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Environmental concerns for marina planning in the Gulf of Suez

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Abstract. This paper presents a case study where numerical modelling was utilized for the first time to estimate shoreline changes during the planning of a private pleasure marina in the Gulf of Suez. The study was made to compliment an environmental impact assessment study (EIA) requested by the Egyptian Environmental Affairs Agency (EEAA). The paper presents data collected during two surveys and the results of the numerical model. The impact of the marina on the sediment budget was investigated using the GENESIS one-line program. One of the main reasons for the study was to confirm that the choice of the marina location ensured minimum erosion of the shoreline. In the model, the sediment transport calibration constants were determined using the results of two surveys. The choice of the formula is discussed in the paper. Two locations for the marina were tested against minimum erosion at the down drift side of the marina. This study was performed in close co-ordination with the EEAA and several solutions were suggested to minimize the expected accretion before the final location was approved.

Keywords: Environment Impact Assessment; GENESIS; Sediment transport.

Abbreviations: EIA = Environment Impact Assessment; EEAA = Egyptian Environmental Affairs Agency.

Introduction

In Egypt, environmental concerns have increased, particularly since the passing of the Law of the Environment in 1994, known as law number 4/1994. Shoreline erosion has been recognized as the prime issue facing the Integrated Coastal Zone Management plan in Egypt. Major erosion problems are found at the northern coasts of Egypt on the Mediterranean particularly around the Nile Delta. Law 4/1994 required that an EIA study be presented for all new developments, and categorized the projects in one of three groups, namely 'white', 'grey' and 'black' projects. All coastal developments are categorized as 'black' projects and have to submit a full EIA.

This paper presents a case study for environmental concerns about possible shoreline changes and erosion due to the planning of Dome Marina on the Gulf of Suez. Dome Marina is located at 29° 26' N and 32° 30' E, or 80 km south of the city of Suez, as shown in the admiralty chart number 3215, Fig. 1. The marina is planned to accommodate 80 boats of different sizes ranging between 12 m and 30 m length. Dome Marina beach topography was surveyed in October 1995. The seabed contours are almost parallel to the shoreline in the south section, with a large submarine canyon (bay) to the North of the beach. A large headland bounds the bay, 2 km north of the site. Ten samples were extracted from the beach material during the survey and analysed. The beach consists of sand with a mean grain size of 0.4 mm along the first 600 m. Remaining beach sections were mainly rocky beaches as sketched in Fig. 2. The shoreline position was surveyed again in September 1996 one year after the first survey. Observations had shown that the South Dome Marina beach is exposed to open sea waves. Due to absence of sandbars, offshore reefs and tidal flats to act as natural barriers, waves are moderate to high in the area. Wave height distribution is discussed later in this paper together with data on wind, tides and currents.

An EIA study had been presented to the EEAA that concentrated on the physical description of the area. Later, it was requested that a numerical model should be performed to estimate the shoreline changes due to the construction of the marina; particular concerns are for shoreline erosion. A one line model, GENESIS (Hanson & Kraus 1989) was used to estimate the sediment budget. Choice of the marina location was later guided by results obtained through application of this model. This work was performed in co-ordination with the EEAA, as it was the first time that such a numerical tool for marina planning was used in the Gulf of Suez. The Gulf has recently received more attention for tourist development, and soon there will be a large port north of the El-Sokhna area. The current paper presents meteorological data in the middle part of the Gulf of Suez and the expected impact of the marina on the sediment budget using the GENESIS program.

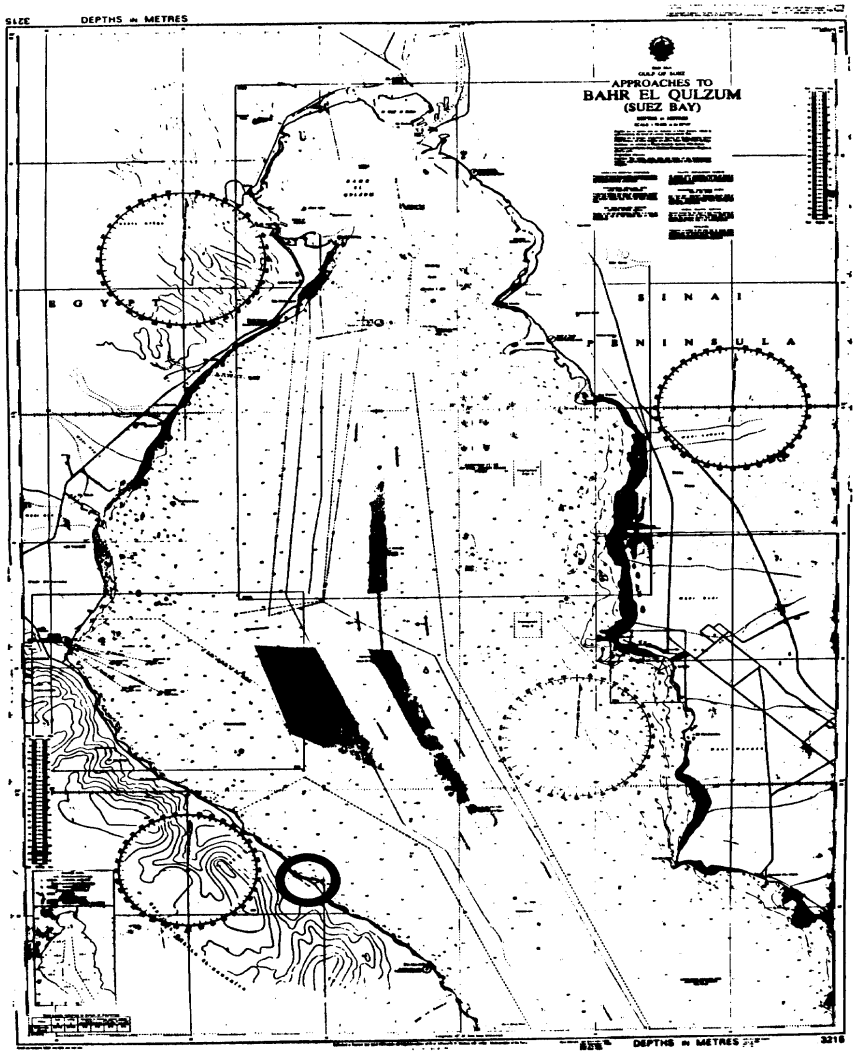

Fig. 1. Location of Dome Marina on the Gulf of Suez.

Meteorological data

Wind

Typically, from November through March an extension of the Azores high-pressure area extends eastward over Egypt and causes predominantly northerly winds over eastern Egypt. An extension of the Asiatic (winter) high-pressure area extends westward over the Arabian Peninsula causing predominantly northeasterly winds over Arabia. These northeasterly winds turn in to a northerly direction when blowing down-slope on the West Side of the mountains of the western Arabian Peninsula and merge with the northerly wind of eastern Egypt. The result is a predominantly northerly wind in the vicinity of the Gulf of Suez. This wind is channelled by the Red Sea Mountains bordering the Gulf into a prevailing NW wind.

From June to September, the eastward extension of the Azores high pressure area covers the Mediterranean and northern Egypt causing northerly winds over the Gulf of Suez and the North Red Sea, the winter high-pressure area being replaced by the Asiatic heat low-pressure area. A westward extension of this Asiatic low-pressure area covers the Arabian Peninsula and augments the northerly winds that caused the Azores high. The result of the northerly wind and its channelling between the mountains is a strongly prevailing northwestern wind over the Gulf of Suez. Since the Azores high blocks or diverts the northern most eastward movement of extra-tropical cyclones over the eastern Mediterranean, there are relatively few interruptions to the northwestern wind direction. Thus the complex interplay of pressure systems in the region surrounding the Gulf of Suez results in prevailing, relatively weak, northwesterly winds in winter occasionally interrupted by storms, and prevailing stronger northwesterly winds in summer rarely interrupted by storms. The spring and fall months are transition periods between summer and winter systems. Table 1 shows the average annual percentage of occurrence of wind speed-direction groups over the middle part of the Gulf of Suez. A strong - 65% of wind - prevails from the Northwest direction, as shown.

Tides

Tidal range in the north and middle parts of the Gulf is relatively large for this region. Water level measurements in Port Tawfik (South of Suez city) from July 11 to August 24, 1985 showed a maximum range of 1.68 m. Analyses of this tidal record revealed 13 constituents and a maximum range (between HAT and LAT) of 2.15 m, the spring range is 1.7 m and the neap range is 0.90 m. Surges and other setups (e.g. wind, wave and pressures) are estimated as 0.15 m (Anon. 1997a).

Currents

Average monthly maximum offshore surface tidal currents in the area is estimated to be 1 ft/sec directed from North to South; these occur for a period of approximately an hour during maximum spring tide. The average monthly maximum surface tidal currents is increased to 1.5 ft/sec when combined with wind currents. The average maximum annual surface combined tide and wind current is 2 ft/sec. The 100-yr maximum surface combined tide and wind current speed is 2.75 ft/sec.

Long shore currents, which are caused near the shore by waves, are of concern for the study of sediment transport in the area and the effects of the marina breakwaters on the shoreline. Near shore currents are the main carrying power for near-shore sediments and are utilized in the model used.

Waves

Ship wave measurements at 29° 23’ N, 32° 37’ E, and a water depth of 60 m had been utilized (Anon. 1997a). This location is ca. 12.5 km southwest of the Dome Marina site. Hindcasting techniques were also used, by utilizing data on wind and the fetch width to confirm the ship wave measurements. The annual average percentage frequency of occurrence of offshore significant wave height (H) from all directions is presented in Table 2.

Near-shore waves were estimated using the above data on offshore waves and utilizing the RCPWAVE module in the SMS (Shore Modelling System) program, discussions of which are beyond the scope of this paper. However, the Regional Coastal Process WAVE (RCPWAVE) (Ebersole et al. 1986) model simulates wave propagation over an arbitrary bathymetry. The mild slope equations were solved for linear progressive monochromatic waves, together with the irrotationality of the wave phase gradient.

Table 1. Average annual % of occurrence of wind speed-direction groups (mph).

Direction	0 - 4	5.0 - 9.9	10.0 -14.9	15.0 -19.9	20.0 - 24.0	25.0 -29.0	30.0 -35.0	> 35.0	Total
N	1.60	3.50	4.50	4.00	2.20	0.70	0.20	0.00	**16.70**
NE	0.40	0.60	0.50	0.20	0.10	0.00	0.00	0.00	**1.80**
E	0.40	0.50	0.20	0.10	0.00	0.00	0.00	0.00	**1.20**
SE	0.60	0.90	0.70	0.40	0.10	0.00	0.00	0.00	**2.70**
S	0.50	0.60	0.30	0.10	0.10	0.00	0.00	0.00	**1.60**
SW	0.30	0.50	0.40	0.20	0.10	0.10	0.00	0.00	**1.60**
W	0.60	1.10	1.20	1.00	0.50	0.20	0.00	0.00	**4.60**
NW	2.50	7.10	13.90	18.30	15.20	6.50	1.60	0.30	**65.40**
Calm									**4.40**
Total	11.3	14.80	21.70	24.30	18.30	7.50	1.80	030	100.0

The GENESIS model

The GENEralized model for SImulating Shoreline change (GENESIS) is a one-line model which calculates the shoreline change over an arbitrary beach (see Hanson 1987; Hanson & Kraus 1989; Gravens et al. 1991). The model includes a wave transformation module to calculate shoaling, refraction, and diffraction. Wave transmission at detached breakwaters and a variety of terminal and internal boundary conditions and constraints can be included.

The governing equation for the rate of change of shoreline position (*y*) can be expressed as:

$$\frac{\partial y}{\partial t}+\frac{1}{(D_B+D_c)}\left[\frac{\partial Q}{\partial x}-q\right] \tag{1}$$

where, t is time, D_B is berm height, D_c is the closure depth, q is source or sink in sediment and Q is the longshore sand transport rate (m^3/sec). The co-ordinate system X and Y-directions are defined in Fig. 2.

The empirical predictive formula for the long-shore sand transport rate (Q) is

$$Q=(H^2C_g)_b\left[a_1\sin 2\theta_{bs}-a_2\cos\theta_{bs}\frac{\partial H}{\partial x}\right]_b \tag{2}$$

where; H is the significant wave height, C_g is the wave group speed, θ_{bs} is the angle of breaking with shoreline, the subscript b denotes breaker, and the coefficients a_1 and a_2 are calculated from

$$a_1=\frac{K_1}{16(\rho_s/\rho-1)(1-p)(1.416)^{5/2}} \tag{3}$$

$$a_2=\frac{K_2}{8(\rho_s/\rho-1)(1-p)\tan\beta\,(1.416)^{7/2}} \tag{4}$$

where K_1 and K_2 are empirical coefficients treated as calibration parameters, ρ_s and ρ are the densities of sand and water, respectively, p is the sand porosity equals to 0.4, and $\tan\beta$ is the average bottom slope from shoreline to closure depth. The first term in Eq. 2 corresponds to the ‘CERC formula’ described in the SPM (Anon. 1984).

Table 2. Average annual % of occurrence of offshore significant wave height groups-direction groups (ft).

Direction	0 - 1.9	2.0 -3.9	4.0 -5.9	6.0 - 7.9	8.0 - 9.9	10.0 -11.9	> 12	Total
N	5.80	5.10	1.50	0.20	0.00	0.00	0.00	**12.60**
NE	1.10	0.70	0.00	0.00	0.00	0.00	0.00	**1.80**
E	1.10	0.10	0.00	0.00	0.00	0.00	0.00	**1.20**
SE	2.10	0.60	0.00	0.00	0.00	0.00	0.00	**2.70**
S	1.30	0.30	0.00	0.00	0.00	0.00	0.00	**1.60**
SW	1.50	0.10	0.00	0.00	0.00	0.00	0.00	**2.60**
W	3.10	1.40	0.10	0.00	0.00	0.00	0.00	**4.60**
NW	13.90	21.60	20.20	10.30	4.00	5.00	0.10	**70.60**
Calm								**3.30**
Total	33.20	14.80	21.70	24.30	18.30	7.50	1.80	100.0

A value of $K_1 = 0.77$ was originally determined by Komar & Inman (1970). A value of $K_1 = 0.58$ to 0.77 was recommended by Hanson & Kraus (1989) and the value of K_2 was also recommended to be 0.5to 1.0 × the value of K_1. These parameters should be treated as calibration or transport parameters (Hanson & Kraus 1989). Their values should be determined by reproducing measured shoreline change and the correct order of magnitude and direction of the long-shore sediment transport rates.

Simulation without the marina

The axis system used in GENESIS was chosen such that the x-axis is nearly parallel to the shoreline, which makes an angle of 35° with the East direction (rotated clockwise). This co-ordinate system is used for all the simulations described in this paper.

Potential sediment transport rate

The sediment budget provides insight on the net sediment transport rates and the resulting shoreline evolution. In this study the net potential sediment transport rates, assuming unlimited sand supply, were estimated at several sections along the beach. The Kamphuis (1991) formula was used for that purpose because it includes the effect of grain size, bed slope in addition to wave period, breaker wave height and the breaker angle. Schoonees (1996) found that the Kamphuis formula gave the best results among 52 long-shore transport formulas for a large data set.

Fig. 3 provides the potential sediment transport rates estimated using the Kamphuis formula, which would represent the maximum possible net sediment transport rates (assuming an unlimited supply of sand) at each beach section. Net rates were calculated by using the yearly averaged wave records for different directions. For each wave direction and condition, the sediment transport rate was calculated and multiplied by its probability of occurrence. Finally the annual net sediment transport rates Q_s were estimated in m^3/yr.

Model boundary conditions

As shown in Fig. 3, the net sediment transport rates are directed towards the South East (from left to right boundary). In the present paper, open boundaries, among other trials, were used for the updrift and downdrift beach sections. A downdrift boundary condition (right boundary) was found to have a small effect on the solution domain. The open type boundary condition was found to be the most suitable boundary condition in this case, as sand could be supplied at each boundary. Such boundary conditions could, however, overpredict the amount of updrift sand supplied. This may be explained by the fact that the beach sections under study are rocky in nature, which will tend to make the actual sediment transport rates less than the potential sediment transport rates.

The beach sections extending from the distances 600 to 1600 m were composed of rock layers and large boulders as described in Fig. 2. To represent this condition a seawall was assumed to extend along these beach sections. The seawall will not permit these beach sections to erode beyond the seawall. The amount of sediment transported over these sections will depend on the amount of sediment deposited from neighbouring beach sections.

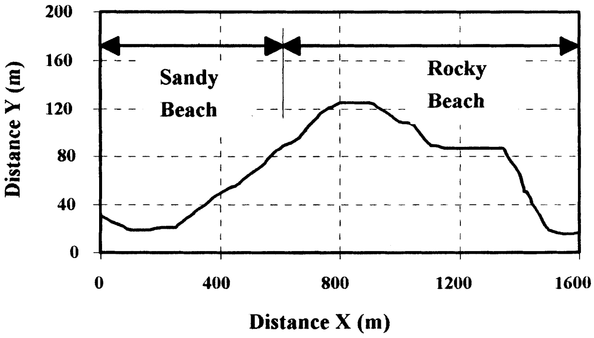

Fig. 2. Beach composition for Dome Marina Beach.

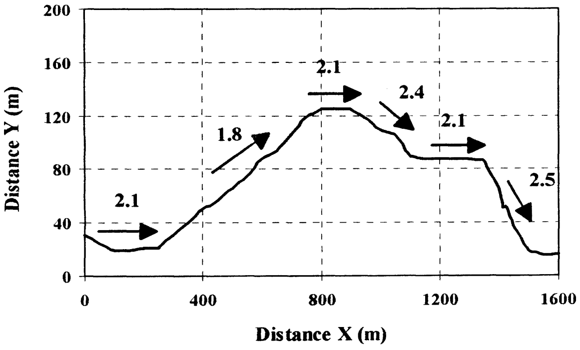

Fig. 3. Potential net Q_s in 10 000 m^3/yr.

In the application, the wave data provided in Table 2 were converted into a wave record covering each month of the year. Therefore a file for a complete year was produced with a time step of 6 h. A grid spacing of 25m (in a long-shore direction) was used in all GENESIS simulations performed. A maximum limiting wave angle of 20° with the *x*-axis was used for the wave data to account for the long headland north of the left boundary. Waves from only three directions were found to be of interest to the sediment transport rates, namely the North, North East and East directions. To account for wave refraction in the bay, an average refraction coefficient was computed and found to be 0.8, so offshore significant wave height values were introduced by multiplying the offshore wave heights by 0.8.

Model calibration

The lack of long term shoreline observations (more than one year), and the limited data on existing marine structures in the area, made it difficult to perform the model calibration and verification. Instead, the model was calibrated based on the best estimate for long-shore sediment rates, and verified using the shoreline change over one year. The shoreline observations over a period of one year showed that beach accretion of 3.0 m occurred along the first 600 m as explained later. Fig. 4 provides the results obtained from GENESIS using the 'calibrated' values of K_1 = 0.2 and K_2 = 0.1 which provided values for Q_s close to those obtained by the Kamphuis formula along the sand beach sections. The shoreline change over a period of one year is shown in Fig. 5, which is close to the actual shoreline change observed over the same period. More long-term measurements for this project may prove useful for calibration of future projects.

Simulation including the marina

The Dome Marina is planned to accommodate 80 boats. The preliminary plan was made as a keyhole marina with dimensions of 180 m along the shore and 140 m perpendicular to the shore. Dredging of 40 m was planned inland. Two breakwaters were considered, a main breakwater to protect the marina from the prevailing northerly wind, and a secondary breakwater for protection from the occasional easterly wind.

The effect of the marina was considered in the model by including a groin and an offshore-detached breakwater for the main breakwater, and a single groin for the secondary breakwater. Two locations were considered for the marina, the first in the North end of the development (sandy beach) and the second to the South end (rocky beach). The first location was found to give a large erosion rate at the down drift side of the marina (south of the marina), where a swimming beach is planned in this location. Results in this paper are presented only for the second option (Anon. 1997b).

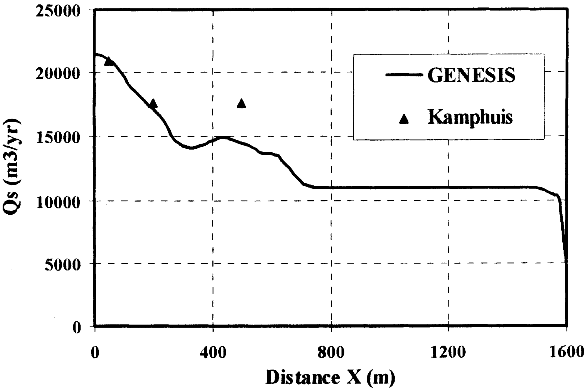

Fig. 4. Calibration of potential Net Q_s.

Fig. 6 shows the results obtained for the shoreline evolution over a period of one year. Deposition at the updrift side of the marina occurred with a maximum shoreline accretion of 20 m at the main breakwater. No erosion occurred downdrift of the marina due to the presence of rock beaches along that region, which was simulated as a seawall. Similar observations were also obtained for a simulation period of 5 years as shown in Fig. 7. The maximum shoreline accretion was found to be 55 m at the updrift of the marina. The actual rate of deposition is expected to be less than values shown in the above figures due to the limited amount of sand available over the beach sections updrift of the study area. The values for the shoreline movement provided above should be considered as the upper limit for these values. Further, numerical results showed that the updrift side of the main breakwater will be filled after nearly 12 years. This value is also expected to be lower than the estimated value due to unlimited sand supply.

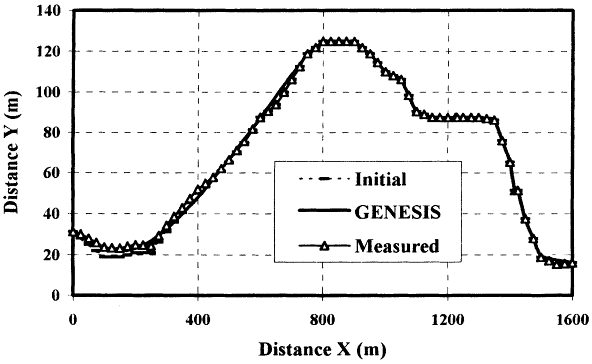

Fig. 5. Model validation.

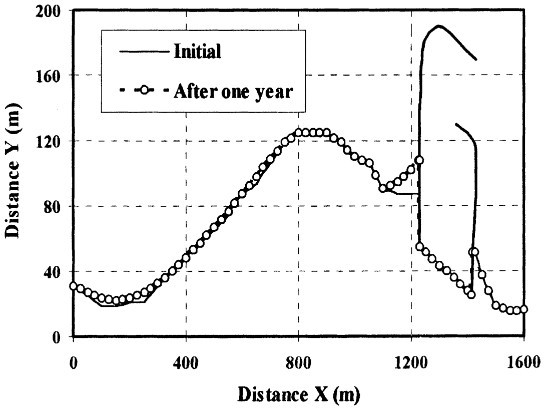

Fig. 6. Shoreline prediction after one year (with marina).

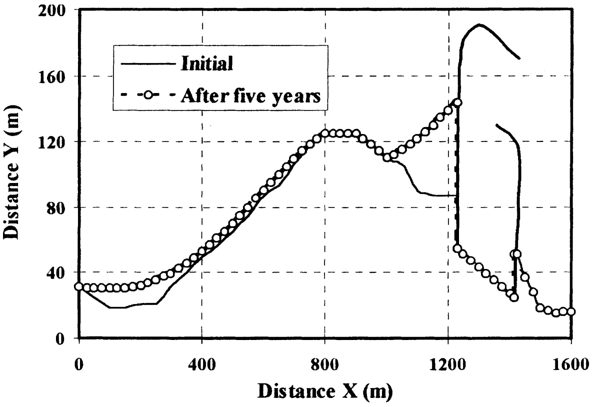

Fig. 7. Shoreline prediction after five years (with marina).

Conclusions

The GENESIS program was used to study the shoreline changes along a study reach in the Gulf of Suez. The program was calibrated by the use of the Kamphuis (1991) sediment transport formula, and verified using two beach surveys one year apart. The model showed that a deposition area developed in the updrift side (northern side) of the proposed marina. The shoreline was found to move a distance of 20 m over one year and 55m over five years just updrift of the breakwater. These estimates are expected to be larger than the actual values due to the limited amounts of sand available at the boundaries, and represent the upper limit for the expected shoreline movement. The results of this study were presented to the Egyptian Environmental Affairs Agency to compliment a previous EIA study, and the project was later approved. A monitoring program was also recommended in the original study and a sand bypass was suggested for the sand accretion up drift. This modelling tool was used for the first time to estimate the sediment transport rate in the Gulf of Suez, which is currently under development. It was also shown that such models may become a useful and economic environmental management tool which are to be used in assessing similar coastal projects.

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