-10 to II-J-16 were built in 1956 to 1960. The Jetty II-J-17 was built around 1989.

The original section of the Jetty II-J-10 could not be retrieved from old documents, but it has been damaged thoroughly without any trace of the original shape; stabilopods and rubble stones were thoroughly scattered and crown concrete slap was broken. A whole repair is necessary to protect the retaining wall behind the beach.

The Jetty II-J-11 is a T-shaped one. The crown concrete slab of its north wing was broken up completely after stabilopods and rubble stones were scattered away. Damage on the south wing is slight. A half of this jetty needs full rehabilitation.

The Jetty II-J-12 is a T-shaped one using deformed concrete cubes for scour protection and stabilopdos for armoring. Many of foundation rubbles have been sucked away and the crown concrete slabs at the heads of both the north and south wings are damaged.

The Jetty II-J-13 is a T-shaped one armored with stabilopods and having the crown elevation higher than other jetties. Damage is slight and the original shape is almost maintained.

The Jetty II-J-14 is a I-shaped one armored with limestone blocks for the trunk and stabilopods at the head section. The Submerged Breakwater II-B-18 is situated offshore of this jetty. The crwon concrete slab has the thickness of 30 cm and looks well maintained, but some portions are damaged owing to scouring of foundation rubbles. The head section requires rehabilitation as its armoring stabilopods and foundation rubbles have been scattered away.

The Jetty II-J-15 is a small I-shaped one armored with limestone blocks only. Damage on this jetty is slight. The Submerged Breakwater II-B-19 is situated offshore of this jetty.

The Jetty II-J-16 is a large multi-branched jetty. The portions susceptible for wave actions are protected by stabilopods. The head section of the south wing shows some subsidence and scattering of stabilopods and rubble stones, and a part of crown concrete slab of a small thickness is damaged. Except these, this jetty is suffering only a minor damage.

The Jetty II-B-17 is a small Y-shaped one. The north wing does not show any trace of the existence of the crown concrete slab, but it seems to have been broken and washed away by waves. The remaining part of the north wing shows lowering of crest toward the head and larger scattering of rubble stones. The south wing stile holds the crown concrete slab though damaged and rubble stones are scattered away. This jetty requires rehabilitation for the whole length.

The Submerged Breakwaters II-B-18 and II-B-19 were built in 1983 to 1985. Stabilopods at their crests are slightly emerged and can be recognized from the shore.

The seawall in the north of the Jetty II-J-10, which had supported a promnade in front of a sanatorium, has been damaged severely by wave actions; the pavement of the promnade was lost for a distance of 60 m. Unless a rehabilitation measure is undertaken, the seawall may fall down and the slope behind it may collapse.

5.4.3 Tuzla Sector

This sector is a cliff coast. No shore protetion facilities have been built in this sector, but a seawall to protect the cliff in front of Tuzla Lighthous is present though its construction date is unknown.

5.4.4 Costinești Sector

This sector is composed of the sub-sector IV-0 “Costineşti,’’ which has only one jetty at the southern end. The Jetty IV-J-01 is a I-shaped one armored with limestone blocks. Its head section is built by laying rectangular concrete blocks to serve as a quay for small leisure boats. Damage to this jetty is slight.

5.4.5 Schitu Sector

This sector is a cliff coast and no shore protetion facilities have been built in this sector.

5.4.6 Mangalia Sector

(1) Sub-Sector VI-1 "Olimp-Venus"

In this sub-sector, there are five resort areas of Olimp, Neptune, Jupiter, Aurora, and Venus. As a whole, sixteen jetties and two detached breakwaters (one emerged and one submerged) have been built. In general, damage on these structures is slight.

[Olimp Resort Area]

The Jetty VI-J-01 is a Π-shaped one with its seaward side protected by two armor layers of 4.5-ton stabilopods. The crest has a high elevation, and the damage is slight. The Jetty VI-J-02 is a small T-shaped one with armoring by limestone blocks and shows no damage. The Jetty VI-J-03 is a jetty jutted out askew to the shore. It is armored with limestone blocks and shows no damage. The Jetty VI-J-04 is a Π-shaped one with its seaward side protected by 4.5-ton stabilopods and shows no damage.

[Neptune Resort Area]

The Jetty VI-J-05 is a large T-shaped one with the length of 250 m, which is connected through a PC bridge to a detached breakwater having a quay behind it for berthing the President's yacht. The major part of trunk section is armored with stabilopods. This jetty shows no damage.

The Jetty VI-J-06 is a L-shaped one with the length of about 200m and having a quay (about 50 m long) at the shoreward side of the wing section. Its seaward side is protected by two layers of stabilopods. The apron of the quay has the elevation of +1.3 to +1.5 m and provided with lighting facilities. This jetty shows no damage. Both the Jetties VI-J-05 and VI-J-06 were built in 1967 to 1970.

The Submerged Breakwater VI-B-01 is located at the southern side of the Jetty VI-J-05 and was built around 1980. One can recognize the legs of stabilopods from the shore.

[Jupiter Resort Area]

Five jetties were built in this area around 1969. The Jetty VI-J-07 is a Π-shaped one. The both wings are protected for about 30 m near the heads with one layer of stabilopods, but the remaining portion is armored with limestone blocks only. No severe damage occurred, but some portions exhibit scattering of rubble stones and breakage of crown concrete slab.

The Jetty VI-J-08 is a T-shaped one. The head portions of the both wings are protected with one layer of stabilopods, and the remaining portion is covered with limestone blocks. The head portion of the south wing shows scattering of rubble stones and scouring of foundation rubbles, and they threaten the integrity of crown concrete slab. Rehabilitation of the head portion is recommended.

The Jetty VI-J-09 is a similar structure as the Jetty VI-J-08. The head portion of the north wing is suffering from scattering of stabilopods and rubbles and breakage of crown concrete slab. The damage on the south wing is minor owing to scour protection concrete cubes placed in front of crown slab, but some slabs are damaged nevertheless. Rehabilitation is necessary.

The Jetty VI-J-10 is a T-shaped one built with deformed concrete cubes. The crown concrete slab of 3 m wide and 0.3 m thick is in good condition though it shows subsidence around the head of the south wing.

The Detached Breakwater VI-B-02 is built between the Jetties VI-J-09 and VI-J-10, and is made of randomly placed deformed concrete cubes. No major damage is observed. .

[Aurora Resort Area]

The Jetty VI-J-11 is a Π-shaped jetty. The head portions of the both wings are protected with one layer of stabilopods and the rest is armored with limestone blocks. No major damage is observed.

The Jetty VI-J-12 is a Π-shaped one similar as Jetty VI-J-11. This jetty has an outlet section of a discharge pipe at it center. Around this outlet, the crown concrete slab is broken and dislocated with scattering of stabilopods and rubble stones. The rest of the structure is not damaged much. A partial rehabilitation will suffice.

The Π-shaped Jetty VI-J-13 has recently been rehabilitated with new stabilopods and fresh limestone blocks. The head portion of the north wing is protected with two layers of stabilopods. Old stabilopods remain near the water surface along the middle section and the south wing. The head portion of the south wing has not been rehabilitated sufficiently.

[Venus Resort Area]

The Jetties VI-J-14 to VI-J-16 are the T-shaped ones protected with an armor layer of 4.5-ton stabilopods. The crown concrete slab of Jetty VI-J-14 maintains a relatively high elevation of about +1 m in good condition. No damage is observed. The Jetty VI-J-15 shows subsidence and partial cracks of the crown slabs of the wing sections.

The Jetty VI-J-16 shows subsidence of the crown slabs at the north wing and the central section. Its south wing indicates scouring of foundation rubbles beneath the crown slab, which will be soon damaged if not rehabilitated. Currently the original shape is maintained as a whole.

(2) Sub-Sector VI-2. “Balta Mangalia”

This sub-sector is a natural beach without any shore protection facility.

(3) Sub-Sector VI-3. “Saturn-Mangalia”

This sub-sector is composed of two areas of Saturn and Mangalia. Eight jetties and one detached breakwater have been built in this sub-sector.

[Saturn Area]

The Jetties VI-J-17 and 18 are the arrowhead-shape jetties armored with one layer of 4.5-ton stabilopods. No damage is observed on the both jetties.

The Jetty VI-J-19 is a L-shaped one with a northward wing, being armored with one layer of 4.5-ton stabilopods. However, stabilopods are lost around the head of the north wing, and the crown slab is broken there with scattering of rubble stones. Rehabilitation of the head portion seems necessary.

The Jetty VI-J-20 is a similar one as the Jetty VI-J-19, but directing its wing southward. Rubble stones around the wing head are scattered and the crown slab is damaged there. Reinforcement of the armor blocks of the wing seems necessary.

The Jetty VI-J-21 is a T-shaped one armored with one layer of 4.5-ton stabilopods. It is generally well maintained, but some portion shows scouring of foundation rubbles beneath the crown concrete slab.

[Mangalia Area]

The Jetties VI-J-22 and VI-J-23 are the T-shaped ones armored with one layer of 4.5-ton stabilopods, built in 1989 to 1990. The crown concrete slabs are 6 m wide, 30 cm wide, and +1.5 m above the sea level. Both the jetties are well maintained, but several portions of Jetty VI-J-22 indicate scouring of foundation rubbles beneath the crown slab, which may lead to breakage of concrete slab.

The Jetty VI-J-24 is a Y-shaped one attached to the north breakwater of Mangalia Port. The head portions of the wings are protected with 4.5-ton stabilopods and the rest is covered with limestone blocks. No major damage is observed.

The Detached Breakwater VI-B-03 was built in between Jetties VI-J-22 and VI-J-23 in 1989 to 1990. It is a rubbler mound breakwater armored with two layers of stabilopods. No major damage is observed.

5.4.7 Limanu Sector

(1) Sub-Sector VII-1 “2 Mai”

The only shore protection facility is a L-shaped, rubble mound jetty , which also serves as a breakwater of the fishing harbor of 2 Mai. The crown of the jetty is paved with concrete slab, which allows vehicle traffic. However, the head section of the breakwater indicates subsidence and damage on concrete slab and the concrete pavement at the access section is in dangerous condition, because foundation rubbles beneath it are being sucked out. Reinforcement of the access section deems necessary.

(2) Sub-Sector VII-2 “Limanu”

This section is a cliff coast and no shore protection facilities have been built.

(3) Sub-Sector VII-3 “Vama Veche”

This section is a natural sand beach and no shore protection facilities have been built.

Table 5.4.1 : List of existing shore protection facilities

NAME OF SECTOR		FACILITY	FACILITY NUMBER		INFORMATION OF FACILITIES	
SECTOR	SUB-SECTOR	TYPE OF FACILITY	Database	Main Report	SHAPE or TYPE	CONSTRUCTION YEAR
I .Constanta	Mamaia	Detached Breakwater	MM 7	I-B-01	stabilopod and cubic concrete block slopetype	1988〜1990
		Detached Breakwater	MM 6	I-B-02	stabilopod and cubic concrete block slopetype	1988〜1990
		Detached Breakwater	MM 5	I-B-03	stabilopod and cubic concrete block slopetype	1988〜1990
		Detached Breakwater	MM 4	I-B-04	stabilopod and cubic concrete block slopetype	1988〜1990
		Detached Breakwater	MM 3	I-B-05	stabilopod and cubic concrete block slopetype	1988〜1990
		Detached Breakwater	MM 2	I-B-06	stabilopod and cubic concrete block slopetype	1988〜1990
		Jetty	MM 1	I-J-01	Z shape	1978
	I-6 Tomis North	Jetty	C8	I-J-02	π shape	After 1984
		Jetty	C7	I-J-03	I shape	?
		Submerged Detached Breakwater	D	I-B-07	stabilopod permeable	After 1986
		Retaining wall			concrete gravity type	1982〜1985
		Jetty	C6	I-J-04	π shape	1983〜1986
	I-7 Tomis South	Submerged Detached Breakwater	C	I-B-08	stabilopod permeable	After 1984
		Jetty	C5	I-J-05	Z shape	1982〜1984
		Submerged Detached Breakwater	B	I-B-09	stabilopod permeable	After 1984
		Jetty	C4	I-J-06	small π shape	After 1986
		Submerged Detached Breakwater	A	I-B-10	stabilopod permeable	After 1984
		Jetty	C3	I-J-07	small π shape	After 1986
		Jetty	C2	I-J-08	Z shape	1973〜
		Jetty	C1	I-J-09	I shape	1971
II. Eforie	II-1 Eforie Nord	Jetty	AG1	II-J-01	Y shape	?
		Jetty	EN8	II-J-02	I shape	1956〜1960
		Submerged Detached Breakwater	T	II-B-01	stabilopod permeable	1981〜1985

II. Eforie		Submerged Detached Breakwater	S	II-B-02	stabilopod permeable	1981〜1985
		Jetty	EN7	II-J-03	I shape	1956〜1960
		Submerged Detached Breakwater	R	II-B-03	stabilopod permeable	1981〜1985
		Jetty	EN6	II-J-04	I shape	1956〜1960
		Submerged Detached Breakwater	P	II-B-04	stabilopod permeable	1981〜1985
		Submerged Detached Breakwater	O	II-B-05	stabilopod permeable	1981〜1985
		Jetty	EN5	II-J-05	T shape	1956〜1960
		Submerged Detached Breakwater	O	II-B-06	stabilopod permeable	1981〜1985
		Jetty	EN4	II-J-06	parallel	1956〜1960
		Submerged Detached Breakwater	N	II-B-07	stabilopod permeable	1981〜1985
		Jetty	EN3	II-J-07	I shape	1956〜1960
		Submerged Detached Breakwater	L	II-B-08	stabilopod permeable	1983〜1985
		Submerged Detached Breakwater	K	II-B-09	stabilopod permeable	1983〜1985
		Belona Europe Marina				1981〜1985
	II-2 Eforie Middle	Submerged Detached Breakwater	J	II-B-10	stabilopod permeable	1983〜1985
		Jetty	EN2	II-J-08	T shape	1970〜
		Submerged Detached Breakwater	I	II-B-11	stabilopod permeable	1983〜1985
		Jetty	EN1	II-J-09	T shape	1970〜
		Submerged Detached Breakwater	H	II-B-12	stabilopod permeable	1983〜1985
		Submerged Detached Breakwater	G	II-B-13	stabilopod permeable	1983〜1985
		Submerged Detached Breakwater	F	II-B-14	stabilopod permeable	1983〜1985
		Submerged Detached Breakwater	E	II-B-15	stabilopod permeable	1983〜1985
		Submerged Detached Breakwater	D	II-B-16	stabilopod permeable	1983〜1985
	II-3 Eforie Sud					
		Jetty	ES-8	II-J-10	T shape	1956〜1960
		Jetty	ES-7	II-J-11	Y shape	1956〜1960
		Jetty	ES-6	II-J-12	T shape	1956〜1960
		Jetty	ES-5	II-J-13	T shape	1956〜1960
		Jetty	ES-4	II-J-14	I shape	1956〜1960
		Submerged Detached Breakwater	C	II-B-17	stabilopod permeable	1983〜1985
		Submerged Detached Breakwater	B	II-B-18	stabilopod permeable	1983〜1985

II. Eforie		Submerged Detached Breakwater	A	II-B-19	stabilopod permeable	1983〜1985
		Jetty	ES-3	II-J-15	Ishape	1956〜1960
		Jetty	ES-2	II-J-16	multileg shape	1956〜1960
		Jetty	ES-1	II-J-17	Y shape	1989〜
III. Tuzula		No facility				
IV. Costinesti	VI-0 Costinesti	Jetty	CS 1	IV-J-01	I shape	〜1985
V. Schitu		No facility				
VI. Mangalia	VI-1 Olimp-Venus					
	(Olimp)	Jetty	O-4	VI-J-01	πshape	After 1970
		Jetty	O-3	VI-J-02	T shape	After 1970
		Jetty	O-2	VI-J-03	parallel	After 1970
		Jetty	O-1	VI-J-04	πshape	After 1970
	(Neptun)	Jetty	N-2	VI-J-05	T shape	1967〜1970
		Submerged Detached Breakwater	N-3	VI-B-01	stabilopod permeable	in the 1980
		Jetty	N-1	VI-J-06	L shape	1967〜1970
	(Jupiter)	Jetty	J-5	VI-J-07	πshape	1969〜
		Jetty	J-4	VI-J-08	T shape	1969〜
		Jetty	J-3	VI-J-09	T shape	1969〜
		Detached Breakwater	J-2	VI-B-02	concrete cubic block sloping type	After 1969
		Jetty	J-1	VI-J-10	T shape	After 1969
	(Aurora)	Jetty	A-3	VI-J-11	πshape	?
		Jetty	A-2	VI-J-12	πshape	?
		Jetty	A-1	VI-J-13	πshape	in the 1970
	(Venus)	Jetty	V-3	VI-J-14	T shape	1989〜1991

VI. Mangalia		Jetty	V-2	VI-J-15	T shape	1989〜1991
		Jetty	V-1	VI-J-16	T shape	1989〜1991
	VI-2 Belta-Mangalia	No facility				
	VI-3 Saturn-Mangalia					
	(Saturn)	Jetty	S-5	VI-J-17	arrow shape	1970
		Jetty	S-4	VI-J-18	arrow shape	1970
		Jetty	S-3	VI-J-19	L shape	1970
		Jetty	S-2	VI-J-20	L shape	1970
		Jetty	S-1	VI-J-21	T shape	1989
	(Mangalia)	Jetty	M-4	VI-J-22	T shape	1989〜1990
		Detached Breakwater	M-3	VI-B-03	stabilopod covered sloping type	1989〜1990
		Jetty	M-2	VI-J-23	T shape	1989〜1990
		Jetty	M-1	VI-J-24	Y shape	after 1976
VII. Limanu	VII-1 2-Mai	JETTY (BREAKWATER)	2M1	VII-J-01	L shape	?
	VII-2 Limanu	No facility				
	VII-3 Vama Veche	No facility				

Note: In column construction year, description "after" means designed year. Actual construction year of those have not been clarified.

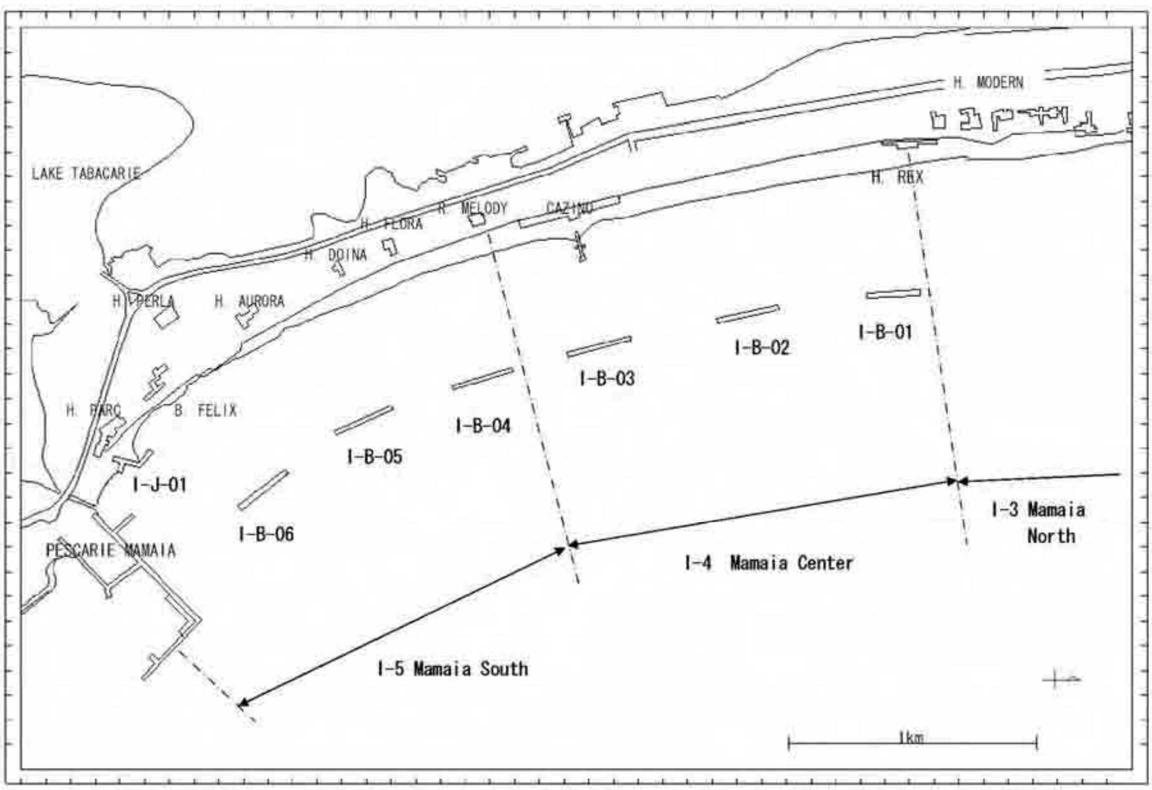

Fig. 5.4.1： Location map of existing shore protection facilities (1)

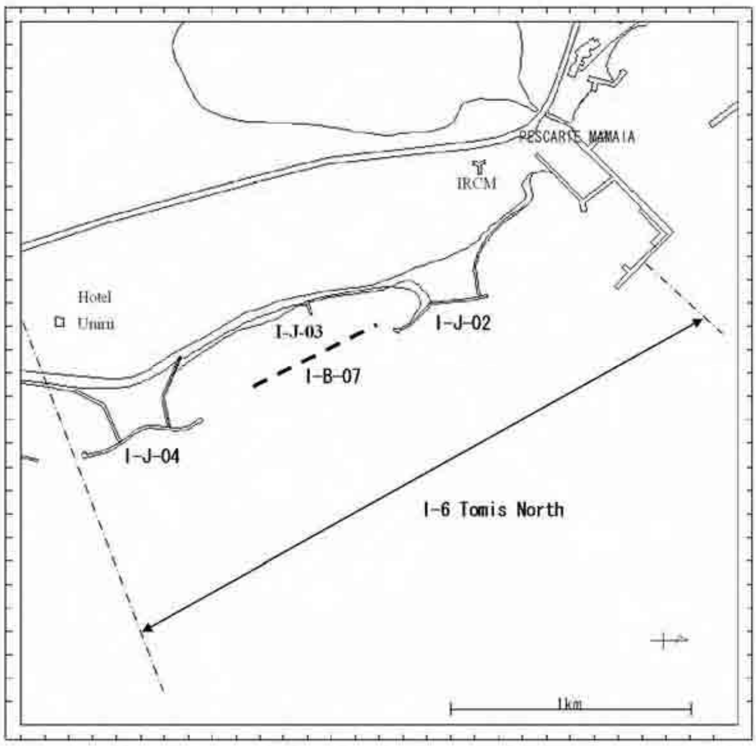

Fig. 5.4.2： Location map of existing shore protection facilities (2)

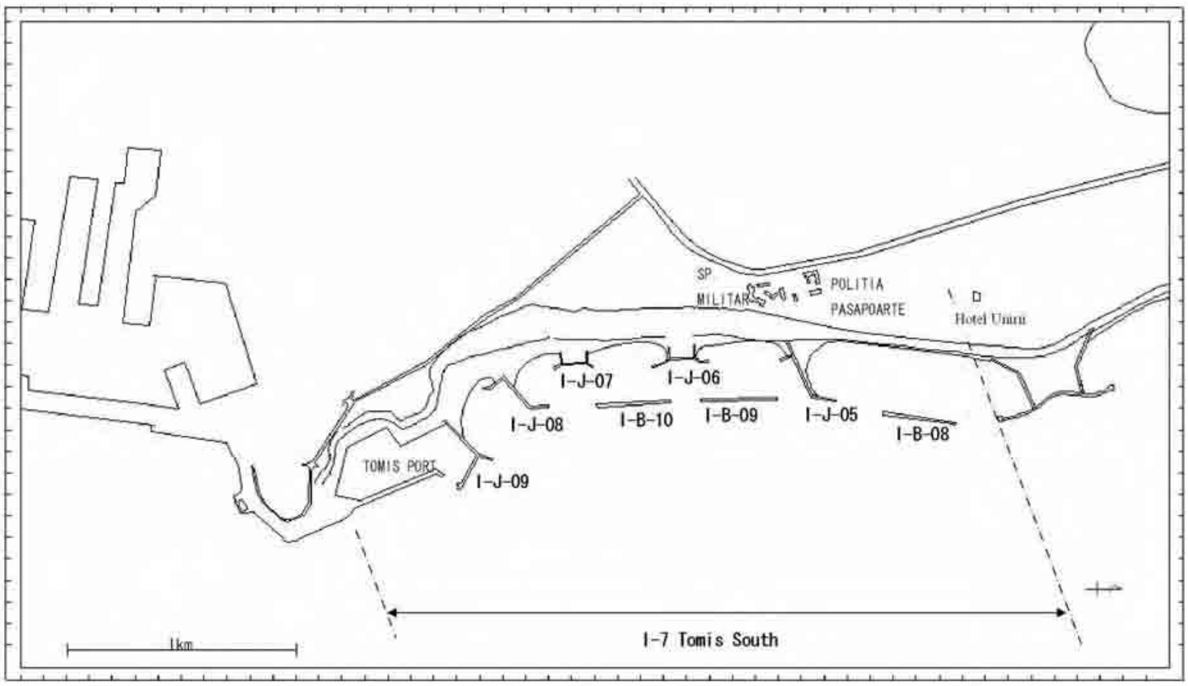

Fig. 5.4.3： Location map of existing shore protection facilities (3)

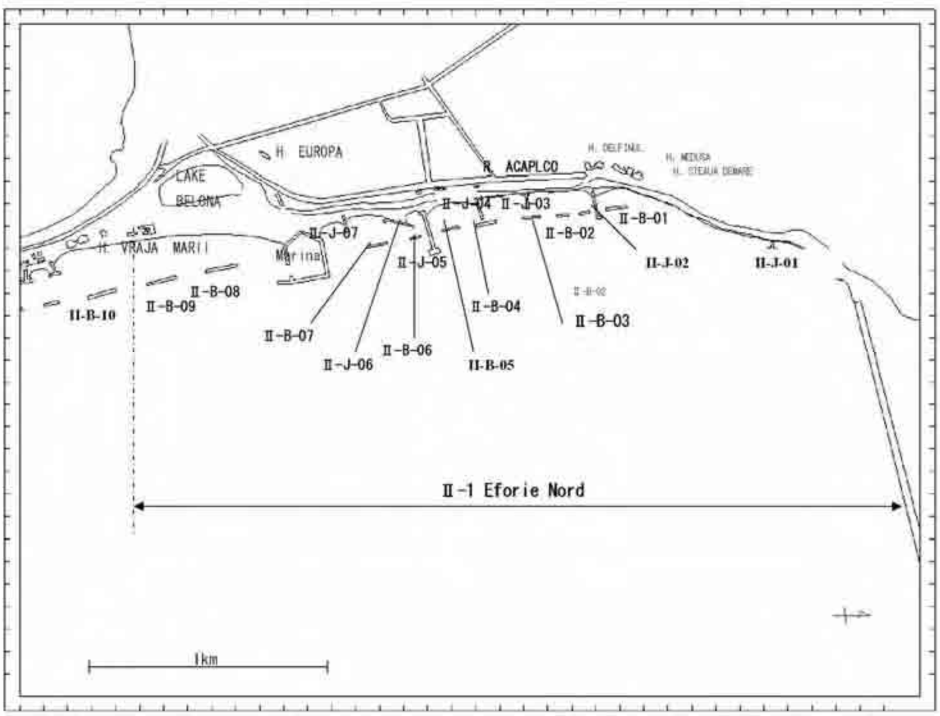

Fig. 5.4.4： Location map of existing shore protection facilities (4)

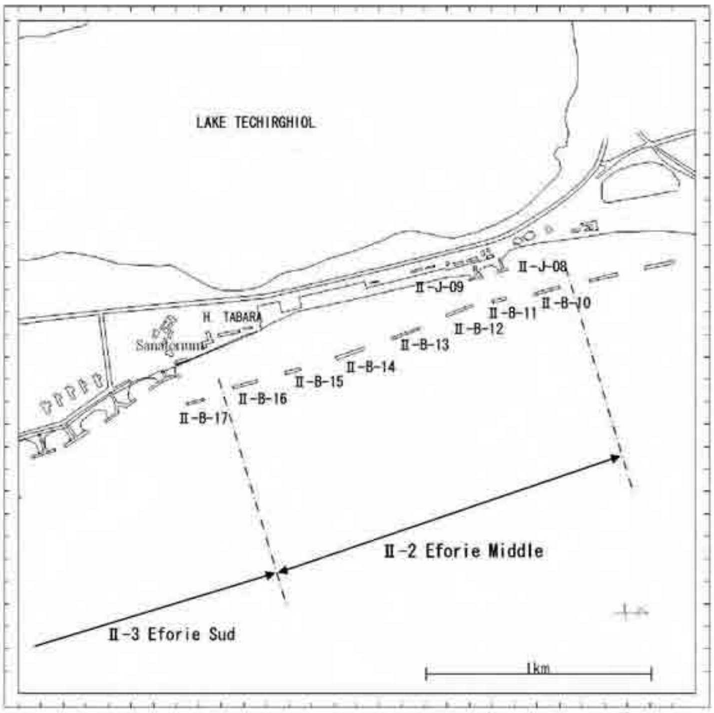

Fig. 5.4.5： Location map of existing shore protection facilities (5)

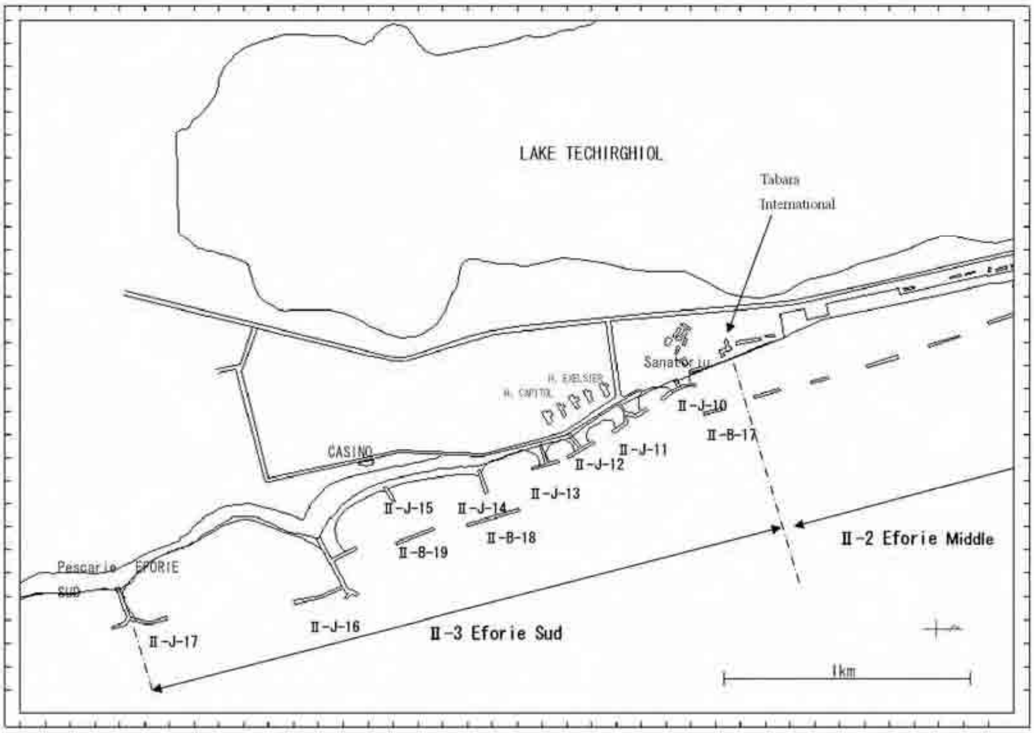

Fig. 5.4.6： Location map of existing shore protection facilities (6)

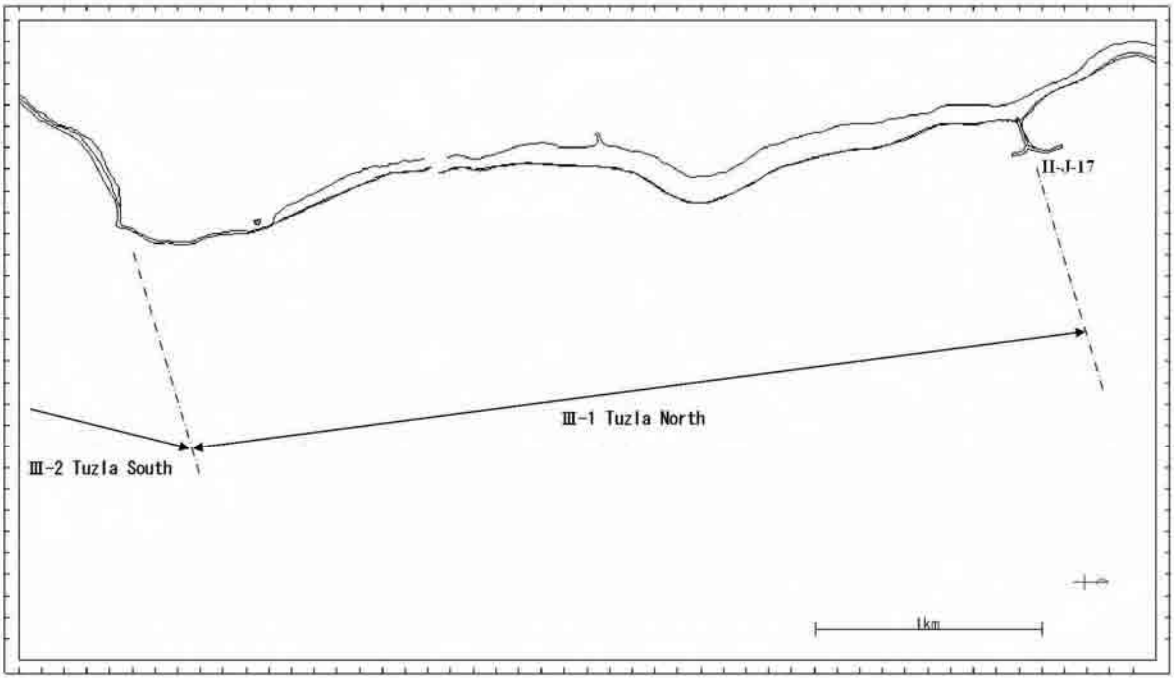

Fig. 5.4.7： Location map of existing shore protection facilities (7)

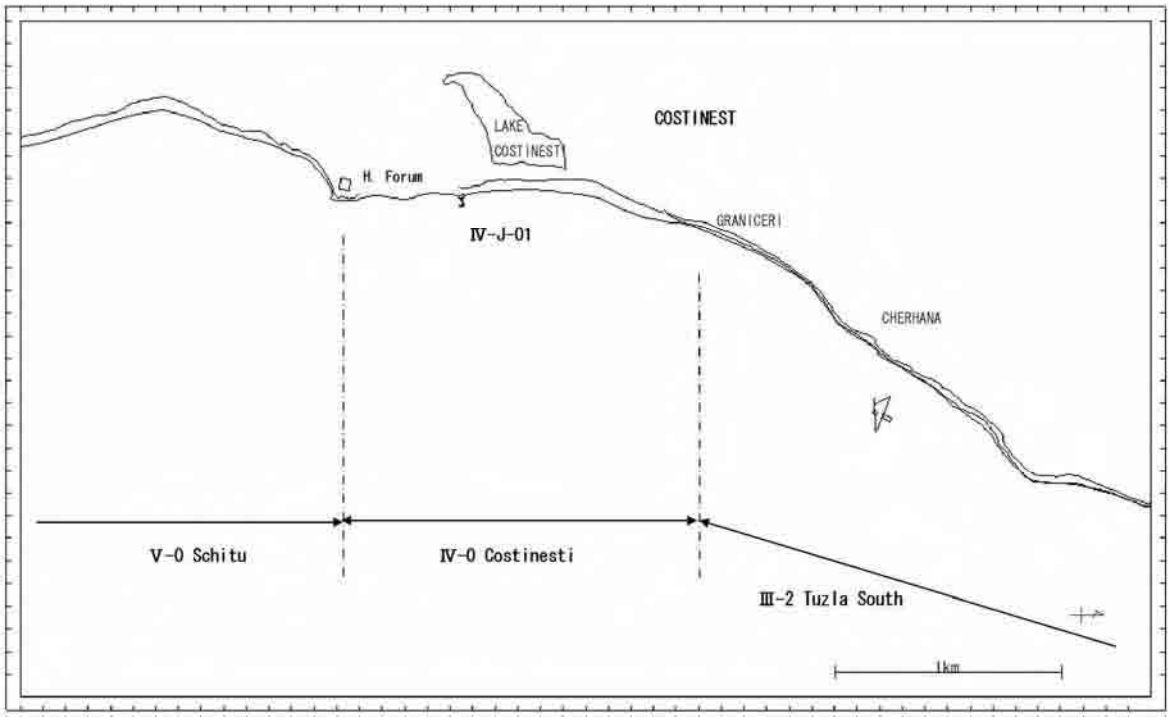

Fig. 5.4.8： Location map of existing shore protection facilities (8)

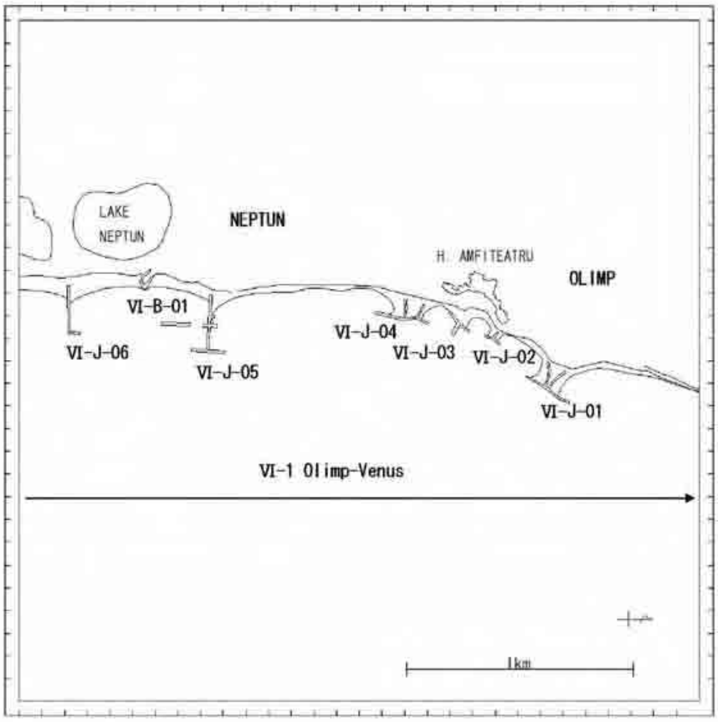

Fig. 5.4.9： Location map of existing shore protection facilities (9)

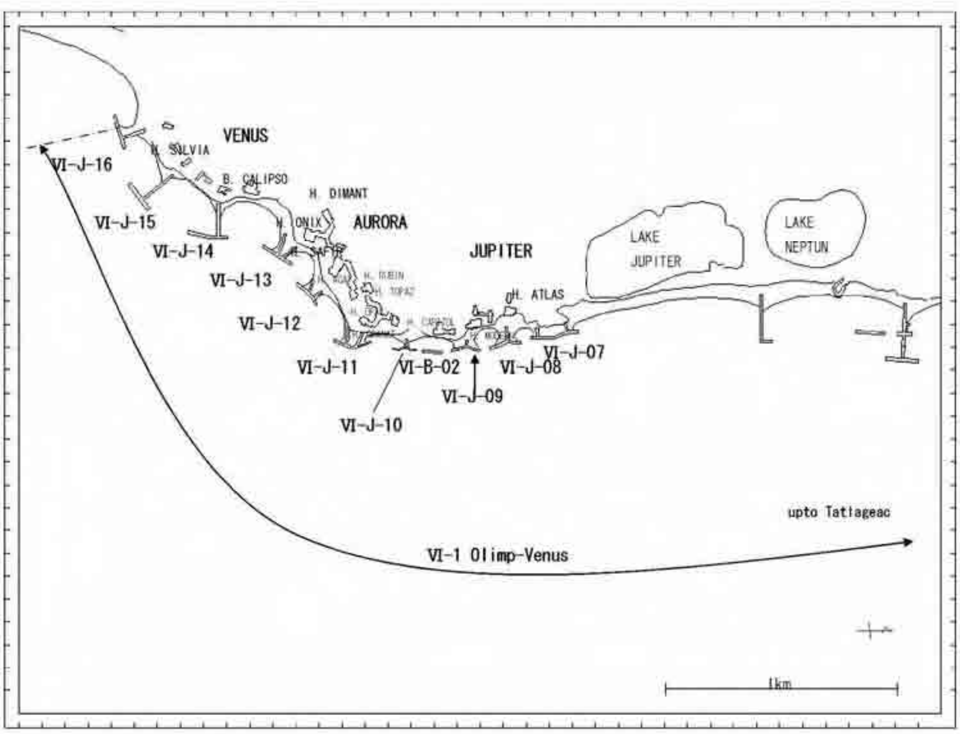

Fig. 5.4.10： Location map of existing shore protection facilities (10)

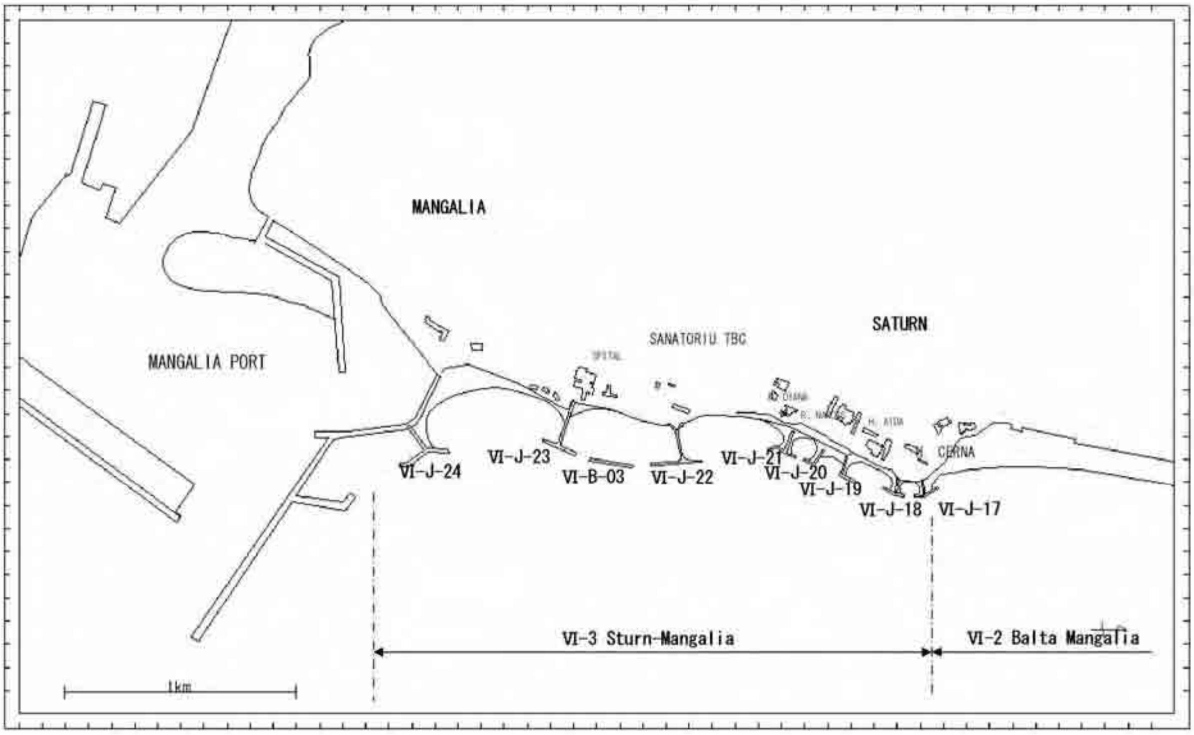

Fig. 5.4.11： Location map of existing shore protection facilities (11)

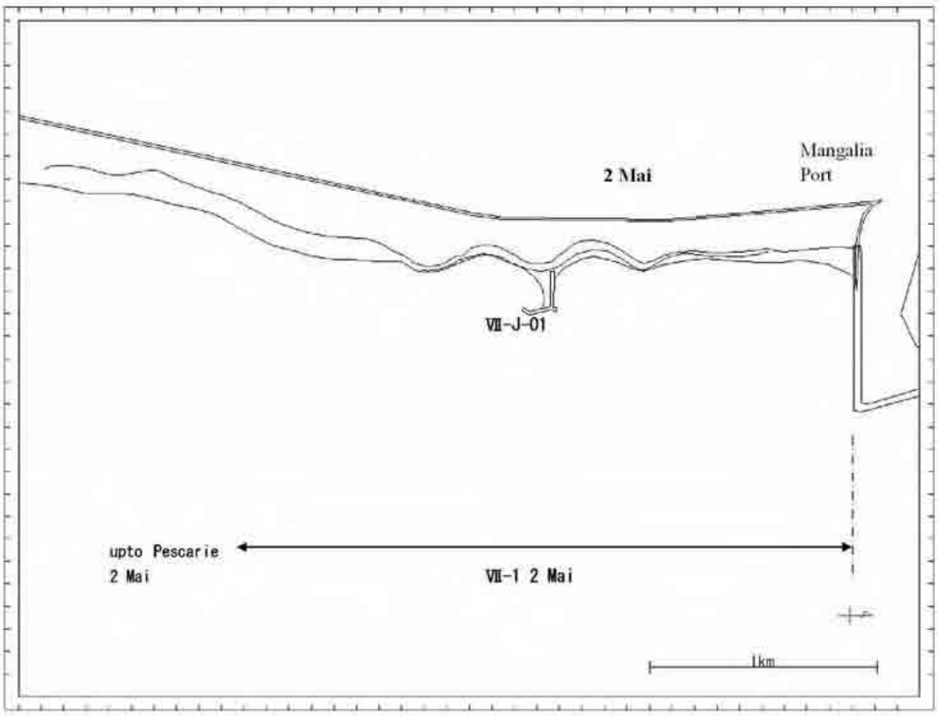

Fig. 5.4.12： Location map of existing shore protection facilities (12)

5.5 Evaluation of Existing Shore Protection Facilities

Survey of the existing shore protection facilities has been made for the structural integrity and their degree of sediment control functioning. Table 5.4.1 lists the summary of the evaluation of the existing facilities. The meanings of the symbols and figures in the columns of "soundness" and "function" are explained in the note below the table. Although the sub-sectors of Eforie Sud, Olimp – Venus, and Saturn – Mangalia have the problem of water pollution due to poor water circulation in the water pools enclosed by short groins, it is not listed in this evaluation.

Table 5.5.1: Summary of evaluation of existing shore protection facilities

NAME OF SECTOR		FACILITY	FACILITY NUMBER		EVALUATION	
SECTOR	SUB-SECTOR	TYPE OF FACILITY	Database	Main Report	Soundness	Function
I .Constanta	Mamaia	Detached Breakwater	MM 7	I-B-01	C	1
		Detached Breakwater	MM 6	I-B-02	C	1
		Detached Breakwater	MM 5	I-B-03	C	1
		Detached Breakwater	MM 4	I-B-04	C	1
		Detached Breakwater	MM 3	I-B-05	C	1
		Detached Breakwater	MM 2	I-B-06	C	1
		Jetty	MM 1	I-J-01	A	0
	I-6 Tomis North	Jetty	C8	I-J-02	B	2
		Jetty	C7	I-J-03	C	3
		Submerged Detached Breakwater	D	I-B-07	invisible	4
		Retaining wall (between I-J-03 and I-J-04)			collapsed	0
		Jetty	C6	I-J-04	C	0
	I-7 Tomis South	Submerged Detached Breakwater	C	I-B-08	invisible	4
		Jetty	C5	I-J-05	B	0
		Submerged Detached Breakwater	B	I-B-09	invisible	4
		Jetty	C4	I-J-06	C	0
		Submerged Detached Breakwater	A	I-B-10	invisible	4
		Jetty	C3	I-J-07	B	0
		Jetty	C2	I-J-08	C	0
		Jetty	C1	I-J-09	B	0
						0
II. Eforie	II-1 Eforie Nord	Jetty	AG1	II-J-01	B	0
		Jetty	EN8	II-J-02	B	2
		Submerged Detached Breakwater	T	II-B-01	invisible	4
		Submerged Detached Breakwater	S	II-B-02	invisible	4
		Jetty	EN7	II-J-03	B	2
		Submerged Detached Breakwater	R	II-B-03	invisible	4
		Jetty	EN6	II-J-04	C	2
		Submerged Detached Breakwater	P	II-B-04	invisible	4
		Submerged Detached	O	II-B-05	invisible	4

		Breakwater				
		Jetty	EN5	II-J-05	B	2
		Submerged Detached Breakwater	O	II-B-06	invisible	4
		Jetty	EN4	II-J-06	B	0
		Submerged Detached Breakwater	N	II-B-07	invisible	4
		Jetty	EN3	II-J-07	B	2, 3
		Submerged Detached Breakwater	L	II-B-08	invisible	4
		Submerged Detached Breakwater	K	II-B-09	invisible	4
		Belona Europe Marina				0
	II-2 Eforie Middle	Submerged Detached Breakwater	J	II-B-10	invisible	4
		Jetty	EN2	II-J-08	D	3
		Submerged Detached Breakwater	I	II-B-11	invisible	4
		Jetty	EN1	II-J-09	D	3
		Submerged Detached Breakwater	H	II-B-12	invisible	4
		Submerged Detached Breakwater	G	II-B-13	invisible	4
		Submerged Detached Breakwater	F	II-B-14	invisible	4
		Submerged Detached Breakwater	E	II-B-15	invisible	4
		Submerged Detached Breakwater	D	II-B-16	invisible	4
	II-3 Eforie Sud	Retaining wall (in front of Sanatrium)			collapsed	4
		Jetty	ES-8	II-J-10	D	4
		Jetty	ES-7	II-J-11	C	0
		Jetty	ES-6	II-J-12	B	0
		Jetty	ES-5	II-J-13	A	0
		Jetty	ES-4	II-J-14	C	0
		Submerged Detached Breakwater	C	II-B-17	invisible	1
		Submerged Detached Breakwater	B	II-B-18	visible slightly	1
		Submerged Detached Breakwater	A	II-B-19	visible slightly	1
		Jetty	ES-3	II-J-15	B	3
		Jetty	ES-2	II-J-16	B	0
		Jetty	ES-1	II-J-17	C	0
III. Tuzula		No facility				
IV. Costinesti	VI-0 Costinesti	Jetty	CS 1	IV-J-01	A	
V. Schitu		No facility				
VI. Mangalia	VI-1 Olimp-Venus (Olimp)	Jetty	O-4	VI-J-01	B	0
		Jetty	O-3	VI-J-02	A	0
		Jetty	O-2	VI-J-03	A	0
		Jetty	O-1	VI-J-04	A	0

	(Neptun)	Jetty	N-2	VI-J-05	A	0
	(Neptun)	Submerged Detached Breakwater	N-3	VI-B-01	visible slightly	0
	(Neptun)	Jetty	N-1	VI-J-06	A	0
VI. Mangalia						
VI. Mangalia	(Jupiter)	Jetty	J-5	VI-J-07	B	0
VI. Mangalia	(Jupiter)	Jetty	J-4	VI-J-08	C	0
VI. Mangalia	(Jupiter)	Jetty	J-3	VI-J-09	C	0
VI. Mangalia	(Jupiter)	Detached Breakwater	J-2	VI-B-02	A	0
VI. Mangalia	(Jupiter)	Jetty	J-1	VI-J-10	B	0
VI. Mangalia	(Jupiter)					
VI. Mangalia	(Aurora)	Jetty	A-3	VI-J-11	A	0
VI. Mangalia	(Aurora)	Jetty	A-2	VI-J-12	C	0
VI. Mangalia	(Aurora)	Jetty	A-1	VI-J-13	A	0
VI. Mangalia	(Aurora)					
VI. Mangalia	(Venus)	Jetty	V-3	VI-J-14	A	0
VI. Mangalia	(Venus)	Jetty	V-2	VI-J-15	B	0
VI. Mangalia	(Venus)	Jetty	V-1	VI-J-16	B	0
VI. Mangalia						
VI. Mangalia	VI-2 Belta-Mangalia	No facility				
VI. Mangalia						
VI. Mangalia	VI-3 Saturn-Mangalia (Saturn)	Jetty	S-5	VI-J-17	A	0
VI. Mangalia	VI-3 Saturn-Mangalia (Saturn)	Jetty	S-4	VI-J-18	A	0
VI. Mangalia	VI-3 Saturn-Mangalia (Saturn)	Jetty	S-3	VI-J-19	C	0
VI. Mangalia	VI-3 Saturn-Mangalia (Saturn)	Jetty	S-2	VI-J-20	C	0
VI. Mangalia	VI-3 Saturn-Mangalia (Saturn)	Jetty	S-1	VI-J-21	B	0
VI. Mangalia						
VI. Mangalia	(Mangalia)	Jetty	M-4	VI-J-22	A	0
VI. Mangalia	(Mangalia)	Detached Breakwater	M-3	VI-B-03	A	0
VI. Mangalia	(Mangalia)	Jetty	M-2	VI-J-23	B	0
VI. Mangalia	(Mangalia)	Jetty	M-1	VI-J-24	A	0
VII. Limanu	VII-1 2-Mai	JETTY (BREAKWATER)	2M1	VII-J-01	C	0
VII. Limanu	VII-2 Limanu	No facility				
VII. Limanu	VII-3 Vama Veche	No facility				

Note: Soundness of structures:

- A: Between little to minor damage or having been repaired;
- B: Between minor to medium damage;
- C: Between medium to serious damage;
- D: Almost totally damaged or collapsed.

Shore protection function:

- 0: Functioning well for sediment control
- 1: Decrease of sediment trapping function due to the settlement;
- 2: Groin crest being too low to control sediment transport especially in storm wave condition;
- 3: Too small sizes to exercise sufficient sediment control function;
- 4: Structural damage too great to function for shore protection.

5.6 Selection of Shore Protection Facilities for the Study Area

5.6.1 Overview of Shore Protection Facilities

(1) General

The coastal area must be protected against the threat of high waves, storm surges, tsunamis, and other causes, which fall upon the coastal area once in a while. Beach erosion is another type of natural threats, which progress gradually year after year. Various facilities have been devised and built to protect the coastal area in the world. Table 5.6.1 presents an overview of these shore protection facilities with their characteristics. They are classified in the following categories:

1) Coastal dike;
2) Seawall: vertical type, large-curved parapet type, wave-dissipating block mound type, sloping type, and foot-protection mound type;
3) Shore-parallel breakwater: emerged type, submerged narrow-crested type, and submerged broad-crested type;
4) Jetty: groin and artificial headland; and
5) Sand control method: beach fill and sand bypass.

(2) Coastal dikes and seawalls

Coastal dikes and seawalls are mostly for protection of the hinterland against high waves, storm surges, tsunamis and so on. Seawalls having vertical or steep front walls have a high capacity of wave reflection. Intensive wave agitation in the front by combination of incident reflected waves causes a rapid erosion of beach there. When a beach is to be preserved, a seawall of sloping type is usually designed. Even so, success of beach preservation depends on the wave reflectivity of seawall, wave characteristics, sediment supply and other factors. Some of seawalls are built to prevent coastal erosion. A typical case is a mound of rubble stones or concrete blocks piled up at the foot of a cliff that is threatened by scouring at foot and eventual collapse. It is built over several hundred meters to a few thousand kilometers of an endangered cliff coast.

(3) Breakwaters

Shore-parallel breakwaters, jetties, and beach fill are for coastal protection against beach erosion. Shore-parallel breakwaters are often called detached breakwaters, and the term of low crested structure (LCS)[1] is also used, because their crests are a few meters high above the design water level. Well-designed shore-parallel breakwaters enhance formation of tombolos or salients behind them and protect beaches there. However, their emerged crests obstruct the offshore view of people strolling on beaches and they are losing popularity in recent days. Instead, shore-parallel breakwaters of submerged type are being favored. Their wave attenuation performance is inferior to the emerged type, however. To maintain good performance of wave attenuation equivalent to the emerged type, a widening of the submerged crest is necessary: submerged breakwaters with the crest width of 40 m or more have been built. Such wide breakwaters of submerged type are sometimes called the artificial reefs, because of similarity with natural rock reefs.

[1] See "Special Issue: Low Crested Structures and the Environment," Volume 52, Nos. 10-11 of *Coastal Engineering* in 2005.

Table 5.6.1: List of various shore protection facilities with their characteristics

Category	Type	Description	Main components	Effectiveness of protection	Environmental influence	Utilization by people
Coastal dike	–	A soil structure with mild slopes, covered by grass, asphalt, stone, concrete revetment, etc.	Sand and/or clay, stone, concrete, etc.	Effective against storm surges and high waves by preventing run-up	High crest may obstruct the view to the sea, but environmental influence is not significant.	A large space is required to provide mild slopes of a high-crested dike.
Seawall	Vertical type	A solid, vertical wall built on the foreshore or reclaimed land to protect the land from storm surges, high waves, erosion, etc.	Concrete, blocks, rubble stones, etc.	Effective against storm surges, high waves, tsunamis	Concrete structures may give impression of unnaturalness and spoil aesthetics of local scenery. Facing with natural stones may be required to preserve the natural. Beach in front of seawall cannot be maintained.	Additional structures of steps, slopes, etc. are required to guarantee people's access to water.
	Large-curved parapet type	A vertical seawall, the front face of which is made in a large concave shape to effectively reflect waves and to minimize wave overtopping.	Reinforced concrete with special form works	Effective against overtopping with relatively low crest	Same as above.	Same as above, but the crest portion may be utilized as promenade.
	Wave-dissipating block mound type	A mound of wave-dissipating concrete blocks is provided in front of a vertical seawall to reduce wave overtopping and reflection.	Wave-dissipating concrete blocks and the rest same as vertical seawall	Effective against high waves, storm surges, etc.	Presence of a concrete block mound gives impression of unnaturalness and may spoil aesthetics of local scenery.	Amenity with waterfront is not feasible, because of no approach to water.
	Slope type	Similar as coastal dike protected by concrete revetment or stone.	Sand and/or clay, concrete, stone, etc.	Effective against high waves, storm surges, etc.	Because of wide space required, beach width may be reduced.	Access to water is easy. Slope can be made in steps, which are often adopted in beach resorts.
	Foot protection mound	A mound of rubble stones and/or concrete blocks at the foot of cliff to prevent scouring.	Rubble stone, concrete blocks	Effective against cliff failure by scouring	Environmental influence is not significant	No access to water is feasible
Shore-parallel detached breakwater	Emerged type	Rubble mound breakwaters of a few hundred meters long for reduction of incident wave energy and protection of beach from erosion. Tombolo or salient is often formed behind them.	Rubble stone, concrete blocks, etc.	Effective against beach erosion. Overtopping of seawalls at shore is reduced. Often built in combination with beach fill.	Aesthetic view from the beach may be spoiled by emerged breakwater crests. Landing of sea turtles for egg-laying may be hindered. They may serve as breeding reef for fish, depending on location.	Beach utilization may be enhanced by creation of safer water area. They may interfere with ship navigation and fishery.
	Submerged narrow-crested type	Same as above, but the crest is set below the low water level.	Rubble stone, concrete blocks, etc.	Effective against beach erosion. Reduction of wave energy is weaker than the emerged one and so is beach	Aesthetic view from the beach is not spoiled. Ecological change may occur by introduction of stone and/or blocks upon sandy seabed, but they may serve as breeding reef for fish,	Beach utilization may be enhanced by creation of safer water area. They may interfere with

Category	Type	Description	Main components	Effectiveness of protection	Environmental influence	Utilization by people
				protection efficiency. Often built in combination with beach fill Not effective in the area with large tidal range.	depending on location..	ship navigation and fishery. Some fishing ground may disappear by covering of seabed with stone and/or blocks.
	Submerged broad-crested type	Same as above, but the crest is made wide to ensure larger wave damping.	Rubble stone, concrete blocks, etc.	Effective against beach erosion. Often built in combination with beach fill.	Same as submerged, detached breakwaters.	Same as submerged, detached breakwater
Jetty	Groin or jetty	A narrow and long structure jutted out from the shore for maintaining and/or advancing the shoreline by controlling longshore sediment transport. Often built in groups. A groin refers to a short structure, while a jetty refers to a long one.	Stone, concrete blocks, etc.	Effective against beach erosion in the coast where longshore sediment transport is predominant, but not effective against storm surge or wave overtopping..	Environmental influence is not significant.	Cross-walk on beach may be hindered by groins extended on the land. People can walk on top of groins and make fishing.
	Headlan d	A structure set perpendicularly to the predominant incident waves in the coast with strong longshore sediment transport by obliquely incident waves. It is aimed to stabilize the shoreline statically.	Stone, concrete blocks, etc.	Effective against beach erosion. Wave action is diminished just behind the structure, but it is not effective against storm surges and high waves over a wide area.	Because of its large magnitude, environmental influence is similar as that of emerged, detached breakwaters.	Cross-walk on beach may be hindered by groins extended on the land. People can walk on top of groins and make fishing.
Sand control method	Beach fill	Artificial widening or creation of beach by placing of sand from outside source	Sand, pebble, etc.	Temporally effective against erosion. Often combined with detached breakwaters and/or groins for long-term stability.	Environmental influence is not significant. Good condition for landing of turtles for egg-laying is preserved. Time of execution should be chosen in consideration of ecological characteristics.	Beach utilization is enhanced by widening of beach.
	Sand bypass	Mechanically transport sand impounded at the up-drift shore of a harbor and/or inlet to the down-drift shore, to remedy beach erosion there.	Pumping station with pipeline or dredger	Effective against erosion of the coast with predominant alongshore sediment transport in one direction.	Same as above	Same above

(4) Jetties and groins

The term of jetty is somewhat confusing, because European people use this term for a deck structure supported by vertical piles, which is extending into a sea. In this report, a jetty is used for a solid structure extended into a sea according to the terminology in USA.

The term of groin also refers to the same structure, but the present report makes a distinction between groin and jetty by assigning the former to a short structure and the latter for a long one, even though the judgment of short or long one is rather subjective. One characteristic of groin is that it is used in groups, while a jetty is often built in single.

The concept of headland control of crenulate-shaped beach was first applied in Singapore as reported by Silvester and Ho[2] in 1972. Various man-made structures that function as headlands have been built since then. Although the original concept was for the coast with predominant waves of oblique incidence, it has been applied to the coast with bi-directional wave incidence at the Ohno Coast in Ibaragi, Japan and was given the name of artificial headland method. A pair of long T-shaped jetties is extended perpendicularly to the shoreline into the outer surf zone, beyond which alongshore sediment transport becomes insignificant. The shoreline between the pair of jetties exhibits seasonal changes of advance and retreat depending on the prevailing wave directions, but its mean position throughout a year remains stable. At the Ohno Coast, forty artificial headlands have been built at the interval of about 800 m to stabilize the coastline of about 32 km long.

(5) Beach fill

Beach fill or beach nourishment is an operation to bring a large volume of sand from some outside sources and place it on eroding beaches or the shore without any previous beach. It is a direct remedy to coast of severe erosion and has been administered at many places in the world. Practice in USA is to make beach fill without any man-made structures to retain sand in position, such as detached breakwaters and groins, and to carry out maintenance of periodical sand supply. The rationale for it is the minimization of total cost in consideration of the interest incurred upon the capital investment.

The southern coast of California, USA, is a typical example of continuous beach nourishment. The coastal cell of the Huntington Beach, about 40 km southeast of Los Angels, has been provided with beach nourishment six times in total of 11 million m^3 of sand over 35 years from 1963 to 1997[3]. Sand had been dredged from the offshore seabed in the depth of around 15 m. There are many other cases of beach nourishment with the sand volume of millions cubic meters in USA. They are all making use of the offshore sand from borrow pits. The Netherlands is planning to nourish its entire coastline with the rate of 6 to 12 million m^3 per year to cope with the problem of the global mean sea level rise.[4]

On the other hand, European and Japanese practice is the execution of beach fill combined with detached breakwaters, underwater sand-retaining dikes, and/or groins. Difficulty in obtaining a sufficient amount of periodical maintenance sand supply has promoted the combination of beach fill with sand-retaining facilities.

At Ostia beach (west of Rome) in Italy, for example, beach fill with 1,360,000 m^3 of sand and selected mixed sandy-gravel was executed over the shore length of 2.8 km since 1990[5]. The

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[2] Silvester, R. and Ho, S.K. (1972): Use of crenulate shaped bays to stabilize coasts, *Proc. 13th Int. Conf. Coastal Eng.*, ASCE, pp. 1347-1365.

[3] Gadd, P.E. et al. (2006): Use of statistical depth of closure to resolve histroical changes in shoreline position and shorezone volume in the Huntington Beach littoral cell, Paper No. 132, Book of Abstract, 30th Int. Conf. Coastal Eng., San Diego, California, USA.

[4] Mulder, J.P.M. et al. (2006): Different scenarios for implementation of Netherlands large-scale coastal policy, Paper No. 343, Book of Abstract, 30th Int. Conf. Coastal Eng., San Diego, California, USA.

[5] Lamberti, A., Archetti, R., Kramer, M., Paphitis, D., Mosso, C. and Di Risio, M. (2005): European

shoreline was advanced by 60 m and the design fill area was 168,000 m^2. At a distance of some 150 m from the shoreline, a sill consisting of a submerged rubble mound parallel to the shoreline was built over the entire length. The crest berm was 15 m wide and located at –1.5 m. No groin was designed at the initial stage, but a few submerged groins were later extended from the submerged breakwater halfway toward the shore to slow down a significant drift of sediment.

(6) Sand bypassing

Sand bypass is a special measure to solve the problems of siltation at the entrance of harbor or inlet and of beach erosion at the down-drift side. Sand is dredged from the up-drift side and transported to the down-drift side through a pipeline, by a hopper dredge, or by dump trucks. It is a site-specific solution and not applied to a coast with long extension of beach.

5.6.2 Combined Use of Shore Protection Facilities

Examples of installation of various shore protection facilities are shown in Fig. 5.6.1; they are all executed in Japan. The examples (a) to (c) employ single components of facilities, but the examples (d) to (f) are combining multiple components to accommodate various requests of citizens and to enhance the disaster resistant capacity.

Combined use of shore protection facilities has gaining support of citizens and planners of infrastructure development. Figure 5.6.2 shows illustrative images of such combination of shore protection facilities. The upper left panel is for protection against high waves. A vertical seawall with its foot protected by a mound of wave-dissipating concrete blocks is not high enough to prevent excessive wave overtopping, because of limitation to the crest elevation. Thus a group of detached (emerged) breakwaters are built to reduce the wave action on the seawall. The upper right panel is the case of a sloping seawall built on sandy beach, but the beach is protected by a group of submerged breakwaters.

The lower left panel is a vertical seawall built on sandy beach, which is protected by groins. When the beach is wide enough and wave run-up does not reach the foot of vertical wall, beach erosion may not occur. However, if the beach is narrow, it faces the danger of erosion by waves reflected by the vertical wall. The lower right panel is a scene of beach fill using sand deposited at the left beach (up-drift) of a headland; sand is excavated by power shovels and transported by dump trucks to the right beach (down-drift).

5.6.3 Strategy for Installation of Shore Protection Facilities in the Study Area

As discussed in **3.5**, **4.1**, and **4.2**, the morphological features of the sub-sectors of the study area differ themselves and the shoreline retreat rates are also different. Thus, the plan of shore protection and rehabilitation needs to be prepared carefully in consideration of the characteristics of respective sub-sectors.

The problems to be solved along the Southern Romanian Black Sea shore can be itemized as in the following:

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experience of low crested structures for coastal management, *Coastal Engineering*, Vol. 52, Nos. 11-12, pp. 841-866.

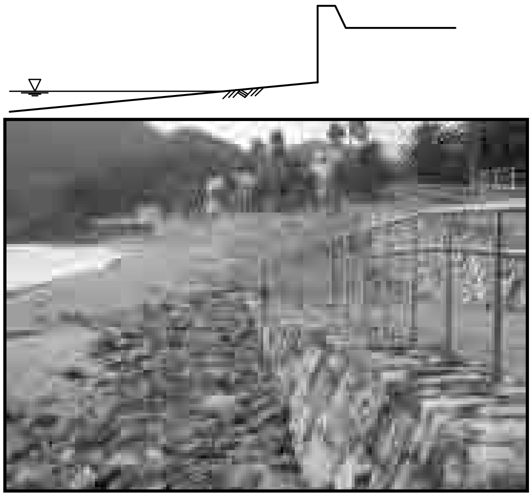
1) Acute beach erosion in the Mamaia South sub-sector;
2) Narrow beach width in many sub-sectors;
3) Danger of cliff collapse mainly caused by geotechnical instability at its upper part;
4) Deterioration of water quality near the shoreline by stagnation of water, induced by closely spaced groins, and by excessive nutrients contained in ill-treated waste water; and
5) Natural process of gradual retreat of cliffs by actions of waves and others.

The counter measures against the above problems are summarized as in the following:

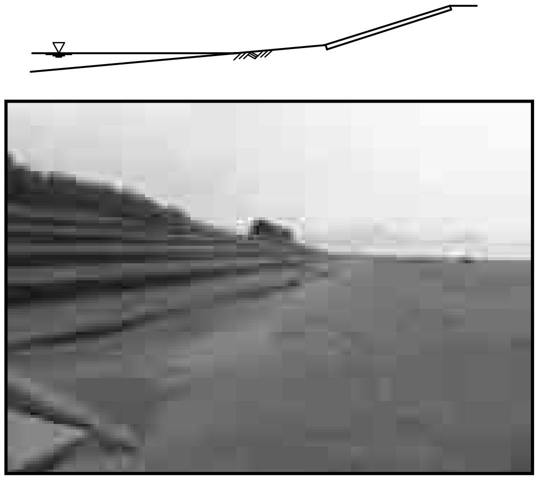
1) The Mamaia South should be given the first priority with beach fill and rehabilitation of deteriorated detached breakwaters; and
2) The sub-sectors having deficiency in beach width are treated by a large-scale beach nourishment. Without beach fill, existing narrow beaches will face complete loss of beach areas in future;
3) Cliff collapse can be prevented by reforming the slope in a gentler gradient and by providing a better drainage system. For this purpose, a widening of the area at the foot of cliff is necessary. Beach fill at Eforie Nord and Tomis North serves for this purpose;
4) Deterioration of water quality is noticeable in the sub-sectors of Eforie Sud, Jupiter to Venus, and Saturn to Mangalia. Existing groups of short groins shall be taken away and a new system of long jetties with wide spacing will be installed; and
5) In the cliff areas of Tuzla and Schitu, people are not living near the cliff edge and agricultural use of the land near the cliff is minor. The expected benefit of preventing the retreat of cliff is too small compared with the cost of constructing foot protection seawalls along the cliff area. It is recommended to postpone the cliff protection measures to some time in the future. An exception is the Cape of Tuzla where a first-grade lighthouse is standing. A special budget is to be allocated for protection of the cliff in front of the lighthouse.

Beach fill in the Study area should be executed with provision of appropriate sand-retaining structures. The American practice of beach fill without structures cannot be adopted because of an expected large amount of maintenance sand supply. Although the beach fill project at Ostia beach was carried out with a long, continuous submerged breakwater alone, it is not recommended here because of significant alongshore sediment transport in both the northward and southward directions as discussed in **4.5.1**. A group of long jetties functioning as artificial headlands is adopted in the shore protection plan in combination with beach fill.

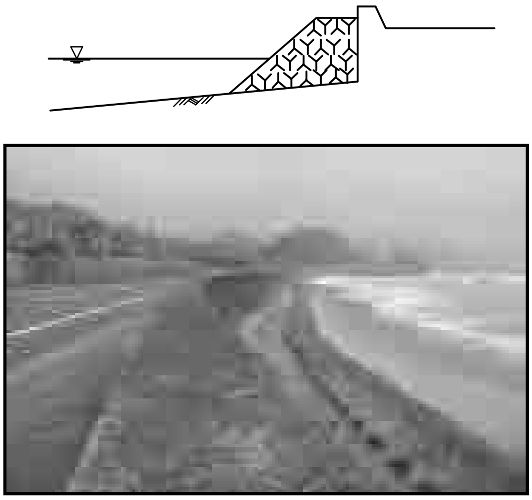
In addition, a wide-crested, shore-parallel breakwater of submerged type will be installed between a pair of artificial headlands if the incident wave energy is estimated too strong for maintenance of stable beach in between. The wide-crested submerged breakwater is arranged in the midway between the heads of jetties with some opening between it and the jetties, so as not to cause stagnation of water between the jetties.



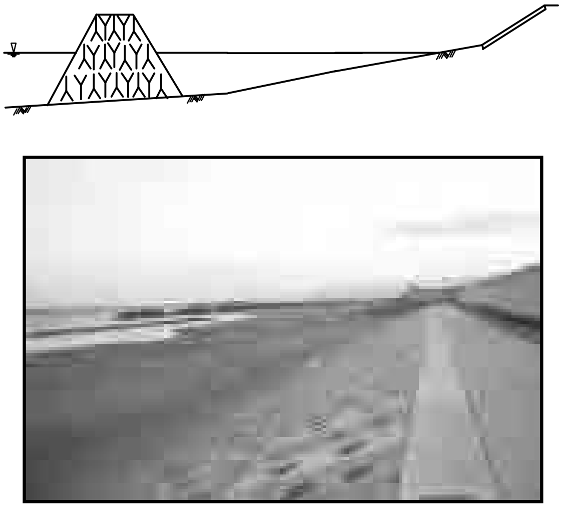
(a) Seawall of vertical type



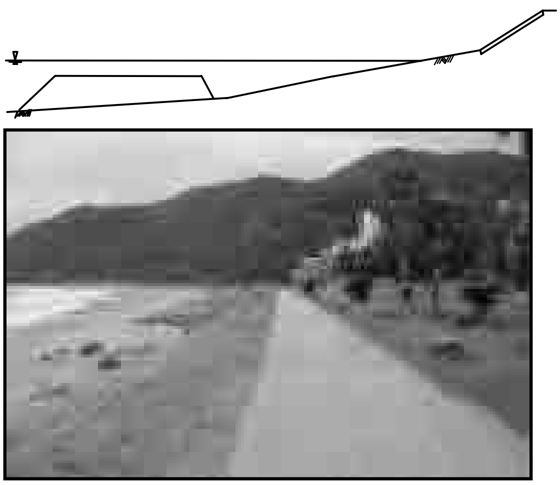
(b) Sloping seawall with steps



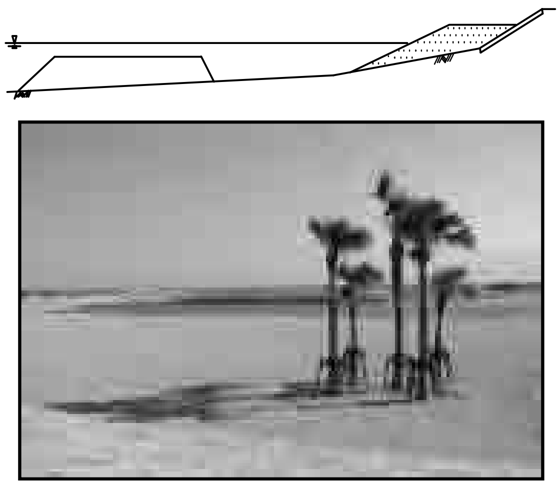
(c) Seawall with wave-dissipating block mound



(d) Combination of sloping seawall and detached breakwater



(e) Combination of sloping seawall and submerged shore-parallel breakwater



(f) Combination of sloping seawall, beach fill, submerged shore-parallel breakwater and groins

Fig. 5.6.1: Examples of installation of shore protection facilities

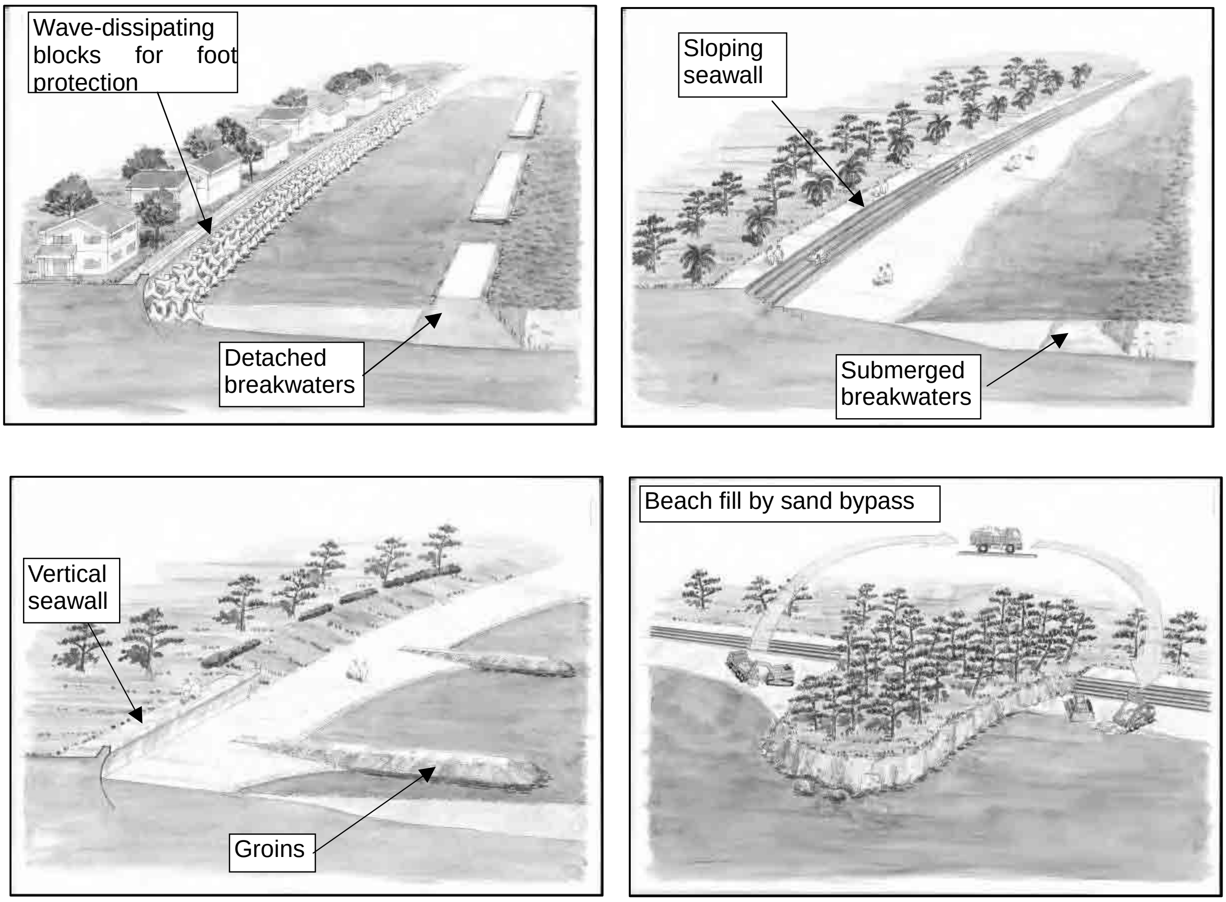


Fig. 5.6.2: Illustrative images of combined use of shore protection facilities

A combination of long jetties, submerged breakwaters in between, and beach fill may not be well known in EU or in USA. However, it is verified as effective for beach protection as will be shown by prediction of the future shoreline change in **5.7.4**.

5.6.4 Comments on Single Use of Nearshore Reef Structures

In shore protection projects in European countries, a system of low crested structures has been gaining popularity (see Lamberti et al.[6]). A technical report[7] submitted by Royal Haskoning to the Government of Romania under the "Project on Implementation of the Water Framework Directive and Integrated Coastal Zone Management in Transitional and Coastal Waters in Romania" proposes the combination of nearshore reef structures (submerged breakwaters) along the isobath of 4 m and beach fill for all the coastal sectors of the Romanian Black Sea shore for coastal protection. However, the report presents only a conceptual design of shore protection projects. No engineering investigations and preliminary designs have been made at the stage of report presentation.

Efficiency of the nearshore reef structures in controlling beach erosion entirely depends on the height of waves transmitted behind the structures. In order to effectively attenuate incoming waves by breaking them on top of the structures, the crest elevation should be as near to the

[6] Lamberti, A., Archetti, R., Kramer, M., Paphitis, D., Mosso, C. and Di Risio, M. (2005): European experience of low crested structures for coastal management, *Coastal Engineering*, Vol. 52, Nos. 11-12, pp. 841-866.

[7] Royal Haskoning: "Report on Coastal Protection: Technical Report," March 2005.

water level as possible and the crest width should be as large as feasible. In the present coastal protection plan, the submerged breakwaters which are sometime called as the submerged breakwaters are designed with the crest elevation at the level of 0.5 m below the datum level and the width of about 10 m (see Fig. F.2.11 in Annex **F.2**). The wave height behind the submerged breakwaters is estimated to be reduced to 30% of the incident waves. However, the submerged breakwaters are to be laid out with the opening between individual elements so as to ensure good water circulation. Therefore, the effective wave height behind the system of submerged breakwaters will be about 70% of the incident waves (see Eq. E.7.8 in Annex **E.7.3**).

With this degree of wave attenuation, the rate of alongshore sediment transport will be decreased to one half of the present situation, because sediment transport is proportional to the wave energy flux, i.e. the square of the wave height. That means, the rate of beach erosion will be slowed down, but the beach erosion itself will not be stopped. Let us examine the case of the Eforie Middle sub-sector. The present rate of the alongshore sediment transport illustrated in Fig. 4.5.5 is around 100,000 m^3 per year in both the northward and southward directions with the net northward transport of about 6,000 m^3 per year. If a series of nearshore reef structures are built offshore, the sediment transport rate will be decreased to around 50,000 m^3 per year in the both directions, but there will remain the net northward sediment transport of about 3,000 m^3 per year. Therefore, the Eforie Middle sub-sector will continue to suffer from beach erosion even though the rate of erosion becomes one half. The incapability in stopping beach erosion is the weak point of using nearshore reef structures alone. Simultaneous operation of beach fill will prolong the life of usable beach but it will require a quite large amount of sand supply for yearly maintenance.

Deficiency of erosion control capacity has been witnessed by the shore protection project of Ostia beach in which a few cross-shore groins were later added to an original single line of submerged sill to slow down the alongshore sediment drift, as described in the last part of **5.6.1**. As proposed in the present coastal protection plan, a set of two jetties of 300 to 400 m long extended toward the sea at an interval of 700 to 1,200 m will create a coastal sediment cell,[8] beyond which only a small amount of sediment will be carried away. By this way, the necessity of sand supply for maintenance of filled beaches will be much reduced. Thus, the combined system of long jetties, submerged breakwaters in between and beach fill is superior to a single use of nearshore reef structures in its capacity of beach erosion control.

5.6.5 Comments on Cliff Protection

The danger of cliff collapse is great in certain areas within the Study area; the northeastern shore of Constanța City, the cliff coast of Eforie Nord, and the coast of Eforie Sud are such places. As briefly described in **3.6.2** and **3.6.3**, a cliff collapse is the result of circular slip of the upper slope of the cliff. A visitor to the cliff behind beaches in Eforie Sud can easily find evidences of circular slips of the cliff slope. Although cliffs in some areas such as Limanu and Costinești are eroded at their feet by waves, most of endangered cliffs are susceptible to the geotechnical instability in the upper part of the cliff, which is induced by the rise of underground water table caused by heavy rain and/or seepage from wastewater discharge pipes.

[8] DGENV European Commission (2004): Development of a Guidance Document on Strategic Environment Assessment (SEA) and Coastal Erosion, p.14.

The solution to the cliff collapse problem is to reshape the cliff slope with a gradient much milder than the present one and to provide it with efficient drainage system. Beach consolidation works that was executed behind Tomis Tourist Port are the best examples. By such measures, the geotechnical stability of a cliff is assured and no cliff collapse will occur. However, reshaping of a cliff slope requires a wide space at the feet of cliff, because the land behind the endangered cliff is often heavily inhabitated and it is difficult to cut in the land for cliff reshaping. Beach fill operations proposed in the coastal protection plan will provide the space necessary for cliff consolidation works as envisaged in **7.3.1 (5)**.

The Scope of Works for the Study appearing in Annex **J.4** does not address to the problem of cliff collapse, and thus the Study does not cover the works related to its solution. A fundamental question is the jurisdiction of the cliff zone, or the question of the delimitation of coastal zone: to which distance the coastal zone extends landward from the shoreline? who will be responsible for cliff stabilization? Such questions should be clarified in the National Committee of the Coastal Zone at the earliest time possible for smooth undertaking of cliff consolidation works.

5.7 Proposal of Plan for Facility Installation and Rehabilitation

5.7.1 Components of New Shore Protection Facilities

(1) Overview

The proposed facility placement and the area for beach fill are illustrated in Figs. 5.7.1 to 5.7.5. The components of proposed facilities are listed in Table 5.7.1 for the twenty sub-sectors defined in Table 5.2.1, together with their implementation time to be described in **5.9.2**. However, in consideration of installation phases of shore protection facilities based on the urgency of coastal protection and rehabilitation, there have been made a few changes in sub-sectoral divisions as below.

1) Mamaia Center : to be implemented in the second and third phases.
2) Tomis Sector : separated into three sub-sectors of Tomis North, Tomis Center and Tomis South. Tomis North to be implemented in the second phase, Tomis Center in the third phase, and Tomis South postponed into the second stage
3) Eforie Nord : separated into Eforie Nord (1) and (2), the former in the first phase and the latter in the third phase.
4) Eforie Sud : separated into Eforie Sud (1) and (2), the former in the third phase and the latter postponed into the second stage.

The proposed plan includes removal of most of the existing facilities, but they are not listed in Table 5.7.1. Details of their locations and standard cross sections are listed in Annex **F**. In the following, description of facility installation plans is given for respective sub-sectors.

(2) Sub-sectors of Mamaia and Tomis

The installation plan of shore protection facilities in the sub-sectors of Mamaia and Tomis is shown in Fig. 5.7.1, together with the plan of existing facilities. The red colored lines indicate new facilities and the yellow colored zones are the area of beach fill.

Table 5.7.1: Components of proposed shore protection facilities

Sub-sector	Area	Phase	Work type	Structure type	Max. depth (m)	Length or volume
Mamaia North		I – 1	New const.	2 sub. groins	–1.5 m	2 × 100 m
Mamaia Center		I – 1	New const.	1 sub. groins	–1.5 m	100 m
		I – 2	Rehab	2 breakwaters	–5.0 m	2 × 250 m
		I – 3	Rehab	2 breakwaters	–5.0 m	2 × 250 m
Mamaia South		I – 1	Rehab	2 breakwaters	–5.0 m	2 × 250 m
		I – 1	New const.	1 sand-retaining groin	–1.5 m	200 m
	River sand fill	I – 1	New const.	Beach fill	–1.0 m	180,000 m^3
	Sea sand fill	I – 1	Alternative	Beach fill	–2.0 m	460,000 m^3
	Sea sand fill	I – 1	Alternative	1 underwater dike	–2.0 m	1,200 m
Tomis North and South	North	I – 2	New const.	2 jetties	–4.0 m	250 m & 390 m
			New const.	1 submerged breakwater	–4.0 m	250 m
			New const.	Beach fill	–1.0 m	270,000 m^3
	Center	I – 3	New const.	2 jetties	–4.0 m	350 m & 390 m
			New const.	1 submerged breakwater	–4.0 m	250 m
			New const.	Beach fill	–1.0 m	270,000 m^3
	South	II	New const.	1 jetties	–3.5 m	440 m
			New const.	2 submerged breakwaters	–4.0 m	250 m & 300 m
			New const.	Beach fill	–1.0 m	370,000 m^3
Eforie Nord (1)		I – 1	New const.	2 jetties	–5.0 m	2 × 160 m
		I – 1	Rehab.	2 jetties	–2.0 m & –3.0 m	130 m & 200 m
		I – 1	New const.	2 submerged breakwaters	–5.0 m	250m & 300 m
		I – 1	Temporary	2 access road	–0.5 to 0 m	1,700 m in total
	River sand fill	I – 1	New const.	Beach fill	–1.0 m	330,000 m^3
	Sea sand fill	I – 1	Alternative	Beach fill	–2.0 m	740,000 m^3
	Sea sand fill	I – 1	Alternative	1 underwater dike	–2.0 m	1,200 m
Eforie Nord (2)		I – 3	New const.	2 jetties	–3.0 m	2 × 190 m
	River sand fill	I – 3	New const.	Beach fill	–1.0 m	63,000 m^3
Eforie Middle		I – 2	New const.	2 jetties	–4.0 m & –4.0 m	290 m & 340 m
		I – 2	New const.	2 submerged breakwaters	–4.0 m	200 m & 300 m
		I – 2	New const.	Beach fill	–1.0 m	430,000 m^3
Eforie Sud (1)		I – 3	New const.	2 jetties	–4.0 m	2 × 240 m
		I – 3	New const.	2 submerged breakwaters	–4.0 m	250 m & 300 m
	River sand fill	I – 3	New const.	Beach fill	–1.0 m	380,000 m^3
Eforie Sud (2)		II	New const.	2 submerged breakwaters	–4.0 m	2 × 300 m
	River sand fill	II	New const.	Beach fill	–1.0 m	260,000 m^3
Olimp		II	New const.	2 jetties	–4.0 m	150 m & 180 m
		II	New const.	1 submerged breakwater	–5.0 m	250 m
	River sand fill	II	New const.	Beach fill	–1.0 m	280,000 m^3
Neptune to Venus		II	New const.	5 jetties	–4.0 to –5.0 m	180 to 360 m
	River sand fill	II	New const.	Beach fill	–1.0 m	260,000 m^3
Saturn – Mangalia		II	New const.	3 jetties	–3.0 to –4.0 m	140 to 300 m
		II	New const.	3 submerged breakwaters	–5.0 m	199 to 275 m
	River sand fill	II	New const.	Beach fill	–1.0 m	160,000 m^3

Note: 1) Submerged breakwater refers to a submerged, detached shore-parallel breakwater with a wide crest, upon which incoming waves are forced to break and dissipated.

2) In the partially modified plan described in **5.7.4,** facilities installation in Eforie Nord (2) is relinquished and the numbers of facilities at Eforie Middle are changed. The above table presents the components proposed in the original plan.

In the Mamaia sub-sectors (North, Center, and South), the deteriorated six detached breakwaters are to be rehabilitated by being provided with mounds of rubble stones armored by 4.5-ton stabilopods behind the breakwaters. A beach fill of about 180,000 m^3 is placed in Mamaia South over a distance of 1,200 m and a beach width of 100 m by utilizing the sand mined from the riverbed of the Danube. If the decision for authorization of the sand mining has to await the outcome of environmental impact assessment, the sand to be mined from the seabed off Midia Port needs to be utilized. In that case, the volume of beach fill sand will be 600,000 m^3 and an underwater dike to retain the nourished sand in position should be built over the entire length of 1,200 m. The increase in beach fill volume is caused by the very mild slope of equilibrium beach profile corresponding to the small diameter of sea sand. The facility installation plan for the case using the sea sand is given in **6.3**. Discussion on the source of beach fill sand is made in **5.7**.

At the north side of the beach fill area, a sand-retaining groin of 200 m long is projected. In the further north, three submerged groins of 100 m long each are planned; one in Mamaia Center and two in Mamaia North. There groins are aimed to reduce the strength of wave-induced longshore currents. As shown in Fig. 4.5.4, the alongshore sediment transport is strongly northward in Mamaia sub-sectors. With protection of Mamaia South by a beach fill, a sand-retaining groin, and rehabilitation of the detached breakwaters, the sub-sector of Mamaia North will face more intensive erosive action. By reducing the strength of longshore currents, it is expected that the shoreline retreat rate in Mamaia North will be decreased.

In the Tomis sub-sectors, existing short jetties are replaced by five long jetties to provide wide beach areas, which are created by beach fill with the river sand of 860,000 m^3 in volume. It is trusted that authorization of river sand mining will be issued after clearance of environmental impact assessment by the time the project of shore protection works in Tomis will be undertaken. To reduce the wave energy incident to nourished beaches, four submerged breakwaters with the crest width of about 10 m and the submergence of 0.5 m are projected. There reported three submerged breakwaters in the sub-sector of Tomis South, they have greatly subsided or been dispersed by wave actions as described in 5.3.1. Therefore, these submerged breakwaters if still existing will be left as they are, and they will not affect the new facility installation.

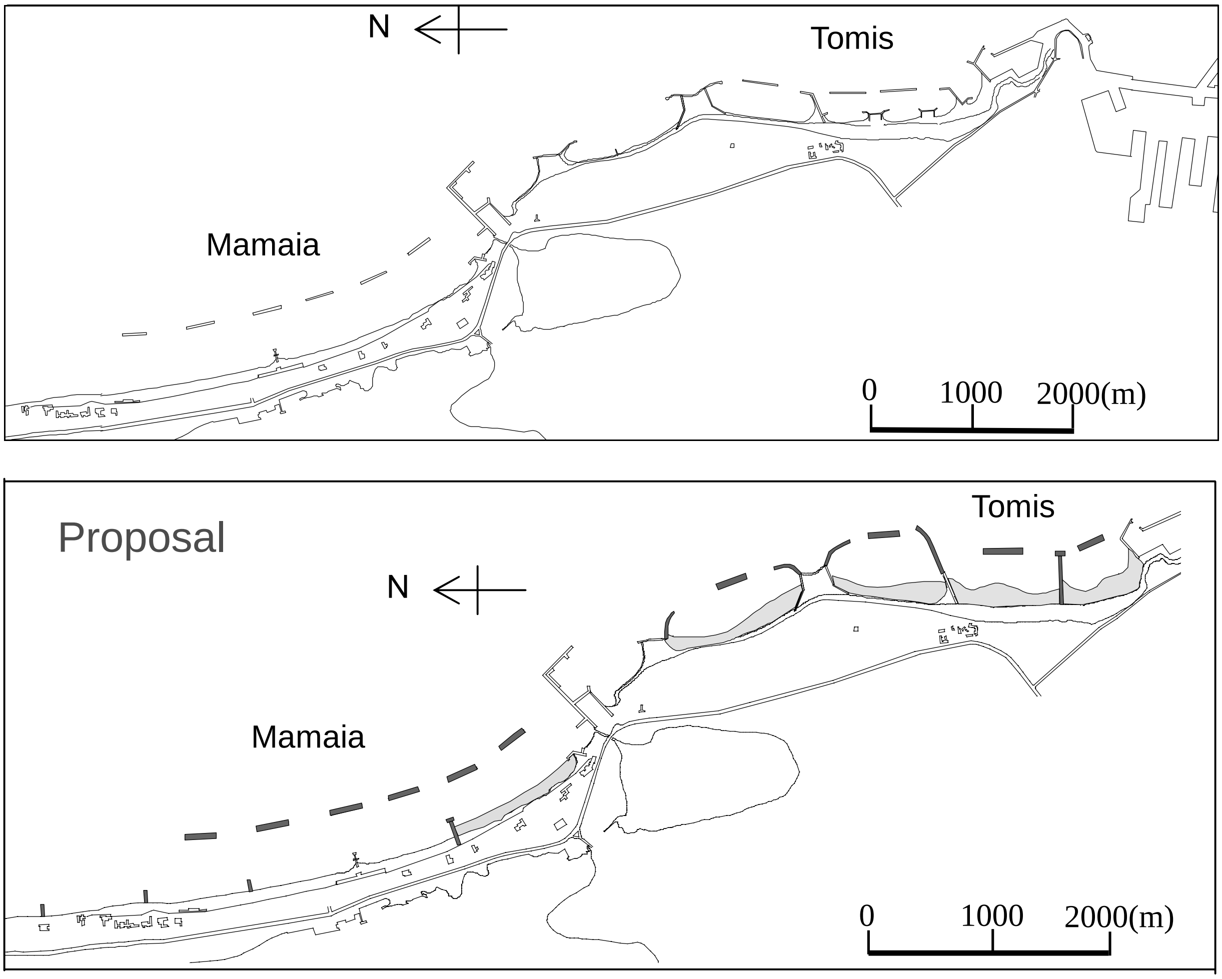
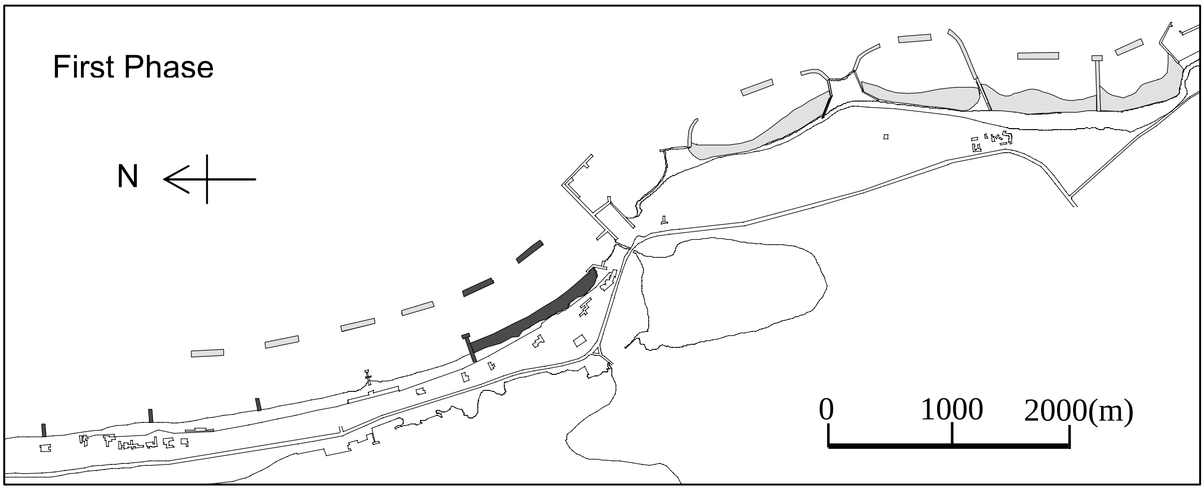
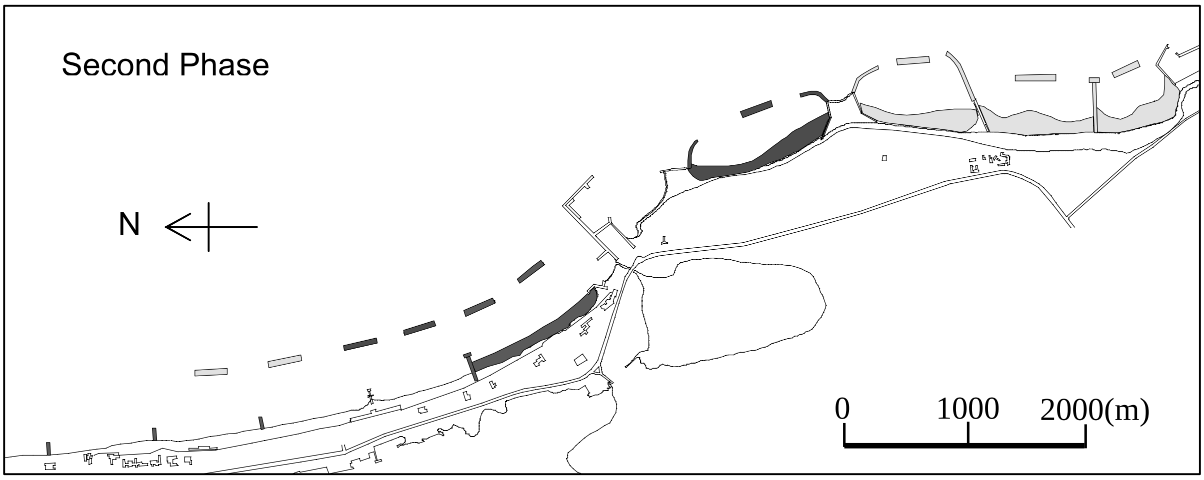


Fig. 5.7.1: Existing and proposed shore protection facilities at Mamaia and Tomis sub-sectors





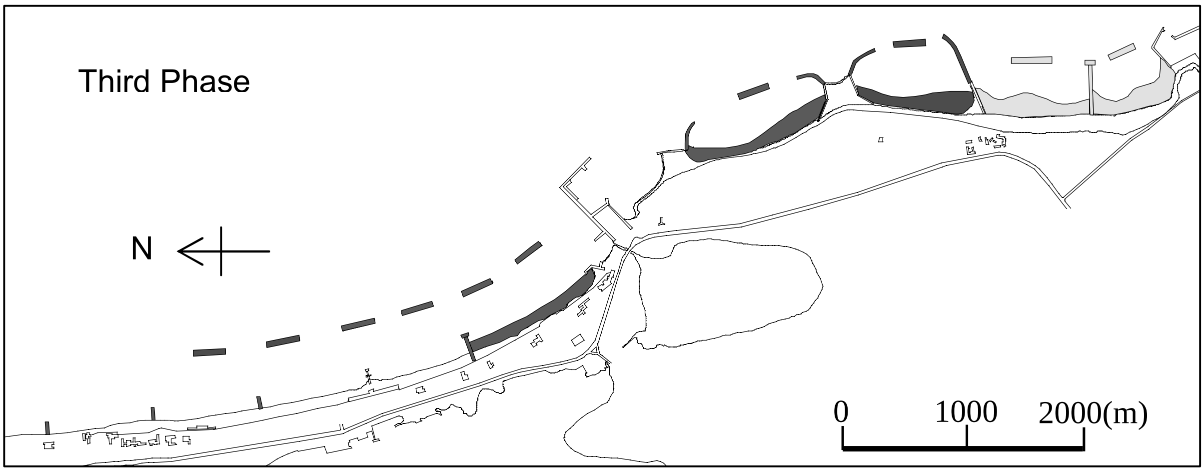


Fig. 5.7.2: Phase-wise plans for facility installation in Mamaia and Tomis sub-sectors

The jetties, groins, artificial reefs, and breakwater rehabilitation are executed over many years. Figure E.5.7.2 illustrates a tentative phase-wise installation plan of new facilities for the Mamaia and Tomis sub-sectors. The first phase of coastal protection and rehabilitation plan will be undertaken in the period from 2007 to 2010. The second phase will be for the period of 2011 to 2015, and the third phase will be from 2016 to 2020. The facilities to be executed in respective construction phases are shown in red colors. The facilities constructed in the previous phases are shown in green colors. The facilities in yellow color indicate those to be constructed in later times.

In the Mamaia sub-sectors, the first phase will be carried out with the rehabilitation of two southernmost breakwaters, construction of the sand-retaining groins and three submerged groins and a beach fill. The second phase is for the rehabilitation of the two central breakwaters. The two northern breakwaters will be rehabilitated in the third phase. The Tomis sub-sectors will be put in construction in the second phase from the Tomis North area; this area needs a widening of beach for the cliff stabilization works for safety of people living on top of cliffs. Then the project for the Tomis Center area will be undertaken in the third phase. The area of Tomis South is postponed for the second stage after 2021, because the area is not threatened by eminent beach erosion and the beach area is maintained in good conditions presently.

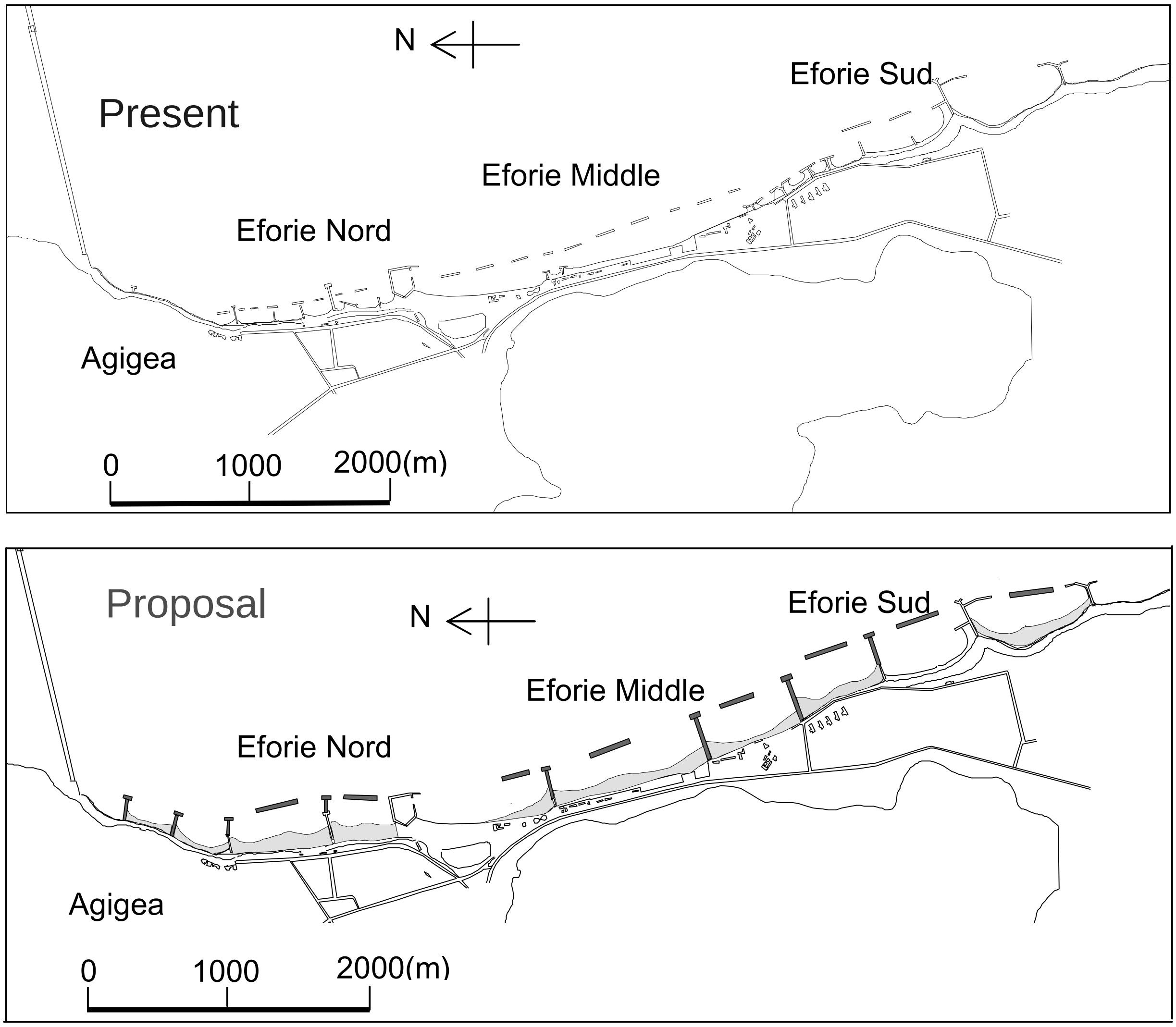


Fig. 5.7.3: Existing and proposed shore protection facilities at Eforie Sector

(3) Eforie Sector

In the Sector of Eforie, eight large jetties, eight artificial reefs, and beach fill with sand of 1,433,000 m^3 in volume are proposed to be built. Two jetties in Eforie Nord are extended from the head of two existing jetties. Other small jetties will be removed not to obstruct new beach fill areas. In addition, one temporary access road of 1,200 m long around the shoreline and another road of 500 m long in shallow water will have to be built to facilitate jetty construction and beach fill operation in Eforie Nord.

Some of submerged breakwaters in water of around 2 m deep will be removed so as not to present dangers for swimmers from the new nourished beach.

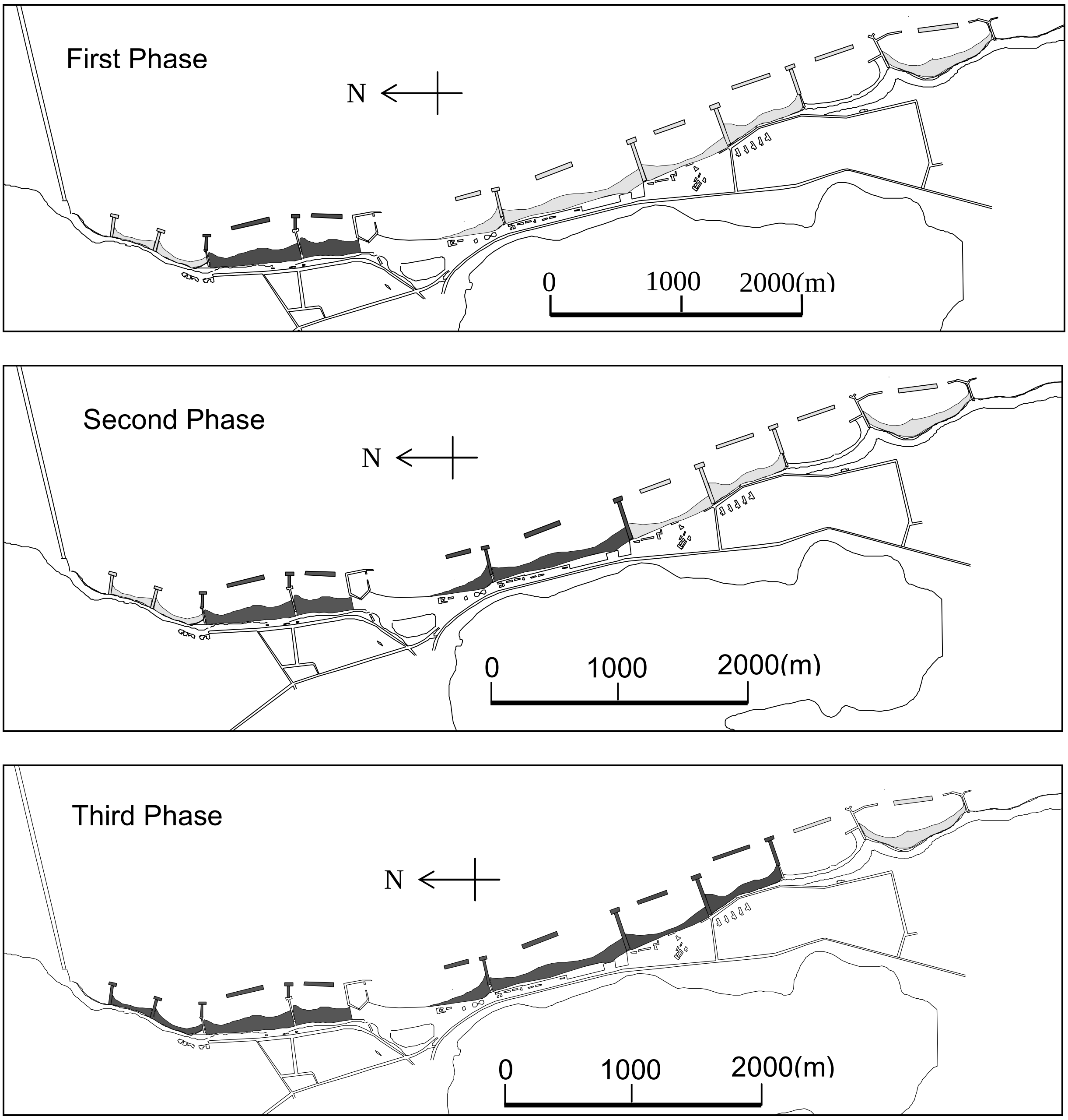


Fig. 5.7.4: Phase-wise plans for facility installation in Eforie Sector

The phase-wise installation plan of the shore protection facilities in the Eforie Sector is presented in Fig. 5.7.4. In the first phase, the section of about 1,100 m of Eforie Nord (1) will be protected by extension of two long jetties, construction of two artificial reefs, and beach fill. The second phase will undertake the protection of the sub-section of Eforie Middle because beach erosion in this area is serious. In the third phase, the northern parts of Eforie

Nord (2) and Eforie Sud (1) are scheduled for execution. A project for Eforie Sud (2) will be planned in the second stage after 2021, because this area is customized by many summer visitors and no problem of water pollution is reported presently.

The beach fill in the first phase shown in Fig. 5.7.4 is based on the condition that the river sand can be utilized in the project. If the sea sand needs to be used because of environmental consideration, the area of beach fill is increased with construction of submerged sand-retaining dike. The volume of beach fill sand will be about 950,000 m^3. The facility installation plan for the case using the sea sand is given in **6.4**.

(4) Costineşti Sector

Because the beach of Costineşti has been stable for many years and there will be no threat of future beach erosion as predicted in Fig. 4.5.13, there is no necessity to provide new shore protection facilities.

(5) Mangalia Sector

The major problem in this sector is degradation of water quality caused by eutrophication rather than beach erosion. It partly owes to poor exchange of sea water hindered by closely built many small jetties, and partly to inefficient treatment of waste water from hotel areas. Another problem is deficiency of beach in the center of Saturn–Mangalia sub-sector.

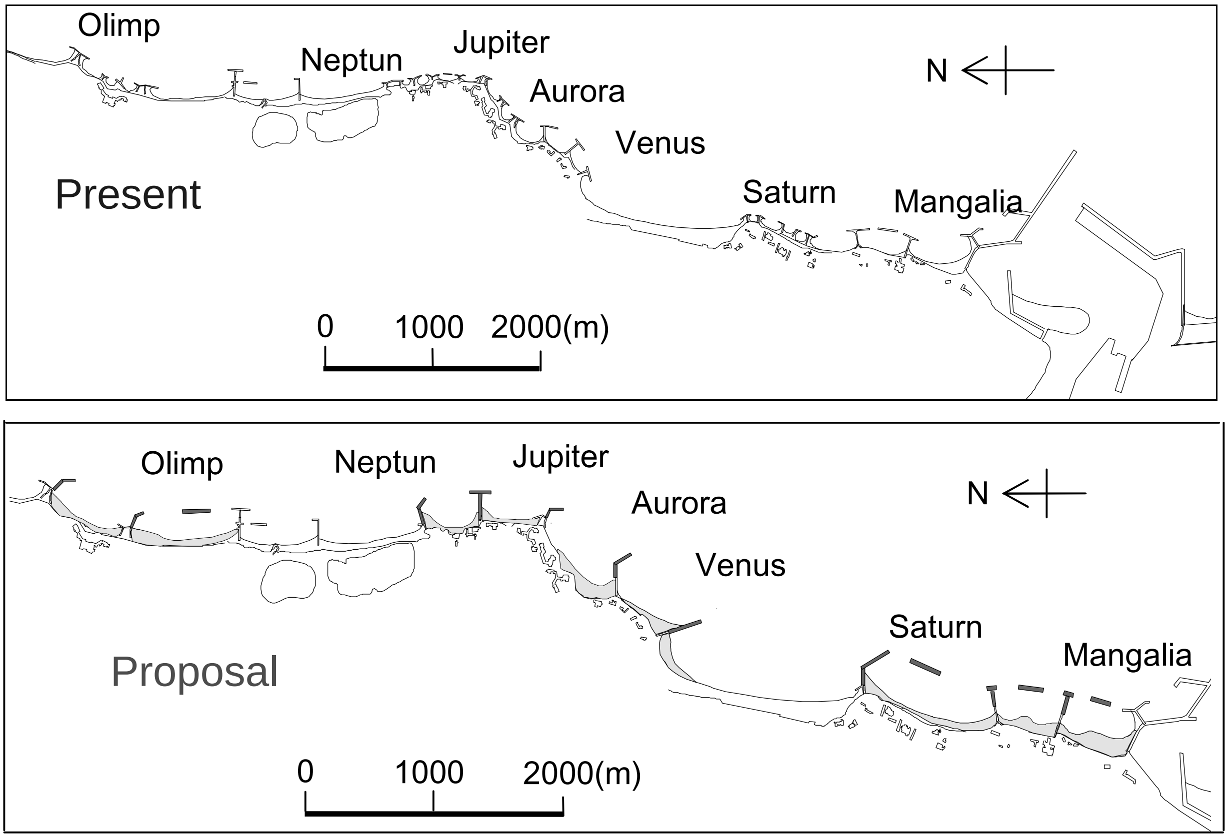


Fig. 5.7.5: Existing and proposed shore protection facilities at Mangalia Sector

Remedy to these two problems is proposed by replacing the closely-located, existing short and jetties by widely-spaced long jetties and a large scale beach fill as shown in Fig. 5.7.5.

Ten new jetties, four new artificial reefs, and beach fill with sand of 760,000 m^3 will be executed. Existing short jetties will be all removed, and exception is two large jetties with berthing facilities at Olimp. Installation of new facilities is proposed for the second stage after 2021. However, if urgent solution of water quality problem is needed, an early implementation of a project with appropriate funding should be considered.

(6) Limanu Sector

This sector is not facing acute beach erosion problem; the alongshore sediment transport rate is presented in Fig. 4.5.8 and the prediction of future shoreline and beach width is shown in Fig. 4.5.15. Furthermore, the littoral zone is one of biologically richest coasts and the water area of 5,000 ha has been designated as the nature reserve of marine aquarium. Therefore, no installation of new facilities is proposed for this sector.

5.7.2 Beach Fill Design with Estimate of Maintenance Sand Volume

(1) Total volume of beach fill sand

The estimated volumes of beach fill sand at individual sub-sectors are summarized as follows:

Mamaia South:	180,000 m^3 (river sand) or 460,000 m^3 (sea sand)
Tomis North and South:	860,000 m^3
Eforie Nord:	393,000 m^3 (river sand) or 740,000 m^3 (sea sand)
Eforie Middle:	430,000 m^3
Eforie Sud:	640,000 m^3
Olimp:	280,000 m^3
Neptune to Venus:	260,000 m^3
Saturn to Mangalia:	160,000 m^3
Total:	3,203,000 m^3 (river sand)

The above total volume of 3.2 million m^3 of sand may look huge, but it represents the overall volume to be executed over 20 years or longer as will be described in **5.8.2**. The annual supply of beach fill sand is around 200,000 m^3 or so. In comparison with many beach fill projects introduced in **5.6.1 (5)**, the beach fill operations at individual sub-sectors are of minor scales.

The above volumes of beach fill sand are based on the analysis of existing beaches and calculation by several formulas, the details of which are presented in Annex **E.7**. Its summarized version is presented below. Terms used in beach fill are defined in Fig. 5.7.6.

(2) Beach width and backshore height

The beach width, which is the horizontal distance between the shoreline and the end of backshore, is determined in consideration of the width of existing beaches and the most optimum width of 50 m, which was recommended by a survey report in Japan. In the present beach fill design, the beach width of up to 100 m is selected for the sub-sectors of Mamaia, Tomis, Eforie Nord and Eforie Sud. For the Mangalia Sector, the beach width of 55 to 65 m is selected. However, the beach width is adjusted to local topography and becomes less than the above.

The backshore height is set at 2.3 m for the sub-sector of Mamaia South, while other sub-sectors is given the backshore height of 2.2 m in consideration of existing beach conditions.

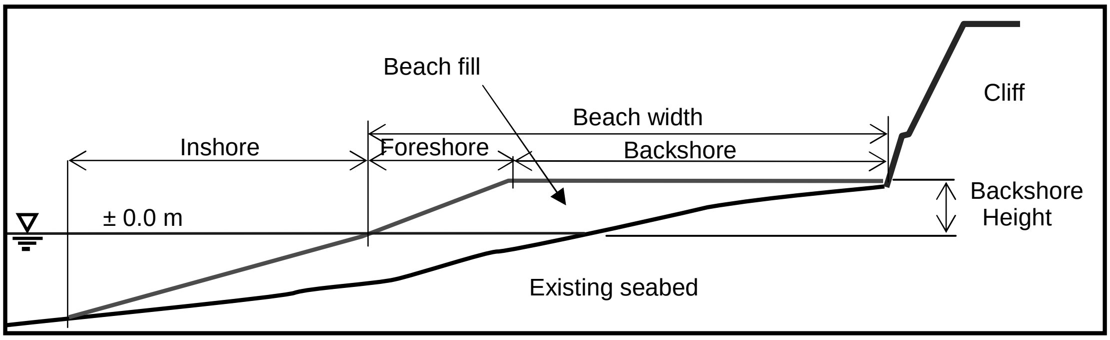


Fig. 5.7.6: Definition sketch of beach fill

(3) Foreshore and inshore slopes

The foreshore is a zone of beach between the shoreline and the berm crest, while the inshore is a zone below the mean low water. The slopes of the foreshore and inshore in the beach fill design are determined from the stability of beach fill profile against incident waves for a given grain size of beach fill sand. With use of the river sand with the median diameter of 0.4 mm, the foreshore slope becomes 1/20 to 1/25 depending on the location and the inshore slope becomes 1/30 for all the locations. If the sea sand with the median diameter of 0.1 mm has to be used, the foreshore slope becomes 1/30 and the inshore slope becomes 1/270 for the sub-sector of Mamaia South. An underwater sill or submerged dike needs to be built around the depth contour of –2 m to retain filled sand in position.

(4) Jetty design

The long jetties to act as artificial headlands are designed to be extended beyond the outer surf zone, which appears when waves with the 95% non-exceedance probability are incident to the shore. Calculation based on Table 3.4.1 (ECMWF data) in **3.4** yields the 95% non-exceedance of $H_{1/3}$ = 2.4 m. The corresponding wave period will be $T_{1/3}$ = 5.7 s according to a general relationship between the significant height and period of wind waves. The outer edge of surf zone can be estimated as $(h_{1/3})_{peak} = (2.0 – 2.2)H_0'$, and this relation[9] yields the water depth of around 5 m. The detached breakwaters of Mamaia beach were built in water of 5 m deep, while the breakwaters of the Yacht Club Europa were constructed in water of –4 to –5 m. Thus, the heads of the artificial headlands are planned to be located at the depth of –4 to –5 m; decision for individual structures will depend on the overall judgment.

The 95% non-exceedance probability of wave height approximately corresponds to the 46% non-exceedance probability of wave energy flux, which is proportional to the square of wave height multiplied by wave period. Therefore, the proposed groups of long jetties will not be able to control the alongshore sediment transport by storm waves. Nevertheless, with installation of artificial reefs between long jetties, the area enclosed by a pair of long jetties and an artificial reef will serve as a semi-coastal sediment cell.

(5) Maintenance supply of sand

The amount of annual loss of beach fill sand is a quite difficult problem. When the all

[9] See Fig. 3.34 in “*Random Seas and Design of Maritime Structures* (2nd Ed.),” by Y. Goda published in 2000 by World Scientific, Singapore.

proposed facilities are installed, the sediment moved out of one cell will settle in a neighboring cell by alongshore sediment transport, and the net loss over the whole area will be small.

In any beach fill project, there will be a certain outflow of sediment toward the offshore, which will not be brought back to the shore and become the sediment loss. In the numerical simulation of the past changes of shoreline position, the cross-shore outflow of 3.0 m^3/m/ year was assumed for the beaches of Năvodari and Mamaia as described in **4.5.2**. For the Eforie and Mangalia Sectors, the shoreline retreat rate of 0.6 m per year, which corresponds to the cross-shore outflow of about 1.5 m^3/m/year, was introduced. If these figures are employed as a reference, the amount of annual maintenance sand supply may become 1,500 to 3,000 m^3 per 1000 m of nourished beach.

However, with an amply supply of beach fill at the start of a coastal and rehabilitation project, re-filling of beach sand will not be required for many years unless an extraordinary storm may attack the coastal area and an excessively large shoreline retreat may occur. This is the policy adopted in the present study.

5.7.3 Alternative Options of Coastal Protection Plan

As discussed in **5.3.1** of this volume, a coastal protection plan over a long stretch of shoreline cannot have any general alternative plan applicable for the whole area except for the “do-nothing” plan. A coastal area is composed of several independent coastal littoral cells, and coastal protection plans need to be prepared for these coastal cells individually. The overall coastal protection plan is an assortment of individual plans for respective coastal cells. Alternative options have to be prepared and compared for individual coastal cells.

Proposal of the protection and rehabilitation of the coast of the Study area has been made as described in **5.7.1** according to the installation strategy discussed in **5.6.3**. One alternative option for shore protection, which needs to be examined for each sub-section, is the “do-nothing” option. In a region that has a wide coastal area with little utilization, one may allow a certain amount of the shoreline retreat with no intervention. The Netherlands employs this option for a limited number of localities, while they resort to the options of beach fill or coastal dike construction for the areas that cannot accept any further shoreline retreat. Adoption of hard solutions (coastal dikes and seawalls) alone is not favored in recent days.

Along the Southern Romanian Black Sea shore, important areas such as Mamaia South and Eforie do not have any room to allow further shoreline retreat. Thus, the “do-nothing” option cannot be accepted for these areas. The cliff coasts of Tuzla and Schitu can accommodate this option, because the benefit of protecting cliff against erosion is minimal. The beach utilization in Năvodari is at a low level presently and the beach is wide presently. Therefore, the area can accept the “do-nothing” option.

The littoral water area in the sub-sectors of 2 Mai and Vama Veche has been designated as the nature reserve of marine aquarium. Because the beaches there are relatively wide to tolerate a certain shorelines retreat in the future, the “do-nothing” option is adopted.

An important unsolved question is the available source of beach fill sand. For the viewpoint of the stability of beach fill profile, medium to coarse sand mined from the riverbed of the Danube is preferred. However, authorization for river sand mining may be postponed until the result is presented on the assessment on possible impact on the river course of the Danube from the viewpoint of international navigation and no significant impact will be acknowledged. In case that the coastal protection and rehabilitation projects in Mamaia and Eforie have to be initiated before the authorization of river sand mining, fine sand to be mined from the seabed off Midia Port or sand being dredged outside the Sulina Channel may have to be used for beach fill. The alternatives using fine sea sand will be further examined during the course of feasibility study. The section **5.8** discusses the question of the sand source in detail.

Various alternative options discussed above are listed in Table 5.7.2 for mutual comparison. The extent of beach erosion under "Do nothing" options has been discussed in **4.5.3.**

Table 5.7.2: Proposal and alternative options of coastal protection plan for the Southern Romanian Black Sea shore

Sub-Sector	Proposal of counter measures	Option A	Option B	Category of the reason of alternative selection
I-1 Năvodari North	Do nothing	Do nothing	Do nothing	No necessity of coastal protection at present
I-2 Năvodari South	Do nothing	Do nothing	Do nothing	No necessity of coastal protection at present
I-3 Mamaia North	2 new submerged groin	Do nothing	Do nothing	Priority of coastal defense and tourism promotion
I-4 Mamaia Center	1 new submerged groins Rehabilitation of 3 breakwaters	2 short, submerged groins	Do nothing	Priority of coastal defense and tourism promotion
I-5 Mamaia South	Rehabilitation of 3 breakwaters Beach fill of 180,000 m^3 with river sand	Rehabilitation of 3 breakwaters Beach fill of 700,000 m^3 with sea sand	Do nothing	Priority of coastal defense and tourism promotion
I-6 Tomis North I-7 Tomis South	5 new jetties, 4 artificial reefs Beach fill of 870,000 m^3 with river sand	Rehabilitation of damaged facilities	Do nothing	Priority of coastal defense
II-1 Eforie North II-2 Eforie Middle	6 new jetties, 3 artificial reefs Beach fill of 840,000 m^3 with river sand	2 new jetties and 2 artificial reefs Beach fill of 900,000 m^3 with sea sand	Do nothing	Priority of coastal defense and tourism promotion Priority of coastal defense
II-3 Eforie South	2 new jetties, 3 artificial reefs Beach fill of 620,000 m^3	Rehabilitation of damaged facilities	Do nothing	Priority of coastal defense and tourism promotion
III-1 Tuzla North III-2 Tuzla South	Do nothing	Do nothing	Do nothing	Adoption of the retreat of the line of defense
IV-0 Costineşti	Do nothing	Do nothing	Do nothing	No necessity of coastal protection at present
V-0 Schitu	Do nothing	Do nothing	Do nothing	Adoption of the retreat of the line of defense
VI-1 Olimp–Venus	7 new jetties Beach fill of 540,000 m^3	Rehabilitation of damaged facilities	Do nothing	Priority of coastal defense and tourism promotion
VI-2 Balta Mangalia	Do nothing	Do nothing	Do nothing	Adoption of the retreat of the line of defense
VI-3 Saturn–Mangalia	4 new jetties, 2 artificial reefs Beach fill of 160,000 m^3	Rehabilitation of damaged facilities	Do nothing	Priority of coastal defense and tourism promotion
VII-1 2 Mai	Do nothing	Do nothing	Do nothing	Conservation of marine ecosystem
VII-2 Limanu	Do nothing	Do nothing	Do nothing	Conservation of marine ecosystem
VII-3 Vama Veche	Do nothing	Do nothing	Do nothing	Conservation of marine ecosystem

Note: 1) Artificial reef refers to a submerged, detached shore-parallel breakwater with a wide crest, upon which incoming waves are forced to break and dissipated.

2) In the partially modified plan described in 5.7.4, facilities placement in Eforie Nord (2) is relinquished and the numbers of facilities at Eforie Middle are changed. The above table presents the components proposed in the original plan.

The reasons of selecting the proposed countermeasures for individual sub-sectors can be categorized as in the following:

a) Priority of coastal defense and tourism: Mamaia North to South, Eforia Nord and Sud, and Saturn – Mangalia
b) Priority of coastal defense: Tomis North and South, Eforie Middle
c) No necessity of coastal protection at present: Năvodari North and South, and Costineşti
d) Adoption of the retreat of the line of defense: Tuzla North and South, Schitu, and Balta Mangalia
e) Conservation of marine ecosystem: 2 Mai, Limanu, and Vama Veche

Table 5.7.3 summarizes the category of the reason of alternative selection for individual sub-sectors from Năvodari North to Vama Veche.

Table 5.7.3: Reasons of selecting the proposed countermeasures among the alternatives

Sub-sector	Proposal of countermeasures	Category of the reason of alternative selection
I-1 Năvodari North	Do nothing	No necessity of coastal protection at present
I-2 Năvodari South	Do nothing	No necessity of coastal protection at present
I-3 Mamaia North	2 new submerged groin	Priority of coastal defense and tourism promotion
I-4 Mamaia Center	1 new submerged groins Rehabilitation of 3 breakwaters	Priority of coastal defense and tourism promotion
I-5 Mamaia South	Rehabilitation of 3 breakwaters Beach fill of 180,000 m^3 with river sand	Priority of coastal defense and tourism promotion
I-6 Tomis North I-7 Tomis South	5 new jetties, 4 artificial reefs Beach fill of 870,000 m^3 with river sand	Priority of coastal defense
II-1 Eforie North II-2 Eforie Middle	6 new jetties, 3 artificial reefs Beach fill of 840,000 m^3 with river sand	Priority of coastal defense and tourism promotion Priority of coastal defense
II-3 Eforie South	2 new jetties, 3 artificial reefs Beach fill of 620,000 m^3	Priority of coastal defense and tourism promotion
III-1 Tuzla North III-2 Tuzla South	Do nothing	Adoption of the retreat of the line of defense
IV-0 Costineşti	Do nothing	No necessity of coastal protection at present
V-0 Schitu	Do nothing	Adoption of the retreat of the line of defense
VI-1 Olimp–Venus	7 new jetties Beach fill of 540,000 m^3	Priority of coastal defense and tourism promotion
VI-2 Balta Mangalia	Do nothing	Adoption of the retreat of the line of defense
VI-3 Saturn–Mangalia	4 new jetties, 2 artificial reefs Beach fill of 160,000 m^3	Priority of coastal defense and tourism promotion
VII-1 2 Mai	Do nothing	Conservation of marine ecosystem
VII-2 Limanu	Do nothing	Conservation of marine ecosystem
VII-3 Vama Veche	Do nothing	Conservation of marine ecosystem

5.7.4 Partial Modification of Coastal Protection Plan at Eforie Sector in Response to Strategic Environment Assessment (SEA)

(1) Conclusions of SEA report

The coastal protection plan discussed in 5.7.1 to 5.7.3 was formulated during the Phase II of the Study from October 2005 to February 2006 and has been presented in the Interim Report submitted in February 2006. The new facilities plan remains as it was even though some additional works were made such as improvement of the prediction of future shoreline change with new facilities installation.

However, the environmental report prepared for the Strategic Environment Assessment (SEA) submitted in February 2007 pointed out grave impact on the biocoenosis in the some water areas of Eforie Sector. The observation of the ecosystem of this sector in the SEA report is introduced in **7.2.2. (1)** (b). Its conclusions can be summarized as follows:

> The area of Eforie Nord (2) offers a natural rocky support (substratum), which provides great microhabitats diversity. There is inhabited the bivalve mollusk Pholas dactylus, which is protected by the Berne and Barcelona Conventions. Beach fill in this area will exterminate the biodiversity on the rocky support for these bivalves.
>
> The area of Eforie Middle has a presence of the sole colony of *Donacilla cornea* and it also shelters a massive population of *Donax trunculus.* Because construction of long jetties will induce adverse impact on the bivalves, they should not be implemented.

It would be unwise to disregard the conclusions of the SEA report and to uphold the original plan without modification. Thus it is proposed to make small changes to the coastal protection plan as discussed in the following.

(2) Coastal protection plan at Eforie Nord (2)

The area allocated as the project Eforie Nord (2) is situated between the south breakwater of Constanța Port and the existing short groin II-J-02. Sea cliff is falling to the sea without sandy beach and there are outcrops of limestone at the water front. Housing development has been taken place on top of the cliff, but the danger of cliff collapse is not imminent. Unless there arises a special demand for new beach creation in this area, need for beach fill project will be few. Thus, in consideration of environmental protection viewpoint, a coastal protection project at Eforie Nord (2) is relinquished.

(3) Coastal protection plan at Eforie Middle

The SEA report does not approve construction of the long jetties EM-J-1 and EM-J-2, which are sketched in Figs. F.1.3 and F.1.4 of Annex F of Volume 3, because of adverse effect on the bivalves *Donacilla cornea*. However, there is a sign of biocoenosis recovery with reappearance of *Donacilla cornea* in considerable quantities recently, as described in **7.2.2 (1)** (c). With regard to beach fill, the SEA report does not oppose it and seems to approve it as the countermeasures for beach erosion problem in this area. Nevertheless the report recommends gradual progress of beach fill operation so that he bivalves will not be buried deep under filled sand.

The two jetties in the original plan have been proposed to protect the filled beach area, but the system of submerged detached breakwaters can also serve for this purpose. Therefore the plan is changed to replace the jetty EM-J-1 with an additional submerged breakwater EM-B-3 between EM-B-1 and EM-B-2. The required length and location of the additional breakwater should be examined in the forthcoming feasibility study when the project will be undertaken. The jetty EM-J-2 serves not only for the sub-sector of Eforie Middle but it provides the northern boundary of the Eforie Sud sub-sector. Although the impact of EM-J-2 should be duly examined in the forthcoming feasibility study, it is proposed to retain the jetty EM-J-2 as in the original plan.

The revised proposal of the shore protection facilities at the Eforie Sector is sketched in Fig. 5.7.7 and the phase-wise plans for facility installation is presented in Fig. 5.7.8.

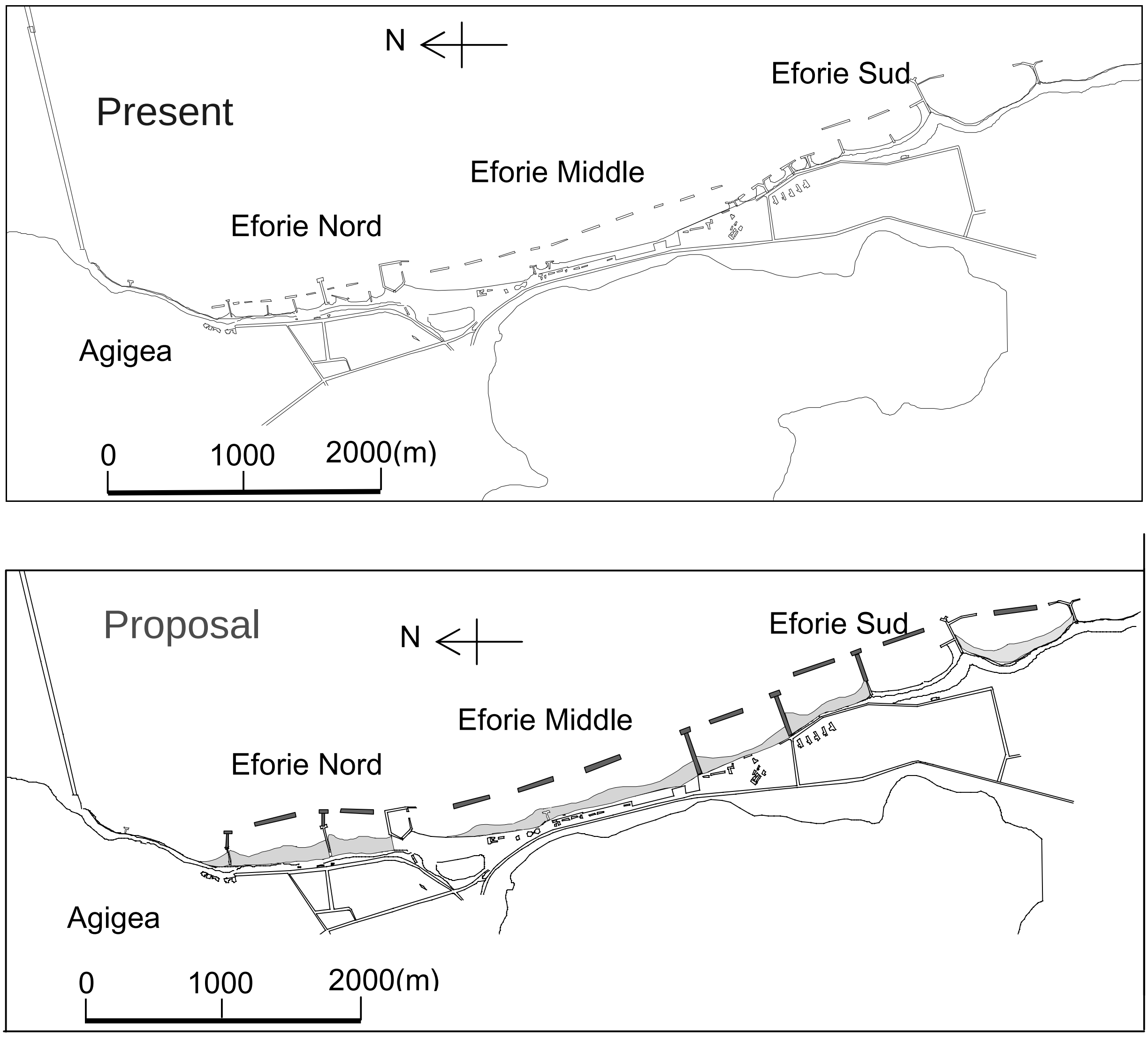


Fig.5.7.7: Modified proposal of shore protection facilities at Eforie Sector

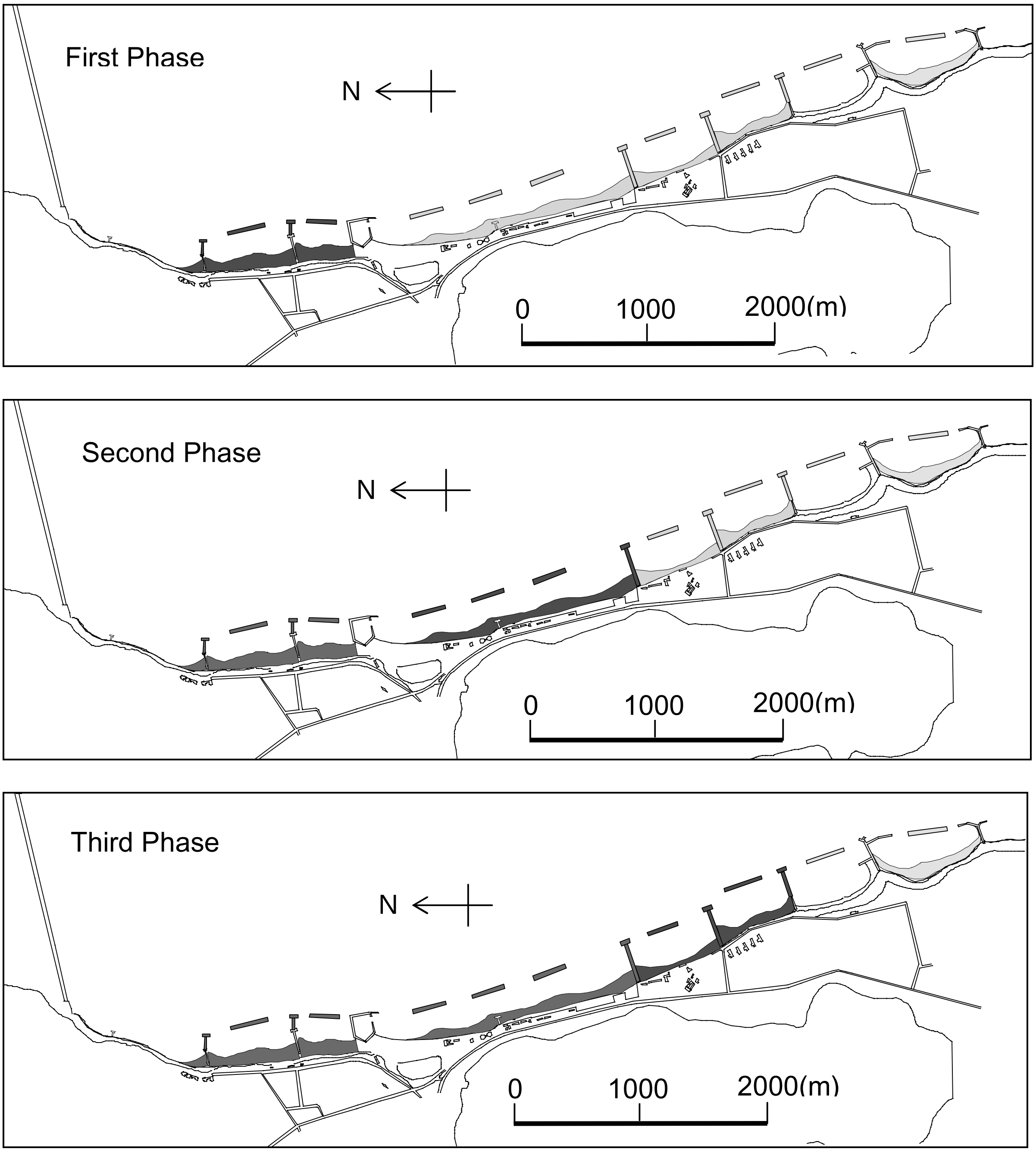


Fig. 5.7.8: Modified phase-wise plans for facility installation in Eforie Sector

The modifications to the coastal protection plan listed above are incorporated in the next subsection **5.7.5** on the future shoreline changes and in the later subsection of **5.9** on the cost estimate and implementation schedule.

5.7.5 Prediction of Future Shoreline Changes with New Facilities

Prediction is made for the changes of the beach width and the shoreline position in twenty years after installation of new shore protection facilities. In the prediction, all the proposed facilities are assumed to have been installed in the same time at the beginning of the numerical calculation. The method and assumption employed in the prediction are the same as those used in the prediction with existing facilities only, which was described in **4.5.3**.

The changes in the beach width and the shoreline positions in the Constanța Sector (Năvodari, Mamaia, and Tomis) are predicted as shown in Fig. 5.7.7, which should be compared with those of existing facilities shown in Fig. 4.5.11. The beach width before installation of new facilities and beach fill is shown by green dotted line in the middle panel. The area of Mamaia South is given a beach width of 100 m by a beach fill operation and the 100-m width almost remains even though local ups and downs appear. The beach in this area would have disappeared in twenty years without beach fill as shown in Fig. 4.5.11. The area north of the sand-retaining groin of Mamaia South will have a slight erosion because the sediment supply from the south is insufficient to cover the sediment transport toward the north, even though a certain amount of sand will move northward across the head of the groin.

Three short submerged groins to be installed in the sub-sectors of Mamaia Center and North are seen to be functioning as planned, because there is a slight shoreline advance behind the northernmost breakwater or between the first and second groins. Around the northernmost groin a tendency of small erosion appears, but the degree of erosion is insignificant. Influence of protecting the sub-sector of Mamaia South can be seen up to the location of the distance 6300 m. When the area of Mamaia South is left to natural process of erosion, this location is predicted to have a slight shoreline advance, but with beach protection at Mamaia South this location becomes a neutral point of erosion (southward) and accretion (northward).

The Tomis area is given a beach fill with the beach width of 100 m initially, but the beach width is reduced to about 50 m in twenty years. Although the beach width varies locally, the filled beach area is preserved as a whole.

In the Eforie Sector, the general shoreline retreat rate of 0.6 m per year in incorporated. The result of the prediction of future changes is presented in Fig. 5.7.8, which should be compared with Fig. 4.5.12. Without coastal protection and rehabilitation projects, the shoreline in this sector showed the tendency of general retreat, but with project implementation the shoreline advances by about 50 m. The shapes of newly nourished beaches are curved ones as seen in Fig. 5.7.3, but they undergo significant changes depending on the local effects of jetties and artificial reefs. One area showing a certain degree of erosion is the north side of the existing large multi-branched jetty at Eforie Sud, because his area is not included in the original beach fill plan as seen in Fig. 5.7.3.

The shoreline change prediction for the Mangalia Section from Olimp to Mangalia is presented in Fig. 5.7.9, which should be compared with Fig. 4.5.14. The general tendency of shoreline retreat is remedied by execution of beach fill operations. Newly created beaches in the Saturn – Mangalia sub-sector are predicted to remain at their positions. The area around the distance 7300 m indicates local erosion, because the area is not provided a new beach fill. It is suggested to review the beach fill plan again when this area is given a coastal protection project in the future.

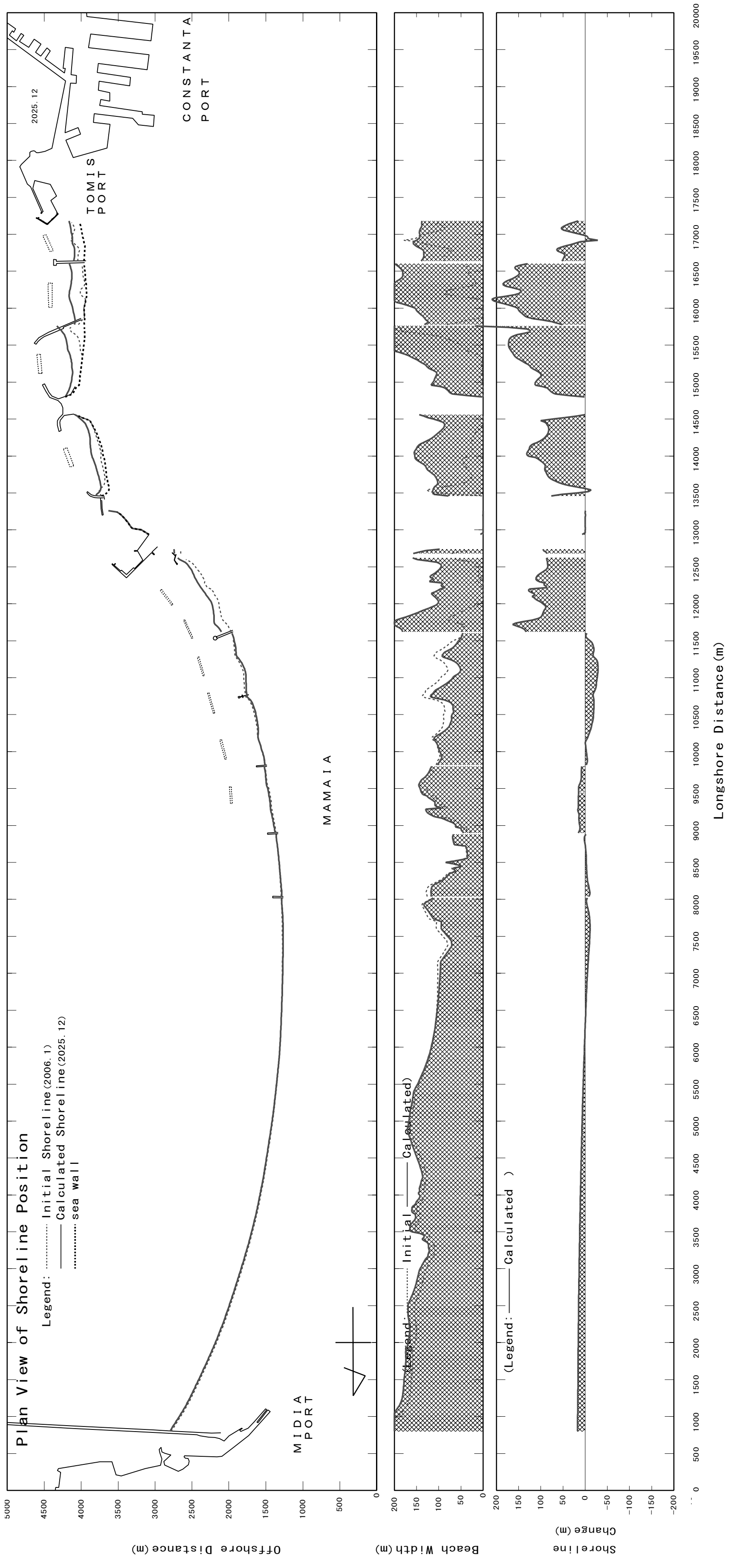


Fig. 5.7.9: Prediction of beach width and shoreline changes in 20 years after new facility installation in Mamaia and Tomis sub-sectors

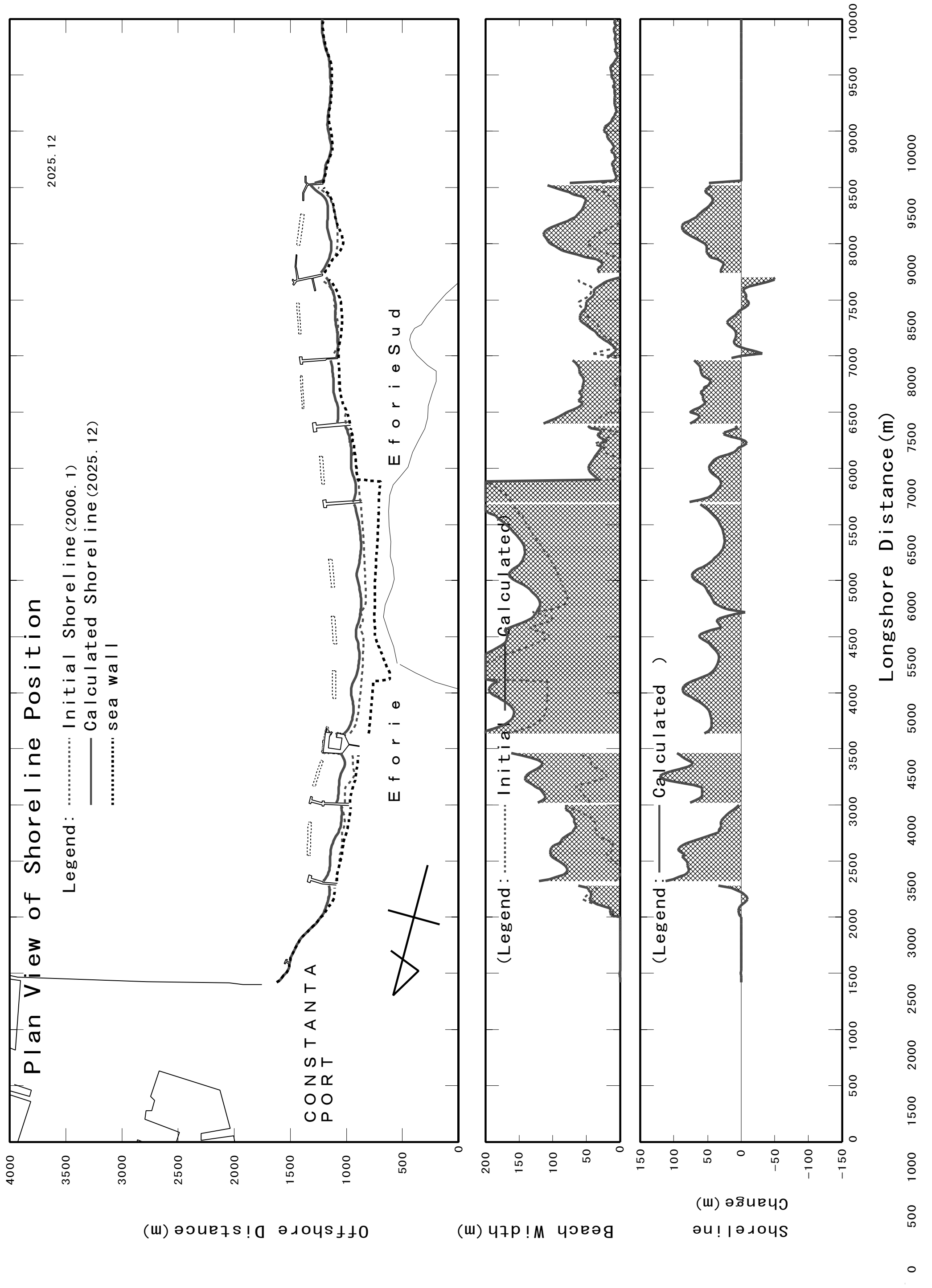


Fig. 5.7.10: Prediction of beach width and shoreline changes in 20 years after new facility installation in Eforie Sector

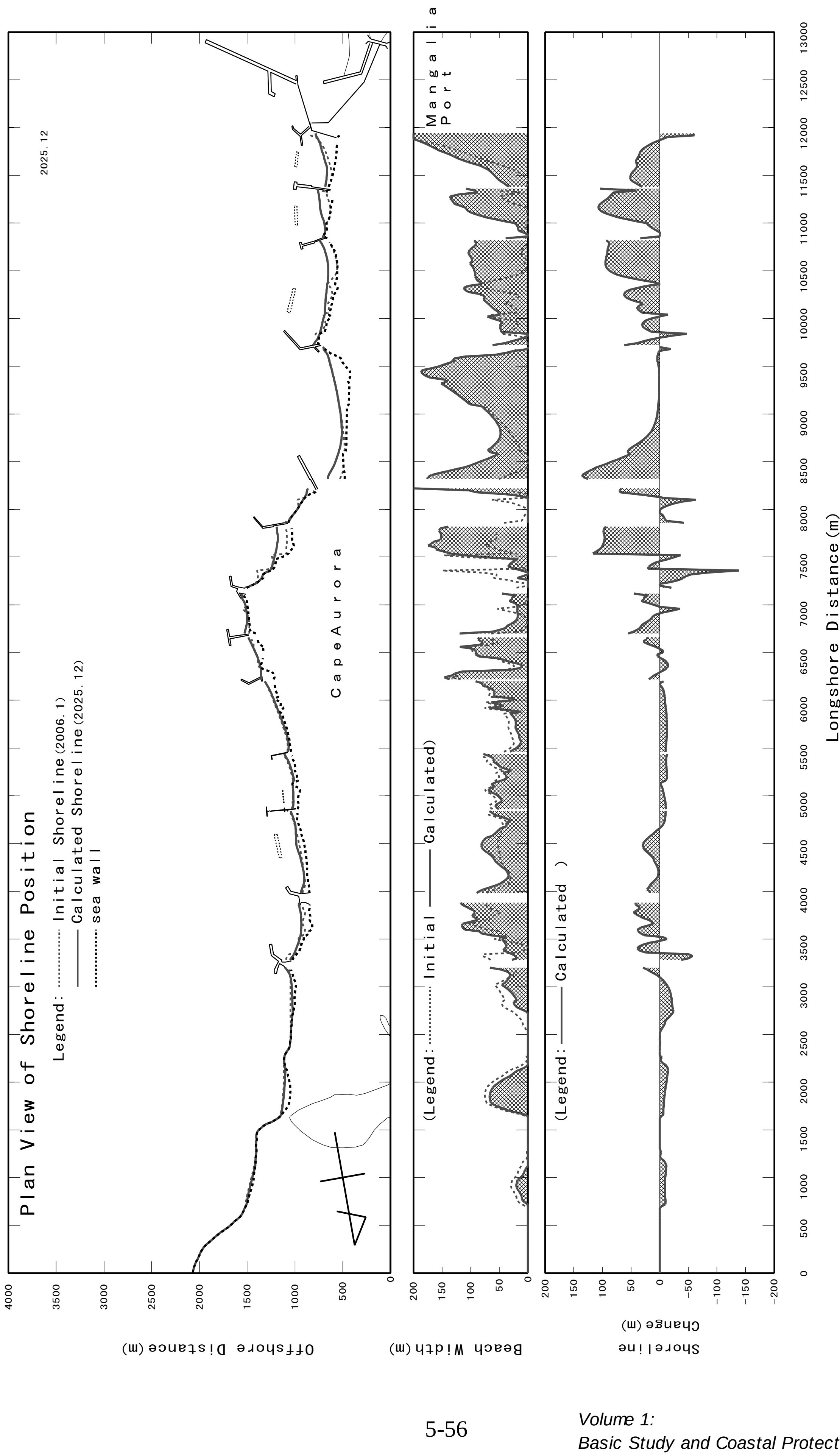


Fig. 5.7.11: Prediction of beach width and shoreline changes in 20 years after new facility installation in Mangalia Sector

5.8 Source of Beach Fill Sand

5.8.1 General

The proposed plan of coastal protection as presented in **5.7** demands the supply of sand for beach fill with the quantity of more than 3 million cubic meters over the period of twenty years or more, of which about one third is destined to the Constanța Sector and two thirds are for the Eforie and Mangalia Sectors. Possible supply sources of beach fill sand are considered as follows:

1) Relic barrier beaches in the offshore seabed
2) Sand layers in the offshore area
3) Sand bars in front of the Sulina Channel
4) Impounded sand deposit at the east of Midia Port
5) Sand shoals on the bed of branch channels of the Danube
6) Sand deposit in the inland

In many beach fill projects in the world, beach fill sand is mined from the offshore seabed where sand layers are present on or beneath the sea bottom. In the Black Sea there are some relic barrier beaches of millions years old on the continental shelf deeper than –23 m as described in Annex **D.1.2**, but the available quantity is unknown and their dredging is considered too expensive as well as undesirable from the environmental viewpoint. In the nearshore area, the rock bed is present on most of the seabed of 10 to 20 m deep as described in **4.3.2**. Therefore, the sources under the items 1) and 2) are not available for the present coastal protection plan.

The Sulina Channel is an international inland navigation channel and the Government of Romania has the responsibility to the Danube Commission to maintain its depth at more than 7.5 m. The River Administration of the Lower Danube, Galati (AFDJG) is carrying out the maintenance dredging with a trailing-suction dredger named the Dunărea, which has the hopper capacity of 2,680 m^3, throughout a year. A major portion of dredging work is outside the channel entrance, where fine sand flushed out from the Chilia branch is transported by wave-induced longshore currents and deposited there as sand bars. The sand bars could provide a source of beach fill sand for the Southern Black Sea shore.

Another possible source of beach fill sand is the sand deposited on the seabed around Midia Port. The seabed is covered with fine sand having the median diameter of 0.1 mm or so, and the sand has been brought there by wave-induced longshore currents along the northern shore of the Romanian Black Sea. The sand from this source could be used for the beach fill in the Constanța Sector, because the sediment in this sector has come from the Danube originally.

The River Danube has been carrying a large volume of aggregate by every flood, and there has been developed many shoals, mostly in the branch channels at the locations at the distance of 300 to 400 km from the base of the Sulina Channel. Active aggregate mining for construction industry has been conducted under the permits issued by the National Agency for Mineral Resources (NAMR) and with authorization by AFDJG and the Ministry of Transport, Construction and Tourism.

The sea sand outside the Sulina Channel and around Midia Port and the river sand of the Danube have a capability of being utilized for beach fill. The items 3), 4) and 5) will be further examined in the following sub-sections.

Sand deposits in the inland can provide good supply for beach fill if they are available. In some marine reclamation projects in several countries, sand from hills has been used as filling materials. However, the geological characteristic of Dobrogea indicates few sources of sand deposits in the inland. The Study team has not found any inland sand deposit within a reasonable distance from the coast. Even if it is found, its excavation will cause significant environmental impact, the mitigation of which will be quite expensive. Therefore, inland sand deposits are eliminated from possible sources of beach fill sand.

5.8.2 Sediment Sampling and Analysis

(1) Locations of sediment sampling

Before the sea and/or river sand can be utilized for beach fill, its grain size characteristics should be examined and a check must be made to confirm that sand does not contain any harmful material for beach areas. To clarify these questions, a field campaign was carried out in June 2006 by the National Institute of Marine Geology and Geo-ecology (GeoEcoMar) under the subcontract with the Study team.

Sediment sampling was executed outside the Sulina Channel (10 samples), within the hopper of the Dunărea (3 samples), around Midia Port (9 samples), at the project site of Mamaia Sud (10 samples), at the project site of Eforie Nord (10 samples), in the Cernavodă area (km 300 – km 301: 6 samples), in the Cochirleni area (km 305 – km 308: 18 samples), and in the Oltina area (km 338 – km 340: 12 samples). The river areas of Cochirleni and Otlina were chosen as representative of active sand mining sites. When the coastal protection and rehabilitation projects are implemented, any other site that can produce sand of good quality will also be utilized. In total, 90 samples were taken and analyzed. Sampling points and results of analysis are described in Appendix C of Volume 2.

(2) Characteristics of grain size distribution

Sieve analysis of sediment samples has been made with the mesh sizes of $1.0/2^n$ mm ($n = -2$ to 10). Grain size characteristics show some variations from a sample to another within the same area. To illustrate the differences between the survey areas, the ensemble averages are calculated with the results listed in Table 5.8.1. There were a few samples which exhibited significant departures from the rest of samples within the survey area, and they are excluded in calculation of the ensemble averages.

Figure 5.8.1 shows the cumulative distributions of sediment grain size at the surveyed areas using the data of ensemble averages. The grain size distributions of the beach sand of Mamaia and Eforie are those at the depth of 1 and 3 m, excluding the samples at depth of 5 m.

The sediment outside the Sulina Channel is fine sand with the median diameter of 0.12 mm. It contains silt and clay fractions (grain size less than 0.063 mm) of about 26% in the total volume, although the silt and clay fractions vary from 0% to 51% depending on the samples. It means that sand bars exist in patches with muddy zones in between. Because of a wide spread of the grain size distribution from coarse sand to fine clay, the standard deviation in the phi units has a high value of 1.33. The hopper of the Dunărea contains more silt and clay, because she mainly operates along the Sulina Channel, where muddy materials are more deposited than outside the Channel.

Table 5.8.1: Grain size characteristics of the surveyed areas

Area	Nos. of samples	Water depth (m)	Gravel % (>4.0 mm)	Sand % (0.062 – 4.0 mm)	Silt % (0.004 – 0.062 mm)	Clay % (<0.004 mm)	Median diameter d_{50} (mm)	Standard deviation[1)]
Sulina	9	10	0.00	74.06	18.52	7.42	0.12	1.33
Hopper of the Dunărea	3	8	0.00	63.01	22.98	14.00	0.10	2.39
Midia	7 (8)[2)]	4 – 10	0.00	86.26	10.29	3.45	0.10	0.84
Mamaia Sud	4 (8)	0 – 5	0.00	100.00	0.00	0.00	0.13	0.21
Eforie Nord	4 (10)	0 – 5	0.00	100.00	0.00	0.00	0.24	0.54
Cernavodă	6	5 – 10	1.12	98.88	0.00	0.00	0.31	0.48
Cochirleni	15 (18)	4 – 9	0.11	99.89	0.00	0.00	0.22	0.39
Oltina	5 (12)	5 – 8	0.85	99.15	0.00	0.00	0.32	0.46

1) The standard deviation is defined as $\sigma = (\phi_{84} - \phi_{16})/4 - (\phi_{95} - \phi_{5})/6.6$, where $\phi = -\log_2 d$ with d being the grain size in millimeters.

2) Figures outside and inside the parenthesis are the sample numbers used for mean calculation and the total sample numbers, respectively.

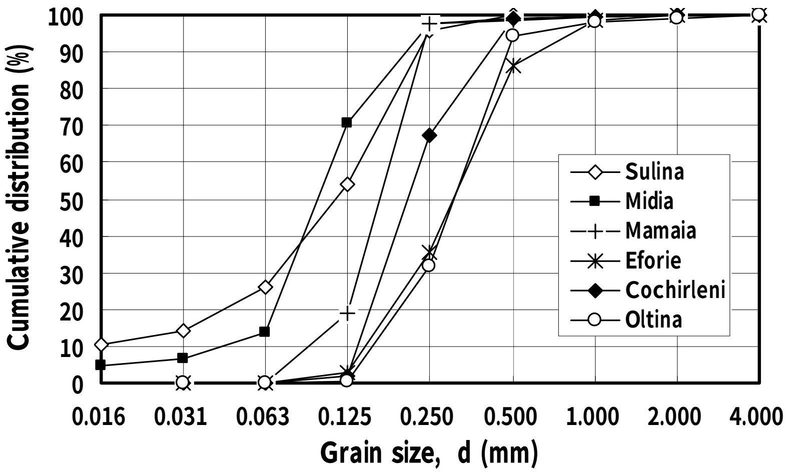


Fig. 5.8.1: Cumulative distributions of sediment grain size at the surveyed areas.

The sediment around Midia Port is fine sand with the median diameter of 0.10 mm with the silt and clay fractions of 14%. One sample at the east of the entrance channel with the depth of 11 m was composed of silt and clay, and thus this sample data were excluded from the ensemble average calculation. Two samples did not contain silt and clay, but other seven samples contained the silt and clay from 4% to 30%.

The sediment in the nearshore water of Mamaia Sud is fine sand with the median diameter of 0.13 mm on the average. The sediment is almost uniform in grain size and no content of silt and clay is found. Two samples were taken at the backshore and they were excluded from the average calculation, because they contained appreciable amount of coarse sand and their grain size distribution differed much form the rest of the samples. The sediment grain size at the water depth 5 m is smaller than those at the locations of 1 and 3 m deep. The median diameter of the sediment at the depth of 1 and 3 m is 0.17 mm. Sand in Mamaia Sud shows a quite narrow spread of grain size distribution with the standard deviation of 0.21 in the phi units.

At Eforie Nord, one sample taken at the shoreline contained gravel and coarse sand, the content of which differed much from the rest of the samples, and it was excluded from the average calculation. The median diameter of sand in the nearshore water is 0.24 mm on the average with the standard deviation of 0.54. The sediment grain size becomes small as the water becomes deep. The median diameter of the sediment at the depth of 1 and 3 m is 0.32 mm.

The six samples of sediment at Cernavodă were taken around the location of km 300 on the right side of the Danube upstream of the entrance channel of the Black Sea – Danube Canal. They were medium sand with the median diameter of 0.31 mm with the standard deviation of 0.48.

Around Cochirleni, 18 samples were taken among which one sample was near the river bank, containing silt and clay as the majority. Another sample was of gravel content. These two samples were excluded from the calculation of the ensemble average. The overall median diameter is 0.22 mm with the standard deviation of 0.39.

Around Oltina, 12 samples were taken and they do not contain any silt and clay fraction. The overall median diameter is 0.23 mm, probably having been affected by the extremely large flood in April 2006. Among them, five samples containing relatively coarse sand with the ensemble median diameter of 0.32 mm are used in presentation in Table 5.8.1 and Fig. 5.8.1.

(3) Heavy metals contents

Sediment samples were analyzed for the heavy metals contents to see if they contain any harmful minerals. Table 5.8.2 lists the major findings of the analysis.

Table 5.8.2: Heavy metals contents of sediment samples

Area	Ba (mg/kg)	Zr (mg/kg)	Sr (mg/kg)	Rb (mg/kg)	Zn-AAS (mg/kg)	Ni-AAS (mg/kg)	Cr (mg/kg)	V (mg/kg)	Co (mg/kg)
Sulina	113 *50–270*	213 *140–315*	184 *166–195*	74 *56–97*	46.0 *20–74*	30.6 *14–44*	70 *40–124*	53 *36–75*	8.8 *2.9–14.6*
Hopper of Dunărea	84 *73–104*	183 *179–190*	187 *182–190*	63 *70–78*	48.5 *49–54*	24.8 *17–30*	54 *50–53*	40 *36–44*	20.6 *16.7–22.4*
Midia	137 *50–317*	232 *194–432*	212 *204–253*	71 *41–121*	37.2 *15–104*	25.0 *11–63*	76 *48–119*	46 *28–75*	13.7 *4.2–33.3*
Mamaia Sud	63 *50–183*	111 *92–139*	291 *204–853*	54 *6-79*	17.1 *12-22*	8.9 *0.3-16.9*	31 *5-49*	21 *5-31)*	3.4 *1.1-6.6*
Eforie Nord	167 *50-342*	138 *105-202*	738 *396-1104*	29 *13-53*	12.3 *5.1-21.2*	7.81 *1.5-15.3*	13 *5-29*	9 *5-29*	5.8 *3.3-13.0*
Cernavodă	184 *50–274*	132 *93–127*	325 *179–220*	68 *5.7–73*	23.4 *18.1–34.3*	34.8 *23.5–42.5*	41 *35–67*	18 *5–40*	13.5 *8.2–39.4*
Cochirleni	108 *50–304*	144 *106–302*	200 *189–210*	65 *60–90*	37.4 *25.9–78.9*	32.22 *28.6–41.7*	52 *44–72*	38 *5–68*	8.1 *3.7–25.0*
Oltina	175 *104–348*	146 *106–306*	204 *190–223*	63 *53–77*	30.6 *23.8–42.8*	2.8 *14.7–34.9*	57 *36–88*	34 *9–50*	8.0 *5.5–14.1*

Note: Each cell indicates the mean in roman letters on the upper line and the min–max range in italic letters on the lower line.

With regards to heavy metals contents, the Romanian regulation concerning sediment sets the following limit concentration (cf. Table 7.7.1.B in **7.1.2** of Volume 1):

Cadmium (Cd):	3.5 mg/kg
Chromium (Cr):	90 mg/kg
Copper (Cu):	200 mg/kg
Lead (Pb):	90 mg/kg
Mercury (Hg):	0.5 mg/kg
Zinc (Zn):	300 mg/kg

Compared with the above regulation, two samples each at the Sulina and Midia Port areas indicate the Chromium (Cr) concentration exceeding the level of 90 mg/kg slightly. The content of Zinc (Zn) is well below the limit concentration. For other heavy metals analyzed and listed in Table 5.8.2, no regulation is established. Results of the analysis of heavy metal concentration of Cd, Cu, and Pb indicate all samples having these concentrations below the above limits (see also Table 5.7.1 in **5.7** of Volume 2).

(4) Organic pollutants in sediment

The results of chemical analysis for organic pollutants are compiled in Table 5.8.3. The content of total petroleum hydrocarbon (TPH) is below 25 mg/kg su, and the Organoclorinate pesticides are below the detectable level. Samples from the Midia and Mamaia areas indicate a certain level of polycyclical aromatic hydrocarbons (PAH), which seem to have the origin from pectrochemical industrial plants located in Midia Port. Two samples at Oltina also indicate a similar level of PAH.However, no specific regulation is in force for PAH.

Table 5.8.3: Concentration of organic pollutants in sediment samples

Area	Total petroleum hydrocarbon (TPH) mg/kg su	Polycyclical aromatic hydrocarbons (PAH) mg/kg su	Organoclorinate pesticides mg/kg su
Sulina	< 25	1.92 (*0.73 – 7.90*)	< 0.001
Hopper of Dunărea			
Midia	< 25	7.31 (*0.67 – 18.43*)	< 0.001
Mamaia Sud	< 25	3.90 (*1.34 – 11.45*)	< 0.001
Eforie Nord	< 25	2.02 (*0.88 – 2.75*)	< 0.001
Cernavodă	< 25	0.85 (*0.01 – 1.38*)	< 0.001
Cochirleni	< 25	1.36 (*0.45 – 2.23*)	< 0.001
Oltina	< 25	6.13 (*0.49 – 17.36*)	< 0.001

Note: PAH is given for the mean in roman letters and the min-max range in italic letters inside the parentheses.

5.8.3 Sea Sand outside Sulina Channel and around Midia Port

(1) Reserve volume of sand

The annual supply of sediment at the entrance of the Danube Delta is estimated as 30 million cubic meters presently, of which about 4% is sand;[10] i.e., about 1,200,000 m^3 per year. The sediment in the mixed form of sand, silt and clay is ejected to the sea by flood flows through

[10] Bondar, C. and Panin, N: The Danube delta hydrologic database and modelling, *GEO-ECO-MARINA*, 5-6/2000-2001, pp. 5-52 (see Table 4).

the branches of Chilia, Sulina, and Sfîntu Gheorghe, among which the Chilia carries the majority of sediment. Although there is no quantitative data of sand deposition outside the Sulina Channel, sand mining in the order of 200,000 m^3 per year can be executed without any apprehension for the beach fill operations contemplated in the coastal protection and rehabilitation plan in the Southern Romanian Black Sea shore.

The fine sand reaching to the east of Midia Port is a fraction of sand flushed out from the Danube Delta. However, the shoreline around Corbu at the northeast of Midia is advancing at the rate of some 4 m per year as discussed in **4.2.2**. The National Company Maritime Ports Administration S.A., which is responsible for administration of Midia Port, has been executing the maintenance dredging with the average volume of about 200,000 m^3 (actual volume fluctuates yearly) to keep the entrance channel in good condition. The nature of sedimentation and the information of the maintenance dredging volume indicate the presence of a sufficient volume of sand reserve in the east of Midia Port.

(2) Mining and transport

Sea sand is to be mined by pump dredgers of either trailer-suction or cutter-suction type. The Dunărea owned and operated by AFDJG is the former type. She can enter into the shallow water area up to the depth of 6 m. There are no other Romanian dredgers that can operate in the coastal water or outside the port area; all other dredgers can operate only in the river area.

The Dunărea is operated with a heavy work schedule, and there is little chance to mobilize her for sand mining operation. Therefore, some dredgers with foreign flags need to be mobilized from their mother ports outside Romania. The incurred cost of mobilization becomes high when the total volume of dredging is not large.

The distance from Sulina to Mamaia is about 160 km. It is uneconomical for a hopper dredger to travel between Sulina and Mamaia every time her hopper is filled. A fleet of hopper barges towed by a tugboat must accompany the hopper dredgers to transport the dredged sand from Sulina to Mamaia, but it take more than 10 hours to transport sand over this distance. It will be quite expensive operations (see **2.5.3 (3)** of Volume 2 for a tentative cost estimate).

In case of the beach fill using the sea sand around Midia Port, a hopper dredge will navigate from the dredging site to the offshore of Mamaia Sud, once her hopper is filled with the sand dredged from the seabed. The hopper dredger will use its pump to eject sand to the beach through a floating pipeline.

(3) Usability of sea sand for beach fill

The question whether the sea sand can be used for beach fill of coastal protection projects needs to be examined from three aspects. The first is the proof of no harmful content. The second is the grain size distribution. The third is the total construction cost.

As described in **5.8.2**, the seabed areas of Sulina and Midia have a few spots where the Chrominum (Cr) content exceed the limit level of the environmental quality criteria. Mining operations of sea sand need to be executed with due caution to avoid such polluted areas.

The grain size of sea sand is very fine with the median diameter of 0.10 to 0.12 mm. The sediment also contains the silt and clay fractions of 26% for Sulina and 14% for Midia as listed in Table 5.8.1. Every care should be taken to avoid the area of high silt and clay content when sand is being mined. Mining and filling operations will also require spreading of some turbidity protection curtains to prevent water pollution by suspended sediment.

From the viewpoint of cost, the sand outside the Sulina Channel is not eligible for use of beach fill because of high transportation cost even the sand quality is almost the same as the sand around Midia Port. The small grain size of the sea sand has two drawbacks for use of beach fill. One is the survival rate of filled sand after filling operation, and the other is the slope of equilibrium beach profile using very fine sand.

The survival rate is defined as the ratio of the volume of filled sand remaining on beach to the input volume. The concept is such that the grain size distribution of natural beach sand is in the equilibrium condition with the incident wave and current conditions. When the sand with the grain size too biased toward the finer fraction is placed on the beach, the finer fraction of filled sand cannot remain on beach, having been carried away offshore by waves and currents, and only the fraction corresponding to the existing distribution condition can remain. As listed in Table 5.8.1, the median diameter of Midia sand is 0.10 mm, while those of Mamaia and Eforie are 0.13 and 0.24 mm, respectively. After exclusion of the sediment at 5 m deep at the both areas, the median diameter is corrected to be 0.17 and 0.32 mm, respectively.

The difference of the median diameter between Midia and Mamaia is not so large, and Midia sand can be used at Mamaia especially because of the presence of detached breakwaters. However, the difference between Midia and Eforie sand is too great, and almost all of the Midia sand placed on Eforie beach will be carried away: see Appendix **D.4** of Volume 2 for details of the analysis of the survival rate.

Even at the Mamaia area, the small grain size of the Midia sand is expected to produce a very gentle slope of equilibrium beach profile. It is estimated as about 1/300. An equilibrium beach profile with the slope 1/300 yields the water depth of 1.5 m at the distance 450 m from the shoreline, where the existing seabed has the depth of 4 m at the opening between the detached breakwaters. Therefore a beach fill with 0.10 mm sand will require an underwater sill with the height of some 2.0 m to contain the filled sand within the planned profile. The total volume of beach fill with the sea sand is larger than that with the river sand, and with addition of the underwater sill the total cost of beach fill with the sea sand is expected higher than the case with the river sand. This aspect will be examined in the feasibility study of the priority projects.

5.8.4 River Sand of the Danube

(1) Guiding principle of examination of river sand availability

As being the second longest river in Europe, the Danube has been carrying a huge amount of sediment toward the Black Sea. As discussed in 4.4.2, however, the amount of sediment transport has been reduced by 50% in the past one century. The factors such as dam construction, sand mining and sand dredging for navigation channel and flood control has caused a general changing of the riverbed in a certain downstream area. On the other hand, the lower part of the Danube within Romania is receiving a quite large amount of sediment by floods from the whole of the Danube river basin in each year.

The present Study is being conducted with the assumption that the river sand of the Danube could be used as the beach fill material. However, sand mining from the Danube is a contentious matter from the political and environmental viewpoint.

From the technical viewpoint, it would be necessary to examine riverbed geomorphological change. In this respect, it has been agreed at the Sixth Steering Committee Meeting in August 2006 that the Romanian authorities could provide a guidance, making use of the EIA study for an EU-financed project on the navigation improvement of the Danube with regard to the possible impact on riverbed geomorphology by the priority projects at Mamaia and Eforie. Thus, the scientific assessment of potential morphological changes by sand mining is not implemented in this Study.

In this chapter, the information collected on the current situation of sand dredging in the Danube is compiled as the reference.

(2) Maintenance dredging for navigation channels

Presently, the sediment on the riverbed of the Danube is dredged for two purposes. One is to secure the water depth required for ship navigation, and the other is to mine sand and gravel for commercial purposes such as aggregate for concrete manufacturing. The former is carried out by the River Administration of the Lower Danube, Galati (AFDJG) and the Administration of Navigable Canals S.H. (ANC). The operation of these maintenance dredging is carried out in coordination with the Ministry of Transport, Construction and Tourism. The commercial mining is made by a number of private enterprises under the governmental control and authorization. In the following, two types of sand mining are discussed separately.

The water level of the Danube varies greatly by season. In a great flood, the water level around Chernavodă becomes 10.0 m or higher above the datum of the Black Sea, but it lowers down to 2.0 m or less during the draught season. AFDJG has the responsibility to maintain the minimum water depth of 2.5 m in the upstream area from Braila at the distance of 171 km from the base of the Sulina jetty. There are several critical areas in which large sedimentation occurs by flood flows between the downstream location of Cernavodă (km 298) and the location called Giurgeni (km 242). The quantity of maintenance dredging varies from 100,000 to 1,000,000 m^3 per year, depending on the severity of floods in respective years. Table 5.8.4 lists the annual volume of maintenance dredging at the critical zones from 1998 to 2004. The average volume of maintenance dredging per year is about 642,000 m^3.

AFDJG is making reconnaissance survey of navigation channels twice a month. When a significant shoaling is detected, a detailed bathymetric survey is carrying out and a contract for dredging operation is made with private companies, which own bucket and/or grab dredgers. The dredge spoils are dumped on nearby shoals outside the navigation channel several kilometers away from the dredging sites.

Table 5.8.4: Annual volume of maintenance dredging executed by AFDJG (units: m^3)

Year	Location							Total
	Girugeni km 242 – km 245	Hârşova km 250 – km 252	Albăneşti km 275 – km 276	Seimeni km 291 – km 293	Cernovodă km 296 – km 297	Caraghe-orghe km 343 – 344	Corabia km 629 – 631	
1998	0	0	0	94,758	0	0	0	94,758
1999	226,400	100,000	79,920	513,368	84,920	6,800	0	1,011,408
2000	309,260	70,240	248,576	458,974	0	0	0	1,087,050
2001	70,560	0	246,636	429,240	0	29,260	59,640	835,336
2002	54,460	83,720	236,453	451,822	0	0	0	826,455
2003	29,540	0	74,018	190,680	19,740	0	0	313,978
2004	47,956	0	92,284	112,077	74,983	0	0	327,300
Total	738,176	253,969	977,887	2,251,018	179,643	36,060	59,640	4,496,285
Average per year	105,454	36,280	139,698	321,574	25,663	5,151	8,520	642,326

The navigation channel from the Danube leading to the Cernavodă locks of the Danube – Black Sea Canal is also susceptible to frequent sedimentation. The Canal celebrated its twentieth anniversary in 2004. Since its opening in 1984, the branch channel had gradually become shallow, despite the maintenance dredging of 30,000 to 50,000 m^3 per year. In the draught season of 2003, several locations of the channel from the junction point (km 299) with the Danube to the locks were shoaled up and the ship navigation became difficult. Thus a large project of channel dredging was carried out in the period of two years from September 2003 to September 2005 with the dredging quantity of about 1,500,000 m^3. The cost of the project was shared by the Romanian Government (60%) and ANC (40%). Although ANC seems not having a long-term plan of maintenance dredging (they make dredging only after some shoaling is found), the mean amount of sedimentation might exceed 100,000 m^3 per year in consideration of previous maintenance dredging and the recent large dredging operation.

The sedimentation taking place in the Danube international fairway and the canal channel is a mixture of sand, silt, and clay. The sand fraction does not exceed 50% on average, and therefore the spoil of maintenance dredging is not suitable for using it for beach fill. However, the area of Seimeni at km 291 – km 293 has a deposit of very fine sand, which is renewed every year by floods. The sand seems to have the grain size distribution almost the same as the sand around Midia Port. However, for civil engineering works and concrete manufacturing, this sand is too fine and has no commercial value.

(3) Procedure of commercial aggregate mining

The sand and gravel mining for commercial purpose is controlled by the National Administration for Mineral Resources (NAMR), which belongs to the Ministry of Industry and Economical Development. Permits of sand and gravel mining, which have to be renewed every year, are issued by NAMR to prospective enterprises. For application of the mining permits, a prospective enterprise delineates a certain area as the sand quarry (a few hectares in size) in some branch channel of the Danube, makes exploration of sand reserves in the delineated quarry, and carries out a certain type of environmental impact assessment. NAMR examines the documents and issues the permit for the delineated quarry when NAMR regards the estimate of sand reserves as appropriate. The enterprise then submits a report of environmental impact assessment to the Environmental Protection Agency (EPA) in the area of jurisdiction. After EPA approves the report and issues the authorization, the enterprise submits the mining application documents to AFDJG for authorization of the dredging works in the Danube.

AFDJG examine the dredging schedule and work plan from the viewpoint of the maintenance of the fairway for international navigation and the safety control of ship navigation. AFDJG prohibits sand mining within the fairway and the 50-m width zone near the river banks as well as around the aids to navigations. The side slope of the mining pits should be milder than 1 on 4, and the bathymetric survey results after completion of sand mining at respective pits must be submitted to AFDJG. Unless AFDJG regards that the dredging works would adversely affect the fairway based on their experience, AFDJG together with the Ministry of Transport, Construction and Tourism authorizes the dredging works.

At the same time, the enterprise applies for the license of using the water area to the regional directorates of the National Administration of Romanian Waters (ANAR), such as the Water Directorate Dobrogea – Litoral (DADL), for the respective area of jurisdiction. Both the permits and licenses require the payment of fees (tariff). Detailed records of aggregate mining are kept at the offices of the regional directorates of ANAR. The Water Directorate Dobrogea – Litoral (DADL) has the jurisdiction over water use in the Danube between Brăila (km 171) and Călăraşi (km 375) and issues the water licenses to more than one dozen companies engaging in aggregate mining. Recent records of aggregate mining within the jurisdiction of DADL are listed in Table 5.8.5.

As explained above, each company acquires an authorization of aggregate reserve from the National Agency for Mineral Resources, but it asks DADL for only a partial quantity for mining in consideration of the tariff payment for water use. The second column of Table 5.8.4 lists the total of authorized volume of aggregate reserve and the third column lists the total volume of actual mining. As seen in the fourth column of Table 5.8.4, actual mining volumes are less than one-fourth of verified aggregate reserve.

Table 5.8.5: Aggregate mining volume in the downstream area of Călăraşi from km 271+500 to km 373

Year	Authorized Max. Mining Volume (1) (m^3)	Mined Volume (2) (m^3)	(2)/(1) (%)
2004	1,010,410.0	138,890.0	13.7
2003	1,056,828.0	83,602.0	7.9
2002	513,515.0	114,645.7	22.3
2001	572,510.0	120,154.0	21.0
2000	552,818.0	83,800.0	15.2
1999	903,200.0	148,396.5	16.4

(4) Description of sand quarry in the Danube

Analysis of the records of the mining permits by NAMR reveals the locations of the sand quarries authorized of their sand reserve and renewed every year. Figure 5.8.2 shows the locations of the quarries where the permits were issued and renewed for several companies in the zone of km 300 to km 350.

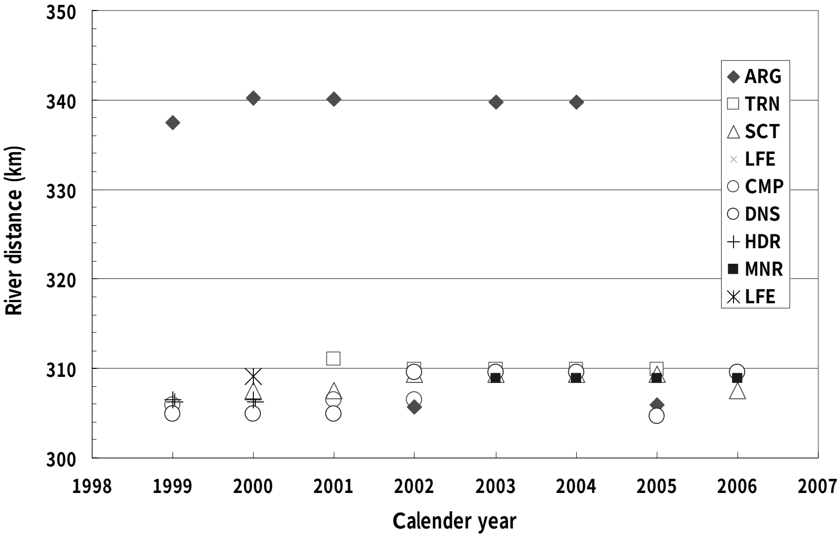


Fig. 5.8.2: Shift of the locations of sand quarries

The area of active sand mining at the location from km 305 to km 310 is called Cochirleni. Figure 5.8.3 is a map of the Danube in the zone between km 298 and km 308, which includes the Cochirleni area. In the zone between km 305 and km 308, sand mining is carried out on the sand shoals in the branch channels between the three islands, the largest of which is Hinog, at the right bank side of the Danube.

The prospective companies carry out sand mining within the limit of authorized amount, depending on the volume of demand. When the actual mining quantity was small, they might have applied the permit for the same quarry. When the demand was large, they explored another site of good reserve as new quarries and applied for the new permits. Figure 5.8.2 indicates the shift of mining locations by various companies over years. In the periods of 1999 to 2004, NAMR authorized the maximum volume of aggregate mining from 500,000 to over 1,000,000 m^3 per year, as listed in Table 5.8.2. The actual volume of mined aggregate remained at the level of 80,000 to 150,000 m^3, thus indicating a large reserve of sand unexploited in the Danube.

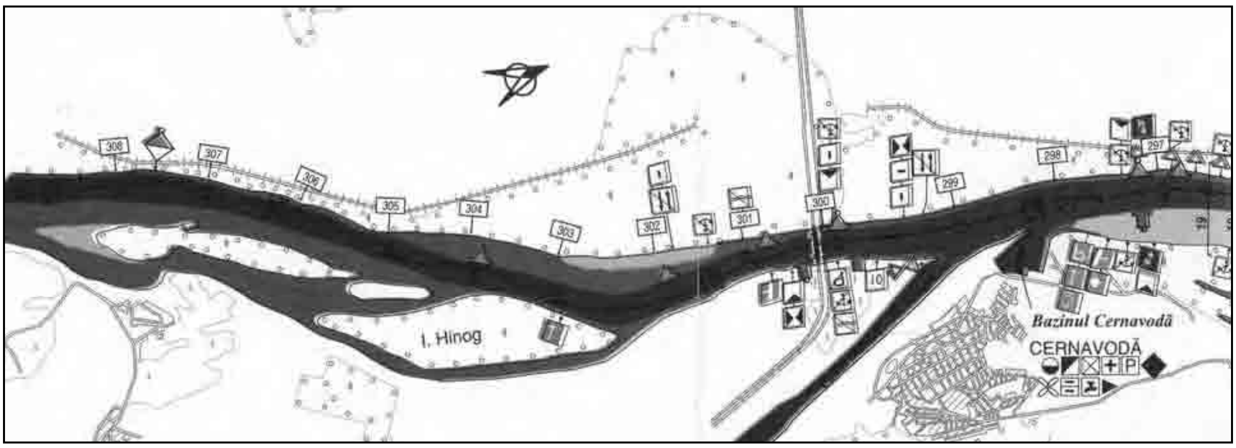


Fig. 5.8.3: Map of the Danube between km 298 and km 308

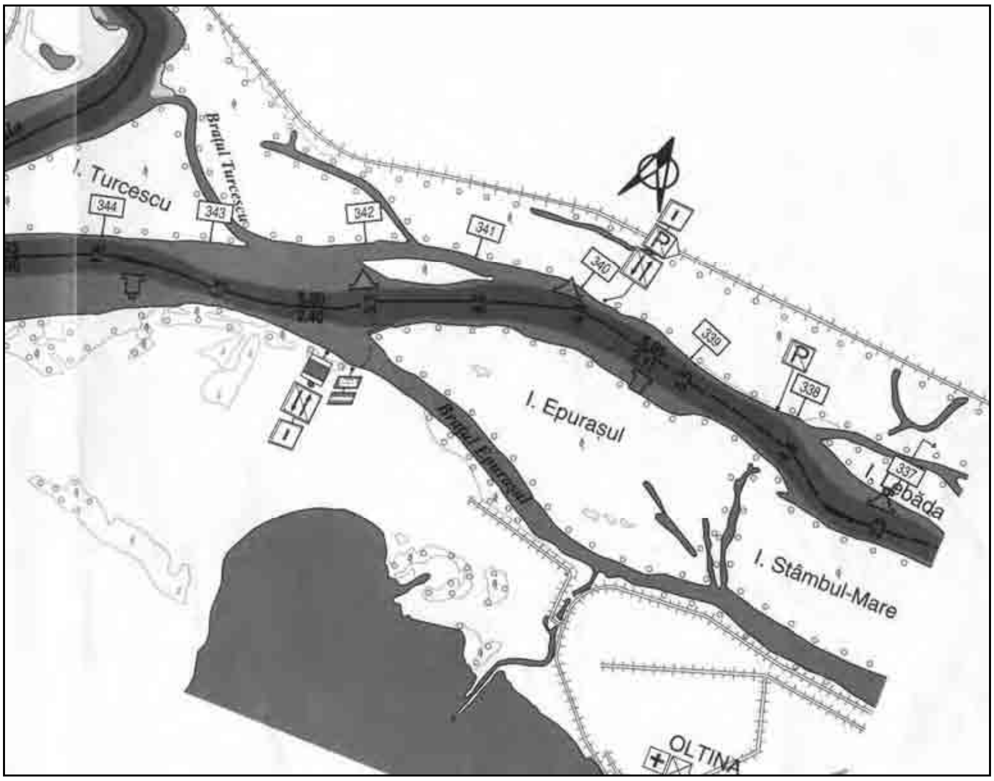


Fig. 5.8.4: Map of the Danube between km 337 and km 344

Another sand mining area is called Oltina. This area was exploited by one company for several years as seen in Fig. 5.8.2, because this area produces medium to coarse sand, which was utilized for spreading over roads to prevent vehicles' accidents by slippage. Figure 5.8.4 shows a map of the Danube around this area. Sand mining was made along the left side bank of the main channel, but the sediment sampling has been made in the branch channel of Epuraşul between the right bank of the Danube and the island Epuraşul to minimize the possible impacts on the flow regime of the main channel when the river sand mining will be carried out for the coastal protection and rehabilitation projects along the Southern Black Sea shore.

(5) Reserve volume of river sand of the Danube

The records of aggregate mining license kept at DADL list the names and locations of the applying companies, the delineated perimeters, the authorized volumes of mining, and the actually mined volumes. In the records of the years 1999 and 2000, however, the data also included the volumes of exploitable reserve that were affirmed by NAMR. Figure 5.8.5 shows the exploitable reserve volume in the area from km 305 to km 376.

The data is composed of three groups. The first group is the locations around km 305.9 to km 307.5, which represent the Cochirleni area. The second group at km 337.5 and km 340.1 are those of Oltina. The third group at km 372.5 and km 373.5 are located around Ostrov. Each bar represented the reserved volume submitted by a specific company and affirmed by NAMR. The area delineated by each company covered the length of less than 1 km and there remained many areas that had not been surveyed by any company for future application of sand mining. Therefore, the reserve volume data shown in Fig. 5.8.5 is only a part of the potential reserve. Even so, there were the sand reserve of approximately 1.7 million m^3 of sand in the Cochirleni area, 1.1 million m^3 in the Oltina area, and 2.6 million m^3 in the Ostrov area in

1990 and 2000. Within the limit of this reserve volume, the mining companies used to apply to NAMR for around 10% of the estimated sand reserve for one year's mining. The actual mining volume was less than half the annual authorization.

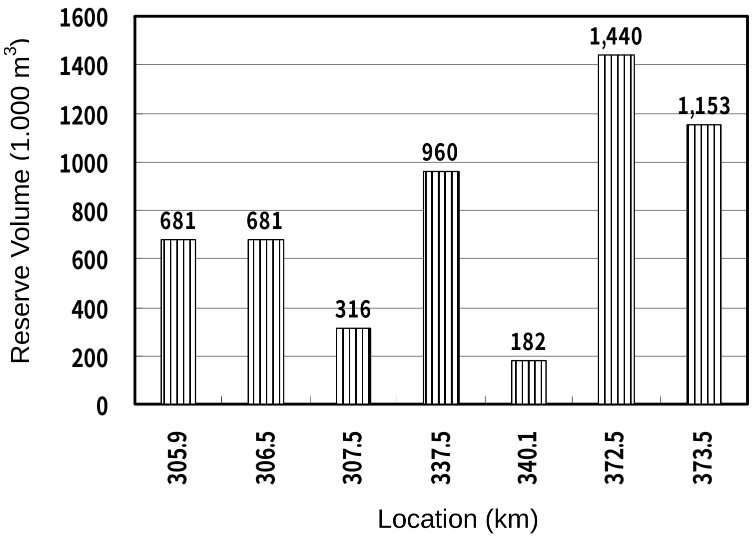


Fig. 5.8.5: Confirmed volume of exploitable sand reserves at various location of the Danube

Presently there is no survey data on the total volume of sand reserve in the riverbed of the Danube. However, the previous records of the annual authorization of the sand mining volume and the available record of reserve volume in 1999 and 2000 shown in Fig. 5.8.5 clearly indicate that there exists a very large volume (several tens of millions cubic meters) of exploitable sand in the Danube.

(6) Mining and transport of river sand

Present mining of aggregate for commercial use is made by employing bucket dredgers and floating cranes equipped with grab buckets. Dredged aggregate is loaded on hopper barges, which are towed or pushed along the Danube to the unloading quays. Sand for beach fill mined from the sand bars of the Danube will be transported through the Danube – Black Sea Canal to the unloading quays, from where dump trucks will be mobilized to carry sand to the designated beaches. The unloading quay will be at Basarabi or Ovidiu for the beach fill at Mamaia and the south harbor of Constanța for the beach area south of Agigea.

(7) Usability of river sand for beach fill

The question whether the river sand can be used for beach fill of coastal protection projects needs to be examined from four aspects. The first is the proof of no harmful material content. The second is the grain size distribution. The third is the availability of sufficient volume of sand reserve. The fourth is possible environmental impacts.

As discussed in **5.8.2**, the river sand is clean of any harmful material. The grain size distribution of the Cochirleni sand is coarser than the Mamaia sand and finer than the Eforie sand. Thus the Cochirleni sand is suitable for beach fill at the Mamaia area. The sand in the Oltina area is slightly coarser than the Eforie sand, and it is suitable for beach fill at the Eforie area.

The reserve volume of sand has been discussed in **(5)** above. As for the volume of sand needed for beach fill, the total volume of the sand to be filled is 3.2 million m^3 over the period of 20 years or more as described in **5.7.2**, of which about 1.8 million m^3 are earmarked for the first stage in the period between 2007 and 2020. With the prospect of the coastal protection and rehabilitation projects to start in 2007, the average net volume of sand mining will be about 130,000 m^3 per year. Such a volume of sand could be easily mined from the sand shoals in the branch channels of the Danube in addition to the current mining volume of 80,000 to 150,000 m^3 against the authorized maximum mining volume of 500,000 to 1,050,000 m^3 as listed in Table 5.8.4. Thus it can be said that a sufficient amount of reserve sand is available for mining of beach fill sand, but the final decision will have to await the conclusion of SEA and EIA..

5.8.5 Flow Regime of the Danube and Possible Impacts of River Sand Mining

(1) River flow regime analyzed in an ISPA project for navigation condition improvement

The Danube has been opened for international navigation since 1854 when an international committee was established for administration of free navigation along the Danube. The committee has been reorganized several times into the present form of the Danube Commission. One of the technical problems that the Danube Commission faces is the lowering of water level in the lower Danube sector (Călăraşi to Brăila) during the draught season from summer to winter. The required navigation depth of 2.5 m is no longer insured at the section between km 348 to km 300 for an average period of 160 days each year.[11] It is owing to a natural growth of the Borcea Branch, which is the bifurcation of the Danube at km 346 since about 100 years ago and is taking a major fraction of the water flow. Figure 5.8.6 is a diagram of river bifurcation of the lower Danube sector.

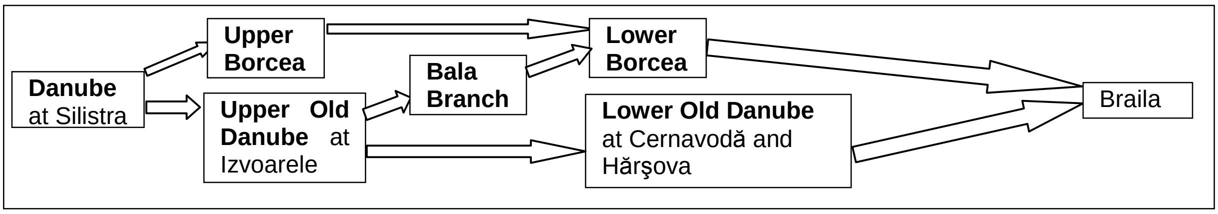


Fig. 5.8.6: River bifurcation of the lower Danube between Silistra and Hârşova

The medium discharge of the Danube is 6,550 m^3/s, while the maximum and the minimum are 15,540 and 1,610 m^3/s, respectively.[12] The flow distribution of the bifurcated channels in Fig. 5.8.6 varies depending on the river discharge. Table 5.8.6 is taken from the report of the ISPA project for the improvement of navigation conditons.[13]

[11] Technical Report Stage I – II: ISPA Program EUROPEAID/114893/SV/RO "*Technical assistance for improvement of navigation conditions on Danube*," Measure 1: Improvement of navigation conditions on Danube between Călăraşi and Brăila and complementary measures, May 2006, p.5.

[12] *op cit*, p. 7.

[13] Report on the Environmental Impact Assessment Study for "*Technical assistance for improvement of navigation conditions on Danube*," Measure 1: Improvement of navigation conditions on Danube between Călăraşi and Brăila and complementary measures, April 2006, p. 114 (Table 2.4-5).

Table 5.8.6: Discharges of bifurcated channels in the lower Danube sector

(units m^3/s)

Discharge at Silistra	Probability of exceedance	Upper Old Danube	Upper Borcea	Bala branch	Lower Borcea	Lower Old Danube
2,000	99.91%	1,970	26	1,650	1,676	320
4,000	79.40%	3,760	237	2,610	2,847	1,150
6,000	47.38%	5,480	517	3,410	3,927	2,070
8,000	23.03%	7,160	843	4,130	4,973	3,030
10,000	7.72%	8,800	1,202	4,790	5,992	4,010
12,000	1.92%	10,410	1,588	5,410	6,998	5,000
14,000	0.43%	12,000	1,997	5,990	7,987	6,010

As indicated in Table 5.8.6, the Lower Old Danube does not receive enough water when the upstream discharge is small. Even at the time of great floods, the branch channel of the Lower Borcea receives the flow rate larger than that of the Lower Old Danube. Because of low flow distribution to the Lower Old Danube, there appear eight critical points of deficient water depths.[14] To remedy the problem of small water inflow into the Lower Old Danube during the draught season, a set of river improvement works has been proposed and its technical feasibility study with environmental impact assessment has been carried out. Among eight critical points, six listed in Table 5.8.7 are located upstream of Hârşova and will be given improvement works.

Table 5.8.7: Location of critical points for navigation in the Lower Old Danube

No.	Area name	Location (km)	Navigation depth under ENR[1)] (m)	Major works[2)]
1	Bala Branch	346+800 – 344+500	1.8	bs, gw, bp, d
2	Epurasu Island	342+700 – 341+800	1.8	gw
3	Seica	328+500 – 325+900	2.1	bs, bp
4	Ceascaru and Fermecatu Islands	324 – 322	1.5 – 1.8	bs, bp
7[3)]	Fasolele Island	292+000 – 291+700	2.3	bs, bp
8	Atarmati	268+500 – 267	> 2.5	bp

Note: 1) ENR: Level of the Regularisation and Navigation Low Water.
2) bs: bottom sill, gw: guiding wall, bp: bank protection, d: dredging
3) The original critical points Nos. 5 and 6 are not given any improvement works.

The proposed works include construction of a bottom sill at the entrance of the Bala Branch and others to reduce the water inflow. With other works of submerged guiding walls, bank protection, and channel deepening by dredging, the flow distribution is expected to be rearranged as listed in Table 5.8.8. The water flow in the Lower Old Danube at the draught discharge of 2000 to 4000 m^3/s increases quite noticeably. With these works, the water depth between Izvoarele and Cernavodă is expected to increase by 1.3 m at a discharge of 2000 m^3/s, according to the results estimated by some mathematical model; the details of computation are not disclosed in the technical report.

The discharge of Lower Old Danube is referred to the hydrometer station at Hârşova, but it should be the same at Cernovodă because there is no bifurcation or inflow of significant tributaries. The rating curve at Hârşova[15] is summarized as listed in Table 5.8.9.

[14] *loc. cit.* 13), pp. 104-105.
[15] *loc. cit.* 13), Figure A2-7.

Table 5.8.8: Discharges of bifurcated channels in the lower Danube sector after improvement works (units m^3/s)

Discharge at Silistra	Probability of exceedance	Upper Old Danube	Upper Borcea	Bala Branch	Lower Borcea	Lower Old Danube
2,000	99.91%	1,897	103	1,053	1,256	844
4,000	79.40%	3,843	157	2,276	2,433	1,567
6,000	47.38%	5,679	321	3,355	3,676	2,324
8,000	23.03%	7,376	624	4,200	4,824	3,177
10,000	7.72%	9,025	975	5,001	5.976	4,023
12,000	1.92%	10,644	1,356	5,742	7,098	4,902
14,000	0.43%	12,236	1,764	6,456	8,220	5,780

Table 5.8.9: Mean relationship between water level and river flow rate at Hârşova

Water level (m)	–0.5	0	0.5	1.0	2.0	3.0	4.0	5.0	5.5	6.0	6.5
Flow rate (m^3/s)	290	490	700	950	1520	2100	2800	3650	4100	4550	5090

(2) Possible change of river flow regime by sand mining for beach fill

Possible environmental impacts of sand mining are threefold; the first is a possible change of the flow regime of the Danube, the second is riverbed morphological change, and the third is an influence on fauna, flora and biodiversity on the riverbed of the Danube.

The first question is concerned with any possible impact on the river regime of the fairway for international navigation. As indicated in Table 5.8.7, the candidate sites of sand mining around Cochirleni and Oltina are not regarded as critical points for maintaining the required water depth more than 2.5 m; the water depth of the fairway at these areas is large enough.

As shown in Fig. 5.8.2, the Danube around Cochirleni has the width of more than 1,000 m between the right and left banks and the international fairway is confined within a narrow zone of 200 m along the edge of the left bank. In the location between km 308 and km 305.5 sits a wood-covered island of 3 km long and 300 m wide near the right bank. Downstream of this island, another island called “Hinog” stretches over 3 km with the width of 600 m along the right bank. A branch channel flows between the right bank and the two islands. Another branch channel of 300 m wide flows between the two islands diagonally to the main channel, and sand mining is mainly carried out in the latter branch channel. Judging from such topographic features, it seems to the Study team that sand mining from the branch channels area little affects the river flow of the fairway for international navigation.

Sand mining around Oltina will also be carried out on the sand shoal in the branch channel of Epuraşul shown in Fig. 5.8.3. In this case too, little influence of sand mining on the main flow of the Danube will be expected.

(3) Possible change of riverbed morphology by sand mining for beach fill

It is a difficult question to answer quantitatively whether the sand mining with the volume of around 130,000 m^3/year for the beach fill may adversely change the riverbed morphology of the fairway of international navigation. One reason is the continuous evolution of the river morphology of the Danube. As described in the technical report of the ISPA project for improvement of navigation conditions of the Danube, the Bala Branch and the Lower Borcea have been growing in width and depth since its appearance about 100 years ago. The Lower Old Danube itself changes the riverbed morphology after big floods, as exemplified by repetitive maintenance dredging being carried out by AFDJG. The area of Seimeni at km 291

– km 293, for example, is the location at which fine sand settles down every time after maintenance dredging as listed in Table 5.8.4. The fairway is located at the left of Fasolele Island, and flow control works are contemplated to reduce the inflow rate to the branch channel at the right.

The median diameter of the riverbed sediment varies between 0.12 to 0.25 mm.[16] The suspended sediment of the Lower Danube has the median diameter of 0.022 to 0.035 mm. The average annual transport of sediment transport at Chiciu – Călăraşi was 1690 kg/s during the period from 1933 to 1970, but it decreased to 470 kg/s in the period from 1992 to 2003. The sediment of the bed load has the median diameter of 0.19 to 0.32 mm. The latter is about 5% of the total sediment transport.[17] The above technical report lists some data on the bed load transport, which is summarized in Table 5.8.10: the source of this data is not revealed in the report.

Table 5.8.10: Bed load transport in the Lower Danube (units: kg/s)

Flow rate (m^3/s)	Chiciu – Călărasi (Danube at Silistrra)	Izvoarele (Upper Old Danube)	Bala (Bala Branch)	Hărşova (Lower Old Danube)
2000	90	89	70	10
4000	260	210	140	52
6000	500	360	220	110
8000	779	530	300	190
10,000	1110	720	380	270
12,000	1470	920	460	360
14,000	1870	1120	550	460
15,000	2080	1240	590	520
Annual rate	617	425	246	145
Total transport (m^3/year)	10,081,000	7,446,000	4,310,000	2,540,000

The annual rate and total volume of bed load transport at the bottom two rows are the estimate by the Study team with the information of exceeding probability listed in Table 5.8.6. The location of Chiciu – Călăraşi is near to Silistra at the left end of Fig. 5.8.6. The technical report of the ISPA project advises to use the data in Table 5.8.10 only as guiding values because of the inherent uncertainty of ±15% in the estimate of the bed load transport.

The sediment transport rate in Table 5.8.10 does not satisfy the continuity condition that was held in the case of water flow listed in Tables 5.8.7 and 5.8.9. The transport rate gradually decreases downstream and the decrease may reflect the deposition on the riverbed between the control sections. The annual rate can be converted to the total volume of bed load transport by using the apparent specific density of sand being 1800 kg/m^3. The result of calculation is listed at the bottom row. The total transport volume of 7,446,000 m^3/year at Izvoarele is larger than the sum of the volumes at Bala and Hâşova by 596,000 m^3/year. It may represent the amount of sedimentation in the section of the Lower Old Danube although it may be due to inaccuracy of bed load measurements.

Compared with the elaborate flow calculation, the feasibility study of the ISPA river improvement project refrains itself from making quantitative estimate of the riverbed

[16] *loc. cit.* 11), p. 12.
[17] *loc. cit.* 11), p. 13, also *loc. cit.* 13), Table 2.2-4a, p. 33

morphological changes and it gives the following comment:[18]

> "The sediment transport model was able to provide only trends of the long-term developments of Danube River between Silistra and Braila as a consequence of river complexity, limited information in this field and large area studied.
>
> (*Concerning the maintenance dredging*:) The morphological assessment showed the proposed project works bring about a slight reduction in the sedimentation process, when enough water depth remains available. Consequently, the conclusion can be (and mention should also be made) that further significant dragging (*sic*: dredging) works will be needed for annual maintenance. In comparison to the current situation, the future reduction of dragging (*sic*: dredging) required annually is estimated to about 20%. Such estimate has to be seen as tentative."

Compared to the natural changes of large scale in the riverbed morphology brought by annual floods, it would be futile to try to quantitatively evaluate the riverbed change induced by the sand mining for beach fill operations. It will be suffice to say that any impact of sand mining on the riverbed morphology will be insignificant in comparison with the natural changes by floods. The topographical features of sand quarries described in **(2)**, the past experience of authorizing sand mining operations, and no incidence of adverse effects on the fairway must be the basis of AFDJG's judgment in issuing the authorizations. At least, AFDJG has not observed any adverse effect of sand mining in the Danube. Sand mining of some 130,000 m^3 per year for beach fill operation in addition to the current mining volume of 80,000 to 150,000 m^3 is well below the current authorization volume of 500,000 to 1,050,000 m^3 per year. It is expected that NAMR will issue the permit of sand exploitation for beach fill and AFDJG will authorize dredging operation of sand mining, when the coastal protection and rehabilitation projects are proposed to be implemented.

(4) Possible impacts of sand mining on fauna, flora and biodiversity

The possible impacts of sand mining on fauna, flora and biodiversity of the riverbed of the Danube are discussed in detail in **5.4** of Volume 2 concerning the feasibility study of the priority projects. It is summarized as in the following. The water level of the Danube in the area of expected sand mining fluctuates widely between the flood and draught seasons by more than 8 m. Fauna and flora are the species than can survive the harsh environment of the Danube river flow. There are some species of flora in shallow water along the river banks, but few flora can grow in the turbid water of several meters deep on the sand shoals. Thus no possible impact on flora will be minimum. As to fauna, there are fresh-water shells of common species. They may disappear temporarily from the area of sand mining, but they will soon immigrate back to the dredged site from the neighboring areas. Thus, it seems to the Study team that the environmental impact on fauna, flora and biodiversity will be insignificant.

5.9 Cost Estimate and Implementation Schedule

5.9.1 Estimate of Construction Cost

An estimate of construction cost has been made for the new facility construction (including demolish of old facilities) and beach fill projects. The estimate is based on the local market

[18] *loc. cit.* 13), pp. 116 and 177.

price converted in Euro. For each facility proposed in **5.7**, its standard cross section is drawn, the required amount of materials is counted, and standard unit construction cost is estimated. Standard cross sections of facilities, the basis of cost estimate, etc. is described in Annex **F** of Volume 3. The result of cost estimate is summarized in Table 5.9.1. Partial modification of the coastal protection plan described in 5.7.4 has been incorporated in this table so that the sub-sector of Eforie Nord (2) is deleted and the numbers of new jetties and artificial reefs differ from those listed in Table 5.7.2.

It should be noted here that the layout of facilities and design of standard cross sections are conceptual ones before reliable bathymetric and topographic maps at respective sub-divisions become available. As will be found in the feasibility study of the priority projects at Mamaia South and Eforie Nord described in Volume 2, the result of cost estimate and the required volumes of beach fill sand in the feasibility study differ from those in Table 5.8.1 to some extent. As individual coastal protection and rehabilitation projects under the present overall coastal protection plan are formulated in the future, respective feasibility studies will be undertaken and revisions in cost estimates will become inevitable.

5.9.2 Implementation Schedule

The installation of shore protection facilities envisaged in Table 5.9.1 needs to be made over a long time span, because of a large investment cost required. Although the coastal protection plan for the Southern Romanian Black Sea shore is aimed at the year 2020 as stated in **1.4**, the cost estimate for the whole plan indicates an annual investment exceeding 20 million Euro for the net construction cost only if the plan is to be executed by 2020. Therefore, the whole plan is proposed to be implemented in two stages: for the initial 14 years and the second stage after the 15th year. The first stage is further divided into three phases.

When the Interim Report was submitted in February 2006, it was anticipated that the processes of the strategic environmental assessment (SEA) and the environmental impact assessment (EIA) would have been concluded before early 2007 and the fund for the first phase project will become available within 2007. However, the prospect as of February 2007 is such that the fund will be available only in late 2007 or a much later date. Because of the uncertainty on the time of the first project implementation, the schedule is given not in the calendar year but the consecutive year after the start of the coastal protection plan.

For the first stage, three phases of implementation are proposed for the periods of five years each, i.e., the first to fourth years, the fifth to ninth years , and the tenth to fourteenth years. Assignment of the implementation phase to each project site has been made in consideration of the urgency of coastal protection and rehabilitation for respective sub-sectors. Figures 5.7.2 and 5.7.4 have already introduced phase-wise facility installation programs for the Constanța and Eforie Sectors.

The implementation of schedule of the coastal protection and rehabilitation of the Southern Romanian Black Sea Shore has been summarized as listed in Table 5.9.2. It is the recommendation of the Study team under the present situation, and it will be the judgment of the authority concerned of the Government of Romania to rearrange the implementation schedule if required by the availability of financial resources and other reasons.

Table 5.9.1: Tentative estimate of construction cost for proposed coastal protection plan

Sub-Sector		Item	Quantity of project	Approximate Cost (thousand Euro)
Mamaia North		2 new submerged groins	200 m in total	280
Mamaia Center	(1)	2 breakwaters (rehabilitation)	500 m in total	5,020
	(2)	2 breakwaters (rehabilitation) 1 new submerged groin	500 m in total 100 m long	5,020 140
Mamaia South		2 breakwaters (rehabilitation) 1 groin Beach fill	500 m in total 200 m long 180,000 m^3	5,020 690 4,730
Mamaia subtotal				20,900
Tomis North		2 new long jetties 1 new artificial reef Beach fill Removal of existing facilities	640 m in total 250 m 270,000 m^3	8,490 3,700 7,070 750
Tomis Center		2 new long jetties 1 new artificial reef Beach fill Removal of existing facilities	740 m in total 250 m 220,000 m^3	9,960 3,700 5,790 970
Tomis South		1 new long jetty 2 new artificial reefs Beach fill Removal of existing facilities	440 m in total 550 m 370,000 m^3	4,140 8,080 9,650 1,410
Tomis subtotal				49,480
Eforie Nord		2 new jetties and 2 jetties rehab. 2 new artificial reefs Beach fill Removal of existing facilities Temporary 2 access road	650 m in total 550 m in total 340,000 m^3 1,700 m in total	6,400 10,350 7,780 500 330
Eforie Middle		1 new jetties 3 new artificial reefs Beach fill Removal of existing facilities	340 m in total 750 m 430,000 m^3	2,740 11,090 10,130 100
Eforie Nord and Middle subtotal				49,420
Eforie Sud (1)		2 new jetties 2 new artificial reefs Beach fill Removal of existing facilities	480 m in total 550 m in total 380,000 m^3	7,280 8,080 8,820 1,600
Eforie Sud (2)		2 new artificial reefs Beach fill Removal of existing facilities	600 m in total 260,000 m^3	8,760 6,200 450
Eforie Sud subtotal				41,190
Olimp–Venus		7 new jetties 1 new artificial reef Beach fill Removal of existing facilities	1,630 m in total 250 m 540,000 m3	20,900 4,740 15,370 3,760
Olimp–Venus subtotal				44,770
Saturn–Mangalia		3 new jetties 3 new artificial reefs Beach fill Removal of existing facilities	600 m in total 610 m in total 160,000 m^3	8,170 10,210 4,550 3,390
Sat.–Mang. Subtotal				26,320

Jetty, groin & breakwater	Total length	7,520 m	84,250
Artificial reef in total	Total length	4,360 m	68,710
Beach fill in total	Total volume	3,150,000 m^3	80,090
Removal of existing facilities and access road			13,260
Grand total			246,310

Note: The above cost estimate does not include engineering fee and contingency cost.

Table 5.9.2: Implementation Schedule of Coastal Protection Plan

Item	First Stage				Second Stage	Total
	First Phase	Second Phase	Third Phase	Overall		
Implementation period	1st – 4th years	5th – 10th years	11th – 14th years	1st – 14th years	After 15th year	
Project sites	Mamaia South with parts of North and Center Eforie Nord	Mamaia Center(1) Tomis North Eforie Middle & Rehab. for Olimp to Mangalia	Mamaia Center(2) Tomis Center Eforie Sud (1) & Rehab. for Olimp to Mangalia	Mamaia to Eforie Sud & Rehab. for Olimp to Mangalia	Tomis South Eforie Sud (2) Olimp to Mangalia & 2 –Mai to Vama Veche	
Feasibility study Cost of F/S	JICA grant	New contract 1.5 million Euro	New contract 1.5 million Euro	3.0 million Euro	4.0 million Euro	7.0 million Euro
Eng. service(D/D) Cost of D/D	New contract 2.8 million Euro	New contract 4.0 million Euro	New contract 4.2 million Euro	11.0 million Euro	8.5 million Euro	19.5 million Euro
Net construction cost	36.2 million Euro	51.9 million Euro	54.0 million Euro	142.1 million Euro	109.8 million Euro	251.9 million Euro
Operational and maintenance cost	1.2 million Euro	2.4 million Euro	3.3 million Euro	6.9 million Euro	5.9 million Euro	12.8 million Euro
Contingency	3.6 million Euro	5.2 million Euro	5.4 million Euro	14.2 million Euro	11.0 million Euro	25.2 million Euro
Approximate project cost	43.8 million Euro	65.0 million Euro	68.4 million Euro	177.2 million Euro	139.2 million Euro	316.4 million Euro

Note 1: All costs are based on the price in 2005 and do not include the price contingency.

Note 2: The cost estimate in the first phase is based on the condition that sand mining from the riverbed of the Danube is authorized and the sand can be utilized for beach fill. If the river sand is unable to use by environmental protection reasons and the sand from the seabed off Midia Port is to be utilized, the cost estimate is altered as follows:

Cost of engineering service:	4 million Euro
Net construction cost:	60 million Euro
Operation and maintenance cost:	2 million Euro
Contingency	6 million Euro
Approximate project cost	72 million Euro

Note 3: The implementation period is given in the consecutive year after the implementation of the first phase project.