

# Protective Works on The Nile Delta Coast

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## ABSTRACT

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The Nile Delta Coast is a dynamic system which in historic times was in equilibrium or experienced an excess of sediment due to the large quantities of sediments discharged to the Mediterranean Sea through the various Nile branches. With the construction of the nine barrages (dams) along the main course of the river commencing at the beginning of the 20th century, the Nile Delta coastal zone has exhibited a sediment deficit and thus erosion, especially around the three main headlands, *i.e.*, Rosetta, El Burullus, and Damietta. This erosion has been particularly alarming since the construction of the Aswan High Dam in 1964, which trapped essentially all the flood sediments in its storage basin. Erosion is not the only trouble affecting the Delta coast. High rates of easterly longshore transport which cause shoaling of the Nile mouths and the outlets of the northern lagoons are also a serious problem; they directly affect coastal navigation and the eco-system of the lakes and consequently fish production. The aims of this paper are as follows: (1) to present a brief review of the major existing coastal problems along the Nile Delta Coast, and (2) to provide a general description of the protective measures that have been implemented in the coastal zone to address these problems.

**ADDITIONAL INDEX WORDS:** Nile Delta, erosion, accretion, protective structures.



## INTRODUCTION

The Nile Delta complex was formed by sedimentary processes which occurred between the upper Miocene period (NIELSEN, 1977) and the present. In classical times, from 500 BC to 1100 AD the Nile had several branches (SAID, 1981; AL-ASKARY and FRIHY, 1986; COERTELLIER and STANLEY, 1987) which have subsequently silted up and been replaced by the present two branches namely Rosetta and Damietta (Figure 1). The central headland of Burullus was formed by the old "Sebennetic" branch 1,000 years ago (ORLOVA and ZENKOVICH, 1974).

The amount of river sediment discharged into the Mediterranean relative to those sediments that are lost by the dynamic factors of wind, wave and current action governs the advance and retreat of the coastline. Prior to 1900, the sediment supply was sufficiently large to maintain a reasonably stable shoreline. The sediment supply by the Nile was estimated to be more than 100 million tons per year (HAMMAD *et al.*, 1979). It came from as far away as the Ethiopian Mountains, some 2,240 km distant. Old maps (SESTINI, 1976) showed that

between 1800 and 1900, the Rosetta promontory advanced 3.6 km (36 m/yr) while the Damietta promontory advanced about 3 km (30 m/yr). During about the same time period, Burg El-Burullus village, east of Lake Burullus outlet, had already been moved to the south two or three times because of a continuous trend of shoreline retreat (CRI/UNESCO/UNDP, 1978).

From 1900 to the present, sediment discharge relative to that lost by dynamic factors was effectively eliminated because of the control works constructed on the river itself and/or coastal interfering with longshore transport, *i.e.*, construction east of El-Arish Port. Shoreline erosion rates accelerated after the construction of the High Aswan Dam in 1964. Although earlier constructed dams had reduced the amount of sediment reaching the sea, it was the High Aswan Dam that is credited with trapping essentially all the rest of the river's load, an amount estimated at being about  $19 \times 10^6$  m<sup>3</sup>/year, (HAMMAD *et al.*, 1979). Some erosion is probably due to profile equilibration of the earlier prograded profiles. However, the dominant erosion is believed to be a result of the strong gradients in longshore transport primarily for those shorelines characterized by significant planform convexity. Although highly

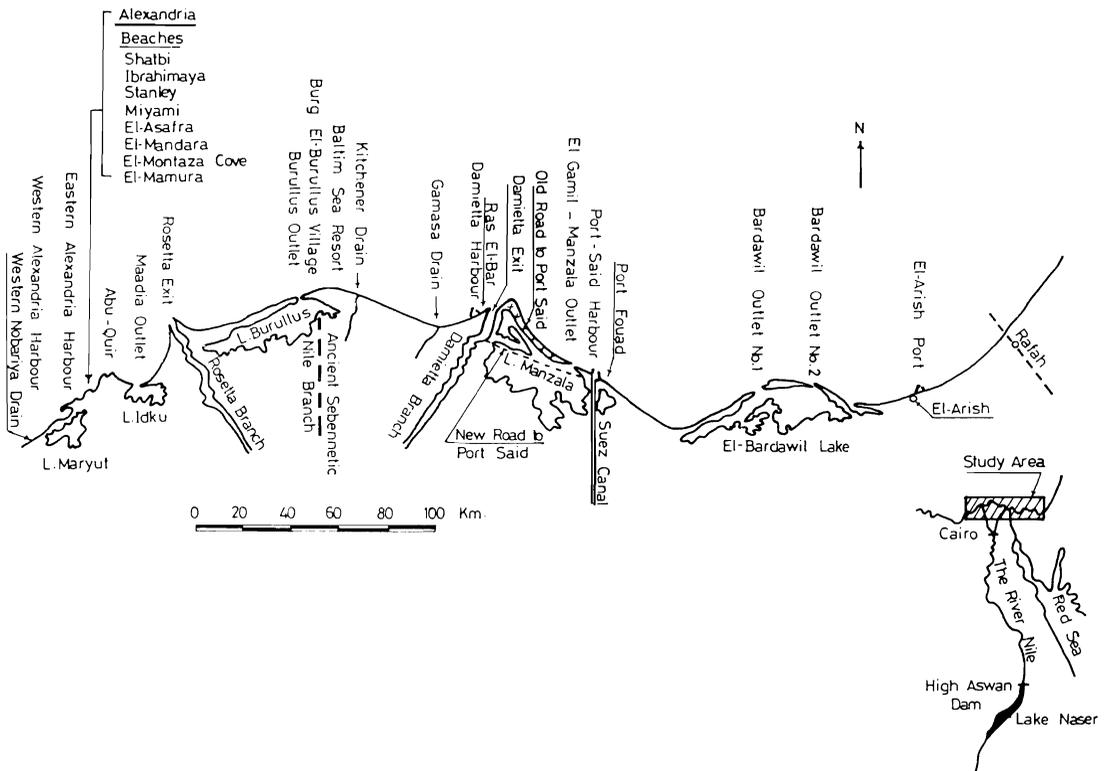


Figure 1. General map of the locations on Egyptian coast discussed in text.

variable, spatially net longshore sediment transport (ranging from 400,000 to as high as 3.2 million  $m^3$  per year) has been estimated (FRIHY *et al.*, 1992; EL-FISHAWI *et al.*, 1991). Siltation in the coastal lake outlets and in the exits of the Nile estuaries presents an additional problem. This could lead to serious impacts, especially on estuaries and lake fishery productivity and on coastal navigation.

This paper presents a brief review of the Nile Delta Coast and its problems. It also provides a general description of the protective measures that are either in the planning stage or have been constructed to address shoreline erosion and/or to improve lake flushing and navigation.

#### DESCRIPTION OF THE DELTA COAST

The Nile Delta Coast (Figure 1) is situated in the southeastern part of the Mediterranean Sea. It extends from the west at Alexandria to the east at Rafah, a total distance of about 450 km. The coastline has two promontories (Rosetta and

Damietta), two positive features of lesser prominence (Burullus and El-Bardawil), and is concave between (Figure 1). According to accepted coastal sediment transport principles, concave shorelines are areas of transport convergence and accrete, whereas convex shoreline segments (promontories) erode.

In the delta there are four lakes connected to the sea: Idku, Burullus, Manzalla and El-Bardawil from west to east. In addition, there is a closed lake near Alexandria, Maryut Lake. There are also four channels which empty into the sea, two distributaries of the Nile at Rosetta and Damietta, and two drains at Kitchener and Gamasa. Three major harbors are located on the coast: Alexandria Harbor, new Damietta Harbor and Port Said Harbor. In addition there is a small one known as El-Arish port (Figure 1).

The coastline is sandy in nature except near Alexandria where rocky formations prevail. Sediment size gradually reduces from 0.35–0.15 mm in Abu Quir Bay to 0.06–0.07 mm in the Damietta-

Port Said coastal stretch. Pockets of much coarser sediment, up to 0.45 mm have been found along the shores in the areas of Abu Quir and Burullus (MANOHAR, 1981).

### COASTAL PROBLEMS ALONG THE NILE DELTA SHORELINE

As noted, problems along the Delta coast can be divided into three types: (1) problems due to reduction in sediment supply, (2) problems due to structures, and (3) problems due to the siltation of lake outlets and the mouths of Nile branches. The following provides more details on each group of problems. Areas discussed extend from west to east.

#### PROBLEMS DUE TO THE LOSS OF SAND

##### Erosion of Alexandria Beaches

There are nine beaches in the Alexandria area that appear to be experiencing slow but persistent erosion. There is evidence that both waves and currents are causing sand loss at many locations including beaches of Shatbi, Ibrahimiya, Stanley, Miyami, El-Asafra, El-Mandara, El-Montaza Cove, El-Mamura and Abu Quir beaches. This area is updrift of modified outlets and thus the erosion is probably due to natural causes.

##### Erosion of Rosetta Promontory

The erosion of this promontory, located some 50 km to the east of Alexandria, started about the time of construction of the Aswan Low Dam (1902). This erosion has been well documented and thoroughly studied by many investigators (NIELSEN, 1977; KHAFAGY *et al.*, 1981; FANOS *et al.*, 1989). Figure 2a shows shoreline positions at various times. The erosion rates for the western part of the promontory for the periods 1900–1941, 1941–1964, 1964–1971, 1971–1982 and 1982–1989 were 18, 33, 93, 230 and 40 m/year respectively, and were 16, 26, 115, 130 and 100 m/year for the eastern part of the promontory during the same periods (FANOS *et al.*, 1989). The old Rosetta lighthouse, which was 950 m inland from the tip of the western part in 1889, became isolated in the sea in 1942. The second lighthouse which was 1 km inland in 1970, became an offshore island in 1976 and still stands as an isolated offshore structure (NIELSEN, 1977). The primary reason for this erosion is the reduction in sediment supply through the Rosetta branch of the Nile River which, prior to dam construction, was estimated

(INMAN and JENKINS, 1984) to be approximately  $13 \times 10^6 \text{ m}^3$  of sand annually.

##### Erosion of Burullus Headland

Erosion of the Burullus Headland stretch, which is located 90 km east of Alexandria and extends for 60 km, has been occurring since the ninth century AD, when the ancient Sebennetic Nile branch (Figure 1) seems to have become inactive and its water and sand were diverted to both the Rosetta and Damietta branches (CRI/UNESCO/UNDP, 1978). The rate of erosion was about 6 m/year (TETRA TECH, 1984) causing erosional damage to El Burg village. Figure 3a shows the shoreline change west and east of Burullus outlet during the period from 1909 to 1989.

On the western side of the lake outlet, erosion occurred from 1909 to 1964. Following construction of the western jetty at the Burullus Lake outlet in 1971, which impounded the strong net easterly transport, accretion occurred to the west of the outlet (FANOS, 1990). The western barrier between the sea and Burullus Lake has a history of southward migration due to wind-blown sand transported from the coast side to the lake side where it is deposited (SHEREET, 1990).

Along the eastern side of Burullus outlet, the shoreline was straight until 1947 when a concrete sea wall was constructed to protect El Burg village from erosion and flooding. This seawall has prevented erosion behind it but has transferred the erosion farther to the east of the eastern terminus of this seawall, where the shoreline is retreating rapidly and continues to cut into the high sand dunes backing the beach in this area.

##### Erosion of Baltim Beach Resort

Baltim Sea resort (Figure 1) is located on a very active convex shoreline some 120 km to the east of Alexandria. This shoreline has a net long-term shoreline retreat of about 4–5 m/year (Figure 4a) (TETRA TECH, 1984). Annual shoreline fluctuations due to moving cusps, however, have been documented to be on the order of about 100 m, and a number of houses have been lost to the sea.

##### Erosion of Ras El Bar Sea Resort

The resort town of Ras El Bar, located 185 km to the east of Alexandria and immediately to the west of the Damietta entrance, has experienced erosion and shoreline retreat resulting in the loss of buildings and streets. It has also adversely impacted recreational resort beaches. Figure 5 shows

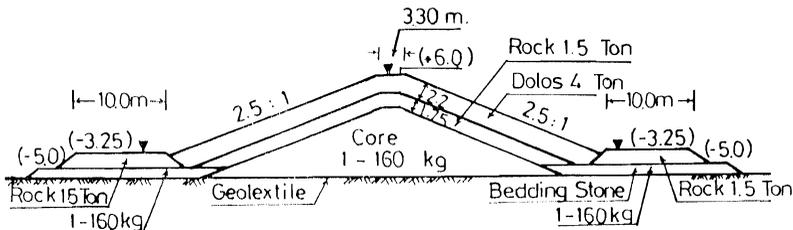
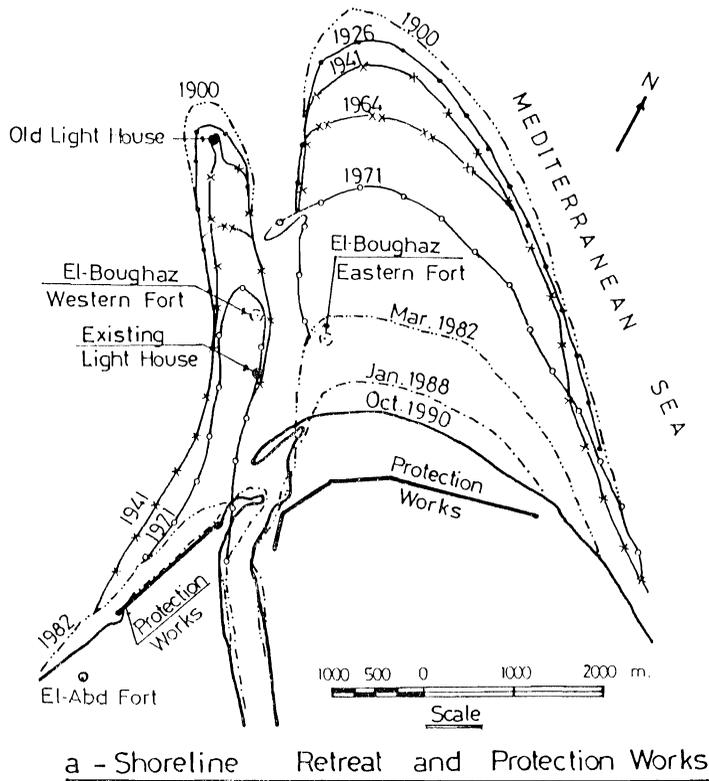


Figure 2. Rosetta Promontory. a, Shoreline retreat and protection works. b, Cross-section of protection works.

the shoreline evolution of Ras El Bar peninsula for the period from 1895 to 1991. The average retreat of this area was about 30 m/yr before the construction of the western jetty in 1941. This jetty has stabilized the northern part of Ras El Bar shoreline, although the remainder of the coast has continued to erode but with a decreasing rate for a distance of 3 km west of the jetty (FANOS *et al.*, 1989). Much of this erosional stress is due to the combined effects of reduced sediment supply from the Nile and also the shoreline and channel

stabilization works on the western side of the Damietta outlet.

**Retreat of the Shoreline along Damietta Promontory**

This promontory is located approximately 200 km to the east of Alexandria. It was formed from the large amounts of sediment brought by the Damietta branch to the coast. They are estimated to be  $6 \times 10^6 \text{ m}^3/\text{year}$  (INMAN and JENKINS, 1984),

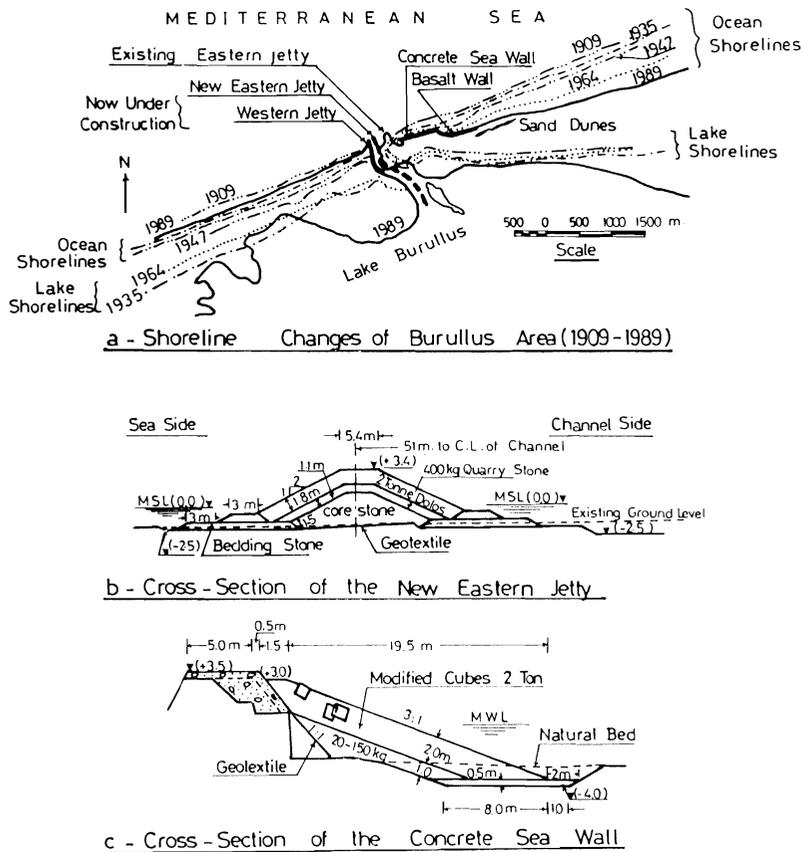


Figure 3. Burullus headland. a, Shoreline changes of Burullus area (1909-1989). b, Cross-section of the new eastern jetty. c, Cross-section of the concrete sea wall.

prior to the start of dam construction in the early 1900's. Figure 5 also shows the severe erosion that resulted in shoreline retreat, destroying the coastal road and its protection, as well as the walls around the lighthouse.

**Flooding of Damietta-Port Said Road**

The Damietta-Port Said road was constructed originally on a recently formed spit to the east of the Damietta Promontory (Figure 1). With the reduction in sediment supply, shoreline retreat destroyed the original road in many areas along the coastline, particularly along the stretch of shoreline immediately to the south of the Damietta spit formation (Figure 1). This erosion also destroyed the protective walls around a lighthouse causing its abandonment and the construction of a replacement to the landward. Thus, the

old road which ran parallel to the coast north of lake Manzala no longer exists. It is expected that with time, erosion will claim the old road entirely and encroach upon land that is presently under cultivation. The Damietta-Port Said road was relocated. However, flooding and wave action now threaten the new road in the vicinity of El-Gamil.

**Erosion of Port Fouad Beaches**

Shoreline retreat along the beaches in the vicinity of Port Fouad immediately to the east of the Port Said entrance has occurred since the construction of the Suez Canal jetties. Recent construction of the eastern navigation canal bypass and breakwaters has further changed the wave climate along this area resulting in additional trapping of the easterly transport longshore sediment. This interpretation is supported by the

accretion that took place to the west of the new breakwater (TETRA TECH, 1984).

### PROBLEMS WITH EXISTING STRUCTURES

As in the case of beach erosion discussed above, problems associated with structures from west to east, starting at Alexandria.

#### Flooding of Alexandria Corniche (Sea Wall)

The Alexandria corniche was constructed between 1903–1940. The problem is created by wave energy penetration through the wide gaps of the breakwater which shelter the eastern harbor. These waves cause overtopping and flooding of the corniche during storm conditions. Along much of the sea wall, there is very little or no beach in front which has led to undesirable wave agitation inside the harbor, high runup and frequent overwash along most of the wall. This problem has probably been worsened by a gradual sea level rise since its construction. The uprush of the waves was especially damaging because of the almost vertical face of the sea wall.

#### Erosion in Front of Abu Quir Sea Wall (Mohamed Ali Sea Wall)

This sea wall is located in Abu Quir Bay and extends from west of El hammara Fort for a total length of about 10 km (Figure 6a). It was initially constructed in about 1780 to protect the low level agricultural land and the old and new industrial coastal developments against flooding. Progressive erosion from deep water to shallow water (CRI/UNESCO/UNDP, 1979), sea level rise of 20 cm since its construction, and the almost vertical face of this sea wall (Figure 6b) caused its deterioration and hence the loss of important residential and industrial improvements.

#### Erosion East of El-Arish Port

Erosion started in 1984 after the construction of the breakwaters of El-Arish Port. This has caused serious erosion for an area 1,500 m long and 50 m inland to the east of the port. About one thousand palm trees have been lost, and many more are expected to be destroyed.

### PROBLEMS DUE TO THE SILTING OF THE MOUTHS OF THE NILE RIVER AND LAKE OUTLETS

The siltation problem is a result of longshore transport, cross-shore transport and the reduc-

tion in river flow. The combination of which has caused a decrease in the equilibrium cross-sectional area of the Nile channels. This problem has progressed to shoaling and at certain times the closure of the Nile and its lake outlets, resulting in navigational hazards and associated impacts on fishing and the national economy. The following are the outlets which are affected by this problem (Figure 1): Maadia outlet, Rosetta exit, Burullus outlet, Damietta exit, Manzala outlet at El-Gamil, El-Bardawil Outlet No. 1 and El-Bardawil Outlet No. 2.

### COASTAL PROTECTIVE WORKS

Protective works on the Nile Delta Coast, which began as early as 1780, are in progress and others are planned for the future. From 1780 to about 1964, all these works were planned and designed according to the recommendations and observations made by foreign experts (PRIEST, 1960; WASSING, 1964). Coastal structures built in the period 1964 to 1975 were based on short-term local studies. Since 1975, a wealth of coastal information and data has been derived and stored in a computer data base (FANOS, 1989). The data have become the basis for the planning and design of the new protection works and also for modifying the previous works. The following describes the protection works completed and under construction progressing from the west to east.

#### West of Alexandria

This new drain at Western Nobariya drain outlet is about 20 km to the west of Alexandria. Two jetties of 65 m length were constructed in 1986 to protect the exit from siltation, and they are functioning effectively. The net longshore sediment transport in this area appears to be nearly zero as indicated by the nearly symmetrical depositional patterns on the two sides of the jetties.

#### Alexandria Beaches

Five beaches, El Shatby, Stanley, Miyami, El-Asafra and El-Mandara, were nourished by medium to coarse sand transported from the desert near Cairo. The nourishment sand was reasonably compatible to that originally present on the beach. On these five projects, only Miyami Beach lost most of its sand at an early stage; the other projects have met or exceeded expectations.

#### Abu Quir Bay

The Abu Quir Sea Wall was built in 1780 and has been maintained by placement of additional

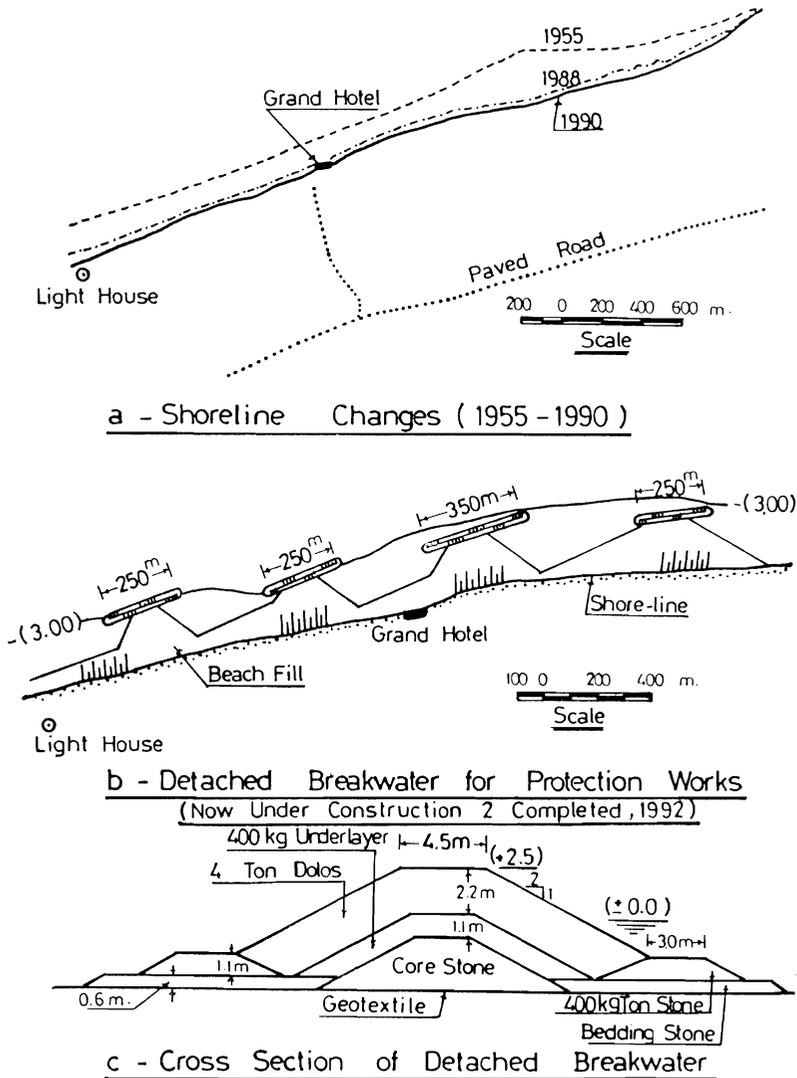


Figure 4. Baltim Sea Resort area. a, Shoreline changes (1955-1990). b, Detached breakwater for protection works (now under construction, 2 completed, 1992). c, Cross-section of detached breakwater.

large concrete blocks. This wall was modified and reinforced in 1980 by constructing a sloping face (2:1) and placing modified cubes of 0.5 ton each as an armor layer (Figure 6c). This modification has performed very well and has stimulated many development projects behind the sea wall.

#### Maadia Outlet Jetties

Two small jetties were constructed in 1962 on both sides of the Lake Idku outlet. In 1980, two

new long jetties (Figure 7) were constructed which significantly reduced siltation of the outlet and improved conditions for ingress and egress of fishing vessels. At this time, a revetment was constructed to the south of the western jetty to prevent Maadia village from flooding (Figure 7).

#### Rosetta Promontory Sea Walls

Two dolos sea walls were constructed as protective works in 1989-1991 (Figure 2). The west-

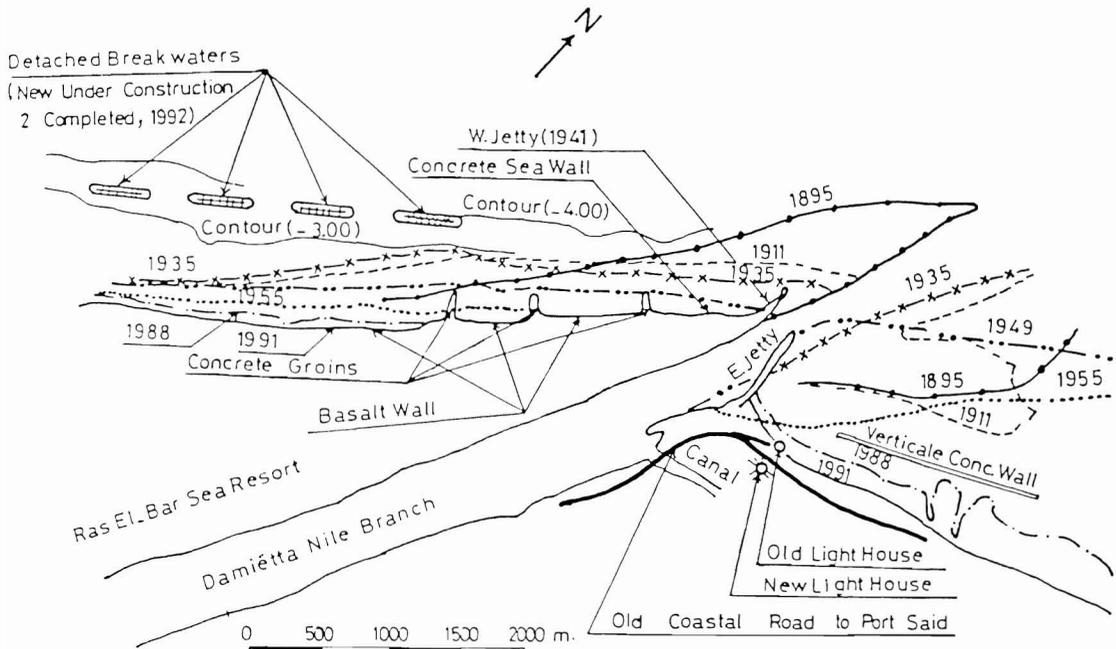


Figure 5. Shoreline retreat (1895–1991) and protective measures (1941–1991) at Damietta Promontory (Ras El-Bar).

ern promontory is protected by a sea wall of 1.5 km length and the northern end of the eastern promontory by a sea wall of 3.5 km length. The sea has reached the western structures and to date is performing well, while the eastern one is still located inland (Figure 2a and b). Four ton dolos were used as armor and are designed to be stable for a scour of 8 m and wave height of 5.3 m.

#### Burullus Headland

In 1972 a jetty was constructed on the western side of the Burullus Lake outlet which, due to the strong easterly directed transport, became completely filled in 1980, advancing the shoreline seaward by more than 500 m (Figure 3a). A new project, now being implemented, consists of an extension of the western jetty to a water depth of 3.5 m and construction of a new eastern jetty which will narrow the channel thereby improving its flushing characteristics. The outlet cross-section was designed according to the detailed study performed by the Coastal Research Institute (FANOS *et al.*, 1986). In addition to the jetties, revetments were built on both sides of the outlet. They will limit shoreline fluctuations due to transport def-

icit (eastern side) and transport reversals (western side) (FANOS, 1990) (Figure 3a and b).

#### Burg El-Burullus Sea Wall

During the period 1937 to 1940, a series of five groins was constructed to limit the erosion in front of Burg El-Burullus village which is located immediately downdrift (east) of the Burullus Lake outlet. In 1950 a wall of 600 m length was constructed between the groins to limit landward retreat. Many parts of this wall have collapsed due to erosion and undermining and extensive maintenance was carried out prior to 1981. In 1982, the concrete wall was modified (Figure 3c). To the east end of this wall a basalt wall was attached in order to provide erosion and flooding protection for the remainder of the village. To date the wall has performed effectively.

#### Baltim Sea Resort

To limit erosion in the Baltim Sea Resort area and to provide a sheltered recreational area, construction of four detached breakwaters, each of 250 m length, was started in 1991 (Figure 4b and c). Sand nourishment is planned immediately fol-

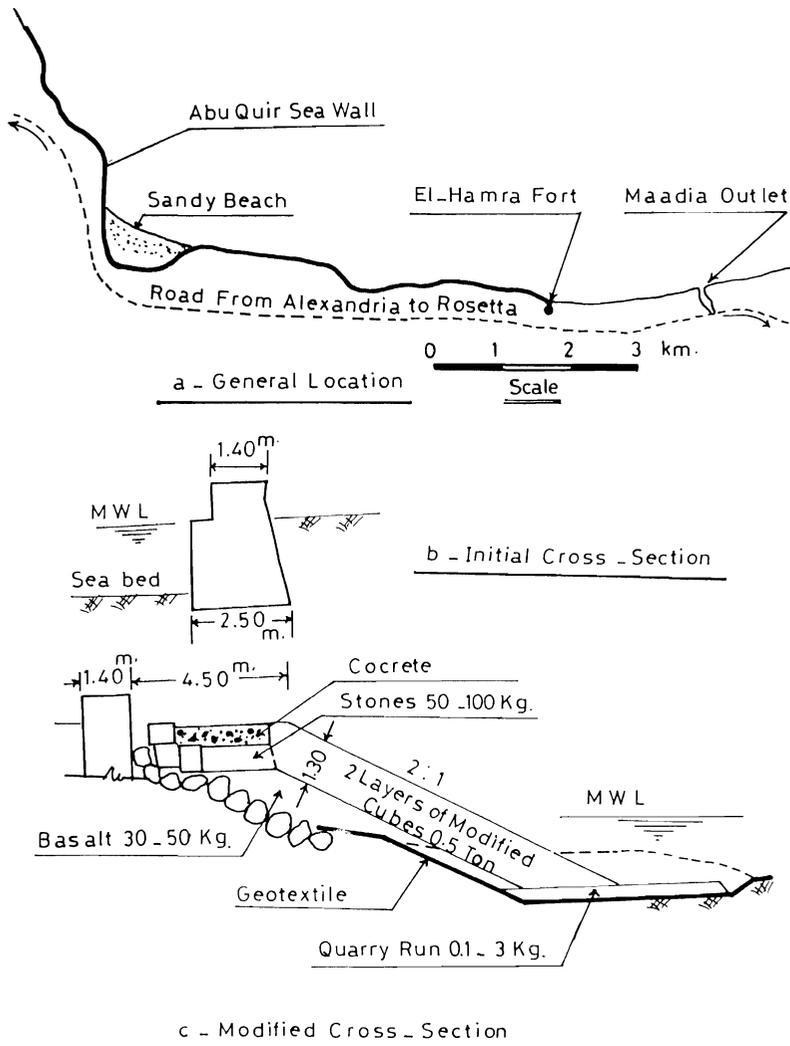


Figure 6. Mohamed Ali (Abu-Quir) wall. a, General location. b, Initial cross-section. c, Modified cross-section.

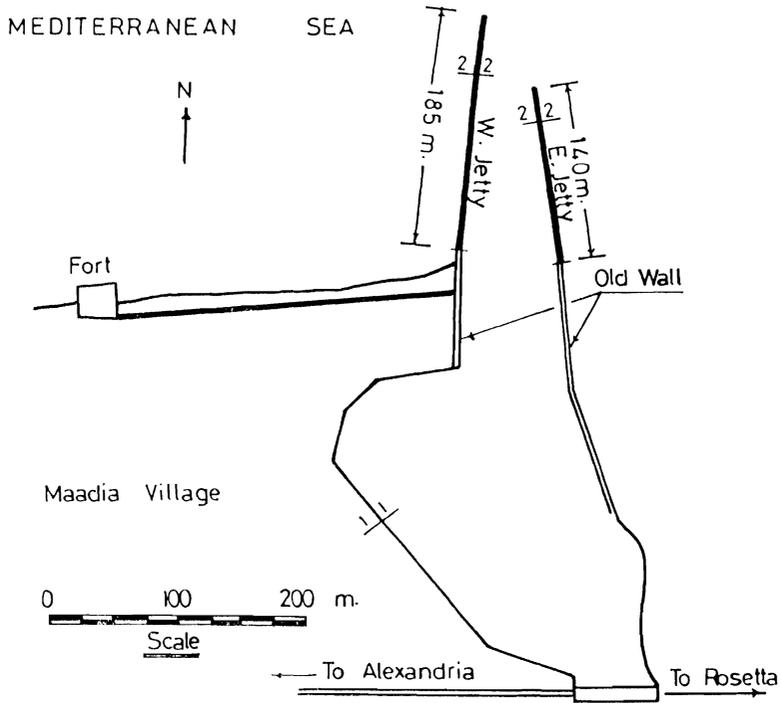
lowing completion of the breakwater construction. The project is almost finished and tombolos began to be built up.

#### Damietta Promontory

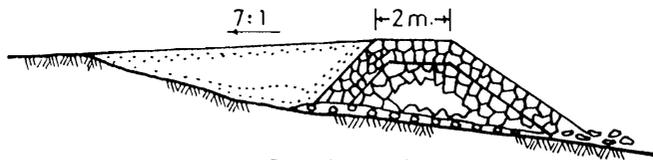
The Ras El Bar Peninsula is located on the western side of the Damietta entrance. In 1941 a jetty was constructed to reduce sand deposition in this branch of the Nile. This succeeded in stopping the reduction of the length of this summer sea resort. Due to progressive erosion at the southern end of this jetty, a seawall was constructed in

1963 to join it with the land. Three concrete groins were constructed in 1971 to the southwest of this wall, with a basalt wall between. Presently, four detached breakwaters are under construction with sand nourishment to the shoreline (Figure 5).

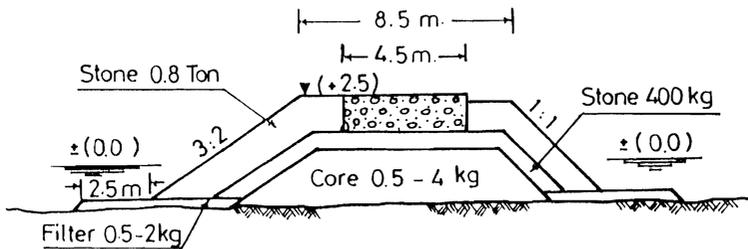
Two short breakwaters were constructed in 1980 on both sides of the navigation channel at the new Damietta Harbor Channel which extends in the sea to 15 m contour. Accordingly, periodic dredging of the unprotected part of this channel is still required due to the siltation caused by the long-shore drift and the on/offshore transport of the



a - Plan of Maadia Outlet



b - Cross Section 1-1



c - Cross Section 2-2

Figure 7. Protective works for Maadia outlet. a, Plan of Maadia outlet. b, Cross-section 1-1. c, Cross-section 2-2.

sediments in this area. A second jetty was constructed on the eastern side of the Damietta Estuary entrance in 1976 to reduce siltation in the outlet. However, some shoaling still occurs and limited periodic dredging is required due to the reduction in the equilibrium cross-section resulting from the impoundments constructed on the Nile.

In 1972 a vertical concrete wall 1,500 m long was constructed to protect the coastal road located in the eastern part of the Damietta Promontory. However, erosion continued (Figure 5) and the road was damaged and is no longer passable. The erosion continued and threatened the lighthouse which was then protected by an earthen embankment in 1991. This protection was also ineffective against the extreme erosional pressures, and the lighthouse has now been abandoned and replaced by one farther inland (Figure 5).

#### Protection of El Gamil Outlet

Two jetties 225 m west and 200 m east length were constructed to protect El Gamil regulator and its outlet from migrating and siltation. Also the two sides and the bottom were revetted. This project is performing very efficiently.

#### Protection of the Highway between Damietta and Port Said

A small bituminous dike of 3,925 m length was constructed to protect the low parts of the coastal road near Port Said from flooding.

#### Protection of El-Bardawil Lake Outlets

There are two controlled outlets to El-Bardawil Lake termed Outlet No. 1 and Outlet No. 2 (Figures 1, 8). The primary purpose of these outlets is to provide for ingress and egress of fish and salinity stabilization. The proposed stabilization projects for the two controlled outlets include: (1) modifying the deteriorated western jetties and extending them to water depths of 5.0 m, (2) constructing new jetties on the eastern sides to water depths of 3.00 m, and (3) in anticipation of future erosion construction of two embankments on the eastern side, one facing the sea and the second facing the outlet with sand filling behind them.

#### Protection of the Area to East of El-Arish Port

Fifteen groins were constructed on the eastern side of the El-Arish port to protect this area from erosion caused primarily by the interruption of

Table 1. Wave characteristics used in the design of jetties and breakwaters.

	Return Period (years)			
	1	10	20	50
Wave height in deep water				
$H_w$ (m)	3.4	5	6	6.8
Wave period (sec)	6	8.5	10	15

longshore sediment transport. The groin lengths are tapered with the greater lengths immediately downdrift of the breakwater.

### DESIGN OF THE PROTECTIVE MEASURES

The design of the jetties and sea walls depends on the waves expected at the structure and the maximum water level in the site. The selection of the design wave depends on the wave period and whether the structure is subjected to the attack of nonbreaking, breaking or broken waves and on the geometrical and porosity characteristics of the structure (COE, 1984).

Directional wave data have been measured over nearly a continuous six year period using a CAS system (Cassette Acquisition System) designed by Scripps Institute of Oceanography (Lowe *et al.*, 1984). The wave rose developed from the measured data showed that the predominant wave direction is NW while the swells are NE. The maximum observed wave height is 7.5 m in deep water and according to a statistical analysis will occur 0.2% of the time. Table 1 summarizes the design wave characteristics.

The various design characteristics of the protective measures have been developed in accordance with the *Shore Protection Manual* (COE, 1984).

### SUMMARY

This paper has presented an analysis of the problems affecting the Egyptian coast and a summary of the protective works which have been implemented or are under construction. The problems can be organized as:

- (1) Erosion due to the absence of sand and Nile sediments such as those at Rosetta, Burullus and Damietta.
- (2) Erosion associated with existing structures such as those at Mohamed Ali Sea Wall, El-Arish Port and the eastern Harbor at Alexandria.

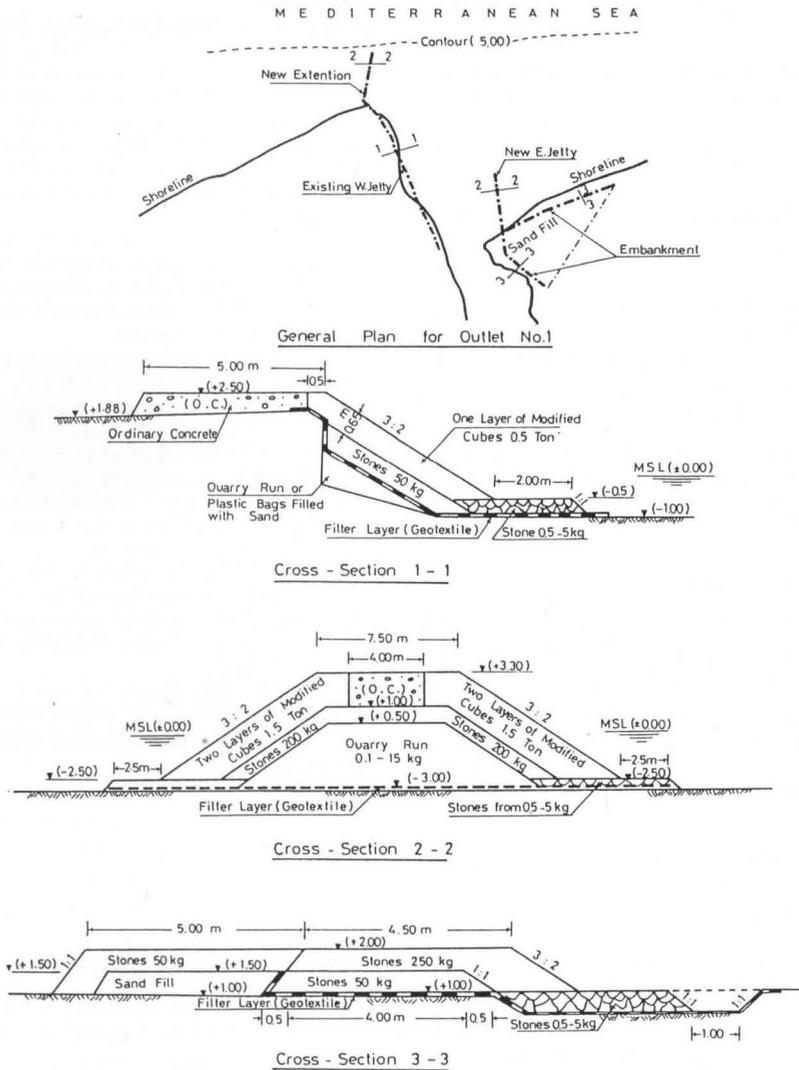


Figure 8. Protection works for El-Bardawil Outlet No. 1.

(3) Siltation problems of the lake outlets and the exit of the Nile branches.

To address these problems various kinds of approaches have been utilized including: detached breakwaters, sea walls, groins, artificial nourishment, jetties, and revetments.

All the protective measures implemented since 1981 are performing quite well. The Coastal Research Institute is conducting a program for documenting the effectiveness of these structures and of their impacts on surrounding neighborhoods.

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