



United Nations Environment Programme



UNEP(OCA)/WG.2/14
September 1988

Original: ENGLISH

Joint Meeting of the Task Team on
Implications of Climatic Changes in
the Mediterranean and the Co-ordinators
of Task Teams for the Caribbean, South-
East Pacific, South Pacific, East Asian
Seas and South Asian Seas regions

Split, 3-8 October 1988

IMPLICATIONS OF CLIMATIC CHANGES FOR THE NILE DELTA

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FIRST DRAFT

NOT TO BE CITED

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SUMMARY

The impact of an atmospheric warming of 3.5° - 4° and of sea levels 50-100 cm higher than at present on the coastal lowlands of the Nile Delta, during the next 50 to 100 years, could be very serious and very costly to remedy.

Its nature and extent depend not only on the present level of population and of economic activity, but also and largely on the degree of coastal development during the next 2-3 decades. Intensification of land use in the coastal zone is inevitable, due to the continued growth of population, and the consequent need to augment food production through the further extension of land reclamation and of lagoonal fishing. Developments will also bring the necessity to improve and expand communications in the coastal lowlands, and will place an increased burden on water supplies.

The lower Nile Delta contains large areas that are under 1m elevation with parts below sea level, including large coastal lagoons. Natural protection is afforded by high sand dunes on some stretches, but others are vulnerable to flooding by winter storm surges. Higher sea levels will accelerate the present retreat of the shores, which has been caused by a decrease first (1910-1964), then by the total cessation of Nile river sand discharge after the building of the Aswan High Dam. Protection of essential coastal uses and of agricultural lands is bound to be necessary.

It is considered that a sea level rise of 10-20 cm in the next 2-3 decades would be of little consequence generally, by itself, but it would aggravate local problems of coastal erosion acceleration of sea level rise from 2 to 10-15 mm a year, would certainly enhance wave attack on harbour installations, on the Nile mouth promontories and on the shoreline stretches that are subject to flooding by storm surges.

Augmentations over 30-50 cm would have more serious effects, imposing extensive measures of protection. A plan of protection would have to be considered at an early stage, and practical measures taken during next 10-20 years, otherwise major disruption is to be expected on the Alexandria to Abuqir coast, at Burullus, Damietta and Port Said. It is also possible that the Burullus Manzala and Bardawil lagoonal barriers might be overcome by the sea. Though coastal retreat will continue, engineering measures of protection would have to be carefully evaluated for their negative, as well as positive effects.

A flooding on the coastal lowlands is not to be expected. In theory, a sea level rise (or relative rise, to include the effects of land subsidence) of 100 cm, could submerge them to within 30 km of the coast or more, affecting 12-15% of Egypt's arable land, 12-15 million people, and 10-15% of the gross national product. However, the cultivated lands are already bordered by dykes, and more protection works are likely to be constructed along with new reclamation, or water preservation schemes. Yet higher lagoon and estuary water levels would mean, if not checked by sluices, easier penetration of salt wedges. Thus the impact of sea level rise will be mainly on the financial resources to carry out protection (re-deployments, and especially headlands, lagoon outlets), adjustments to harbours infrastructures.

The main consequences of higher average temperatures will be increased rates of evaporation, and therefore of the salinity of waters and soils, with negative impacts on ground water and on reclaimed land agriculture (e.g. continued or greater need for salt flushing by freshwaters).

In general, the greater temperature and CO₂ concentration could favour agriculture (maybe with some shift in crops) and a changed system of crop rotation; the necessary technical adjustments could be carried out by agro-bio-technology in the coming decades. Agriculture however could be negatively affected by increased evapo-transpiration and soil salinity and may require more irrigation and fertilizers (especially nitrogen). A possibly increase of weeds and pests could heighten insecticide use, thus magnifying the pollution problems of surface waters.

The lagoonal ecosystems and hence fish resources, would probably adjust to gradually changed conditions of salinity and water temperatures. They would be affected however, sooner than climatic changes, by artificial schemes of lagoonal management. Careful consideration would have to be given, therefore, in the implementation of the latter, to their environmental repercussion 2-3 decades from now.

The socio-economic structures of the lower Nile Delta will be affected comparatively more by population increase and urbanization, and by economic trends external to Egypt, than by climatic changes; nevertheless indirect effects would be those of water supply and food production.

Research on the cyclicity and prediction of Nile water supply, in association with a model for climatic change in Eastern Africa-Indian Ocean, will be essential, in order to estimate the entity of future water resources.

Beach tourism, especially at some of the present resorts (Alexandria, Baltim, Ras el Barr, Port Said), will certainly suffer from a rise of sea level; but other resorts with wider and more stable beaches, if properly developed, might take over as the main recreational centers of the Nile delta.

Present territorial planning that involves population and the use of natural resources and of land, and covers time spans of 2-3 decades, will have to take the longer-term climatic changes into account.

1. INTRODUCTION

The surface of the Nile Delta (20.000 km²) represents only 2,3% of the area of Egypt, but as much as 46% of the total cultivated area (55,040 km² in 1985) - itself only 5.5% of the 1.001.449 km² of the country. It contains approximately 50% of Egypt's population of 50 and half millions inhabitants (1986).

The lower Nile Delta, from the Mediterranean shore to the 5m contour, not only harbours 20% of Egypt's population, but also the vital communication and industrial centers of Alexandria and Port Said (pop., respectively, of 3 1/2 millions and 300.000), which are as well the most important centers of summer tourism, essential recreation outlets for the overcrowded cities of the interior. Its importance is further underlined by its high level of agricultural and fish production (the coast and lagoons account for 60% of the fish catches). Besides being the site of expanding aquaculture activities, the coastal lagoons are important wildlife centers. They represent one quarter of total Mediterranean coastal wetlands, and as they are the major wetlands in the Southeast, they are vital staging places in the bird migration routes from Central Asia, and are a major wintering area for birds of nearly the entire Palearctic region.

An extensive part of the delta coast between Alexandria and Port Said lies below 1m elevation, and parts are below sea-level (Fig. 1.1). The lowland belt to 2 m, is 30-60 km wide, with an area of at least 4840 km². Besides Alexandria and Port Said, it includes the towns of Kafr el Dawar, Rosetta, Damietta, Mataria, El Manzala and Qantara. The larger centers of Damanhur, Kafr el Sheikh and Mansoura are not much higher, situated at more or less the 4m contour.

For many decades, and especially since the final closure of the Aswan High Dam in 1964, the coast of the Nile delta has been in a state of disequilibrium, with pronounced beach erosion at the Rosetta, Damietta and Burullus promontories. Owing to the total lack of Nile sediment supply, coastal retreat is expected to be a lasting phenomenon. So far it has only affected a few summer resorts and local infrastructures, but its consequences would be much worsened by a significant rise of sea-level, which would quickly extend the threat to lagoonal fishing, agriculture, and to several new economic developments near the sea.

To the effects of sea-level rise one must add those of geological land subsidence, which in certain parts amounts to as much as 50 mm per ten years. Reclamation of former lagoons and marshes has caused additional, and faster subsidence in some areas; others could be affected by sinking, if groundwater extraction were to become excessive. Apart from the Alexandria region and the area of Port Said, the coastal zone of the Nile Delta is still sparsely occupied and relatively little used. However, as Egypt growing population is crammed in the Nile valley and delta with a population density among the highest in the world, the expansion of agricultural and inhabited areas is one of the basic elements of the country's development strategy. Although crop yields are high, domestic food demand has outpaced food production and at

present the country imports more than half its food requirements. Further urbanization could worsen this problem.

The socio-economic outlook of the Nile Delta coastal zone for the decades ahead, is therefore dominated by the need to feed, house and employ its fast increasing population. The latter, in the area below the 3m contour, could pass from 10 mill. today, to 12 1/2 millions, already in AD 2000.

The increase of arable land has been accomplished so far by the reclamation of the lagoon margins, but its further extension is limited by encroaching on fishing and by soil salinity. Industry and commercial activities will continue to expand in the Alexandria to Abuqir belt, and at Port Said. Government plans envisage also the development of the Rosetta, Baltim, and especially of the Damietta area, following the completion of a new harbour and town. An increase is also possible in the number of beach resorts, in addition to the existing ones of Baltim Beach, Gamasa and Port Said, to relieve the overcrowding of the shrinking, and pollution-threatened beaches of Alexandria.

One of the main problems of land use expansion is the availability of water, water quality and the maintenance of the physical parameters of the lagoons, in view of their importance for protein production.

Due to limited rainfall, the Delta region is totally dependent on the river Nile for its water needs for urban, industrial and agricultural uses. Variations in rainfall in the Nile catchment areas of East Africa have had, historically and recently, a profound effect on water availability in Egypt. Nevertheless, there still are unused and under-used sources of water, such as ground and waste-water and the winter surplus of surface water, when irrigation requirements are reduced. The implementation of these uses involves technical difficulties (e.g. the high salinity of irrigation and ground-water in the northern part of the Delta), and environmental implications, in the case of the proposed transformation of the coastal lagoons into large storage reservoirs.

A growing environmental concern of the northern coastal zone is pollution. Alexandria is faced with a critical waste water problem due to its high rate of population increase and the rapid industrial growth of the last two decades; parts of nearby lake Mariut and the Alexandria sea front are now badly polluted. Farther east, the Idku and Burullus lagoons are beginning to be affected by the influx of pesticides and fertilizers.

The construction of more fixed facilities along the coast, such as new harbour and lake outlet structures, and an uncontrolled building of beach resorts, could add negatively to the existing instability of the shoreline, as they have elsewhere (e.g. along the northern Adriatic coast of Italy).

One immediate concern in the un-avoidable development of the coastal zone, is the need for a guided development that will not produce a deterioration of the environment. It is essential that long-term development planning takes into account the impacts of climatic change and acknowledges the need for the conservation of natural resources.

The aim of this contribution is to evaluate the likely impacts of climatic changes on the Nile delta coast and the bordering lowlands, given their morphology and the present/projected level of land use. It purports also to evaluate what needs to be done soon, i.e. in the next 10-20 years, in order to decide what measures should be taken by 2020 (30 years hence) to minimize, or adapt to the changes that would be caused by an atmospheric warming of 3° and sea level rise of 50-100 cm.

2. THE SOCIO-ECONOMIC SETTING

2.1 Economic setting and population

The Nile Delta constitutes 46% of the cultivated and densely populated land of Egypt. It contributes 30-40% of agricultural production, 60% of fish catches (Mediterranean and lagoonal). Most industrial production is concentrated in the delta, near Cairo and Alexandria; the latter is the country's main commercial port. The Suez Canal at Port Said is one of the main sources of foreign exchange, besides oil exports, tourism and remittances of Egyptian workers abroad.

Assuming that agricultural output in the delta is distributed as arable area, and assuming that all other sectors of economic activity are distributed as population, approximately 15% of Egypt's current gross domestic product (GDP) originates in the area likely to be affected by a 1m sea level rise. Also, large areas targeted for priority development in land reclamation projects, lie below the 1 meter contour. However, apart from Alexandria, Kafr el Dawar, Damietta and Port Said all the main population, commercial and industrial centers (Damanhour, Kafr el Sheiky, Mansoura, Tanta, Ismailia) are situated above the 3m contour (Fig. 2.1).

Agriculture is still the largest sector of the national economy, but due to the expansion of industrial activities in the last three decades, its share in the GDP has decreased from 40% in the 1950's to 29% in 1974, and dropped to 17% in 1984-85. Today, agricultural production, especially of cereals, has become insufficient to satisfy domestic needs. Growth has been slow (2.5% in 1980-85), as compared with 8.5% of industrial production. In the early 1970's, Egypt was still a net exporter of agricultural products. Now, it is forced to import over one half of its food requirements and 70% of its wheat.

As a result, in the balance of trade a surplus of 300 mill in 1975 has become a deficit of \$ billions in early 1980's; imports now largely exceed exports (Table 2.1).

Cotton production, the traditional, main cash export crop for which Egypt is justly famous, due to its quality and quantity, has decreased from 400-500,000 tons (1973-1983) to 350,000 tons at present.

There are two reasons, at least, for the inadequate performance of agriculture and the rise of food imports. One is the growth of urban population, with farmers producing little more than their own needs. The other is the government's control on cropping patterns and farm prices. In the decade up to 1984-85, this had been responsible for a 20% decrease of the cotton cultivated area, 10% of the wheat and rice areas. On the other hand, at the same time, the area dedicated to fruit and vegetables, which are not subject to quotas and fixed prices, and are increasingly exported, has risen by 23%.

Along with the process of industrialization, urbanization has been intense, especially in Cairo and Alexandria, the focuses of internal migration (much more than any of the other towns, e.g. Tanta, Kafr El Sheikh, Port Said, Mansoura). Urban population in Egypt now stands at 45%. Alexandria has swollen from half million inhabitants in the 50's to its present three millions, to which one must add 0.5-1 million summer visitors, attracted by the beaches. Unlike in Cairo, urban and industrial expansion in Alexandria is physically restricted, as the city stretches for 10 km over a 1-4 wide, 2-10 m high dune ridge, between the sea and Lake Mariut. This narrow strip is now a continuous sequence of high rise buildings; urbanization is rapidly pushing towards Abuqir.

Table 2.1

Egypt: Key Economic Indicators

	<u>Units</u>	<u>1982</u>	<u>1983</u>	<u>1984</u>	<u>1985</u>
Population	100	44670	45920	45820	48500
Gross Domestic Product	LEm	20290	24634	27595	32596
GDP per capita	LE	454	537	602	670
Inflation	%	14.9	16.1	17.1	13.5
Agricultural Production	1975=100	112	111.8	114.0	118.3
Food Production	1975=100	112.0	113.8	115.8	120.2
Exports	LEm	2184	2250	2198	2599
Petroleum & Products	% of share	66.1	66.8	53.3	57.5
Cotton	%	12.6	13.7	15.4	15.5
Imports	LEm	5720	6474	6783	6276
Balance of trade	Sm	-4408	-4744	-3206	-2571
Tourists	'000	1423	1497	1560	1650
Suez Canal Dues	LEm	658	679	665	654

(Source: The Middle East Review, 1988, p.57)

Exports and imports

Exports (1984)

Crude oil	46.9%
Raw cotton	15.5
Oil products	10.2
Cotton yarn	7.0
Oranges	2.4
Cotton fabrics	2.3
Potatoes	1.2
Rice	0.5

Main imports

(in order of quantitative importance)

Motor vehicles

Wheat

Iron bars

Cement

Timber

Chemicals

Tobacco

Fats, oils

etc.

In consequence of its population increase and rapid industrial growth the city of Alexandria is faced with a critic waste water problem, which has created health hazards on the beaches and been detrimental to fishing.

The urbanization of Port Said (pop. 470,000) has been much less evident, despite its potential as a commercial and industrial centre at the entrance of the Suez Canal. This has been due mainly to lack of space, squeezed between the sea and two lagoons. Incentives have been provided, however, by the creation of new land by reclamation in the west and fill-ins in the east, with the excavation of the new Suez Canal Bypass.

The building of the Aswan High Dam, which stores the annual Nile flood waters, has permitted not only the year-round irrigation of all presently cultivated land, and a more intensive use of the soil with several crops a ydear, but also the extension of cultivated land by the reclamation of wetland areas near the coastal lagoons and at the desert fringes of the Nile Delta.

Land reclamation is a government priority. About 1 million feddans (1 feddan = 1.04 acres, 0.43 ha) have been reclaimed in the past 20 years, but about half of this has, for a variety of reasons, such as poor management, proved unproductive. Additional areas targeted for reclamation lie east of the Suez Canal and SW of Alexandria.

The availability of water resources is a major worry. Lake Nasser is at its lowest level since its ultimate filling in 1978, because of the last years drought in the Blue Nile catchment area. Other problems of agricultural expansion are water and soil quality, due to salinization.

Given that tourism is one of the main resources of Egypt (LE 338.3 million earnings in 1985), the beaches of the Nile Delta are still little used and mainly on a national scale, serving Cairo and the cities of the lower delta. The erosion of Alexandria's small beaches has already resulted in the fast development of the western coast (Agami to Marsa Latruh) and of North Sinai (Arish). Government development plans for future expansion are directed to these areas, as well as to South Sinai, the Red Sea coast and Upper Egypt, rather than the Nile Delta.

The present population of Egypt is 50.6 millions, concentrated in the Nile valley and delta, with high population densities (Fig. 2.2). The highest densities are found in the central delta, along the Nile branches, the Mahmoudia Canal (Kafr Dawar, Mahmoudia districts) and the El Saghir Drain (Mansoura to Matarya). Population is much lower and less densely distributed in the areas that are below 1-2m, with sparse villages, and small towns up to ±5000 inhabitants (including the fishing centers of Edku and Baltim).

The economically active part of the population is estimated to be 25-30%. Occupation has changed significantly since the 60's, with an overall decrease in agriculture and services (now 50%, 20%), and a marked increase in industry (now 30%). In the less urbanized lower delta, however, the role of agriculture, commerce and fishing is still predominant:

area	Rosetta District (1984)	Lake Burullus (1982)
Agriculture	40%	10%
Fishing	15%	54%
Commerce & Tertiary	30%	25%
Crafts, industry, construction	15%	11%

The Egyptian population is growing at the rate of 2.3-3% per annum, due to high fertility factors, as well as to recent improvements in health and a decrease of the mortality index. Projections of population size for the next decades depends on growth rates and the scenarios of economic development considered (Tables 2-2, 2-3). If the rate of population growth falls to 2% by 2000, the total population of Egypt could be an average of 64 millions; the share of the lower delta ($\pm 3m$) would be about 12 millions.

Table 2.2

National Population Estimates, 1974-2000 ^{1/}
United Nations Projections ^{1/}

	Population size (000)	<u>Medium</u>		Annual growth rate	Populat. size (000)	Annual growth rate	<u>Low</u>	
		CDR	CDR				Populat. size (000)	Annual growth rate
1975	36.916	38.6	12.8	2.58	36.916	2.64	36.916	2.52
1980	41.995	35.2	11.4	2.38	42.120	2.51	41.870	2.23
1985	47.303	32.1	10.1	2.20	47.745	2.39	46.802	2.02
1990	52.806	29.7	9.1	2.06	53.811	2.29	51.777	1.85
1995	58.540	28.3	8.4	1.99	60.347	2.24	56.798	1.73
2000	64.672				67.493		61.943	

Source: FADCO as taken from

Source: United Nations, World Population Trends & Prospects by Country 1950-2000: Summary Report of 1978 Assessment. New York: 1979.

^{1/} This set is composed of three alternative projections. The medium projection is thought by the UN to be most realistic as it is based on the past observed demographic trends, expected social and economic progress, on-going policies, and the prevailing public attitudes toward population issues. The other two, high and low, projection alternatives represent a plausible range of variation that is not exhaustive.

Table 2.3

Population projections according to Blue Plan

	Growth rate	1985	2000	2025
Scenario T ₁ (reference trend)	2.3	46.900	65.700	90.400
Scenario T ₂ (worse trend)	2.1	46.100	65.700	93.300
Scenario T ₃ (moderate trend)	2.7	46.900	63.900	90.400
Scenario A ₁ (alternative reference scenario)	2.8	46.800	62.200	85.000

Table 2.4

Lake Burullus Area: Tentative Projections of Population by
Economic Sector, 1982 to 1990 and 2000
On the Basis of Recent Trends

SECTOR	1982	1990		2000		Av. Annual Growth 1982-2000
		Popul.	Av. Annual Growth rate	Popul.	Av. Annual Growth Rate	
Fishing	47.000	57.785	2.6	71.130	2.1	2.3
Agriculture	8.700	13.350	5.5	20.890	4.6	5.0
Industry-handicraft and housing constr.	9.600	11.785	2.6	14.790	2.3	2.4
Tertiary	21.700	26.440	2.5	33.190	2.3	2.4
TOTAL AND AVERAGE	87.000	109.360	2.9	140.000	2.5	2.7

Source: IFAGRARIA, 1984

Table 2.5
Total Population Projection of Damietta Governorate
and New Damietta City

Type	Year	1985	1990	1995	2000
Induced Manufacturing		10,000	16,000	22,000	28,000
Total Active Population (induced)		25,000	41,000	57,000	74,000
Activity Rate		40%	35%	32%	3%
Induced Population		63,000	118,000	178,000	230,000
Excess Population		-	48,000	106,000	213,000
Refined Excess Population			25,000	72,000	169,000
Baseline Population East		679,000	752,000	840,000	939,000
Total Population of New Damietta City		63,000	143,000	250,000	400,000
Total Population of Diametta Governorate with Development		742,000	870,000	982,000	1.230,000

Source: F.R. Harris, Damietta Master Plan, 1979

Population increases foreseen for lower delta areas
(other than Alexandria and Port Said) are:

Burullus region: from 95,000 (1988) to 140,000 (2000)
Damietta area: from 750,000 (1985) to 1,230,000 (2000)

In the Damietta area density will increase from 425 inh./ha to 550 inh./ha by the year 2000 AD.

It has been calculated that re-settlement can take place only in urban areas (Assen 1986): only 8% of the extra 30 million people by 2005 could be resettled in new reclaimed lands as farmers. Assuming the planned density of 9200 inh./Km.² for the new cities, the area required will be of 760,000 feddans. Thus, urban encroachment on agricultural land would continue, unless new towns are built entirely in the desert.

2.2 Agriculture

In the Nile Delta the most important crops by cultivated area are clover (barseem), maize, cotton, wheat, rice, fruits and vegetables. Maize, rice, cotton, sugar beats and soya beans are the predominant crops of the lower coastal zone, especially in the reclaimed areas (Fig. 2.3). Considerable market gardening is developed near the larger town, e.g. in the Mariut-Abuqir areas near Alexandria-Kafr Dawar-Damanhour.

Clover is widely grown as animal fodder and to increase the nitrogen content of the soil. Broad beans are also a common crop, for animal and human consumption, and for soil regeneration.

Rice production has increased with perennial irrigation and lowland reclamation, where it is a favoured crop because of high yields even in moderately to highly saline soils. The fortune of cotton in Egypt has been due to soil fertility, long and dry summers, frost-free autumns and controlllable irrigation, but the extent of cultivation has diminished, as more land has been devoted to food production.

Fruits and vegetables (lentils, broad beans, tomatoes, carrots, aubergines, etc.) have become a high priority objective. Onions and potatoes are exported. Main fruits produced in the lower Nile Delta are oranges, mandarines, dates; vineyards are located in the NW delta.

With the greatly increased frequency of cropping on irrigated land, and the shift to perennial irrigation, which greatly reduces the deposit of alluvium on the soil, soil fertility has declined in many parts, necessitating the use of artificial fertilizers. Superphosphates and nitrates must be applied on a generous scale (more fertilizer is used in Egypt than in the whole of the rest of North Africa, a considerable amount being imported). In an effort to combat soil exhaustion the Egyptian government laid down in 1956-60 that basically one third of every holding should be cultivated in grain, and only a third in cotton (ref. Fisher, 1978, Beaumont et al., 1988).

3 year rotation:

1. Nov.-March clover
 April-Oct. cotton
2. Nov.-May beans
 June-Oct. fallow
3. Nov.-May wheat
 June-Oct. maize

2 year rotation:

1. April-Nov. cotton
 Nov.May wheat or beans
2. May-June fallow
 July-Nov. maize
 Nov.-March clover

Winter crops (shitui): wheat, beans, barley, onions, flax.

Summer crops (sefi): cotton, rice, corn, millet.

Autumn crops (nili): rice, corn, millet.

The expansion of cultivated land has become an impelling priority in Egypt. According to the Ministry of Irrigation, 2.8 to 3 millions feddans (40% of the total land now under cultivation) could be reclaimed by the year 2000, even with the available water resources; over one half of that surface is north of Cairo, mainly in the eastern delta and north Sinai. It is estimated that the irrigation water needed would be at least 8.76 billions m^3 a year.

The reclamation schemes carried out, under way or proposed since the 1950's are shown in Fig. 2.4. The most significant delta projects are:

1. At the western desert fringes of the delta: (a) the Tahrir Province (started in 1957, 200.000 feddans are watered from a Nile derived canal and from wells, seven new villages, housing 25.000 people were created); (b) the Nubarya desert scheme (ultimately covering 300.000 feddans, this project is supported by loans from IDA, mainly to establish sugar beets production).

2. A scheme in the Mariut region has included the draining and reclaiming of parts of Lake Mariut; a notable feature is the use of Alexandria sewage water for irrigation besides Nile water.

3. Large lagoonal-swampy areas (120.000 feddans) south of the Idku and Burullus lagoons were drained at great cost; the reclaimed soils still contained 10% salt.

4. In the Suez Canal region: (a) south of Port Said there is a project to irrigate 200.000 feddans, with the construction of 1000 new settlements; (b) the plain of Tineh, east of the Suez Canal, is to be watered by the El Salam Canal, which is derived from the Nile south of Damietta and, by underpassing the Suez Canal delivers 13.000 mill. m^3 of water for a 1680 km^2 reclamation (including a 576 km^2 agro-industrial project to produce vegetables, fruit, livestock and dairy products), along with the creation of numerous new communities

At present on the basis of economic criteria, and given a relatively high budget for land reclamation and agriculture development, about 1 million feddans are considered a priority, and are already in some stage of project preparation, construction and development. Eighteen percent of the total reclaimable area to be irrigated includes deltaic clay soils. They are the only soils suitable for level basin irrigation, though from the onset the reclamation requires an adequate drainage system, in order to avoid water-logging and salt accumulation. A leaching program to remedy excessive soil salinity, by means of subsurface drainage, using excess winter water is under way (ref. the 1986-1995 Drainage Project Five). (Other areas or reclamation land have their irrigation problems, the calcareous loam soils of the Nubarya project, and the sandy desert soils off the Nile valley and delta).

Another problem of agriculture productivity and expansion in the delta, is water consumption and irrigation methods. Water requirements vary according to crops, for instance they are lowest for wheat and barley (1030-1140 m^3 per feddan), moderate for maize and clover (2660 m^3), and cotton (3740 m^3), but quite high for rice (10-16.000 m^3).

Present irrigation efficiency is estimated at 50%. Egypt could make do with much less water than it presently consumes, as inefficient irrigation methods contribute significantly to wastage. Live basin irrigation and the traditional crop husbandry, as practiced in the old lands of the delta, are not suitable in the newly reclaimed delta margin lands. The Ministry of Irrigation has suggested that the present average mean water use of 8000 m³ per feddan/year, should be reduced to 7420 m³ on clay soils, and to 5250 m³/year on sandy soils. Irrigation practices need to be changed to face, if not a future reduced water supply, increased losses due to evaporation, water intensive crops may have to be phased out.

Finally, there is the problem of an actual loss of arable land. Between 1952 and 1980 a total of 1.072.000 feddans of new land was reclaimed from the Nile valley and the delta, however the actual amount of land available appears to have been much less, as considerable areas of existing land are estimated to have been lost: by 1980, as much as 20.000 feddans lost each year due to urban-industrial developments and brick making (now forbidden by an Act of 1985), and because of the problems of waterlogging and salinity, exacerbated by the perennial irrigation methods, as more intensive cropping and less concern with drainage has resulted in a general rise of the water table.

2.3. Fishing

Marine fishing (Mediterranean and Red Sea) accounts for 25% of Egyptian fish catches (125.000-160.000 tons a year) versus 60% from the coastal lagoons of the Nile delta and 15% from the Nile river. The entity of fish catches in the Mediterranean has been strongly influenced by environmental conditions such as the cessation of the Nile input of nutrients after 1964, and in the last two decades the increase of water and sediment pollution.

Marine catches in the early 70's had decreased to 20% of the pre-1964 amount (17.000 in 1969 versus 90.500 in 1962); most affected the sardines (*Sardinella*, esp. *S. aurita*, which has previously constituted 30-40% of total fish landings), due to the sharp decrease in primary productivity (zooplankton blooms responding to the phosphate and silica inputs by the Nile). The pre-1964 sardine catch, up to 13.000 tons/year, had become 465 tons in 1978; prawn catches (*Palaemon serratus*, *Metapenaeus*) only 36 tons versus the 1880 tons of 1964.

Marine fish production in the period 1975-1983 varied from 12.000 to 20.000 tons a year (in 1984, at Alexandria 3751 tons, at Rosetta 2840 tons). The most active marine fishing centers are Alexandria (west and eastern harbours), Abuqir, Rosetta, Burg el Burullus, Damietta and Port Said. The main fish species marketed are: *Mullus barbatus*, *Nugil cephalus*, *Pagellus*, *Sardinella*, *Solea solea*, *Temnodon saltatus*, *Box salpa*; squids, crabs and shrimps.

In spite of the use of advanced fishing equipment in recent years, statistical reports indicate a decline in catches (Fig. 2.5). One cause is considered to have been the spread of pollution (Halip *et al.*, 1985), Saleh and

El Karashily, 1985) which has affected especially the bottom fauna (ref. section 6). Some species may have, however, benefited from increased organic matter in the sea, such as sardines (5631 tons landed in 1981), and Mullus barbatus, a bottom feeder.

Of much greater importance for fishing are all the lagoons of the delta coast and lake Mariut. Manzala is said to produce 16 to 35% of all Egypt's fish, 12.000-15.000 tons are produced yearly from Burullus. Fishing activities sustain a large number of people: 35.000-40.000 fishermen in Manzala; 47.000 in Burullus.

Fish production has increased along with the increased year-round drainage water discharge after 1964, which has freshened the lagoonal waters and consequently altered the ratio of fresh-water to euryhaline fishes. Only in Lake Mariut there has been a decline of fish production, due to pollution.

Quantitatively the main species caught are mullets (Mugil capitus, M. cephalus) tilapia (Tilapia nilotica, T. galilea), but also crabs, shrimps and eels (esp. in the Idku and Manzala lagoons). The mullets spawn in the sea and migrate into the lagoons in winter-spring, where they attain maturity. Tilapia, instead, is an entirely freshwater fish. Catches are generally higher in summer-autumn. In the Bardawil lagoon, where salinities range 40‰ to 100‰, all fishes spawn in the sea: Solea vulgaris, Sparus aurata, Liza ramada, Dicentrarchus abrax, mugils.

The efficiency of fishing in the lagoons depends on various factors:

1. The maintenance of the flow of the lagoon outlets, paramount to fish migration and to the collection of fish fry for aquaculture.
2. The quantity of drainage water discharged into the lagoons.
3. The extent of plant cover and the variations of environmental conditions (e.g. winds, temperature, salinity).
4. Environmental control, i.e. the enforcement by the government of laws meant to prevent overfishing and illegal methods of fish farming.

In the Bardawil lagoon the fisheries are entirely dependent on the maintenance of the two artificial outlets, without which the lagoon would quickly return to the state of a large salty mudflat. Fish farming is growing in importance and is sponsored both by local government and the Ministry of Agriculture (Aquaculture Development Programme; General Authority for Fish Resources Development).

Important fish farms are near Alexandria (Nozha aerodrome), by the south shores of Idku (a 2000 feddan farm producing nearly 5000 tons a year) and in Manzala. The Manzala lagoon has been chosen officially as the center for marine and brackish-water aquaculture development. In Burullus and Manzala there is also a considerable number of private farms, consisting of seasonally opened and closed basin (hoshas).

There are several experimental fish farms (e.g. Delta Barrage near Cairo, Mex and Mariut in Lake Mariut; El Khubeza in the Idku lagoon; the Serw, Manzala and Rashwa farms in Manzala) they deal with the acclimatization of fishes, use of fertilizers for feeding and are based mainly on mugils (M. Cephalus, Capito, saliens, chello) Tilapia (T. nilotica, aurea, galilaeae, zilii). Fish rearing in rice paddies has also been tested (Bishara, 1983).

Limitations to aquaculture are the scarcity of mullet fry, traditionally caught near the lagoon outlets and in the Nile estuaries, due to pollution and disturbance by mechanized navigation; the build-up of aquatic macrophytes (ref. Beheira Governorate project to clear the Idku lagoon of weeds and vegetation); and conflicts between agriculture and aquaculture interests, about whether land at the edge of the lagoons should be reclaimed or left for fishing. At present, considering the poor returns from the salty soils of the newly reclaimed lands, aquaculture ought to be given a priority. According to the Ministry of Agriculture, in fact, the economic value of fish farming (LE 1600 per feddah) is superior to that of any crops, except cotton and citrus fruits.

2.4. Industries and communications

In the coastal region of the Nile delta industry is concentrated in Alexandria, (40% of Egyptian industries, 13% of GNP). It is essentially geared to the primary needs of the country: food processing, textiles and clothing, shoes, chemicals fertilizers cement, small scale metallurgical, mechanical manufacturing; a steel plant is being developed at Dakheila.

Manufacturing industries depend on imported raw materials, and are supported by local energy production (oil refineries based on Egypt's considerable oil production).

Other industrial centers, also related to natural gas production (e.g. Abuqir Bay gas field) are at Kafr El Dawar (chemicals) and at El Tabia, near Abuqir (cotton mill, rayon fiber plant, paper and cardboard, dying materials, food canning, cotton dying and finishing); there is a shipyard in Abuqir. Textile plants are located in Damietta; at Port Said light industries are associated with the Custom Free Zone (Fig. 2.5).

Industry in Egypt has experienced a period of rapid growth. In 1974-1982 industrial investment reached 24% of total investments. Today 75% of industrial production still comes from the public (state) sector, but the private sector has considerably expanded in recent years, it had a 10% per year growth rate in the period 1982-1987, and is expected to grow at 7.2% per annum in the 1987-1992 Five Year Plan. Much hope is pinned on the private sector by the government, with an emphasis on diversification and import substitution, since the state sector is still hindered by several financial and structural problems. However, the first rapid expansion of agro-allied and of consumer industries, has been followed by a slowdown caused by fixed government prices and by shortages of foreign exchange.

Industry is expected to expand considerably in the next decades (at rates of 2.8 to 7.7%, according to different scenarios of economic and political development, due to population and internal market growth, ref. Blue Plan).

Industrial development can be underpinned by existing and further discoveries of natural gas reserves. The needs for traditional manufactured goods will continue to be significant, while industries that are in decline in the north Mediterranean countries (e.g. steel, cement), will keep on expanding. Table 2.6 suggest a considerable increase of manufactured consumer goods and of basic industrial goods.

The future of industry in a developing country like Egypt will depend however not on market expansion alone, but especially on internal development policies and international free exchanges (north-south, east-west), and on availability of energy, diversification in the production of consumer goods may entail seeking export markets, but competitiveness in this field could require a painful remodelling of many enterprises. The best prospects could be seen in a balance between the growth of medium-small sized enterprises, springing from the internal dynamics of society, and the expansion of large scale industry inspired by western models.

Population and urban-industrial expansion will require better communications in the lower delta, than those existing today. To the Alexandria harbour, the main commercial port (16 mill. tons imported, 1.5 mill. exported in 1980), have been added a new harbour at Dakheila (to serve industries SW of Alexandria), a new military at Abuqir, the new port of Damietta (designed mainly for imports, it is to handle initially 800.000 tons/year, and a maximum of 6.000.000 by early XXI century) and new facilities at Port Said.

While communications between the ports/centers of production on the coast and in the delta, and Cairo are satisfactory, there is a lack of major east-west road and rail links. Roads and railways in the delta are antiquated and slow. Half the total freight in Egypt moves by road, the rest is shared ± equally between the railways and waterways.

Water transport is less developed however than might be expected; in the delta it is limited to the Nubarya canal the Rosetta branch of the Nile (where guaranteed by high water level is guaranteed by the Edfina barrage and the Damietta branch, upstream of Zifta (Fig. 2.6). Other canals are quantitatively of lesser importance (incl. the Mahmoudia canal, and waterways towards and through the Manzala lagoon). On the Damietta branch a connection with the New Duniyat harbour has been recommended and would be necessary.

Table 2.6

A projection of the value of Egypt's industrial production

Agro-industries	1383		10.000	
Textiles, clothing, etc.	752	72%	7.500	44.4%
Other	143		2.000	
<u>Base industrial products:</u>				
Cotton ginning	15		30	
Chemical, petrochemical	240		7.200	
Paper, etc	55	16.4%	1.370	27.5%
Non-metallic	95		180	
Metallic	78		2.100	
Cement, glass, etc	37		2.100	
<u>Manufacturing:</u>				
Metallic	180		4.500	
Non-electric	28		300	
Electric/electronic	90	11.6%	2.200	28.1%
Transport equipment	50		700	
Others	2		2.800	

Source: UNEP, M.A.P. Preliminary report on Blue Plan Scenarios, 1987, based on Institute of Planning, Study No 10, 1980).

3. THE PHYSICAL ENVIRONMENTS

3.1. Climate

Despite the fact that the Mediterranean coast of Egypt is a semi-arid area owing to lack of rainfall and to a high temperature, its climate can be considered to be of Mediterranean type. The weather is highly seasonal in nature and is strongly related to the high pressure systems whose limits overstep the boundaries of the Mediterranean area and extend towards the north Atlantic, Eurasia and Africa.

The Eastern Mediterranean climate is controlled by the following factors:

1. The cyclonic depressions formed in the central and eastern Mediterranean (the Atlas and Azores depressions are not very effective there);
2. The high winter and summer pressures over Egypt-Ethiopia, and the Arabian peninsula (Fig. 3.1).

During winter, a semi-permanent low pressure area known as the "Cyprus Low" is usually located over the Eastern Mediterranean (Fig. 3.2). This low pressure results partly from topographic features, partly from stagnation of winter low pressure areas that move east. The winter months are the windiest; the dominant winds are from NW and WNW; less frequently from N and NE.

In the period from November to March-April, storms of cyclonic type, associated with moving depressions that usually follow an ESE direction, appear regularly. Low pressure centers generally move along the northern side of the eastern Mediterranean; isobars can sometime be relatively straight over the sea and average fetch lengths of 250, exceptionally of 600 nautical miles, can be encountered. Such moving storms are responsible for the generation of the highest waves on the Egyptian northern shores.

Weaker storms occur mainly in the area between Crete and the Nile Delta. They are mostly cyclonic, with average length of 150 nautical miles and weak pressure gradients. Such storms last about two days on average, when they derive from NW; the east-derived storms are much less frequent and short-lived, and are characterized by shorter fetches.

Several thunderstorms occasionally affect the Egyptian coastal area, accompanied by sustained winds of 43 to 60 knots for short periods and instantaneous wind gusts in the range of 70 to 87 knots. These thunderstorms occur particularly between October and May (less frequently in the summer and early fall).

During the spring months (April to May) a gradual weakening and dissipation of the Cyprus Low occurs. A high pressure ridge develops eastward over the Mediterranean (an extension of the semi-permanent Azores High), and a low pressure zone develops over the Arabian peninsula and the north-central Sahara. These pressure features are relatively weaker than the winter pressure

systems, and the result is a decrease of the average wind speeds over the Mediterranean.

The air pressure gradients become weaker over the eastern Mediterranean, where isobar directions shift to WNW from WNW to NNW. In May, with the influence of the Arabo-Persian depression. The anticyclonic ridge of the Sahara is broken, and winds begin to blow from SW to NE. When the depressions are fed by strong currents of polar air, these southern hot and dry winds (Khamessin, Ghibli) become violent, raise ground temperatures to their maxima, lower the relative humidity to few percents, and transport sand and dust.

In the summer (June to September) the high pressure ridge that runs east-west across the central and eastern Mediterranean, and the low pressure area over the north-central Sahara, reach their maximum development. As a result winds speeds during the summer are greater, on average, than in the spring. July is the windiest month. The dominant winds are from the WNW and west (Table 3.1).

Table 3.1

Annual Wind Frequencies in the Offshore Regions

Wind Speed (Knots)	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE
7-10	3.78	5.75	11.35	5.1	4.56	2.55	3.32	1.75	1.54	0.85
11-16	1.97	2.08	4.68	1.57	1.26	0.86	1.36	0.75	0.55	0.32
22-27	0.31	0.46	0.48	0.1	0.07	0.07	0.12	0.06	0.06	0.01
39-40	0.07	0.10	0.04	-	-	-	-	-	-	-

Source: Harris (1978) based on ship observations (1850 to 1950).

During July and August a secondary cell of low pressure centred over Cyprus, combined with zones of high pressure north of Libya, produces a constant northwesterly flow of air between Crete and Cyprus. The corresponding surface ("etesian") winds between mid-June and mid-September produce swells that reach the Nile delta coast.

From mid-September, the Arabo-Persian depression disappears progressively and high pressure belts from SE Europe and North Africa extend over the central and part of the eastern Mediterranean, producing a very calm sea in October.

Temperatures in northern Egypt vary considerably according to the season, and also there are notable differences between day and night temperatures. Mean maximum temperatures are about 23.9-27° C, according to location on the coast. The mean minimum temperatures vary between 14.2° C and 19.5° C (January-February); absolute minimum temperatures are 6° to 9° C in January. Maximum temperatures range from 30° to 32°, June to September (Tables 3.2, 3.3, 3.4).

From May onwards, for 10-15 weeks, it is entirely dry over the south Mediterranean coast and the Middle East. Humidity however, is high with frequent nocturnal condensation (dew). In Egypt, Mediterranean-type rains are caused by the cyclonic depressions that travel eastwards. The first rains may appear at the end of September. Annual rainfall varies considerably from one locality, and from one month to another. It falls mainly in winter, between early October and March, at other times it is a rare event, in the form of occasional thunderstorms. Significant precipitation is limited to the coastal belt (Fig. 3.3), especially over the stretches exposed to NW Alexandria receives 150-200mm of rain a year, as opposed to 74-80 mm at Port Said (Fig. 3.3). Further east rainfall increases again, with 97 mm/year at El Arish, and 223 mm at Rafah, near Gaza.

Table 3.2
Egypt - general climatic data

	Average Annual Temp.	Average Jan. Temp.	Average July Temp.	Average Annual Precip.	Relative Humidity	Evapo- ration mm/day
Marsa Matruh	19.2	9.2	14.6	24.0	154	68.3
Alexandria	20.2	13.6	226.2	166	70	5.3
Baltim	19.0	15.0	26.5	154	68	-
Port Said	21.2	14.5	27.1	173	70	-
El Arish		14.2	25.0	97	70	-
Sakha	20.1	14.8	27.0	55	69	3.9
Cairo	21.9	13.8	28.6	42	50	2.8
El Fayoum	22.2	13.6	29.1	19	48	4
Luxor	24.1	14.6	31.2	4	34	4.8
Aswan	25.2	16.0	3.2	-	22	-

Table 3.3

Mean temperatures, Mediterranean Coast of Egypt

Site	J	F	M	A	M	J	J	A	S	O	N	D
Marsa Matrouh	18.1	18.9	20.3	22.7	25.5	27.8	29.2	29.9	28.7	27.0	23.4	19.7
Dhabaah	18.0	19.0	20.5	22.8	25.2	27.9	29.2	29.8	28.6	26.9	23.6	19.8
Burg El-Arab	16.7	17.7	19.0	24.6	26.0	28.9	29.3	30.4	27.3	27.3	23.1	19.5
Alexandria	18.5	19.2	21.2	23.8	26.6	28.4	29.7	30.6	29.5	27.8	24.5	20.5
Sakha	19.4	20.6	23.0	27.1	31.2	32.0	34.0	33.6	32.1	29.9	25.9	21.5
Baltim	17.9	18.0	20.4	22.6	25.9	29.0	29.8	30.5	29.0	27.3	24.1	19.4
Port Said	18.1	18.6	20.2	22.5	25.6	28.5	30.4	30.8	29.2	27.3	24.1	19.8

Mean monthly minimum, °C

Marsa Matrouh	8.1	8.4	9.7	11.8	14.5	18.2	20.2	21.0	19.7	16.8	13.3	10.0
Dhabaah	7.3	7.9	9.5	12.0	14.8	18.4	20.9	21.2	19.7	17.1	13.2	9.4
Burg El-Arab	6.4	8.0	8.8	10.8	15.0	18.1	19.9	19.4	18.6	14.9	12.1	8.8
Alexandria	9.3	9.5	11.2	13.4	16.5	20.2	22.6	22.8	21.2	17.7	14.7	11.1
Sakha	6.1	6.3	7.9	10.4	14.2	17.0	19.0	18.4	17.7	15.6	12.6	8.3
Baltim	12.0	11.9	13.9	14.8	17.4	21.2	23.1	24.0	22.0	20.3	17.2	13.3
Port Said	11.4	12.0	13.6	16.8	19.6	22.4	24.1	24.9	23.8	21.8	18.5	13.6

Mean monthly temperature, °C

Marsa Matrouh	12.8	12.4	14.9	17.4	20.2	23.2	25.0	25.6	24.4	21.8	18.2	14.4
Dhabaah	12.7	12.8	15.1	17.1	19.3	23.3	25.0	25.4	23.8	21.3	18.0	14.1
Burg El-Arab	12.9	13.0	14.2	17.9	20.6	24.0	25.2	25.9	24.7	21.9	17.5	14.4
Alexandria	13.7	14.2	15.9	18.3	21.4	24.3	26.0	26.6	25.3	22.7	19.4	15.5
Sakha	12.8	13.4	15.4	18.8	22.0	25.0	26.5	26.0	24.9	22.8	19.2	14.9
Baltim	14.7	14.8	16.8	18.5	21.4	25.1	26.3	27.1	25.5	23.6	20.5	16.1
Port Said	14.3	14.8	16.4	18.8	22.0	25.0	26.7	27.4	26.1	24.1	20.9	16.3

Table 3.4

Mean monthly percent relative humidity during day time

Site	J	F	M	A	M	J	J	A	S	O	N	D
Marsa Matrouh	65	64	63	64	67	70	73	72	67	66	66	68
Dhabaah	66	61	60	59	60	68	70	67	66	68	67	62
Burg El-Arab	74	69	63	59	64	61	71	70	66	64	66	61
Alexandria	70	67	65	65	67	70	72	71	68	68	70	71
Sakha	74	73	70	64	60	63	67	69	70	71	74	76
Baltim	74	66	61	66	63	67	71	69	68	67	70	72
Port Said	73	70	68	71	71	72	73	73	70	69	72	74

Rainfall decreases rapidly south of the coast (e.g. Sakha, Tanta 50 mm a year, Cairo 40 mm/year). Besides its limitation to winter, rain may fall only for a few days in a year, the averages do not reflect its irregularity. The erratic distribution of rainfall and its insufficiency is worsened by the high insolation and evaporation. Relative humidity is high at the coast, with values highest early in the morning, and lowest at noon; it drops south of Cairo. During the Khamessin period (March-May) the relative humidity may be reduced to below 10%. The recorded rates of evaporation are high, from 3.9 to 7.9 mm a day.

3.2. The marine parameters

The submarine part of the Nile delta is made by the continental shelf to the depth of 200 m, which is a belt only 10 km wide in the west (Alexandria, Abuqir), but widens to 50 km north of Rosetta and 70 km north of Port Said, and unlike the regular bulge of the coast, has a straight east-west orientation. Beyond the continental margin, the deposition of Nile sediments during the Pleistocene had contributed to the building of the vast submarine fan (Nile Cone) which extends from 1000 to 2500-3000 m depths.

The marine region of the Nile delta shares the general characteristics of circulation, salinity and density of the Eastern Mediterranean (Levantine Basin), but variations occur near the coast due to shoreline and submarine irregularities, and to the influence of fresh water discharge.

3.2.1. Topography and sediments

The continental shelf of the Nile delta is characterized by a series of flat surfaces, separated by mild slopes and local scarps, which mainly trend E-W, (Fig. 3.5). The main surface levels are at depths: 15-27 m (upper terrace), 40-55 m (intermediate terrace) and 65 m to 139 m (lower terrace complex) (Summerhayes et al., 1978).

The upper terrace, or delta platform, is mostly covered by terrigenous sands, except where transgressed by the muds of the Rosetta and Damietta cones (which are 25-30 m thick) and by mud blankets that are related to older Nile mouths. By contrast, the lower terraces are overlain by bioclastic sediments ranging from pure algal coralline debris and shelly sands and gravel to muds with bioclastic debris and a high CaCO_3 content (Summerhayes et al., 1978) (Fig. 3.6).

3.2.3. Salinity and water stratification

The salinity of surface waters off the coast of Egypt varies between 39‰ in April to 39.4‰ in February (Morcos and Hassan, 1976). Temperature varies between 16°C, in February and 26°C, in August (Morcos, 1972).

In summer and autumn, there is a strong salinity stratification with a minimum between 50 m and 75 m (38.5‰), sandwiched between two layers of maximum salinity, at the surface and between 150 and 300 m (Fig. 3.7 A). The

layer of subsurface minimum salinity may be developed under the influence of the main surface current that flows eastward from Gibraltar; an alternative source has been indicated in the surface, less saline layer of the preceding spring.

The East-West transect of salinity (Fig. 3.7 B) shows that the main area of Levantine Intermediate Water (LIW) formation is to the east of 28°E. The presence of AW (Atlantic water) to the west evidently hinders the formation of the LIW. The AW (Atlantic Water) deflection to north before long. 28°30' E, is in agreement with the wintertime detachment of the surface circulation from the African coast in this region.

Similarly the intermediate layer of maximum salinity between 150 and 300 m, has a tendency to become deeper and less saline towards the west. It is generally believed that it has its source in the surface water of the northern part of the Levant Sea, from where it sinks in winter and spreads towards the south and west. During winters, a well mixed state of vertical salinity is found down to 300 m.

Before the cessation of Nile river discharge, the physical parameters of water over the continental shelf were strongly influenced by the Nile flood. Since 1965 the distribution of salinity has changed (Fig. 3.8). A characteristic feature in summer is the occurrence of a surface layer of high salinity, about 20-30 m thick, overlying a subsurface layer of lower salinity (Fig. 3.9). The surface layer has a maximum value of 39.46‰, at 33°N Lat, 32°E Long. Seaward of this salinity nucleus, the isohalines show a gradual decrease in surface salinity to 38.76‰. This layer may represent a trapped water mass originating somewhere in the eastern part of the Mediterranean Sea formed under the influence of the special circulation pattern in that region (El Din, 1976).

Since the Aswan High Dam closure, transparency has increased, dissolved oxygen levels have decreased (but still remain high as characteristic of the Eastern Mediterranean), water temperature has not changed substantially. In summer, waters are evenly stratified from 26°-27°C at the surface, to 18°C at 75 m. In winter, waters to 100 m depth are well mixed at 17°-18° (Fig. 3.10). In Abuqir Bay surface, where water temperatures follow air temperature, the annual average is 22.6° (28.6° August-16.1°C February).

In general in late summer to October, the Mediterranean circulation is stabilized with a thermocline in 40-50 m depth; in November and December, when the winter storms start, the thermocline is broken in a few days and displaced to 150-200 m depth, through vertical mixing; several water masses form on the continental shelf and conditions become unstable and complex. The winter conditions continue, but with decreasing intensity, until the transitional period of April - May.

The horizontal distribution of dissolved oxygen at the surface (Emara et al., 1973) has shown periodical seasonal changes, in obvious correlation with the temperature variations. The highest values (4.91-5.96 ml/l) occur in winter when the surface temperature is at a minimum, the lowest absolute values

(4.39-4.91 ml/l) in the summer, when the surface temperature reaches a maximum (26.1-28-9°C). Surface water was generally close to saturation with values ranging between 90-105% during the entire year.

In Abuqir Bay, the distribution of water masses is largely dependent on the mixing of inflowing Mediterranean water with: a) the polluted water from the El-Tabia pumping station; b) the brackish water of the Edku lagoon discharged through the Maadiya outlet; and c) the Nile water from the Rosetta mouth. Since 1966, the amount of Nile water discharged into the Mediterranean through the Edfina Barrage has been greatly reduced (on the average about $3000 \times 10^6 \text{ m}^3/\text{y}$), and, contrary to the previous conditions, most is discharged during winter. The discharge from the El-Tabia pumping station includes drainage water from the Beheira Province. In the bay the occurrence and distribution of mixed salinity water is controlled by the velocity and frequency of the prevailing northwesterly winds and by the amount of lake discharge. Usually, the coincidence of increased amounts of drainage water in summer, with low velocity NW winds, favours a lake-sea current.

3.2.3. Surface and bottom currents

Water circulation in the Mediterranean is characterized by a counter-clockwise gyre (Fig. 3.12). The Atlantic water surface flow follows the north coast of Africa, pressed south by the Coriolis effect; the layer thins from around 150 m near the Strait of Gibraltar to 40 m off Sicily, and in the Eastern Mediterranean, where its velocity is lower, more so in summer than in winter. Along the African coast the main current is affected by winds which, because of the summer thermocline, create additional currents of a magnitude about 1% of the wind velocity (maximum 0.25% m/sec) in a direction about 90° to the right of the wind.

In the Eastern Mediterranean the intermediate water layer moves slowly, possibly at 5-10 cm/sec. The velocities of the surface geostrophic currents off the Egyptian coast are stated to be 0.5-1.0 knots (0.25-0.50 m/sec), though velocities and directions are much influenced by wind (El Din, 1973). Off the Nile delta the surface current was responsible for transporting much of the fine silt-clay of the Nile flood over all the Levantine Basin (turbid flood water could be traced as far as Lebanon, a few weeks after discharge).

Near the delta, a weak clockwise eddy in Abuqir Bay and a stronger one (60 cm/sec, Murray et al., 1981) off Damietta are present. In Abuqir Bay the main clockwise eddy has a return flow though the sea bottom valleys in the middle of the bay; a secondary counter-clockwise eddy exists in the southwestern part of the bay.

Information about bottom currents and the extent and pattern of sediment movement on the continental shelf is still limited, as to measurements, coverage and duration. Manohar (ASRT/UNESCO/UNDP, 1976) had concluded that summer swells and winter waves should be capable of lifting sediment to depth 60 m. In fact, NE of Damietta strong bottom currents are said to have created a field of actively migrating sand ridges at depths 25-60 m (Coleman et al., 1980; Murray et al., 1981) (Fig. 3.13). Elsewhere, however (e.g. Abuqir Bay,

north of Burullus, north of Bardawil) long-period measurements had shown that near bottom current velocities were faster than 10 cm/sec (max. of 20-30 cm/sec) only 10-15% of the time (ASRT/UNESCO/UNDP, 1976; Gerges, 1981; Manohar, 1981).

3.2.4. Waves

The constant NW surface winds over the central and eastern Mediterranean in summer, generate swells with periods 9-10 secs and heights of 0.8-1.5 m, lengths 100-200 m. Wave fetch can be as much as 1000-1500 km from the Ionian and Aegean seas. From November to April WNW to ESE moving depressions cause cyclonic storms that last 4-7 days, a dozen of which strike the NE Egypt coast each winter. Storm waves have periods of 7-8 secs, are 1.5-2.5 m, up to 3 m, high and approach mainly from NW, secondarily from N, seldom from NNE, NE (Manohar, 1981) (Fig. 3.14).

3.2.5. Sea level variations

The tidal excursion is low, with a mean range of 12-30 cm (Fig. 3.15), but extreme ranges of 60-130 cm have been recorded with a 20 years cycle of recurrence (Sharaf El Din and Moursy, 1977). The tides along the Nile delta coast are semi-diurnal nature with two high and two low waters in a tidal day with comparatively little diurnal inequality.

Table 3.5

Tidal ranges on the Nile Delta coast

Location	Extreme Range (m)	Mean Range (m)
Alexandria	1.17	0.26
Maadia	0.59	0.12
Rosetta	1.05	0.20
Burullos	0.93	0.14
Ras El Bar	1.18	0.17
Port Said	1.32	0.33

Normally, the main effect of tidal oscillations is on the dynamics of the lagoon outlets. During storms, however, sea level can rise up to 1.5 m (wave set-up in conjunction with high tides). Thus several stretches of the coast tend to be flooded each year.

Water levels are expected to be magnified under the joint occurrence of storms and spring tides. Spring tides occur once every 14 days and storms ("Nauwat") occur along the Nile delta coast with a frequency of about 15 per year with a duration of 3 to 4 days. This suggests that spring tides and "Nauwat" could coincide about twice a year.

Data regarding maximum annual water levels recorded at Burullos (5 years), Ras El Bar (5 years), Alexandria (23 years) and Port Said (25 years), (Manohar et al., 1977) suggest 50 year recurrences to be 126 cm and 100 cm at Ras El Bar and Burullos, respectively, with a 20 year recurrence of 95 and 80 cm high tides.

3.2.6. Water pollution

In Alexandria and in Abukir Bay, pollution has become a serious problem (UNESCO/UNDP, 1987; Dowidar et al., 1976). About six million m³/day of agricultural drainage water, carrying agro-chemicals and trace metals, are disposed of west of the city (Mex pumping station), together with industrial wastes. Untreated domestic waste-water is released through more than 20 outfalls distributed along the coastline. Mex Bay, near Dakheila, is subjected to heavy mercury contamination from two sources, the wastes of a chloro-alkali plant and the agro-chemicals; concentration in water and sediments exceed the background levels.

The mercury level in the fish frequently rises above the standards recommended by WHO. It is highest in demersal fish such as the flatfishes and the mullidae, but also in the scombrids. Most of the mercury in their edible tissues is in organic form (70% - 90%), which is the most toxic. It is also in the Mex fish that DDT and its major degradation products, reach their highest level. The same pattern is recorded for PCBs (up to 1.3 mg/kg in the liver tissue on a wet basis).

One year monitoring of the bathing beaches of Alexandria showed that of the 12 main beaches, seven greatly exceeded all internationally-agreed standards of microbiological contamination, and five remained heavily contaminated at all times. A steady aggravation appears to have been taking place in the last few years, undoubtedly due to the increased population density.

The effects of pollution in fish resources appear to be both locally positive, by the organic input through domestic waste-water effluents, and negative, from the threat of industrial wastes. In Abuqir Bay the fish life cycle is at present seriously endangered by the smothering effect of the "black liquor" which is released in continuity by the El-Tabya paper mills (2 million m³/y, heavily loaded with particulate cellulose and lignin). The fishery statistics show a sustained drop in the landings of mullet and of shrimps, both from the bay and from the connected Edku lagoon. Flatfish such as Solea Solea from the bay have decreased in average size as a result of the deterioration of bottom fauna.

There is a high flux of chlorinated hydrocarbons into the bay from waste through the Edku lagoon outlet and the mixed industrial El-Tabya effluent. Hexachlorocyclohexane (HCH), DDE and DDD were found to be the major compounds in sea water. It is in the Abuqir sediments that the highest level of chlorinated hydrocarbons is encountered. Sediments along the whole coastal zone appear to be a sink also for PCBs and for herbicide derivatives,

trichlorophenols and PCPs. DDT, absent from water samples, was present in all sediments.

The pollution of Abuqir Bay is still more or less limited to the southwestern part. The polluted water, however, may extend under certain conditions eastward and northward, and thus affect other parts of the bay. Its spread is easily detectable and traceable because of its low oxygen content. Although mass mortality of fish and other animals have not been reported in the bay, the plankton content of the polluted area is very low and benthic life in front of the El-Tabya outfalls is completely lacking. It is expected that continued, and increasing, discharge of industrial wastes will damage marine life in the entire bay.

4. GEOLOGY AND GEOMORPHOLOGY

The Nile delta is very flat, only 18 m above sea level at Cairo, 150 km south of the coast. One third lies below 3 m elevation, and several parts of the latter area are below sea level. The coast has an arcuate shape with the protrusion of the two cusped subdeltas built by the Rosetta and Damietta branches of the river Nile. The shoreline has a length of 315 km., between Alexandria and the Bay of Tineh. East of the Tineh, the Bardawil lagoon is enclosed by a spit, the origin of which is related to the eastward drift of Nile sands.

The Nile Delta physiographic provinces of concern in this report are:

1. The lower delta plain, with its wetland belt characterized by active geological subsidence. The depressions of the present and former wetlands alternate with 1-3 m high transversal ridges formed by the present and former stream channels and canals (Fig. 1.1).
2. The delta front, with its 1-10 km wide sand belt made of beaches, dunes and backshore sandy plains, and shaped by the coastwise movement of sediment by littoral currents and by winds.

The lagoons cover large areas, although their size has been considerably reduced in recent decades, because of land reclamation (Table 4.1). They are shallow, dotted with islands and communicate with the sea through a single outlet each. Besides the Nile mouths, there are only two canals that open directly to the sea, the Kitchener Drain east of Burullus, and the Gamasa drain.

Table 4.1

Size reduction of coastal lakes due to reclamation since 1964

	Before 1964	1985	
	feddans		Km ²
Maryut	33,000	25,000	63
Idku	45,000	27,000	147
Burullus	136,000	81,000	462
Manzala	300,000	200,000	1,350

4.1. The formation of the Nile Delta

Unlike other major deltas of the world (e.g. Mississippi, Niger) the delta built by the Nile river is of relatively recent geological age. A paleo-Nile started to advance across a marine embayment in the Late Pliocene, and developed especially in the Pleistocene, through the periods of major climatic changes associated with the four glaciations. Sea level rose and dropped at times of glacial maxima and climatic optima. In the period of low sea level stands, large quantities of sands and muds were transported and dispersed far into the Eastern Mediterranean forming a large submarine fan. At the time of the last glacial maximum, 18,000 years BP sea level stood 120 m below the present. The rise occurred, through periods of standstill and perhaps reversals, until 8-7000 years ago, averaging 12 mm/year.

In the period between 8000 to 5000 BP, when the rate of sea level rise began to taper off, the marine transgression had reached its maximum extent, as far as 10-20 km south of the present lagoons. The deltaic regression started with the development of small delta lobes (Coutellier and Stanley, 1987; Sneh et al 1986; Sestini, 1988), related to several Nile river distributaries, which are named with reference to the known river channels and mouths of the V-III centuries BP (ref. accounts by Herodotus and Strabo) (Fig. 4.1). In the east the lobes built by the Tanitic, Mendesian and Pelusiac, and the later Damietta branches overlapped each other in time. The lobes, typically deflected eastward, were probably cusped subdeltas with a notable asymmetric growth of beach ridges.

Two thousand years ago the main flow was through the western (Canopic) and the central (Sebennytic) Nile branches. The Rosetta and Damietta branches were then no more than canals. The disappearance of the older distributaries occurred mainly in the II-V centuries AD, the eastern branches (Tanitic, Pelusiac), and perhaps the Sebennytic branch, persisting until the IX century (Toussou, 1934).

The position of the coast about 2000 years ago can be estimated with reasonable approximation from historical information. In Abuqir Bay the extent of the Canopic delta lobe is well documented by archeological and geological data. The growth of the Rosetta and Damietta cusped heads can be calculated by reference to the position by the sea of the respective towns at the time of their foundation in the IX Cent. AD. Off Rosetta, advance from 900 to 1800 AD was 10 km, at Damietta 15 km; southeast of Port Said, similarly dated progradation between 850 and 1800 AD was about 9 km. A series of old shorelines near Tineh (Sneh & Weissbrod, 1973), can be traced through the relict beach ridges of the Manzala lagoon islands. The coastal bulge at Port Said appears to be the remnant of an advancement by the ancient Mendesian and Tanitic branches between 3000 to 1400 BP (Coutellier & Stanley, 1987).

Although in Late Dynastic-Ptolemaic times much of the northern delta was lakes and swamps, as shown by archeological records, the Burullus and Manzala lagoons were not as extensive as today. Smaller lagoons or lakes, may have represented interdistributary bays, closed-in by the coastwise extension of

spits issued from the various cusped subdeltas. They may have developed also out of flood basins, especially during stages of higher Nile floods. The lagoons expansion during the last 2000 years has been irregular, mainly due to subsidence behind a stable beach barrier. There is a record of a rapid spread of swamps and lagoons since the V-X centuries, also in coincidence with major earthquakes (Tousson, 1934; cf. Ben Menahem, 1979).

Coastal changes can be followed from maps since early XVIII cent., and with more precision from topographic surveys since early 1800. Throughout the last century there was a steady advance of the Rosetta and Damietta promontories, respectively averaging 30 and 10 m/year, and accretion in all the embayments towards the east. The shores east of Baltim Beach Resort, as far as Gamasa, and east of the Port Said protrusion, were advancing. The only exception was a slow retreat of the Burullus promontory, from west of El Burg to Baltim Beach (800 m in 100 years?), a tendency probably dating back to the disappearance of the Sebennytic mouth, which was located farther north. Stretches of the Manzala barrier were also retreating.

The typical morphology of the promontories was well displayed in maps of the 1810-1910 period of active progradation and in pre-1964 air photographs. In late XVIII-early XIX centuries the fast growing Rosetta promontory was characterized by a channel bifurcation with a middle-ground mouth-bar, which in 1857 had become a large E-W lunate bar. Later the channel became unique, with very active advance to north and the rapid growth of a succession of beach ridges to northeast, that enclosed narrow, crescentic lagoons. This river-discharge dominated morphology was displayed in even larger scale by the Damietta subdelta, where bundles of reciprocally cutting ridges witness to periods of advance and retreat (Fig. 4.2).

About 1910, an overall 25% decrease of Nile discharge, due to reduced monsoonal rainfall over eastern Africa (Rossignol-Strick, 1983), started the present period of coastal instability and of headland recession. From 1910 to 1965 the Rosetta promontory receded by 2,5 km (with the destruction of the first lighthouse); the Damietta promontory by about 2 km.

4.2. The present coastal and lowland morphology

The lowland belt of the Nile Delta under 2 m elevation, is 30 to 55 km wide. It can be subdivided into six sections on the basis of the higher-ground watersheds that are ± normal to the coast.

4.2.1. Alexandria to Abuqir

In the west, the Alexandria coast from Agami to Abuqir is cut into a fossil dune ridge 5-10 m high (up to 20 m south of Dakheila harbour), there are 2-3 m cliffs and numerous small pocket beaches between rocky capes (Fig. 4.3, 4.4). Besides the harbours of Alexandria-Dakheila and Abuqir, the coast is intensely built-up, with a major 20 km road by the sea (the Alexandria "corniche") protected by a bulkhead wall. Intense recent urbanization has occurred near Montaza and at Maamura.

South and east of Alexandria lie lake Mariut and a large (840 km²) agricultural area, both 1-3 m below sea level, which extend over the sites of former lakes Mareotis and Abuqir (Fig. 4.3). Drainage is provided by pump stations at Mex (Alexandria) and El Tabya (Abuqir), and marine flooding is prevented by the 10 km long Mohamed Ali 4 m high sea-wall. The Abuqir and Mariut lowlands are separated by the elevated (1-2 m) ridge of the Mahmoudia Canal (with the Alexandria-Tanta road and railway). On this ridge lies the only important town of the Alexandria hinterland, Kafr El Dawar. Lake Mareotis had become dry by the end of the XVIII century, but flooding was artificially caused during the Napoleonic invasion of Egypt. Land reclamation gradually followed in the second half of the last century; Abuqir lake was finally drained in 1882. Most of the plain is now < - 2 m. The level of Lake Mariut is maintained at - 2.8 m by pumping at Mex. The lake is divided into three basins, by the El Umm Drain (which crosses the lake, but is not connected with it, being at a higher water level), and by road and railway embankments. The Nozha aerodrome, to the NE, is an artificial basin 5 km², isolated from the lake since 1939 and used as a fish farm. The western end of Mariut is cut-off and has become a 30 km long (> 110 km²) saline lake, which is periodically flooded, and has salt-marshes at the edges.

4.2.2 Maadia to the Rosetta Nile

The Abuqir lowland and Idku lagoon are separated by a ridge, 1 m (in parts 2-3 m) high above sea level, that follows the course of the former Canopic branch of the Nile (Fig. 4.3). Lake Idku has a depth of 1-2 m and several islands; its outlet is 250 m wide and is presently protected from silting by two jetties, 250 m long. The outlet is important for navigation, fish migration and the discharge of agricultural drainage. The plain south of the lake (..... km²) is interrupted in the western part by a series of ancient (<5000 y/BP) dune ridges 4-7 m high, that are stabilized by plants. Some of the islands in lake Idku are also made of dune sands. The only towns of importance are the fishing centers of Maadia and Idku.

The eastern shore of Abuqir Bay is flanked by a sandy desertic plain up to 6 km wide, with scattered low dunes. Parts of the plain are below sea-level and become flooded by rain during storms. There is a discontinuous narrow strip of 1-2 m dunes by the beach.

Much higher and extensive are the Idku and Rosetta dunes, in several parts between 10 and 20 m. Although the dunes are active, moving with the predominant NW winds, they are cultivated (orchards and date palms) in the lower parts and hollows, especially on their south and east sides. At the western margin of the Rosetta dunes the El Rashidya Canal (with the Abuqir-Rosetta railway embankment) has permitted a certain westward expansion of agriculture.

In the Rosetta promontory the Nile has formed a ridge of land >1 m (the river levees are generally 2-3 m high) that protrudes between the lowlands of eastern Abuqir Bay and the western depression of the Burullus lagoon. The latter is an area characterized by fluvial ridges, dunes and patches of land below sea-level (former lakes, now reclaimed).

The effect of the recent strong erosion of the Rosetta promontory is that a large quantity of sediment is constantly shifted in the Nile estuary and the shape of the mouth is ever-changing; shoals and sandbars are formed across, generally attached to the western shore, blocking the channel. Of the two forts built in 1860, only the eastern one is still standing, while the 1945 lighthouse has been overcome by the sea (Fig. 4.2).

The town of Rosetta is protected by the high dunes, but to the north there is a fairly large agricultural area (Gezirah El Khadra), which lies under <1 m and borders on the marshes of the promontory; for decades it has been protected by a 2 m earth dike, now complemented by a sea wall under construction.

4.2.3 The central region (Rosetta to Gamasa)

The central region comprises the barrier between Lake Burullus and the sea, the south shore and islands of Lake Burullus, and the coastal belt from El Burg to Gamasa, including the low lands of Biheiret El Bessar (Fig. 4.5).

The barrier tapers out from the southwest, where it is about four kilometers wide, to a few hundred metres in the northeast, near the lake outlet at El Burg. It is formed by a few meters wedge of sand over lagoonal clays.

Between Abu Khashab and Hanafi the coast is flat and the barrier between the sea and Lake Burullus is mostly a backshore plain (0.5-1 m elev.) with low dunes (1 - 2 m) on the south side, isolated or in continuous belts. Between lake and sea rise also a few, conspicuous isolated dunes (e.g. Kom Mastaro, 12 m; Kom El Maqsaba, 9 m; Tell el Meqluba, 7 m). In winter the plain tends to be flooded by storm surges.

The shore is straight and smooth and the beach sands are relatively fine grained and increase in size toward Hanafi. They are much coarser grained (0.250-0.500 mm) at Burullus, as far as Gamasa, than either at Rosetta or at Ras el Barr.

The outlet of the Burullus lagoon has always been unstable, but before the 1940's its tendency to migrate eastwards, due to littoral drift, was balanced by strong in- and out-flows between sea and lagoon. The need to keep the channel open for fishing needs, prompted the erection of fixed structures. As a first 250 m long jetty on the west side stimulated erosion on the east side, a sea wall (now restructured, 1.8 km long and about 3 m high) was built to protect the town of El Burg (Fig. 4.6).

Between Burullus and Gamasa the shore is characterized by large asymmetric beach cusps with an average length of 400-600 m, a width of 80 m, exceptionally reaching 200 m. Because of their eastward movement, the shoreline at Baltim Beach Resort has a variable position from year to year.

East of El Burg, the coastal zone is a distinctive morphological unit, in the average 10 km wide, characterized by sand dunes and sandy depressions. In the Baltim peninsula, between Lake Burullus outlet and the Kitchener Drain, there are two belts of dunes, a main one along the coast, up to 18 m high, and a smaller and lower one (2-5 m) between El Burg and Baltim town. In the area between the two belts there are several basins; some are permanent lakes, others (below sea level) are flooded during winter and used as salt pans. Date palms and vegetables are grown on the sandy soils; the main resource of El Burg and Baltim is, however, fishing.

Between Kitchener Drain and Gamasa the dunes rise over a backshore plain for one to two kilometres inland. The dune belt is more continuous and higher in the south, although there are some large gaps and many parts are below sea-level. This area is still largely uninhabited.

Lake Burullus (65 x 6-12 km) is very shallow (1.6 to 0.5 m), especially in the eastern part, which has a tendency to become muddy and more brackish, due to agricultural drain discharge. As many as 50 islets dot the lake; some form alignments which may represent elevated relict stream channels.

The south shore of the lakes has moved 10-12 km north since 1800, partly due to sedimentation, partly to land reclamation. Large areas in the northern part of the lower delta, as far as Kafr El Sheikh, have been marsh and swamp for centuries. Before reclamation in the 1960's, a variety of distinctive lower delta plain morphological units could be mapped (Fig. 4.8).

The plain below 1 m elevation is very extensive. The only reliefs of significance are thin sinuous ridges, generally 2 m (locally 5-6 m) high, that are the remnants of past Nile channels (the Sebennyitic and Thermoutiac branches, Tousson, 1934). The Sebennyitic branch probably discharged north of the Baltim Beach Resort area, as shown by borehole information (Fig. 4.7). The cultivated plain is separated from the belt of marshes near the lakeshore, by a continuous dyke, which is generally 3-4 m high.

4.2.4 Gamasa to the Damietta Nile branch

In this stretch there is a zone 4-5 km wide with a flat backshore plain and dunes; the dunes (max elev. 2-3 m) form two belts, a discontinuous northern one with N-S trending seif dunes, a southern continuous one that is oriented E-W. Between the dunes, at several places there are very low areas, especially NW of Damietta, where the new harbour and industrial area are located (Fig. 4.8). The beach is smooth and has a low gradient, no dunes line the upper beach. At the Damietta mouth of the Nile there are various protective structures (a pier at the tip of Ras El Barr tongue, a seawall and several groins, built partly to stabilize the estuary, partly to protect the beach resort).

East of the mouth, the shore at present is oriented almost E-W (the old Damietta-Port Said road and its low protection wall, have been in constant need of repairs, due to shore retreat). Eight km eastwards, the coast turns SE, with a large protrusion, resulting from the growth, since the 1950's, of a series of new curved spits. This part of the Nile subdelta is made of a series

of beach ridges with lagoons in between. The ridges, composed of very fine sand a few meters thick, rest on marine silty clays (Anwar *et al.*, 1984). It is a region without cultivations and almost uninhabited.

By contrast, the Damietta Nile embankment is intensively cultivated and has a high population density (Fig. 2.2). The alluvial ridge is 2-3 km wide, one meter high (the 2 m contour is located 24 km south of Damietta) except for the levees of the Nile ($\pm$ 2 m) and the town of Damietta, where the ground is about 1-2 m above sea level.

4.2.5 Damietta to the Suez Canal

The mean features of the shoreline east of the Diba Embayment is the narrow width (few 100's m) and low elevation (no dunes) of the lagoonal barrier, the two narrow (canalized) outlets of the Manzala lagoon, which are armoured by short piers, and the 4.5 km long jetty at the east end of the Suez Canal entrance. Port Said was built over an area of only ... km², but recent reclamation south of the west side of the Suez canal and of Port Fouad, after the excavation of the new Canal Bypass, have double available land for urban and industrial uses (Fig. 4.10). The natural elevation of the city is no more than 1 m.

The vast Manzala lagoon is very shallow (approx. 1 m). Numerous chains of islands subdivide it into several basins which are connected by shallow, relatively narrow channels (Fig. 4.11); the islands are rapidly growing in size and number, due to reed growth and silting. The northern part is almost cut-off by large islands and by the new Damietta-Port Said road. This part is in communication with the Nile through the Inanya Canal, east of the Damietta Nile mouth. A navigation canal (2 m deep) extends from Damietta to El Mataria and to Port Said. The bottom sediments of the lagoon are silty clays in the western part, which is under the influence of freshwater discharge (major canals and drains, e.g. Bahr Saft, Bahr Hadous, Ramsis drain, had built fairly large, digitated deltas in the lagoon). The sediments become more sandy towards north and northeast.

The lowland under 2 m adjacent to the western shore of the lagoon is quite extensive; it is divided into lower (<1 and <0 m) and higher (1-2, even 3 m) sections. The outstanding alluvial ridge is that of the Saghir Drain, which follows the trace of the ancient Mendesian Nile branch. It supports the towns of Birimbal and El Manzala and the main road and railway to Mataria. The lands north and south of this ridge are well drained and cultivated; the lake margin is dyked all along the northwestern part.

The south and southeastern parts of the Manzala lowland were until recently an extensive area of marshes, lakes and salt pans. The area under 1 m and below sea level, extends as far south as a line from Qantara to Tineh, and to a distance of 15 km north of Ismailia (Fig. 1.1).

4.2.6. East of the Suez Canal to North Sinai

Between Port Said and Tineh there is a cut-off portion of lake Manzala (El Malaha lagoon) and a salty sand plain. The Malaha lagoon (12 x 15 km) is very shallow, mostly a few dcm, locally up to 1 m depth (but it can be totally dry at times); the western part has been reduced by the excavation of the Suez Canal Bypass. The plain is almost entirely composed of NW-SE trending ancient beach ridges, which converge in the south, east of Tell Farama. Flooding is common in winter from rains and sea washovers.

East of Tineh, there are large salt flats and gently undulating dunes, 5-10 m high. The Bardawil lagoon is 85 km long, and has a maximum width of 22 km; it is closed by a thin sand barrier (300-1000 m), which is frequently overtopped by waves. There are three outlets through this barrier, two are artificial and in constant need of dredging; the natural outlet is at the eastern end of the lagoon. The average depth of the lagoon is 0.5 m (max 3 m), the bottom is sandy. Salt marshes line the south and eastern shores.

Apart from the lagoon, there is no low lying land in north Sinai, because of the development, close to the coast, of high dunes (up to 50 m). No land is suitable for large scale cultivation. Most of the dunes are stabilized by shrubs, and by gypsum and carbonate cementation; some dunes are moving, or partly moving, especially around the date palm groves, and to the south of the salty areas.

4.3. Subsidence

Considerable subsidence of the coastal zone is indicated by the 10-50 m thick layer of post 8000 BP nearshore marine, lagoonal and deltaic sediments, with rates of deposition as much as 5 mm a year in the NE part of the Nile Delta (Coutellier and Stanley 1987). At the margin of Abuqir Bay, 15 m of now compacted lagoonal/beach deposits represent sedimentation since 4800 ± 150 y/BP (UNDP-UNESCO, 1978). Other evidence for continued subsidence during the last 2000 years is the following.

1. Roman ruins (Alexandria to Abuqir) today at 5-8 m below sea level, lie deeper than accounted for by a sea level rise of 1.5/cm/100 y.
2. The occurrence in the lagoons of drowned river banks and beach ridges, and of submerged ruins.
3. The many areas that are at present below sea level by 1-3 m (Figs. 4.3, 4.4, 4.8, 4.9). They include reclaimed lands south of the Burullus lagoon, where drainage waters have to be pumped upwards to the lagoon.

In the Suez Canal region, north of Ismailia, a sinking of 50 cm in 80 years was documented by Goby (1952), on the basis of continue precise surveys, while at Port Said, tidal gauge records for the period 1922-1950 have suggested a subsidence of 4.8 mm/year (Emery et al., 1987). Thus, the eastern part of lake Manzala (Port Said and the northern part of the Suez Canal zone) appear to subside quite fast, at the rate of 5 mm/year (Emery et al., 1987; Stanley, 1988).

4.4. Soils

The soils of the Nile Delta lowland belt are genetically related to the major morphologic units of alluvial plain deposition, as these were still shown in a natural condition before land reclamation (Fig. 4.10): sand dunes, coastal sandy plains, Nile levees and channels (silt to fine sand), Nile flood basins made of silt, areas of marshes. Modifications have been introduced by agriculture according to its date.

The sandy soils of the coastal littoral belt are rich in CaCO_3 . The thickness of the "A" zone is generally 40 cm in the areas between the sand dunes.

Deposited in the brackish water of lagoon-lakes and swamps, the clay soils of the fluviomarine marshlands contain little lime but much salt and gypsum. The exchangeable Na and Mg are high and the soils are therefore saline/sodic. They are all heavy clays, but locally loam subsoils may provide better drainage. The clay soils of former swamps are rich in organic matter.

South and between the lakes, recently reclaimed areas have soils generally made of fine textured clay, and silt, poorly drained naturally unless mixed with shells. The water table is shallow, about 50-100 cm from the surface. The soils are saline sodic (Salorthids) with a high concentration of salts on the surface before reclamation. Vast areas were leached, drained and irrigated with Nile water, frequently applied to improve the physical properties of the clay impermeable soils and to decrease their exchangeable sodium content.

4.5. Coastal processes

In the Nile Delta wave energy concentration is particularly high on all NE-trending coastal stretches and the promontories (Inman and Jenkins, 1984; Manohar, 1981). The NW oriented stretches are attacked more by NW and N waves in consequence of refraction, than by the less frequent NE and NNE waves (Fig. 3.13)

The oblique wave approach generates a strong longshore current system (mean velocities of 20-50 cm/sec, maximum of 80-140 cm/sec). The eastward littoral drift drives the beach and nearshore sands of the Nile Delta as far and beyond north Sinai. The erosion and intensity of sand transport are considerable, but coastwise rates are uneven, because wave refraction produces a complex pattern, with pronounced zones of convergence and divergence due both to the variability of wave approach and intensity and local shoals. Conservative estimates are that one million m^3 of sand are moved yearly, yet being as low as 60.000 m^3 a year in the shadow zones and in the embayments east of the promontories (Tetratich, 1986).

In addition, large amounts of sand have been and continue to be subtracted from the beaches by the offshore winds. Estimates of sand losses are in the order of 200.000 m^3 yearly, west of the Rosetta mouth, of 400.000 m^3 a year in the Burullus-Ras El Barr coast (Tetratich, 1986).

Prior to the final 1964 closure of the Aswan High Dam, the Nile in Egypt carried at flood time (July-Sept.) about 150 mill. tons of sediment, 15% of which is estimated to have been deposited south of Cairo, 20% in the delta. A yearly average of 85-90 mill. tons was discharged into the sea in late summer, 65% through the Rosetta, 35% through the Damietta branches. One third was fine to very fine grained sand (0.125-0.065 mm), which was deposited in the immediate vicinity of the mouths, and then reworked in winter by waves and littoral drift, though still close to the shore.

Two thirds of the Nile sediment was carried in suspension. Given the high salinity of the Mediterranean water the consequent stratification of the Nile fresh waters created a large eastward deflected surface plume of suspended fine silt and clay. Such turbid plumes are still formed today, as shown by satellite images (UNDP/UNESCO, 1978; Klemas and Abdelkader, 1982), most of the coarser sediment in suspension stays in a 2.5-7 km wide belt nearshore, where coastal processes are most active, with on- offshore and lateral sand movement through a system of submerged sand bars (Manohar, 1981). At a few points on the coast (e.g. in the middle of Abuqir Bay between Rosetta and Burullus, east of Port Said), there may be offshore sinks, with sands being moved off the coast, onto the continental shelf (Inman and Jenkins, 1984).

During the winter storms, the deeper fine-grained bottom sediment (silty clay) off the Rosetta and Damietta capes is stirred into suspension and moved seaward, mainly east (Summerhayes et al, 1978). At present, as all these processes of coastal activity carry on, the only source of sand is the shore itself, and the shallow marine offshore to 30 m depth, where areas of relict (Holocene) sands have been mapped (Summerhayes et al, 1978), in some with active sediment movement (Coleman et al, 1980).

Retreat is continuing on all the most exposed parts of the coast, though the beginning of instability has been noted also elsewhere. There are a number of stretches where shoreline variability has created problems in relation to local, existing or planned uses (Fig. 4.14).

The following is a brief review of the present behaviour of these coastal stretches, as they appear 25 years after the cessation of Nile discharge, and after 20 years of monitoring by the Coastal Research Institute, the Suez Canal Authority, the Coastal Protection Authority etc. (UNDP/UNESCO, 1978; Tetrattech, 1986).

- (a) At Alexandria, as the coast is directly exposed to the NW and N waves, the eastern and western harbours outer sea walls are in constant need of attention due to frequent overtopping by waves. The small beaches of the city are retreating because there is no littoral drift supply of sand (sediment movement is complicated by the rocky capes, islands and shallow submerged rocks).
- (b) In Abuqir Bay, the Mohamed Ali sea wall acts mainly as a vertical structure, that can be undermined by scouring. The wall is subjected to violent action by storm waves: waves 1.8-2 m high are common during

winter storms and are said to cause 10-20% damage; damage from the less frequent >2.5 m high waves could be as much as 40%. The wall has had to be renovated in the period 1981-1984. The shoaling problems of the Idku outlet have been remedied by the existing piers, but flooding is common in the town of Maadia, and there is a tendency to erosion towards the west. The eastern Abuqir Bay shore is fed from the erosion of the Rosetta promontory, but as the dominant feature of littoral drift is a nodal zone located about 18 km east of Idku outlet, where sediment is moved seawards, the beach nearshore zone has steepened and is no longer in equilibrium. Because the beach is low and unprotected, washovers of the backshore plain are frequent during NW storms.

- (c) The accelerated retreat of the Rosetta headland and proceeds more by the down cutting of the Nile west bank, than by erosion on the NE side. The rate of retreat 1970-1987 had increased to 80--120 m/year. While erosion causes a regression of the beach barrier, the sea progressively cuts into the top layer of beach sands, exposing the underlying finer grained marine sediments (Fig. 4.8). A seawall, or dyke, 6m high, is being constructed which should eventually check the progression of retreat before this involves agricultural land. In the long term, however, consideration may have to be addressed to erosional effects at the western end of the wall.
- (d) East of the Rosetta promontory, for 30 km, the shoreline tends to be stable and will presumably continue to be so for another 2-3 decades. East of Hanafi, however, to 6 km west of the Burullus outlet the shore is narrow and the swash zone has tended to steepen with some retreat. It is a stretch of historical retreat, but this may also have been influenced by the structures at the Burullus outlet. Here the jetties help to maintain an open channel and have reduced silting, but a large spit has formed at the entrance on the east side, and shoaling is common nearshore in the months of low outflow (January-April). Trapping of sand west of the outlet and the strong summer outflow prevent littoral transport in the breaker zone, the town is protected from erosion by a renovated sea wall, but at the east end of the latter, a serious downcutting of the sand dunes by 6 m/year has occurred since 30 years. Land has however extended towards the lagoon (Fig. 4.6).

Further east, the Burullus headland is retreating (by an average 10 m/year), with erosion of the dunes. At Baltim Beach Resort, where the shore had been periodically fluctuating with a cyclic erosion-accretion pattern associated with the migration of mega cusps, there is now a slow retreat, averaging 3 m/year. Short of beach protection (i.e. sand nourishment), the present resort town will be destroyed by 2000 AD. Active longshore and seaward sand transport prevails eastwards to Gamasa; the coast is stable or accreting, but a certain steepening of areas beyond the breaker zone has been recorded, an indication that further retreat at Cape Burullus, and perhaps a diminishing sand supply, could eventually unbalance this stretch as well.

- (e) The stretch from Gamasa drain to Ras El Barr is one of moderate longshore activity, but a drift nodal point lies 7 km west of Ras El Barr, and retreat has occurred in the eastern part (e.g. 250 m from 1945 to 1975), in association with the retreat of the Damietta headland. The New Dumyat Harbour development is located astride this stretch of zero drift. The jetties will cause accretion on both respective, western and eastern sides, and probably modification to the local wave climate and current regimes (the 2 km long west jetty extends to 8 m depth and the area is exposed to N and NE waves, as well as to the NW waves). Artificial sediment bypassing may become necessary by 2000 AD.
- (f) Due to the predominant NW wave approach, erosion of the Damietta promontory has been characterized by a flattening with a considerable eastward transport of sand, as far as a nodal point 8.5 km east of Ras El Barr. The entire promontory is under erosion, to 3.5 km west, and the Ras El Barr protective structures have been only partially, or temporarily effective. Circulation in the Nile estuary is at present entirely tidal (there is no river flow from the Faraskur dam) and dredging is necessary. Sand movement is caused by a frequent state of agitation, whatever the wave regime, possibly due to refraction from the structures, as well as from offshore shifting sand bars. East of Ras El Barr there is an earth dyke that extends as far as the spit; its envisaged revetement into a stronger structure, could eventually increase the erosional problems of the Nile mouth area.
- (g) The whole stretch Damietta to Port Said is very unstable due to a very active longshore sand migration. The spit has been growing by 90-100 m/year and the shoreline for 15 km eastwards is under its dynamic influence, with a series of erosion-accretion patterns; the Diba embayment and hump are features that move by 100 m/year; eventually they, and the spit, might encroach on the new Manzala lagoon outlet.

The stretch 19 km west of Port Said is a unit in itself. It is a weak area, except for the four km west of the Port Said western jetty, which has been accreting for over 100 years, though at slower rate in the last decades. It is characterized by long term retreat (the barrier between lake and sea was reduced from 1000 m to 200 m width between 1810 and 1945, and some retreat has occurred since then), and by frequent flooding from the sea.

East of the Suez Canal, the erosion of the Port Fouad beach has naturally resulted from the lack of sediment supply from NW. Long-term erosion of the formerly advancing coast, east of Port Fouad and the new Canal Bypass jetties, is inevitable; this and the frequent flooding of the plain, as far as Tineh, could have a negative impact on new land reclamation schemes there.

Various projects of coastal protection are now under consideration by the Coastal Protection Authority. Generally, the factor of a possible increase of sea level rise is not taken into account. A positive approach, nevertheless, is the proposal to establish "set-back" lines, for development at no less than 250-500 m away from the shore (Fig. 4.14).

5. HYDROLOGY AND WATER RESOURCES

The Nile delta coastal zone is almost totally dependent on the Nile for its surface and ground-water needs. The building of the Aswan High Dam has permitted the storage of the annual flood and the year-round irrigation of all lands presently cultivated; in addition to electricity production, a substantial amount of water has become available for agricultural expansion. However, there is still a pressing need to pay close attention to the most efficient use of the stored water, especially to allow new land reclamation. Various projects are under consideration for optimal water conservation, in the face of the basic needs of power generation, navigation, urban and industrial uses, after taking the losses due to evaporation and percolation into account.

Measures to conserve water (ref. Master Water Plan, 1984) regard increased usage efficiency and the reduction of non-beneficial flows into the Mediterranean. Water used for irrigation, and the urban-industrial waste waters are returned to the river, and drained through the coastal lakes and canals to the sea. Extra water also flows to the sea in winter, when irrigation requirements are reduced.

Egypt now receives, by international agreement, 55,5 bill. m³ of Nile water through the High Dam lake. In future this quantity might be increased by various water-saving projects in the Sudan and neighbouring countries. However, variations of monsoonal rainfall over the highlands of East Africa have been considerable in the more recent and distant past with a profound effect on Egypt's water resources and well being. Witness of such impact is the present low water situation in the Lake Nasser reservoir, in consequence of years of drought in Ethiopia.

5.1. The Nile today

The course of the river Nile is divided roughly into three parts: the lower Nile to Aswan (First Cataract); the middle Nile, between Aswan and Khartoum, and the two upper branches, White Nile from Ugands, and Blue Nile from Ethiopia (Lake Tana) (Fig. 5.1). At present the Blue Nile furnishes on average 68% of the flood discharge and 72% of the sediment load; it is fed by the summer monsoon rains that fall over Ethiopia.

The discharge minima in winter reflect the equatorial rains in East Africa supplied more sluggishly by the White Nile, the flow of which is strongly retarded by the swamps of the Sudd, in southern Sudan.

In this century from 1902 (first Aswan Dam) to 1964, aqueous discharge at Aswan was an average 84 bill. m³ year, mostly (93%) between July and November, with a peak in the flood months of August-September. The range was 45.5 to 140 billions m³/year. Between Aswan and the sea, as much as 60% of water discharge was lost, due to irrigation, evaporation and seepage. Thus before 1964 actual water discharge into the sea averaged 50-60 bill. m³, 65% of which through the Rosetta branch ($42.9 \times 10^9 \text{ m}^3$ in 1959-1963). During the low level season, the estuaries were kept closed by the Faraskus (Damietta) earth dam and the Edfina (Rosetta) weir dam. The average discharge into Lake Nasser from Sudan, 1967-1980, has been 69 bill. m³/year; the highest was in 1978 (137 mill. m³).

The first Aswan Dam was built in 1902 and was further elevated in 1921 and in 1933. It had a storage capacity of 5 bill. m³. The capacity of the High Dam reservoir is 164.000 million cu.m³. It stores the flood water up to 84 bill. cu. meters, but evaporation losses are high: 2000 mm/year, or 15 billion m³ a year. The High Dam provides a controlled mean annual discharge of 58.60 bill. m³ of water downstream, which has enabled an expansion of the cultivated area by 1,3 mill. feddans, and a conversion of 700.000 feddans from basin to perennial irrigation. About 10.000 MW of electricity is generated annually, navigation condition along the Nile have improved and flood protection is now guaranteed.

To all intends and purposes the Nile below Aswan has been reduced to the status of an irrigation canal. Barrages at Esna, Asyut, Naga Hammadi (south of Cairo) keep the level of the river high enough all year for perennial irrigation in the valley.

Today the Nile delta region receives 35 billions m³ of surface Nile water; 33% of this amount is lost due to evapo-transpiration (12%) (which is calculated to be around 0,331 m/year, Kashef, 1981), and to infiltration to ground water aquifers (21%). The remaining surface water ($\pm 67\%$) is channelled across the delta through a system of feeder canals originating from the Delta Barrage, and from the Ismailia canal (Fig. 5.3).

Discharge of water to the sea takes place through the Rosetta and Damietta Nile branches, the lagoon outlets, the Mex (Alexandria) and El Tabyia (Abuqir) pumping stations, and the Kitchener and Gamasa drains (Fig. 5.3). In total, the average amount of water that flows out to sea is about 13-16 billions cubic meters (6 of which through the Rosetta and Damietta mouths), the average winter-excess flows are of 4 bill. m³ (1984-85, as opposed to 6 bill. m³/year in the 70's to early 80's).

The largest outflow is through the Rosetta estuary (± 25 m³/sec, increasing to 550 m³/sec in January-February), the Idku (134 m³/sec), El Burg (145 m³/sec) and El Gamil (125 m³/sec) outlets. Maximum flows through the Kitchener and Gamasa drains, and the Damietta estuary, are under 50 m³. sec.

5.2. Nile discharge variations

The most significant aspect of Nile discharge for water resources in Egypt has been its variability. In the last 100 years natural flow has varied from 150 billions m³ in 1978, to a minimum of 45.5 bill. m³ in 1913 (Fig. 5.4). In general, floods were 25% larger in the XIX Cent., averaging 120 bill. m³/year. This higher discharge was due to heavier rainfall over Ethiopia (Rossignol-Strick, 1973). By contrast, seven dry years (1979-1986) in the watersheds of the Nile have caused a drop of nearly 21m in the level of Lake Nasser, and forced successive emergency withdrawals, until the lake has hit an all-time low of 143m above m.s.l. (ref. its "full" level at 164 m), with deleterious consequences for power generation (Fig. 5.5).

Records of flood highs available from the Roda (Cairo) "Nilometer" from 622 AD and from the delta Barrage gauge from 1846 (Tousson, 1934), have shown

the existence of a short and long term cyclicity of flood volumes. In spite of large amplitude variations (30% or more of the annual flood discharge) there is a recognizable and statistically valid small scale cyclicity between high and low peaks of 8-12 and 20 years (Hassan, 1981; Hamid, 1984) (Fig. 5.4). Such cyclicity has also been evidenced by historical records in earlier times (e.g. low levels in 53-63 AD, 151-170 AD, and 254-265 AD). It is worth noting that the high flood period of 1968-1977 and the low flood period 1979-1986, have been of similar duration.

Larger cycles include 60-90 years periods which can be verified back to the X century (for instance, stages or Nile minima had been 1010-1090, 1282-1343, 1416-1534, 1645-1714, 1796-1833), and to earlier times: periods of higher floods from 500 BC to 410 AD low floods in the V-IX centuries (Butler, 1976; Said, 1981); repeated high floods in the epoch 3790 to 3725 BP, catastrophic low levels around 4130-4080.

In the present century there have been five episodes of extremely low Nile, corresponding to the great Sahelian droughts, affecting the region from western Sahara to Somalia: 1911-1915 (when the total discharge of the Nile was only 45% of the average flow), 1918-1928, 1941-1944, 1969-1972 and 1973-1976.

Years of high Nile flood have been associated not only with high tropical monsoon rains, but also with high pressure and more stormy weather over north Europe and the easter Atlantic. Hassan (1981) has shown that time of extreme fluctuations, or protracted lows, corresponded to periods of sunspot dearths. Nile floods and North and East African droughts, both have disclosed interesting chronological relationships with both solar and lunar periodicities (Fairbridge, 1984). Fairbridge has also compared the tentative curve for the earlier Nile discharge with the evidence of Late Pleistocene to Holocene climatic fluctuations (pollen records, ice-cores oxygen isotopes) and with sea level changes; he stated that there is a close chronologic parallelism, implying a common cause, probably charges in solar radiation.

5.3. Hydrology of the lagoons

The quantity and quality (esp. salinity) of drainage water flowing in and out of the coastal lakes are well known from measurements made by the Water Re-use Project of the Ministry of Irrigation. Some of the data are reported in Table 5.1. At present the total inflow of water into the wetlands is in the order ofm³/year; of this bill.m³/year flow out to sea.

At present the inflow of drainage water dominates the water balance, and hence the water quality. In spite of an evaporation rate of 170mm/month (in Burullus) to 200 mm/month (in Manzala), in June-July, with a total calculated loss of 2 bill.m³/year for the two lakes, the outflow is much greater than the tidal and occasional storm surge inflow of Mediterranean water (the rainfall contribution is negligible).

The tides do not cause an appreciable variation of water level; changes are due to seasonal differences in drain and canal discharge, highest in July-September (Burullus), June-October (Edku), September-January (Manzala, Fig. 5.6) through drains and pumping stations (three main drains flow into the Edku

lagoon, one canal and five pumping stations discharge into Burullus (Fig. 5.3), seven major canals and drains reach Manzala (Fig. 4.11).

Table 5.1

	Present area	Drain discharge	Outflow	salinity	Temperature	
					winter	summer
Mariut	63	?		1.09-263‰		
Idku	71	÷ 2 bill.		4.3-14.8‰	12.1°	28.5°
Burullus	504	÷ 9 bill.	6.2 bill.	0.5-21‰	13°	29°
Manzala	1350	÷ 6 bill.		1.44-10.6‰	11.3°	30.5°
Bardawil	700	--		41-68‰ (up to 70-120‰)	12.7°	30.5-34°

Salinity values in the lagoons are related primarily to the balance between drain water and the influx of marine water; thus salinities are quite low near the inner margins (0-5-1‰) and increase towards the outlets, where they reach values of 15-20‰. In Burullus, the higher values of the eastern part are due also to the saline drain water from the Baltim pumping station. In Manzala the northern part of semi-enclosed shallow lagoons is more saline, due to evaporation. But salinity is also related to water temperatures (which follows air temperatures), and to evaporation; it is generally higher in summer, with a maximum in July.

In general, Nile freshwater has low salinity (300ppm), drain waters salinities of 1000-2500 ppm (but they are greater in the periods of reduced flow), though some drains are highly saline year-round.

Because the lakes are shallow, and the waters are well stirred by the frequent winds (from SW in winter, NW in spring-summer, occasionally from north and NE), there is no temperature and salinity stratification.

The hydrology of the Bardawil lagoon is totally different. For centuries it was a dry salt and mud pan, occasionally flooded by storms, with local development of salt marshes. The two present outlets (Boghaz I, II) were artificially excavated in 1950. Salinities in the lagoon are normally 40‰, but rise to 120‰ in sheltered parts, 30‰ in the open parts, when the outlets become blocked. Salinity increases from the surface to the bottom, and from the northern to the southern parts; there is a definite stratification, and water levels vary according to marine inflow (which is high, after N, NW storms).

The degree of pollution of the coastal water bodies of the Nile delta varies, from considerable in Lake Mariut, to still minor, but growing, in the main lagoons. Water quality has been badly affected by agricultural waste

waters carrying pesticides and fertilizers. Drainage water investigated by the Water Re-use Project were found to be often highly saline and sodic, even toxic. Halim and Guegis (198..) have reported that drainage water is affected by the soils it permeates; soil silicates and nitrates from chemical fertilizers dissolve in large amounts and there is an enrichment in nutrient salts (P,N) with silicate to phosphate and nitrate to phosphate abnormally high ratios (400:1 and 40:1), and a high content of dissolved humic material. Consequently in Manzala and Burullus, during the last two decades, there has been an increase in phosphate, a decrease in dissolved oxygen. A part of Lake Mariut has been badly affected by agricultural waste waters carrying pesticides; it also receives untreated sewage and industrial discharges from Alexandria and through El Galaa Drain, from Kafr El Dawar. Phosphorus had increased 15 times between 1963 and 1978; P loading there is now 13.1 mg L⁻¹/year, and there are strong eutrophication tendencies. Eutrophy problems have recently appeared in Burullus, once one of the cleanest lagoons (Beltagy, 1985); organism have also revealed high concentrations of Hg, Cd, Cu and PCB's.

5.4 Groundwater

A recent water resources management program conducted by the Egyptian Ministry of Irrigation for the purpose of land reclamation (ref. Kashef, 1983) has indicated that the delta has large groundwater resources in the Main Delta Aquifer, a condined aquifer that increases in thickness from about 250m in the south to about 900m at the coast. The base is a clay aquiclude with a slope of about 5m/km (40 times as much as the ground surface). The aquifer is limited by the Mediterranean to the north, the Suez Canal to the east, and tapers off towards the western Desert.

Clay layers and pockets have been encountered within the main aquifer, possibly dividing it into several connected and disconnected smaller aquifers: they consist mainly of unconsolidated mixtures of sand and gravel.

The upper confining layer is made of clay and silts, it is 3m thick at Cairo, 40-60m at the coast (Fig. 5.7). In the thick zones there are lenses of sand. The coastal geohydrology takes place in the clayes toplayer, whereas the regional geohydrology involves the main aquifer.

In the recent past, the potentiometric (piezometric) levels in the Delta aquifer used to fluctuate in response to the river stages. After the construction of the High Aswan Dam and the closure of the Nile by this dam in 1964, a transitional stage passed for four years, after which the potentiometric levels reached a more or less stable pattern (Fig. 5.6).

The present potentiometric levels are slightly higher than those before 1964 due to the low irrigation efficiency and the slight increase of the almost stationary and regulated water levels of the Nile. The present fluctuations in the potentiometric levels do not exceed about one meter. The hydraulic gradients of groundwater flow in the Delta increase from about 8 cm/km in the South to about 12 cm/km in the North. Near the river and the canals, the gradients increase to more than 50 cm/km. The rate of flow across piezometer contour +4 (Fig. 5.8) was estimated at 0.31 km³/yr. Areas of upward and downward leakage were mapped in the delta on the basis of the recorded

differences between the potentiometric levels of aquifer and the water-table levels in the confining clay layers.

The recharge of the aquifer is mostly from the Nile (the contribution of rainfall is minimal). The aquifer is recharged through the infiltration of excess irrigation water and seepage from the extensive network of canals and drains. One major canal (Ismailia) which derives its water south of the delta, contributes to the delta aquifer about $0.695 \text{ km}^3/\text{year}$. The seaward flow of the aquifer was estimated (Kashef, 1983) to be about $0.030 \text{ km}^3/\text{yr}$ across the piezometric contour line of +1.0.

The annual infiltrated recharge to the aquifer could amount to $6.4 \text{ km}^3/\text{year}$, as the (1980) total withdrawal of ground water was about $2.42 \text{ km}^3/\text{year}$, the balance of 3.98 km^3 should represent the potential water surplus for future development, unless unaccounted losses or errors in the estimated values would appear in the future.

The balance of $3.98 \text{ km}^3/\text{year}$ is approximate, but if assumed correct, it would indicate an annual gain to the aquifer. If this were to be repeated annually, a detrimental situation could develop, leading to water logging. On the other hand, if the water withdrawal should increase more than at present level water logging would be reduced, leading to better land production, but the danger of increased salt water intrusion would appear. The amount of groundwater used in the Nile delta is estimated to be $2.4 \text{ bill.m}^3/\text{year}$ both for agriculture and urban-industrial purposes. Cairo and Giza use about 19%, most is used in the western (40%) and eastern delta regions (35.5); the least in the central northern parts.

Safe use for irrigation occurs only in the middle and southern part of the delta (where calcium amounts to $2.5 \text{ mg}(1)$). Groundwater in the northern Nile delta is generally unsuitable for irrigation due to the presence of high amounts of soluble salts derived from sea water invasion (Shata and El Fayoumi, 1970).

Special care is needed to prevent lime accumulation and soil alkalinity; where groundwater is used, more frequent irrigation and leaching at frequent intervals are needed to prevent soil drying (Ghandour et al, 1985).

The quality of groundwater is therefore a serious hindrance to its extensive use in the lower delta. The salt water wedge intrudes deep in the interior of the aquifer, to about 130 km from the sea (Fig. 5.9).

The interface between fresh and saltwater was found (by electric logging and other methods, Kashfi, 1980) to extend to about the potentiometric confined clay layer of the aquifer; the merging fresh water is lost in the northern marshes through evaporation, south of the potentiometric countour line +1.0 (Fig. 5.10).

Most probably salt water intrusion in the delta in the past was more pronounced than today, because of the flat topography and lesser recharge to the aquifer. The recent waste in irrigation water, with all its detrimental effects, acts as a huge source of recharge, reducing the extent of salt water

intrusion, while increasing water logging, which is detrimental to agriculture).

5.5. The utilization of water resources

Usage demands on Nile water were as follows in 1985 (Ministry of Irrigation, 1985): hydropower generation and navigation, at least 1.6 bill. m³/year; urban and industrial, 2.43 bill. m³/year; agriculture, 29.4 bill. m³/year. The water available at present to Egypt, by international agreement with Sudan, is of at least 55.5 bill. m³/year (ref. summary in Fig. ...).

About 6.5 bill. m³/year are returned to the river after irrigation use, mostly in upper Egypt. Evaporation losses are high, on account of present extensive waterlogging of farmland and of the large network of canals and drains, and the extensive lagoonal areas. According to Kashef (1981) it could amount to 3.6 bill. m³/year. Downward losses due to underground percolation may amount to bill. m³/year, but an estimated 2.42 bill. m³ are extracted from the aquifer, of which 1.6 bill. m³ for urban-industrial supplies and 0.82 bill. m³ for agriculture.

The largest withdrawals of surface waters for urban-industrial needs occur in the Cairo metropolitan area (pop. 6.4 mill.), while that used by Alexandria and Port Said, is a fraction of this amount, and Tanta and the central delta use groundwater. Some urban-industrial waste water is re-used for irrigation.

The water needs of industries and cities are expected to grow to 10.8 bill. m³/year by the year 2000. By the same date, the irrigation of all the potentially reclaimable land (2.4 mill. feddans) would require an extra 20 bill. m³/water a year. The 1964 Water Master Plan of the Ministry of Irrigation mentioned that water would be sufficient to irrigate an extra 1 mill. hectares, above the present 2.4 million ha. Other reviews of water resources (ref. Assen, 1983) have indicated that no more than 277 ha could be irrigated in total, i.e. an addition of only 0.3 mill. ha.

After completion of the Awan High Dam increases of water resources can come only from water saving schemes in the upper Nile basin, such as avoiding the water losses by evaporation in the Sudd, and/or raising the East African lake levels. The Sudd, canalized bypass projects Jonglei I and Jonglei II would produce 2.3 bill. and 9 bill. m³/year of extra water for Egypt (i.e. respectively 57.8 and 64.5 billions m³ of water/year).

It is clear that, if future industrial and agricultural developments that are meant to meet the demands of an increased population, are to proceed successfully, measure must be taken to conserve water by increased efficiency of usage. Reclamation efforts will have to be reduced, unless some combination of the following is enacted: (a) increased efficiency of the irrigation system, and improvement of farm management practices; (b) utilization of irrigation technologies, such as drip and sprinkler methods; (c) substantial re-use of drainage water and of city waste waters; (d) increased use of groundwater; (e) a limitation of the amount of water that flows to sea in winter, when irrigation needs are less, and its storage for summer uses.

The re-use of drainage and waste waters will certainly expand, provided that treatment plants are built to deal with water salinity and pollution. The use of ground water could also be intensified (Kashef, 1980). Since the annual recharge is estimated to be 6.4 billions m^3 , if losses and withdrawals are maintained at present levels, as much as 4 billions could be available for further developments. But, to account for insufficient present knowledge, overlooked errors and losses, a 2 billions m^3 extraction would be a safer goal.

Proper water resources management would be necessary (e.g. location of withdrawal stations, continuous monitoring of groundwater systems and of salt water intrusion, etc) and developments could be safely started only in the southern part of the delta and along the Nile branches, while extra usage in the northern areas would be delicate, requiring careful investigation, including on possible subsidence effects.

In the months of low irrigation demand (esp. during the winter closure of the irrigation system) water releases for power generation at Aswan exceed the aggregate demand for irrigation and all other uses. In the period 1975-85 water discharged to sea through the Rosetta branch ranged 4 to 11 bill. m^3 , 82% in Nov.-February; spills in the other months (0.015-0.073 bill.) are due to the difficulty of matching water release with demand.

The capture of the surperfluous Nile water flow and its storage in a portion of the Burullus and Manzala lagoons, would permit the saving of at least 2-3 bill. m^3 of fresh water to irrigate 200.000 to 300.000 feddans in the vicinity of the two reservoirs.

The plan envisages the bounding of 670 km^2 of the Manzala lagoon by a 121 km long, 2.5-5m high dyke, that would keep the lake level 0.5 to 1.5 above msl (elevations, according to different options). Water would be brought in from the Damietta branch, upstream of the new Damietta Barrage, by a 8 km long feeder canal; an additional 0.82 bill. m^3 of drainage water could also be fed into the lake. The lake water would then be pumped into the El Salam canal for irrigation use. 500 to 976 mill. m^3 of water could be stored (values depend on the reservoir volume); without increased evaporation, salinity is expected to range 400-1000 ppm.

In Burullus, an area of 470 km^2 would be encircled by a 114 km long dyke, and 1-2 bill. m^3 of water would be diverted into the lake by means of a 15 km feeder canal; 0.97 bill. m^3 could be added from drains. Water would be used to irrigate an extra 41.000 feddans to be reclaimed along the south shores of the Burullus Lake. Salinities would vary from 400 to 1100 ppm.

These large scale projects, as much as they are feasible from an engineering viewpoint, should not be considered as isolated solutions, but within the general system of water and land management in Egypt. Not only there would be a question of choices of whether to develop the lagoons for fisheries, aquaculture, water storage or instead to allow more land expansion; also, a large number of technical and environmental aspects suggest multiple feedback impacts within a complex system. Impacts, likely to be further influenced by those of climatic changes.

Examples are:

- the lakes optimal size and water levels in relation to sea water infiltration, rates of evaporation, seepage;
- the amount of water to be stored in relation to the amount and timing of the Nile surplus (itself related to Aswan releases and to future flood volumes), and to the possibility of a "staggered" winter closing period;
- actual future salinities and distribution of nutrients, and their, and water depths effects on vegetation and natural fish breeding;
- the reservoirs impacts on health.

6. ECOSYSTEMS

6.1. The marine environment

Although much reduced by reclamation, subject to many threats and nowhere protected officially (the only nature reserve in Egypt is near El Arish in North Sinai) the lagoons and wetlands of the Nile delta are vast natural ecosystems of considerable biological importance. Many stretches of shore-line and dunes are yet in a natural state and the shallow lagoons present a variety of morphological and vegetational biotopes that support a rich aquatic and bird fauna. The lagoons are extremely important for migrating and wintering birds, particularly as they are the only extensive brackish water bodies on the NE coast of Africa.

Productivity in the lagoons is much higher than in the adjacent Mediterranean Sea; fish yields for instance average 24 tons km⁻² in the lagoons versus 1 ton km⁻² in the sea. The quality of Mediterranean water remains good, but biological productivity has been severely affected by the sharp decrease of phosphates and nitrates that followed the cutoff of the Nile flood (the 1800 tons/year of phosphore and 110.000 tons of silica were reduced by over 95%) (Whaby and Bishara, 19...; Halim and Girgis, 198...). Today, Minor phytoplankton blooms still occur, in winter; biomass near the coast is 2-20 times larger than in deeper water, due to water mixing and to drainage and Nile discharge.

The shallow Abuqir Bay near Alexandria, is an important area for fish spawning (e.g. Mugil, Sparus, etc). It is being increasingly affected by industrial and agricultural pollution. The adsorption of pollutants by bottom sediments has produced a marked change in the proportion of the pelagic, versus the bottom (demersal) fauna (ref. marine fauna composition, Table 6.1) the ratio being 1:1 in the former, 0:1 in the latter (Saleh and Karashily, 1985). Decreased fish catches (Fig. 2...) are related to these impacts on the bottom fauna.

Table 6.1

Marine fauna of Abuqir Bay, Egypt

<u>Pelagic</u>	<u>Demersal</u>
Caranx alexandrinus	Trachypenaeus curvirostris
Julis pavo	strebbingi
Pagrus mormyrus	monoceros
Mugil capito	Portunus pelagicus
Sciane aquila	Solea solea
Sardinella	Mullus barbatus
Mugil cephalus	Trigia hirunda
Morone labrax	Penaeus semisulcatus
Serranus scriba	kerathurus
Pagrus pagrus	Carcinus mediterraneus
	Donax trunchulus

Some species appear not to have been much affected (*metapenaeus*, *Mullus barbatus*). The composition of the fauna has changed in consequence of the disappearance of some species (e.g. *Trichurus*, *Merluccius*, prawns like *Penaeus kerathurus* have moved to deeper areas), others have declined (*Pagellus*, Box loops, *Epinephelus*), while others have increased in number (e.g. the crab *Protunus pelagicus*, *Solea*, *Teuthys*, *Sargus*, *Chrysophis*, *Sardinella*). Nematod worms, *Caulerpa prolifera* and *Gammarus aquicauda* appear to have proliferated in the more polluted areas.

6.2. The brackish lagoons

The lagoons of Idku, Burullus and Manzala present similar features in being shallow, with a flow pattern controlled by drain discharge and a current towards the outlets, and subject to wind influence. In them, and in Lake Mariut, nutrients are supplied by the drains, with concentrations decreasing away from the inner shores. The environment provides optimal conditions for primary producers (phyto- and zooplankton): the water is well mixed in regard to salinity, temperature and nutrients, there is no stratification. An important factor is the proximity of the photosynthetic layer to the layer of organic decomposition and sediment storage; nutrients are made available also by wind stirring of the bottom. Organic production is enhanced by high summer temperatures (average July temperatures of 26°-27°C, with peaks of 36°C recorded in shallow areas). Productivity has doubled in the last 20 years, due to increased amounts of drainage water.

A considerable percentage of the water bodies are covered by aquatic plants (Fig. 6.1), especially near the south shores and near the islands, with high productivity near the mouths of the drains.

Apart from Lake Mariut, which is not connected with the sea, the fauna of the brackish lagoons is characterized by a mixture of marine forms (fishes like mullets, *Morone*, *Chrysophis* and crustaceans like *Penaeus kerathurus*, *Callinectes sapidus*) and euryhaline to freshwater fishes (e.g. *Tilapia* and the brackish shrimp *Palaemon*). *Mugil*, *Anguilla*, *Solea sparus* and several other fishes enter the lagoons for breeding; the fry of these fishes aggregate in very large numbers near the lagoon outlets (as well as in the Nile estuaries) at different times of the year, but especially in winter-spring.

The Bardawil lagoon has a different ecology, due to the lack of a fresh water input. Nutrients enter from the sea, and most fishes are euryhaline marine species.

The sediments of the lagoon bottoms are generally silty clays near the margins, mostly sand-silt-clay mixtures in the center, inner sand becoming more common near the outlets and the outer barriers. Organic matter (1-7%) and phosphorus (0.116-0.103) are higher in the finer grained sediments. There is a gradient of nutrients (phosphorus, silica, nitrites and nitrate) northwards and westwards (or outlet-wards). Oxygen in Manzala lagoon ranges 73% to 126% saturation up to 216% in plan areas near drains. Primary producers lay a greater demand on nitrates (which are usually depleted in summer) than on phosphates, and especially on silica. In Manzala (Halim and Gieges, 1985) a heavier eutrophication load is indicated by a decrease in oxygen concentration,

with values as low as 54.4% recorded in the early 1980's. Phosphate has increased from 0.54 ug-atom litre⁻¹ in 1963 to 1.36 in 1987.

The highest bottom biomass was recorded (Samaan, 197..) in areas devoid of hydrophytes (17.48 gm fresh weight/m²); the lowest in the plant areas and in the region of lake-sea connections (8.98 gm wg/m²). The bottom fauna is made of brackish-water forms that can tolerate wide ranges of salinity, mainly the polychaete *Nereis*, aphipods (*Corophium*, *Gammarus*) and pelecypods (*Ancylus*). The area covered by *Potamogeton* and *Ceratophyllum* are ne benthos-poor, especially where the plant cover is dense (6 gm wt/m²).

Large parts of the lagoons (Fig. 6.1) are covered *Phragmites communis*, *Potamogeton*, *Typha latifolia* and *Juncus acutus*, *J.maritimus*. In Burullus and Manzala the shores of islands (especially on the down wind side) are thickly covered by reeds. The submerged plants are *Potamogeton pectinatus* and *P.crispus*.

In Burullus, south of the fish farms, there is a belt of brackish water marshes with *Sueda fruticosa*, *Salicornia fruticosa*, *Juncus acutus*, *Inula erythroides* and *Phragmites australis*.

In the Manzala lagoon vegetation and open water alternate, vegetation consists mostly of *Phragmites australis*, *Typha*, *Ceratophyllum demersum* and *Potamogeton pectinatus*. Extensive *Salicornia* marshes are found along the coastal road between Damietta and Port Said. The submerged plants (*Potamogeton*, *Ceratophyllum*) propagate mainly by rhizomes, their main growth period is in the spring. The plants produce oxygen, but nutrients are drastically reduced in the plant belts.

The phytoplankton is characterized by continuous blooms that increase at the time of high drain discharge. In the Idku lagoon phytoplankton production was estimated to be 0.604 gm C/m²; the lagoons are considered to be mesotrophic. There are significant phytoplankton variations related to the distribution of nutrients. The zooplankton is characterized by a mixture of estuarine forms (copepods, balanus, Cladocea, Daphnia, Moinia, Diaphanosom) and various coastal Mediterranean forms (esp. the euryhaline *Acartia latisetosa*).

Although a considerable number of fishes is found in the lagoons (Table) the predominant species are tilapias (esp. *Tilapia nilotica* and *T. zillii*), followed by mugils. The proportions of freshwater to marine fishes depend on chlorosity, on the seasonality of drain discharge versus marine inflow. In Manzala lagoon Ezat and Hosny (1983) found the following proportions: *Tilapia* (86%), mugils (9.5%), *Morone labrax* (2.1%), *Anguilla* (1.6%); other fishes make about 1% (*Bagrus bayad*, *Labeo niloticus*, *Haplochromis desfontainesi*, *Hemichromis bimaculatus*, *Clarias lazera*, *Sciaena aquilla*, *Umbrina cirrosa*, *Morone punctata*, *Hemirhamotus far*, *solea solea*, *Sparus auratus*). In the Burullus lagoon, mullets make 15-30% of fish catches.

The tilapias thrive in the plant belts, because of the high oxygen saturation values, and because they feed on the algae that cover the leaves of *Potamogeton* and *Ceratophyllum*, and on the amphipods and snails that themselves feed on the algae and diatoms. The mullets, instead, are associated with the

pelagic ecosystem of herbivores (copepods, cladocerans, rotifers, shrimps, mysids, snails). In lake Manzala carnivorous fishes constitute only 3% of the total.

Besides the wide salinity tolerance displayed by various fishes, shrimps also are adapted to salinity variations from 3‰ to 35‰; euryhaline crustaceans can adjust, but at the lower end of their temperature range. High temperatures affect also the young mullets.

6.3. The Bardawil lagoon

The shallow Bardawil lagoon (average 0.5m, max. 3m) is very saline and has a high productivity. The bottom is covered by a seagrass (*Ruppia spiralis* and *Cladopora*); vegetation near the shore is poor (*Zostera nolti*) due to the high salinity. The phytoplankton is poor (mainly *Synedra*). There is a rich zooplankton and bottom fauna (copepods, ostracods, tintinnids, nematode worms, mollusc, shrimps and crabs).

All the fishes migrate between the lagoon and the sea, of a total of 65 species, one fifth are East Mediterranean fishes; 17 of 31 Red Sea fishes are present. The most common fishes are *Sparus auratus*, mugils (six species), which are particularly adapted to the high salinity; *Dicentrarchus*, *Argyrosomus*, *Umbrina*, *Epinephelus*, *Atherina* and *Aphanius*.

6.4. The bird fauna

The coastal lakes of Egypt present a variety of biotopes that are suitable to wintering, migrating and nesting birds: e.g. the sandy islands, the reed beds and marshes, fish culture basins and the mudflats. It has been estimated (Meininger and Mullie, 1981) that no less than 800.000 birds winter in the Burullus (Table 6.3 - the upper parts of the columns refer to species estimated to occur >1000 individuals each) are ducks (wigeons, coots, shovelers, pochards, ferruginous duck) the whiskered tern, teals, gadwails, mallards, plovers, stints, redshanks and sandpipers. It has been suggested that suitable part of the lagoon are made into a wildlife reserve.

In the Manzala lagoon the most common birds are shelducks, shovelers, coots, avocets, Kentish plovers, the little stint and the whiskered tern, redshanks and black-headed gulls. The nearby El Malaha lagoon has been an important wintering area for the black-necked grebe, the greater flamingo, the cormorant. Flamingos and the slender-billed gull nest there.

Mariut, Idku and Bardawil are important localities for staging birds, though active hunting (esp. in Mariut), land reclamation that reduced the marginal marshes, fishing activities and pollution have reduced the typical habitats of migrating birds.

Not much is known about breeding birds (Meininger and Mullie, 1981).

The Bardawil lagoon does not seem to be an important wintering area, but is an important staging place in the route of migrations from central Asia. Most common passing species are the little egret, the avocet, the garganey, the

sanderlings, little stints, the white winged black tern, grey and purple herons, dunlins and Aythia ferina.

Not much is known (Meininger and Mullie, 1981) about nesting birds. Burullus seems to be an important locality for terns; probably onesting in Idku are the little bittern (Ixobrychus minutus) the purple gallin ule and the reed warbler; in Manzala the avocet, flamingos, the little tern and the slender-billed gull; in Bardawil Charadrius alexandrinus, Haplopterus spinosus, Sterna albifrons, Larus excubitor, Recurvirostra avocetta and Charadrius litchernauti.

Table 6.3

The most common birds of the Egyptian lagoons

IDKU	BURULLUS	MANZALA	EL MALAHA
Larus ridibundus	Anas penelope	Tadorna tadorna	Tadorna tadorna
Calibris minuta	clypeata	Anas clypeata	Podiceps nigricollis
Tringa totanus	Aythia ferina	Fulica atra	Phalacrocorax carbo
Charadris hiaticula	Fulica atra	Recurvirostra avocetta	Phenicopter ruber
Anas acuta	Chlidonias hybridus	Charadris hiaticula	Recurvirostra avocetta
Larus minutus	Aythia niroca	alexandrinus	Larus genei
ridibundus	Anas crecca	Calidris alba	ridibundus
Anas clypeata	strepera	minuta	Calidris alpina
Charadris alexandrinus	platyrhynchus	alpina	
Tringa erythropus	Philomachus pugnax	Tringa totanus	
	Larus genei	Chlidonias hybridus	Pelecanus crispus
		Larus ridibundus	Anas crecca
		Anas crecca	Fulica atra
Tringa ochropus	Charadrius	Aythia ferina	Calidris minuta
glareola	alexandrinus		Phalaropus fulicarius
Egretta garzetta	hiaticula		Stercorarius parasiticus
alba	Calidris minuta		Larus ridibundus
Larus fuscus	alpina	Others*	argentatus
Anas crecca	Tringa totanus		Ghelocheilidon nilotica
penelope	Larus ridubundus		
clypeata	argentatus		
	Egretta garzetta		

* More rarely seen: Tahybaptus ruficollis, Podiceps cristatus, Calonectris diomedea, Ixobrychus minutus, Nyctycorax nyctycorax, Ardeola ralloides, Bubuleus ibis, Egretta garzetta, E. alba, Ardea cinerea, Phenicopter ruber, Anas penelope, Marmaronetta angustirostris, Rallus aquaticus, Porzana porzana, Gallinula chloropus, Porphyrio porphy, Rostratula bengalensis, Haematopus ostralegus, Charadrius hiaticula, C. pecuarius, C. leschernauti, Pluvialis apricaria, P. squatarola, Haplopterus spinosus, Vanellus vanellus, Calidris temminckii, Gallinagogallinago, Limosa limosa, Numenius arquata, Tringa stagnatilis, T. nebularia, Actitis hypoleucos, Arenaria interpres, Larus melanocephalus, Sterna caspia, S. Sandvichensis.

7. AN EVALUATION OF THE IMPACT OF CLIMATIC CHANGE

7.1 Introduction

An analysis of the consequences of the rise of air temperature and of sea level for the Egyptian coastal region of the Nile Delta, few to several decades from now, requires the projection of numerous geographical elements, both physical and socio-economic. The ultimate aim is to evaluate the impacts on human occupation and activities in the coastal lowlands, of a rise of sea level of up to 100 cm. Essentially, this would affect the entire region below 2m elevation, including the major cities of Alexandria and Port Said, the smaller towns of Rosetta and Damietta, extensive agricultural lands and the coastal lagoons.

The management and eventual protection of this coastal region will have to be based on 'cost effectiveness', that is, on an assessment of the value of the threatened land uses, not only in terms of their present functions in the context of the local needs and of those of the hinterland, but especially of those of decades ahead. There will be a growing need to protect the present, as well as the planned and future coastal use developments.

The remedial actions to be taken would be either an extensive physical protection of the shores, or making a choice between: (a) irreplaceable coastal uses, such as national and military harbours, lagoonal fishing, specialized agriculture), to be defended; and (b) uses that could be shifted elsewhere (e.g. industries, roads, airports), or (c) the adoption of different approaches to the exploitation of the shoreline and wetlands.

The immediate task should be the identification of all the 'high risk areas and a re-examination of the present factors of coastal dynamics and of lagoonal ecosystems, in the context of increasing air/water temperatures and sea levels.

For the lower Nile Delta the premises of an impact analysis are:

1. The present erosional state of the coast, because the lack of river sediment discharge since the building of the Aswan High Dam.
2. The rapid urbanization of the coast from Alexandria to the western part of Abuqir Bay, and in Port Said.
3. The necessity to intensify land use in the lagoonal areas for the expansion of agriculture (by additional land reclamation) and of fishing productivity; and near the coast, with new housing, industrial and communication schemes. These projects are imposed by the continuing demographic growth of Egypt; population in the 0-3m coastal zone will be already over 12 mill. in early XXI Cent.
4. The fact that water resources are entirely dependent on the Nile and that both surface and subsurface waters in the lowlands are quite saline. The necessity to increment fresh water reserves is forcing consideration of large scale plans to transform part of the lagoons into reservoirs.

The foreseeable consequences of a major climatic change would be:

1. The direct physical impacts of the sea on the harbours and on shoreline uses (including summer resorts); the accelerated retreat of the promontories and the break-through of the low-lying coastal sand barriers.
2. The indirect effects of higher sea level on the functioning of the lakes, either as freshwater reservoirs, or as brackish lagoons, with an emphasis on fishing like today.
3. The indirect impacts of higher sea level, in addition to raised temperature (i.e. with higher evapo-transpiration) on the further salinization of coastal soils and aquifers, which would magnify the problems of reclaimed lands agriculture.
4. The effects of overall climatic changes on hydrology, that is on Nile water supply and aquifer re-charge, due perhaps to changed precipitation patterns in East Africa, and on rainfall at the Mediterranean coast.
5. The consequences of higher temperatures, in association with man-made changes, for fishing and wildlife in the lagoons.

The impact of climatic change on the social and economic structure of the lowland region would derive from the effects of 1-4 above, but would also have to be evaluated in the context of:

- (a) population and economic growth;
- (b) the value of agricultural production;
- (c) to what extent development according to government plans will create new land uses in the 0-2m coastal zone (new towns, beach resorts, agricultural schemes, new roads, expanded aquaculture) by 2000-2010
- (d) the extent of environmental problems (e.g. pollution);
- (e) external factors, for instance world trade and political trends (ref. Blue Plan scenarios).

7.2 Impacts on weather and marine parameters

The four General Circulation Models examined by Wigley (Chapter 1) suggest that average temperatures in the Nile delta region will increase in consequence of a doubling of CO₂ in the atmosphere, by 3.5°-4° C (range of 1.2°-3.5°C), the increase perhaps being greater in winter than in summer.

Summer temperatures would become more akin to those of the upper Nile valley south of Cairo, with a considerable increase in the rate of evaporation, but probably with a greater relative humidity than at present.

Wind directions and frequencies will depend on changed or unchanged circulation over the Eastern Mediterranean, and on climatic changes over Saharan North Africa and over East Africa. Would the NW winds continue to be dominant, in so far as related to air flux from centers of low pressure in the Central Mediterranean that move towards the Middle East zone of high pressures? What alterations, if any, would affect onshore wind frequencies, esp. the Khamessin and its dust storms?

Changes of wave regimes and energy, and frequency of storms, might arise, if there are significant modifications in the general air circulation.

According to present modelling, precipitation over coastal Egypt could remain the same, or maybe increase slightly. Much will depend on what will happen to the interaction between the winter-spring, Central and Eastern Mediterranean depressions, and the polar continental air from the Iranian plateau, which normally tend to shift the depressions to SE and bring rain to Egypt and nearby countries. Cyclogenesis could either decrease (due to lesser contrasts between lands and sea), or increase, because of greater evaporation and atmospheric moisture. The probability is that rainfall would continue to be very irregular. Higher rainfall would benefit the desert regions west and east of the Nile Delta, where dry farming is practised. Another possibility is that monsoonal rains could reach the SE Mediterranean, as a less rare event as it has occurred in the past (Wigley and Farmer, 1982). The intensity of monsoon circulation is expected to increase, hence more rainfall over the Nile catchment areas (but if the tropical easterly jet, which is an essential part of the monsoon system, moves northward, rainfall could be reduced instead).

The continental shelf of the Nile delta is open to the influence of the Levant Basin marine water circulation, and therefore more directly affected by climatically-induced changes of water temperature, salinity and density. Climatic changes could have a significant impact, in the long run, on water circulation in the Mediterranean (surface and deep, e.g. the Atlantic Water, and the Levantine Intermediate Water), because both evaporation and wind are responsible for surface circulation. Water temperature and salinity should increase, with a more marked summer stratification, a decrease of dissolved oxygen (esp. in summer) and a greater turnover rate of nutrients.

7.3 Impacts on coastal stability

While the Nile delta coast has been subject to natural changes for centuries, with alternate accretion and erosion in many areas, the 1964 cutoff Nile sediment input was a major shock for the shoreline, forcing it to large scale adjustments in its natural evolution. It appears that the period of coastal studies of the 70's (ref. UNDP/UNESCO 1978, Tetrattech 1986) was one of wind and wave conditions below average intensity, and that much heavier assaults on the coast are to be expected in the next decades.

Consideration of coastal evolution with the added factor of sea-level rise can be made in regard to either the state of the shore and lowlands as they are at present, or as they will be 2-3 decades ahead when, presumably,

coastal defence schemes will have been implemented (ref. Coastal Protection Master Plan).

Today, the degree of risk exposure of the different sections of the coast varies. Artificial or natural protection already exists in critical areas, but many weak stretches are undefended against an increased frequency of wash-overs. The threat is to urban and other developments that are likely to be carried out near them (Fig. 2-7).

Along the Alexandria to Abuqir coast increased wave overtopping of harbour structures and of the 'corniche' road, the gradual shrinking not only of the city's pocket beaches, but also of the wider beaches of Mandara, Montaza and Maamura, is to be expected even with a mere 10-20 cm S.L. rise. There would be increasing damage to tourist and other housing and a gradual deterioration could set in of the more exposed, sea-side parts of Alexandria, probably with notable repercussions on buildings and land values.

The threat of erosion of the Abuqir Bay coast will continue, in step with the retreat of the Rosetta promontory and the migration of the sand drift nodal zone towards Maadia. The Mohamed Ali sea wall could become increasingly exposed to undermining, which may pose a threat also to the adjacent shores (e.g. Edku outlet), and to the sub-zero lands behind it.

At the Rosetta headland the submerged delta cone is already eroded to 25-30m depth, or more. The gradual retreat of the emergent part should reach a position of 6km from Rosetta by 2020 AD, with the potential loss of 2500 ha of agricultural land. However, this should not happen, because the protective wall that is being built is sufficiently high to take care of sea level rise. The wall could require extension both to the SW and the East, to prevent erosion due to wave refraction. Today, erosional problems are serious especially at the Nile mouth and on the west side of the promontory. The overall retreat has been accompanied by accretion to the east. This accretion would eventually slow down. There would be an increasing threat of saline percolation for the reclaimed area between the Rosetta Nile and the Burullus lagoon.

The western part of the Burullus barrier is not likely to be breached, but would be flooded more easily and frequently. The high risk stretch, 1.5 km long, lies just west of the ED1 Burg outlet. It is loose and narrow. At and near the outlet, short retreat has been halted by defence structures, but erosion and steepening beyond the breaker zone will continue and ultimately cause the undermining of the seawall and jetties. The village of El Burg will eventually have to be shifted southwards. If extensive precautions are not taken (beach sand nourishment, for instance) the sands of the barrier will be lost, the sea will break through and a new, and perhaps wider outlet could be formed.

Erosion will increase in the future, also along the coast between Burullus and a point 15km east of Kitchener Drain, and the shore will eventually recede. Artificial sand feeding would be the only sensible way to control the Baltim Sea Resort stretch, which is very fluctuating due to the drifting of beach cusps.

The fate of the Damietta promontory and adjacent areas will depend upon the progress of offshore erosion, and possibly upon the thickness of the more easily erodable recent sediments, as stiffer lagoonal clays occur at shallow depth. The tip of Ras el Barr and the Nile estuary cannot possibly be armoured as a lasting bulwark against direct wave attack, with a rising sea level. Particularly vulnerable would be parts of the Ras el Barr peninsula and the El Souffara Canal access to the north part of the Manzala lagoon. The coast west of the New Dumyat jetty may remain stable due to the impounding of sand drift, but as the shore is low, flooding could occur over large parts of the New Dumyat town.

The coastal stretch NW of Port Said is likely to remain stable, in its gradual retreat, due to the active littoral sand drift, without breakthroughs, except in the El Gameel stretch of the lagoon outlets. Particularly vulnerable to flooding would be the proposed tourist resort of Diba, and the Port Said beach. Elevation of the coastal road into a protected dyke may become necessary, independently of the building of a retaining dyke for the proposed freshwater reservoir.

In conclusion, the main problems to be envisaged are the threat of direct damages to the cities of Alexandria, Port Said, Dumyat New Town, especially to port structures, urban sea-fronts and beaches; the storm surge flooding of the presently, naturally or artificially, unprotected low-lying stretches, and the risk of breakthroughs in the Burullus, Manzala and Bardawil barriers.

The coastal barriers would otherwise survive, retreating and encroaching on the lagoons, like they have done in the past, so long as a sand supply is maintained by longshore drift, from the erosion of the Rosetta and Damietta promontories. Because of the longshore movement of sand, new lagoonal outlets will naturally tend to become strongly asymmetric, due to sand bars, and ultimately much reduced in width. The danger is of a reduction of sand supply in consequence of the protective structures erected at the Rosetta and Damietta headlands.

The lagoon outlets, open as they are at present, would experience greater dynamic problems, of current scouring and of greater tidal flow, as opposed to the greater drain discharge flows of today. After a rise of 25 cm of sea level, the outlets will have to be regulated by sluices, to prevent higher water levels in the lagoons, and the effects of salinity on their inner margins, yet devised in a way to preserve the outlets' dynamic and ecologic roles.

It is not unconceivable that the most vulnerable parts of the Nile Delta coast could be and will have been protected, though at considerable cost, against the effects of a greater sea level rise 4-5 decades ahead. The cost will become much larger later on and could impose agonizing choices, considering the priority that will have to be given to the vital economic structures of Alexandria, Damietta, Port Said and the Suez Canal.

The major impact will be therefore, financial. Technical problems will be no less relevant. In principle, all the Nile Delta coastal uses could be 'defended'; the question is how to do it, without the negative side-effects that usually follow the erection of fixed coastal structures.

Government authorities and coastal engineers will have to appreciate that shore developments and their consequent protection schemes must be executed in harmony with coastal processes and morphology. There is otherwise the danger that the effects of sea level rise, instead of being checked, could get disastrously out of control.

7.4 Impacts on surface and ground water

The future of the Nile Delta water resources is dominated by two variables: a) increased surface evaporation, and (b) the behaviour and trends of Nile supply, versus the need for increased water use.

Prediction of the periodicity of Nile floods depends on a model of climatic change for East Africa - Indian Ocean, on whether monsoonal precipitation will increase or decrease; and on the past factors of variability and their future behaviour. If the 7-9, 19-20 and 60-80 years cycles constitute any basis for prediction, the next century, and the decades 2020-2030 could perhaps be periods of higher floods. In which case, higher Nile water supply could offset evaporation losses (though, these might increase in the catchment area as well).

In lower Egypt irrigation practices would have to be further changes to face, if not a reduced water supply, increased losses due to evaporation. Crops with a high water requirement (e.g. rice, sugar cane) could be jeopardized.

Greater rates of evaporation will badly affect the lowlands, in regard to increased salt accumulation in soils, and increased salinities in the shallow and un-flushed parts of the lagoons. Already, in the present semi-arid climate hypersaline areas occur (or occurred, before reclamation) in several parts of the lower delta. There will be a greater need of fresh water to flush the salts, or else drains into the lagoons, and/or coastal reservoirs, will become more saline.

The present problems of surface water pollution, already serious near Alexandria, and in danger of growing elsewhere in consequence of urban and industrial expansion, could become acute, unless they will have been controlled.

Quality, and perhaps availability of groundwater could become a serious problem in the lower delta. Already, in all areas of the plain below 5m elevation groundwater is saline, poor for irrigation and unsuitable for drinking. Increased water extraction from the deep aquifer because of population and economic growth demands, even if carried out with caution, would require treatment facilities and might pose the threat of land subsidence, especially in parts that already are sinking naturally.

The flow of the deep aquifer would be affected by a sea level of 1m. The main average seepage to the sea would diminish by about 5%; this, in case fresh-water recharge is not enhanced, would cause salt water intrusion to proceed further inland. Sea level rise will have a negative effect on interface motion, and a detailed investigation would be required to quantify the impacts.

In the coastal zone and wetlands sea level rise would have serious consequences for the shallow aquifers. The coast-parallel sand ribbon is only a few to several meters thick (except in correspondence of former Nile outlets). Seepage through this layer, for a rise of 1m, could be up to 10 mill. m³ of sea water a year for Lake Burullus, i.e. about 30% of the direct seepage loss of the entire aquifer to the sea (Kashef, 1983)

Not only must the entire water defence system be improved, but a more powerful drainage system is required to cope with regional infiltration of sea water towards the wetlands.

In this context, the proposal to convert large parts of the Manzala and Burullus lagoons into freshwater reservoirs at 0.5 to 1.5 m above sea level, would require a serious re-thinking in regard to saline penetration, as well as on other impacts on the hydrologic balance.

7.5 Impacts on marine and lagoonal ecosystems

Marine ecosystems on the inner continental shelf will be affected mainly by temperature changes, and by whatever changes may take place in the water chemistry and the abundance of nutrients (naturally, or induced by pollution) that affect primary productivity. It is thought that more Red Sea species will migrate towards the Mediterranean through the Suez Canal.

The lake and lagoonal ecosystems (aquatic vegetation, euryhaline to freshwater fishes, migrating fishes and birds) would be directly affected by increases of water salinity and of temperature; the latter due to greater evaporation and more saline drain waters. Higher water temperature would favour primary (hence fish) productivity, but as life in the lagoons depends on complex interrelated environmental conditions, local excessive temperatures, high salinity and (maybe) less dissolved oxygen overall, would be dangerous for many species. Temperature not only affects the survival and distribution of fish, but also their growth, rate of development, activation of reproductive processes and susceptibility to diseases. A salinity increase in the inner parts of the lagoons would have a negative impact on *Potamogeton pectinatus*.

More marine fishes would migrate into the lagoons, and the more salinity-tolerant lagoonal species could benefit (e.g. *Tilapia zillii* and *T. aurea*, as opposed to *T. nilotica*, as well as shrimps); though, depending on the fate of the plant areas, the main nursery and feeding grounds.

On the whole, the natural impacts on ecosystems (marine and lagoonal) could be minimal, and anyway gradual and self-adjusting. However, the ecosystems of 2025 may not be the same as today, because already affected by the, more immediate, anthropic impacts of pollution, and of the altered hydrological conditions, due to lagoonal management schemes.

Fauna and flora and the proportions of the different types of commercial fish will certainly change in the next 2-3 decades, especially if the lagoons are transformed into fresh-water lakes. The impact on wintering birds would be catastrophic, due to the loss of many environments that are vital for them.

As the lagoons are now, it would be desirable that they are kept in communication with the sea, even by artificially opening new outlets, to facilitate fish migrations, the flushing of excessive plant cover and of agricultural pollutants, and for water renovation. In future, the quantities of drainage water are expected to decline, due to increasing re-use for irrigation. The salinities of the remaining flows would increase.

7.6 Impacts on the economy of the coastal zone

Approximately 15% of Egypt current GNP originates in the area likely to be affected, directly or indirectly, by a 1m sea-level rise. A considerable amount of development is to be expected in the Nile Delta coastal zone (1-2m) over the next 2-3 decades (barring local or international crisis). They will include urban expansion, new industries, new roads (especially E-W), more reclaimed land and aquaculture farms, perhaps also walled-in freshwater reservoirs in parts of the major lagoons. It is likely that the coast will be by then also protected physically at + bearable costs (anyway, imposed by the economic value and vital functions of the existing population centers). Additional protection would be inherent also in several of the development schemes that are being proposed (e.g. raised roads, dune shields, reservoirs and land reclamation dykes).

One major problem will be the location of new settlements and towns, by the shore and in low-lying areas, in the face of the vulnerability of the coast to sea level rise.

However, no serious or very significant consequences of sea level rise is to be expected until 2010-2020 AD, with estimated increases of 15-20 cm (except for higher water levels in the lagoons - unless these will be no longer in direct communication with the sea). By that time the present poles and axes of economic development will have expanded further, in industrial and commercial activities. All these areas are nevertheless above 2m. With higher temperatures, the by then more numerous, larger and more crowded urban centers could experience serious difficulties with freshwater supplies and waste disposal. If groundwater will have been used to greater extent, treatment plants would be required.

Problems could arise also with public health. Malaria and schistosomiasis are known to occur in the regions south of the lagoons, any further spreading of these diseases should be prevented (the health aspects of climatic change need to be investigated).

The impact for the economy of Egypt of a sea level rise over 50cm later on, on infrastructures by the shore, will be much more considerable. By 2030 AD technical and financial assessments of these consequences should have been made. Failure to adopt appropriate counter-measures will result in serious

economic losses, through direct destruction, flooding, or gradual deterioration.

Agriculture, at least some crops (e.g. rice, cotton, fruit trees like banana and dates; corn) would probably benefit from higher temperatures, but would certainly be affected by increased evaporation and soil and water salinities. Agricultural management could become more expensive, and a greater application of fertilizers and pesticides (if imposed by changed soil conditions and by a possible increase of weeds and pests) could increase the pollution of surface waters.

Fishing, if gradually adjusted to changes, should not be much affected, except quantitatively, in the types of species caught or reared in aquaculture basins. Impacts on fishing by anthropically changed hydrological conditions in the lagoons, will be felt well before those of atmospheric warming, or substantial sea level rise.

The impacts of sea level rise on beach tourism will undoubtedly be negative at several locations of the Nile Delta, like Alexandria, Ras El Barr and Port Said. However, those outside the delta, on the western and eastern Mediterranean coast, will not be affected, and other delta locations, with wider and more stable beaches, if properly developed might take over as alternative resorts.

3. CONCLUSIONS

The likely consequences of the predicted doubling of a CO₂ concentration in the atmosphere for the Mediterranean coast of Egypt are a rise of average temperature of 3-4°C some time in the latter part of the next century, and an increase of the level of the sea of up to 1m above present, at a rate of 15-20mm/year. Rainfall might change little, or possibly increase, but evapotranspiration and humidity will certainly increase.

In the Nile delta the coastal zone that lies under 1m elevation covers an area of 4,000 km² and is 30 to 50 km wide. It is the region most likely to be affected by sea level rise, an economically very valuable region, since it contains several large lagoons and lakes, all of which are important fishing centres, with growing aquaculture activities, and areas of recent and potential land reclamation. The lower Nile Delta contains 30% of all the reclamation projects in Egypt that are vital to increasing food production in a country where population grows at the rate of 2.7% per annum.

Population, although with high densities in comparison with other Mediterranean countries, is unevenly distributed. It is concentrated mainly along the two Nile branches, as well as in Alexandria and Port Said, and in general in the lands that are 2-3m above sea-level. The present population of the belt ± 3m contour is about 10 millions. It will increase to 12½ mill. by the year 2,000 A.D., though a growth rate decline (from 2.7 to 2%) could occur in consequence of official policies and changes in social attitudes.

The socio-economic setting of the coastal zone in the decades ahead is therefore dominated by the necessity to develop, in order to increase food production, export earnings, employment and housing. Several official development projects indicate that the main axes and polar areas of demographic and economic expansion will be in the Alexandria to Abuqir, Rosetta-Idfina, Damietta in Port Said areas; additionally, along the high ground alignments Kafr El Dawar-Damanhour, Kafr El Sheikh Sidi Selem, Mansoura-El Manzala-El Mataria, as well as in the Baltim region. Development will include the expansion of present industries, which are essentially geared to the primary needs of the country (food processing, textiles and clothing; chemicals, fertilizers, cement; small-scale metallurgical, mechanical and manufacturing). These industries are in part dependent on imports of raw materials, and on energy sources, foreign or local (Alexandria oil refineries, Abuqir Bay and Abu Madi gas fields). Of particular importance will be the developments near Damietta and in Port Said, in consequences, respectively, of new harbour construction and of land expansion.

Apart from the Alexandria-Abuqir stretch, Port Said, and of short coastal stretches at few other localities, the shoreline of the Nile Delta is still little used. The coast however is in a state of sediment deficit and has been subject to erosion since the final closure of the Aswan High dam in 1965. The headlands of Rosetta and Damietta have been retreating at the rate of 80-120m year. Lately, a steepening of submerged beach profiles has been noted also along traditionally advancing stretches, east of the promontories in the direction of the active littoral sand drift (e.g. east of Baltim Beach resort and of Port Said). The pocket beaches of Alexandria are shrinking because of

lack of sand. Engineering structures built locally for the regulation of lagoonal outlets, and the defence of settlements and beach resorts, have not produced particularly negative counter-effects, but are retarding the general trend of shore retreat.

Besides wave attacks on harbour structures and on the promontories, several stretches of the coast are subject to flooding by storm surges. The zones of weakness of main concern lie west of the outlet of Burullus lagoon, and the stretch of the Manzala outlets 15-9km west of Port Said.

At Rosetta, the extrapolated retreat associated with a 2mm/year sea level rise could bring the shore to within 6km of the town by 2,020 AD but with a rise of >10mm/year the shore could be 4km closer. Loss of agricultural land will however be prevented by a dyke under construction. In the Damietta area, the main danger is from the counter-effects of the jetties of the New Dumyat harbour and from the flooding of the industrial and residential quarters that are being developed on land that lies below one meter above sea level.

The first stage of relatively low rise of sea level in the next two decades should be used to prepare for the following period of a more dramatic rise, by erecting new dykes and dune shields and fixing the existing dunes with vegetation. Dune fields are an effective but also finite, non-renewable protection; their dynamics must be studied and their continued efficiency insured. The raising of existing, in-construction and planned dykes would become a necessity in 2-3 decades from now.

The development of the coastline could follow general set-back lines, but on some stretches this cannot evidently be applied (e.g. Alexandria, Port Said). The concept of sacrificial lands, to be given up to erosion or flooding because uneconomical to protect, appears to be of difficult application in the Nile Delta. Economic and political considerations will obviously rule out a natural development of the shore and impose protective measures. The main question will be the financial resources necessary to implement the extensive coastal protection required, even against a 50cm rise of sea level.

The most serious negative effects of sea level rise on the Egyptian coast would be on ports, lagoonal fishing and lowland agriculture and therefore, indirectly, on population centers, which are tied to ports and their industries, and to agriculture and related industries. Alexandria will lose its attraction as a summer resort city, but the recreational use of beaches is not threatened elsewhere. It could in fact expand, provided that resort facilities are not built close to the shore and are kept on an open pattern.

The efficiency of fishing and aquaculture, as they are practiced today, relies on the maintenance of certain environmental conditions. Open, or controlled, communications with the sea are necessary to fish migrations and tidal flushing to help to limit choking by aquatic plants and to control pollution from fertilizers and pesticides. Wider and additional outlets would in effect be beneficial, though the type of fish catches would change to include a greater proportion of euryhaline fishes, like in the Bardawil lagoon.

Even if the lagoons, or parts of them, are transformed into freshwater reservoirs (with due dyke protection), salinity and temperature are bound to rise in consequence of (a) saltwater intrusion from the sea, (b) greater evaporation, and (c) influx of saline waters from (probably reduced) agricultural drainage outputs.

Such changes will have profound effects on the marginal, marsh and reed ecosystems, and probably on lake bottom biotopes, and therefore the present composition of the lagoonal fauna (especially of birds) will be altered considerably.

The lake margins are, or will be, completely dyked, but higher, more saline water and increased soil salinity will impair the efficiency of agriculture in newly reclaimed lands.

Until recently, few crops were grown for export (e.g. cotton); lately, there has been an increasing export of fruits and vegetables. The multi harvest, seasonal crop-rotation system could be favoured by higher temperatures and CO₂ levels, but water supply and quality could become more critical. The delta coastal zone is almost totally dependent on the Nile for its surface and underground water needs. Variations of rainfall in the Nile catchment areas have a profound effect on Egypt's water resources, witness the present low water level situation of Lake Nasser reservoir, in consequence of years of drought, which has imposed policies to substitute water-intensive crops with others requiring less irrigation (e.g. sugar cane versus sugar beet).

Another potential problem is the increase in pests and parasites which would require an even greater use of pesticides, with a further input to drainage water and lagoonal pollution.

In conclusion, coastal developments in the next few decades in the Nile Delta need to be carefully planned and directed to locations that could be most economically and effectively defended, and would not produce environmental problems likely to aggravate those that would arise from the climatic changes. Given the State control of territorial planning in Egypt, it should be possible to avoid the mistakes made elsewhere of a freezing the coast that would eventually lead to greater sacrifices.

9. RECOMMENDATIONS

In spite of the persisting uncertainties on the manner and timing of climatic changes, a considerable warming of the atmosphere, with its attendant sea level rise effect, appears now to be inevitable. The most sensible action to take in the next years is to evaluate more precisely the impact it will make on the environment and society.

The most urgent need is, therefore, to elaborate scenarios of the coastal situation of the Nile delta in 2020 that incorporate the interactions between the trends of social and economic development, and those of the state of the environment. Considerations are to be made of the future:

- a) rates of coastal erosion and land subsidence;
- b) actual changes of climate, even if not drastic at first;
- c) impacts of pollution and of water management schemes on ecosystems;
- d) cyclic fluctuations of Nile floods;
- e) population and industrial growth (with their food supply and commercial/financial implications).

The scenarios would assist present territorial planning that involves population management and the use of natural resources during the next 20-30 years, to take the implications of longer term climatic changes into serious account.

To start with, a data base should be set up to hold information that already exists, or has to be collected, so that the physical and social-economic models can be processed. The following investigations are recommended.

1. Topography. The assembly of data from the latest surveys; new repeated surveys, especially of the high risk areas and of those suspected of subsidence.
2. Subsidence. Initiation of studies on subsidence from ground water data (ref. Venice and north Adriatic coast of Italy); namely, south of Alexandria, near Rosetta, Damietta, around the Manzala lagoon to Port Said.
3. Monitoring of coastal dynamics. Periodical surveys with beach profiles, controlled air photography, monitoring the continued rate of headland retreat, modelling of risk areas and the impacts of new fixed structures according to various increments of sea level rise.
4. Subsurface data. Extend a programme of borings to the coastal area, especially the lakes sand barriers, both to study groundwater and salinization and to evaluate mechanisms of barrier retreat.
5. Dune studies. Evaluation of the effectiveness of dune protection, especially including the rates of dune growth.
6. Detailed soil survey, with experimentation on the reaction of clays and loams to salt increases.

7. Waste disposal and pollution. Studies on the relations between increased agricultural and industrial activities and the pollution of surface waters, especially with lesser water flushing and/or greater water salinities.
8. Ecosystems. Collate and quantify all existing data on lagoonal ecosystems (physical parameters, productivity, bottom and fish fauna, vegetation, bird fauna) that could be fed into alternative models for sea-level rise, increased temperatures and man-made alterations to the lagoonal hydrology.
9. Climate. Research into existing climatic data (temperature, evaporation, rainfall, wind directions), to evaluate cyclic trends, number, frequency and intensity of storms, wave approach and intensity.
10. Water supplies. Evaluation of published, and of new analyses of data on climatic changes in the catchment area of the River Nile and their effects on water supplies in Egypt with an estimation of their future trends. Evaluation of the state of groundwater information.
11. Population. Analysis of present and projected demographic distribution in the coastal areas, and projected urbanization needs especially water.
12. Economic data. Analysis of present economic parameters and trends to assess the economic performance of all the parts of the coastal lowlands during the next 2-3 decades (e.g. agricultural crop capacity for domestic/export use; freshwater and marine fisheries; light/heavy industries; transportation needs; tourism potential).

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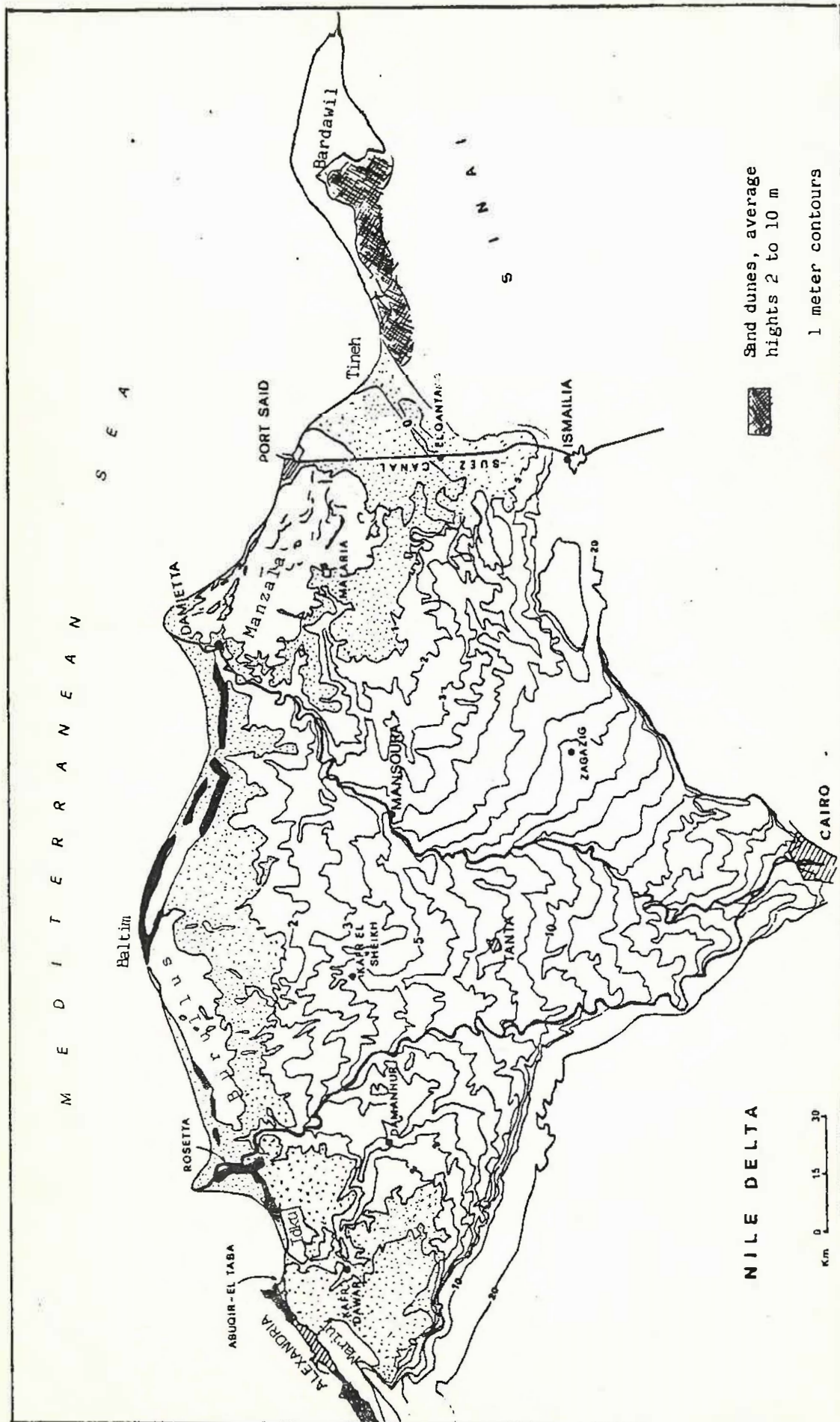


FIG. 1.1

Topography of the Nile Delta

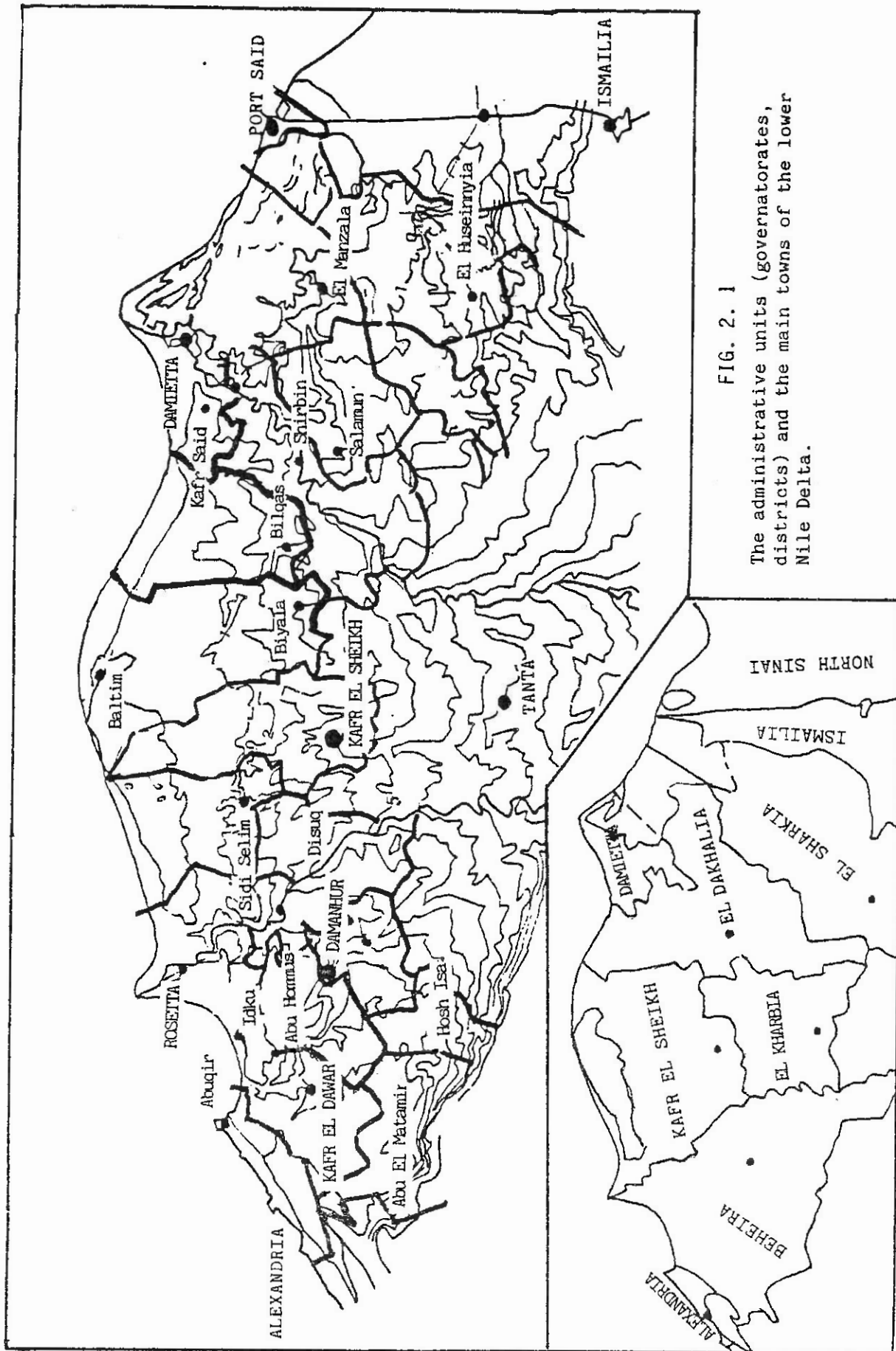


FIG. 2. 1
The administrative units (governorates, districts) and the main towns of the lower Nile Delta.

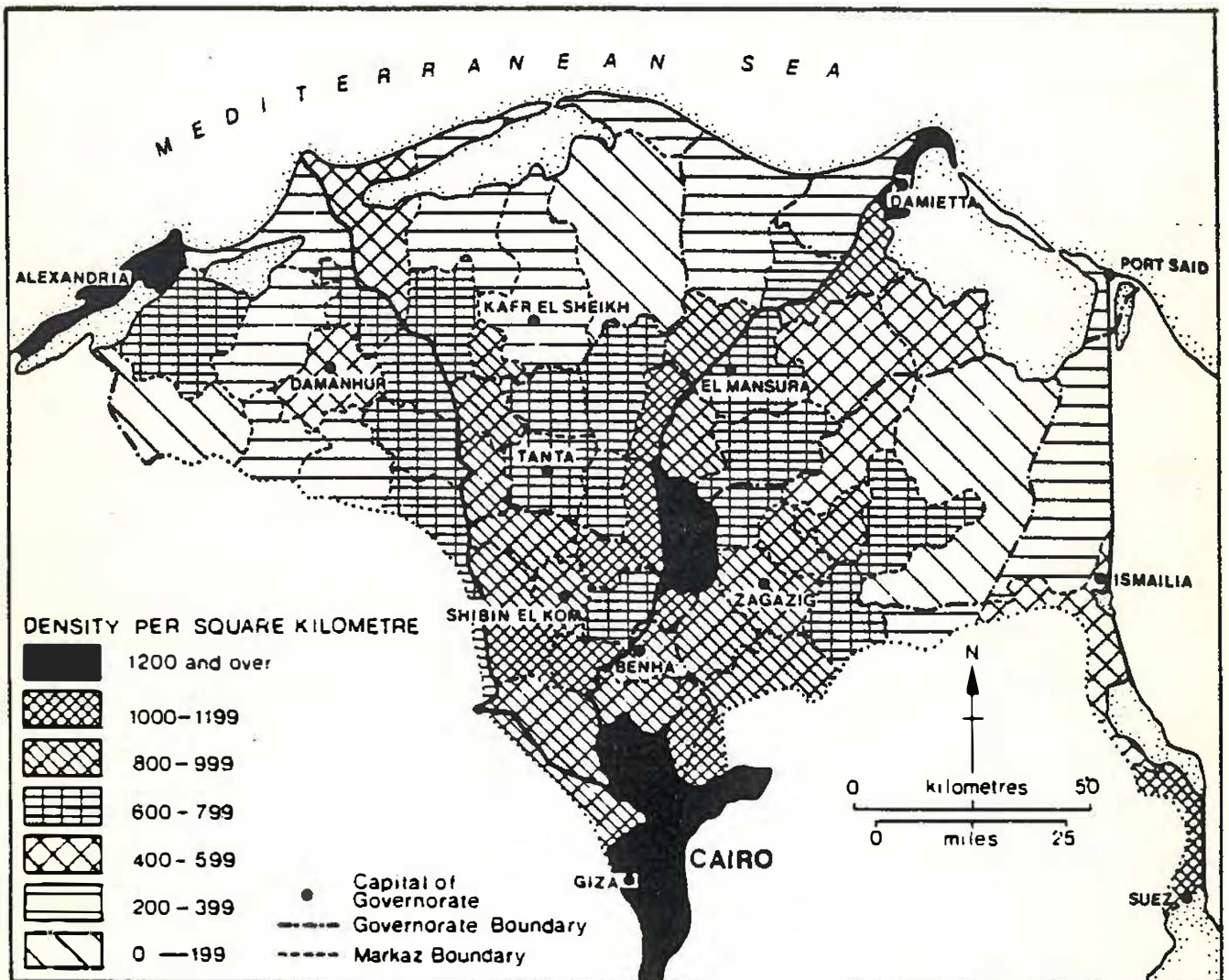
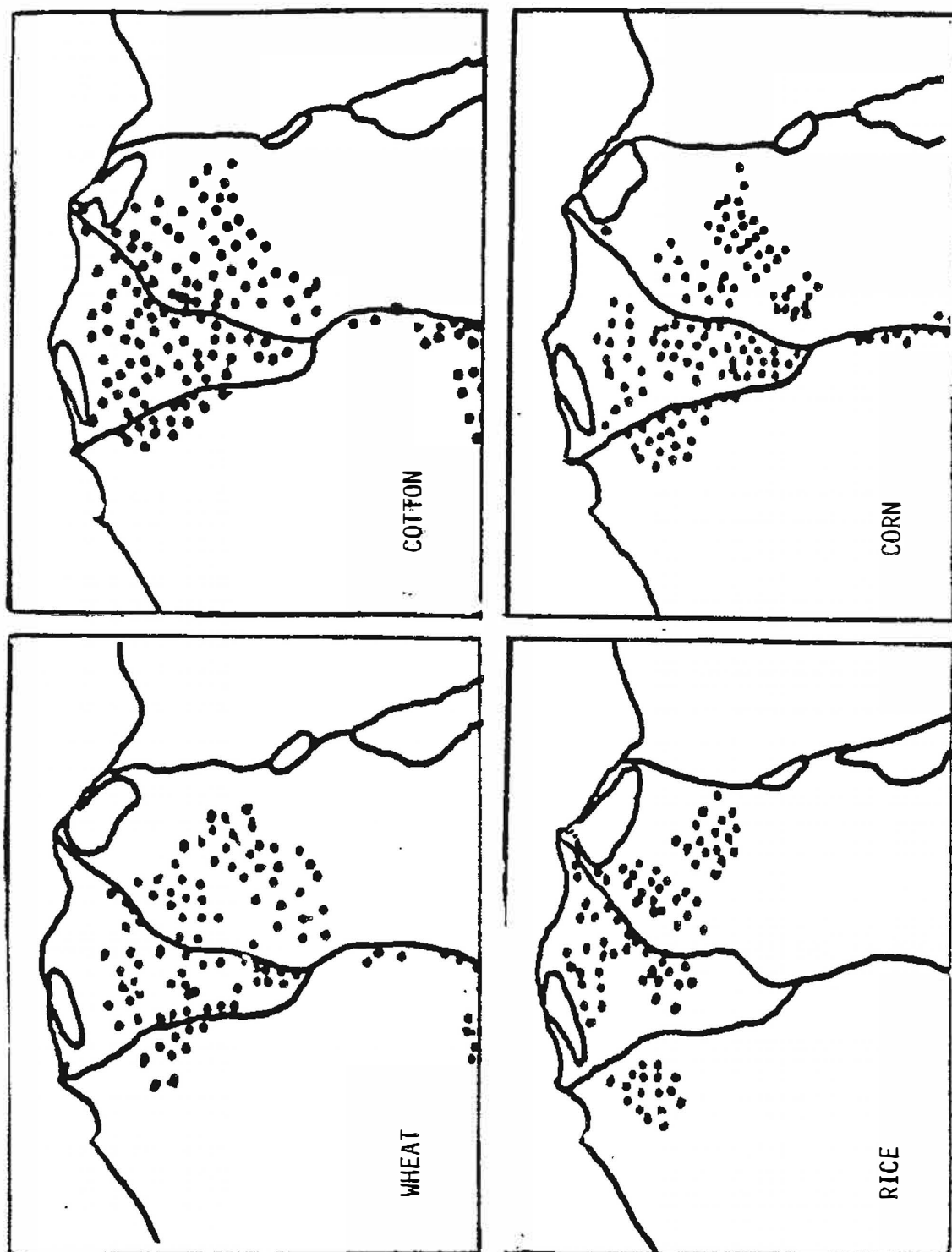


FIG. 2.2

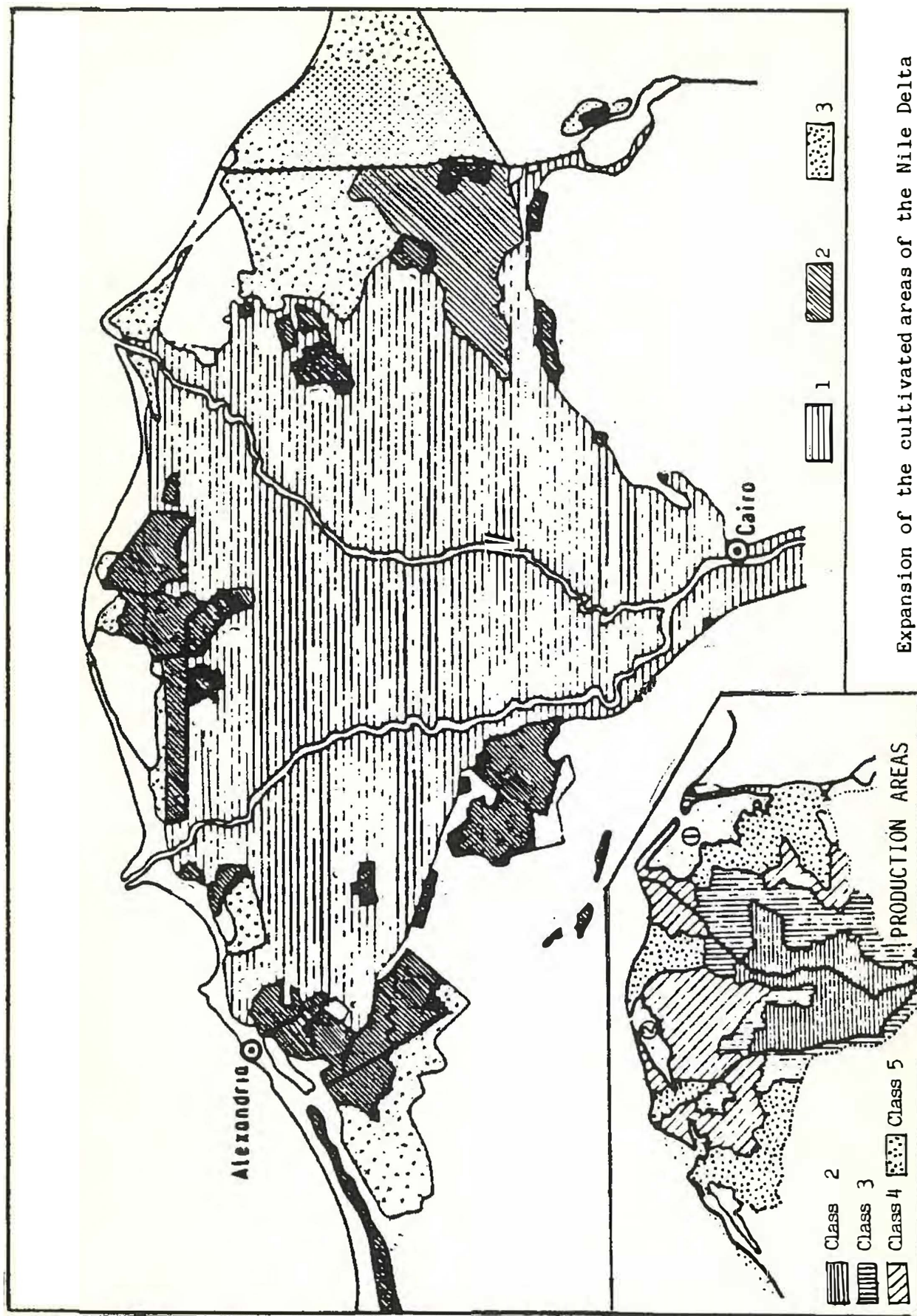
Population density in the Nile Delta (1971 Census)

(From Fisher 1978)



(Fram: Economic Atlas of Egypt)

FIG. 2.3



Expansion of the cultivated areas of the Nile Delta 1960-1986 (from Fisher 1978, Beaumont et al.1988).
 1. Cultivated in 1960. 2.1960-1985 reclamation projects. 3. Possible future reclamations.

FIG. 2. 4

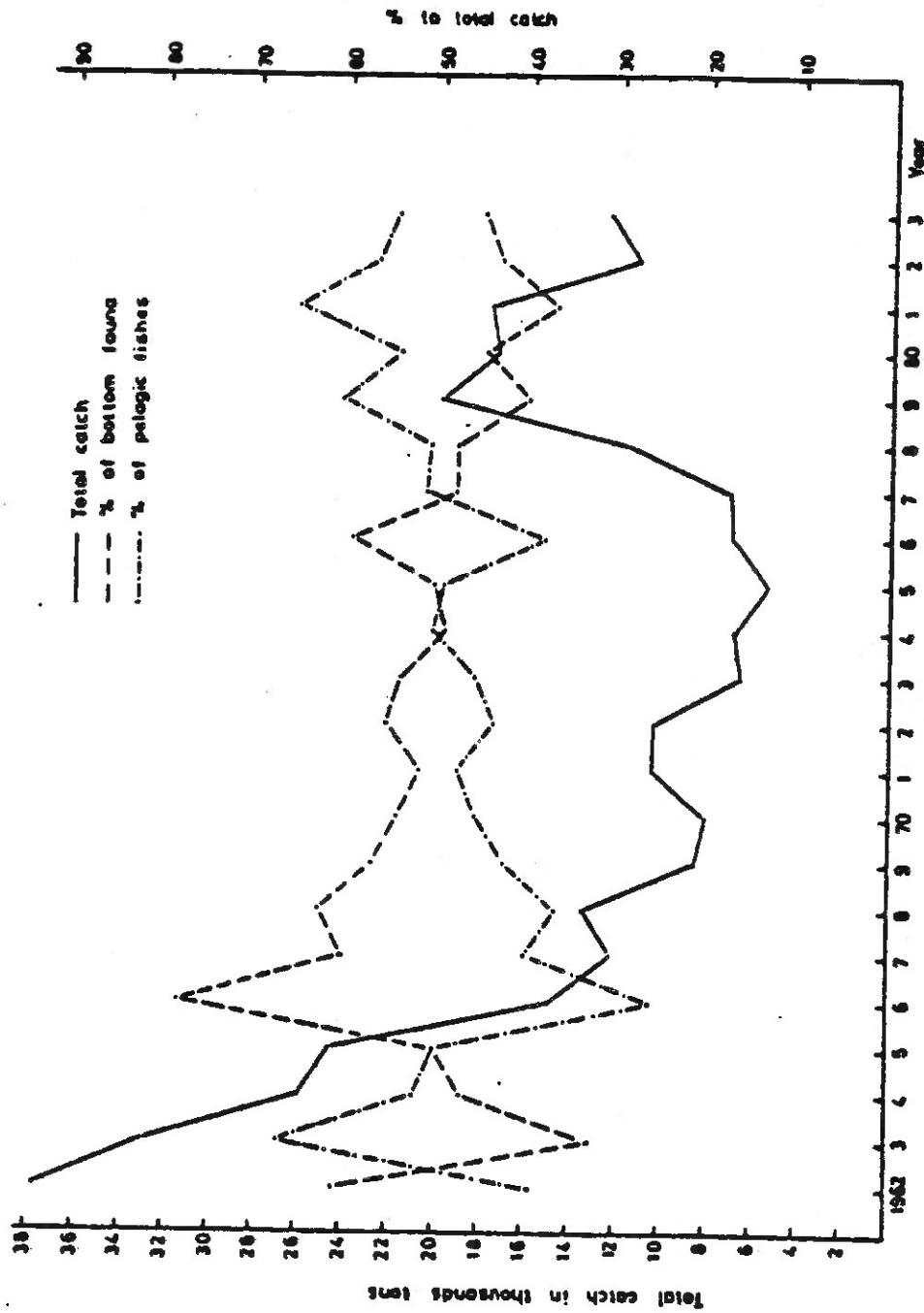


FIG. 2.5 Annual variation of total catch, % of bottom fauna, and % of pelagic fish in the Mediterranean sea in front of Egypt. (From Saleh & Karashily 1987)

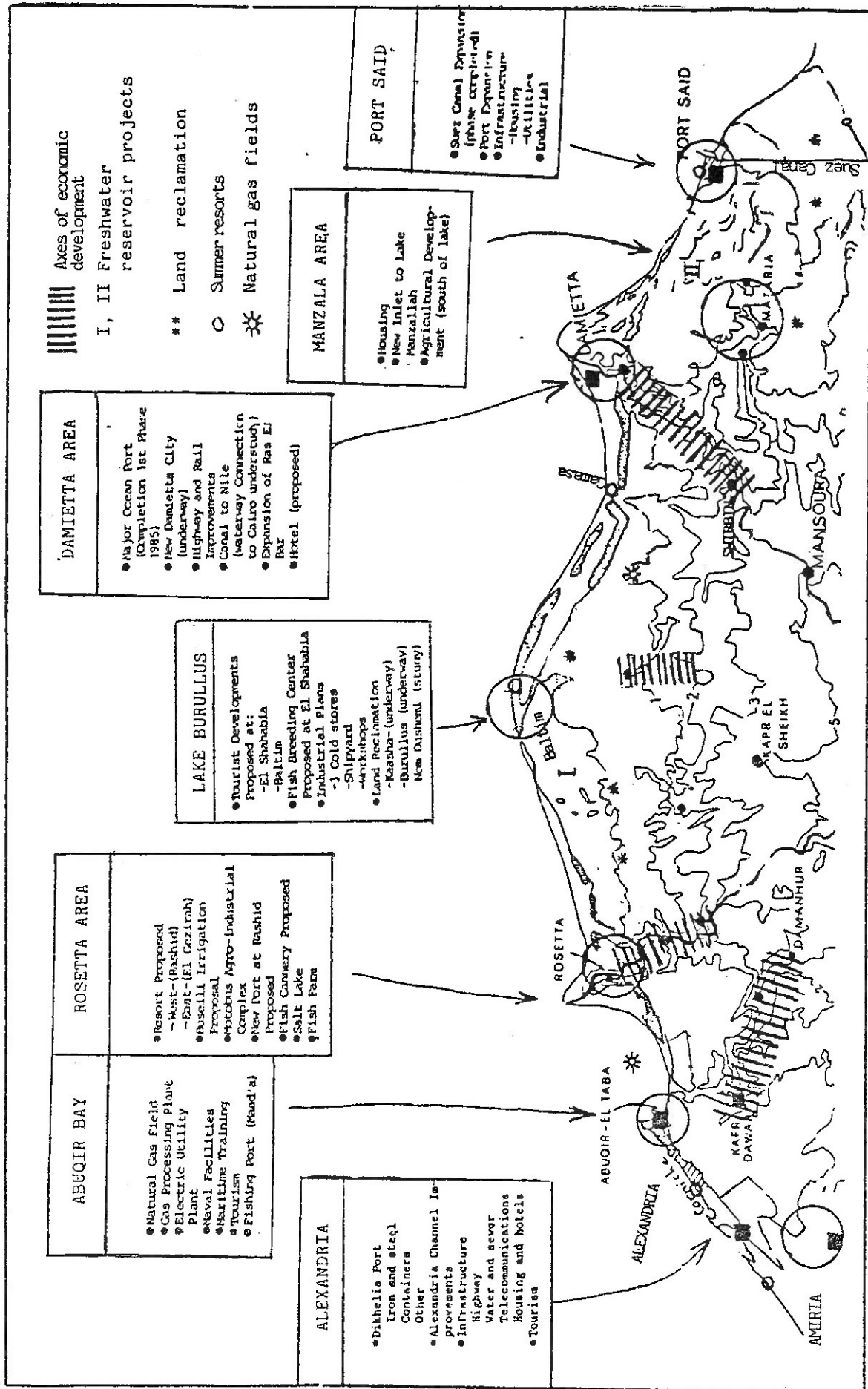


FIG. 2.7

Main developments, projected or under execution in the coastal areas of the Nile Delta (source: Tetrattech 1986)

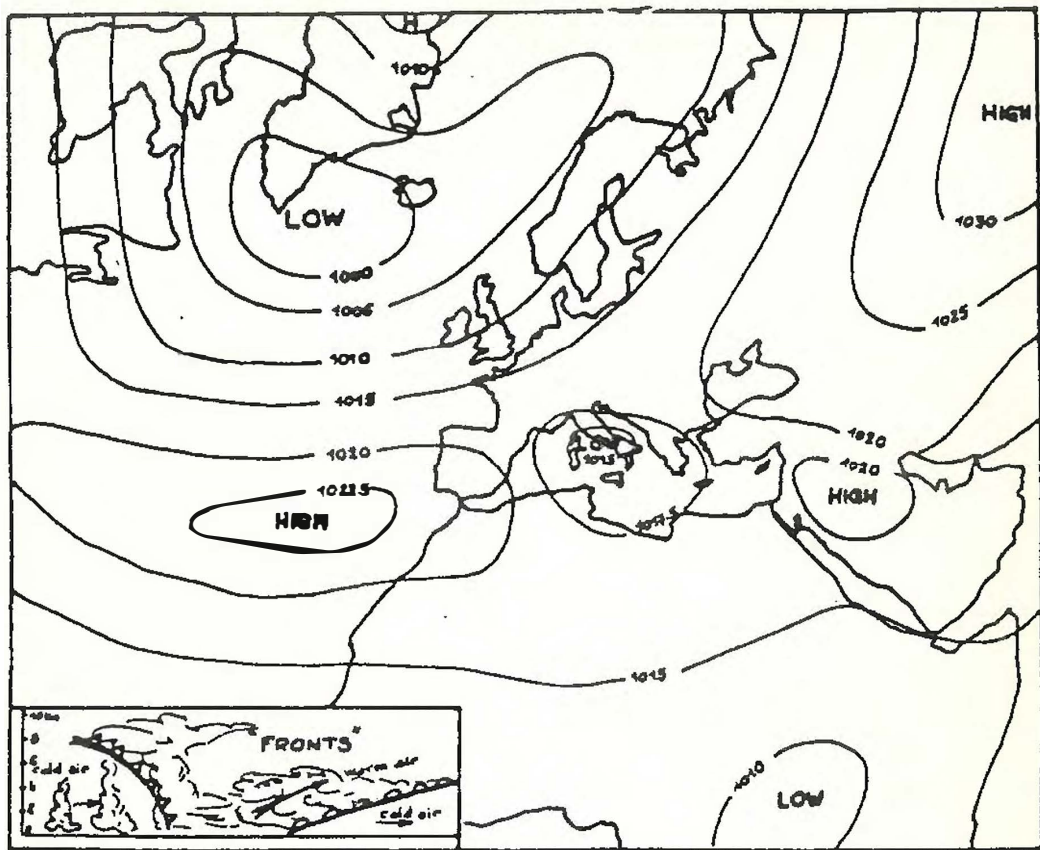


FIG. 3. 1

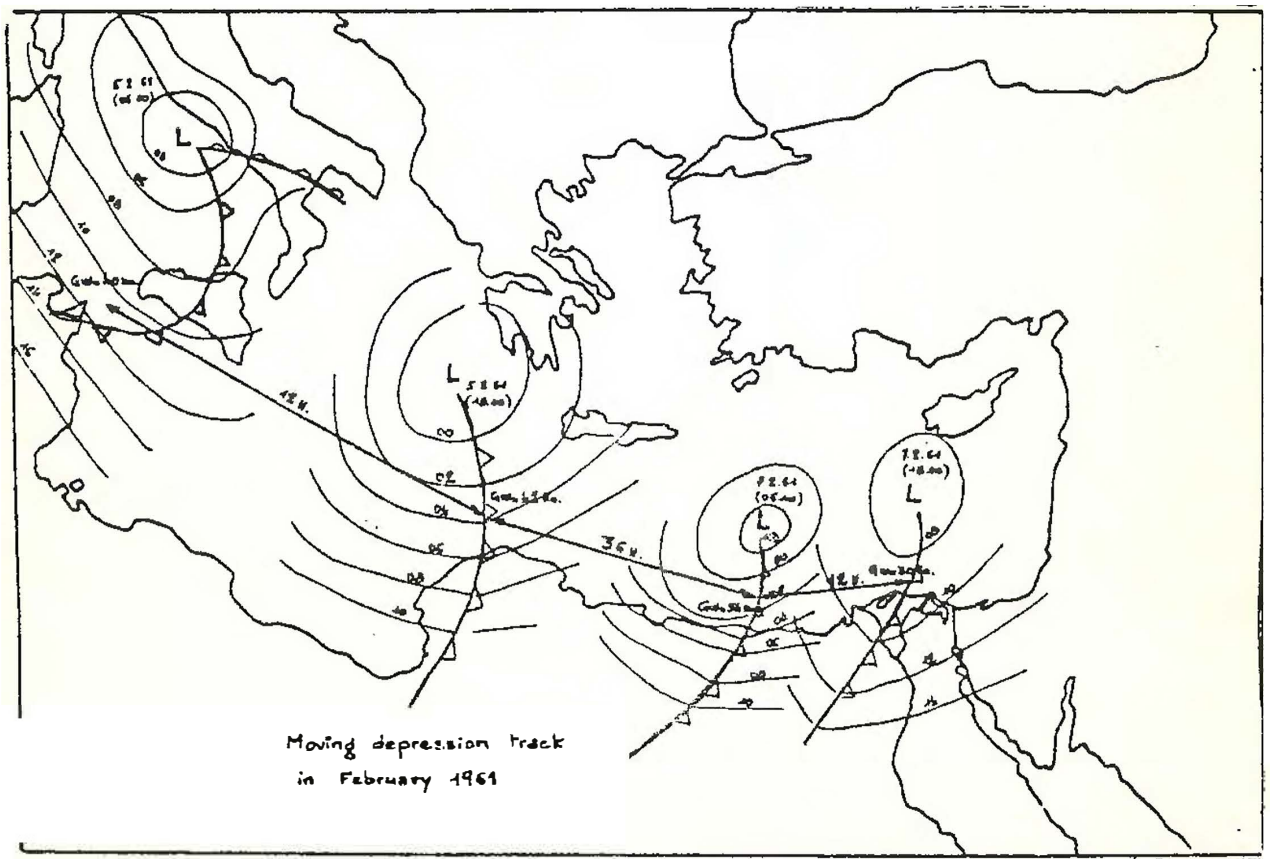


FIG. 3.2 Moving depression track, Febr.1969
(From ASRT/UNESCO/ UNDP 1976)

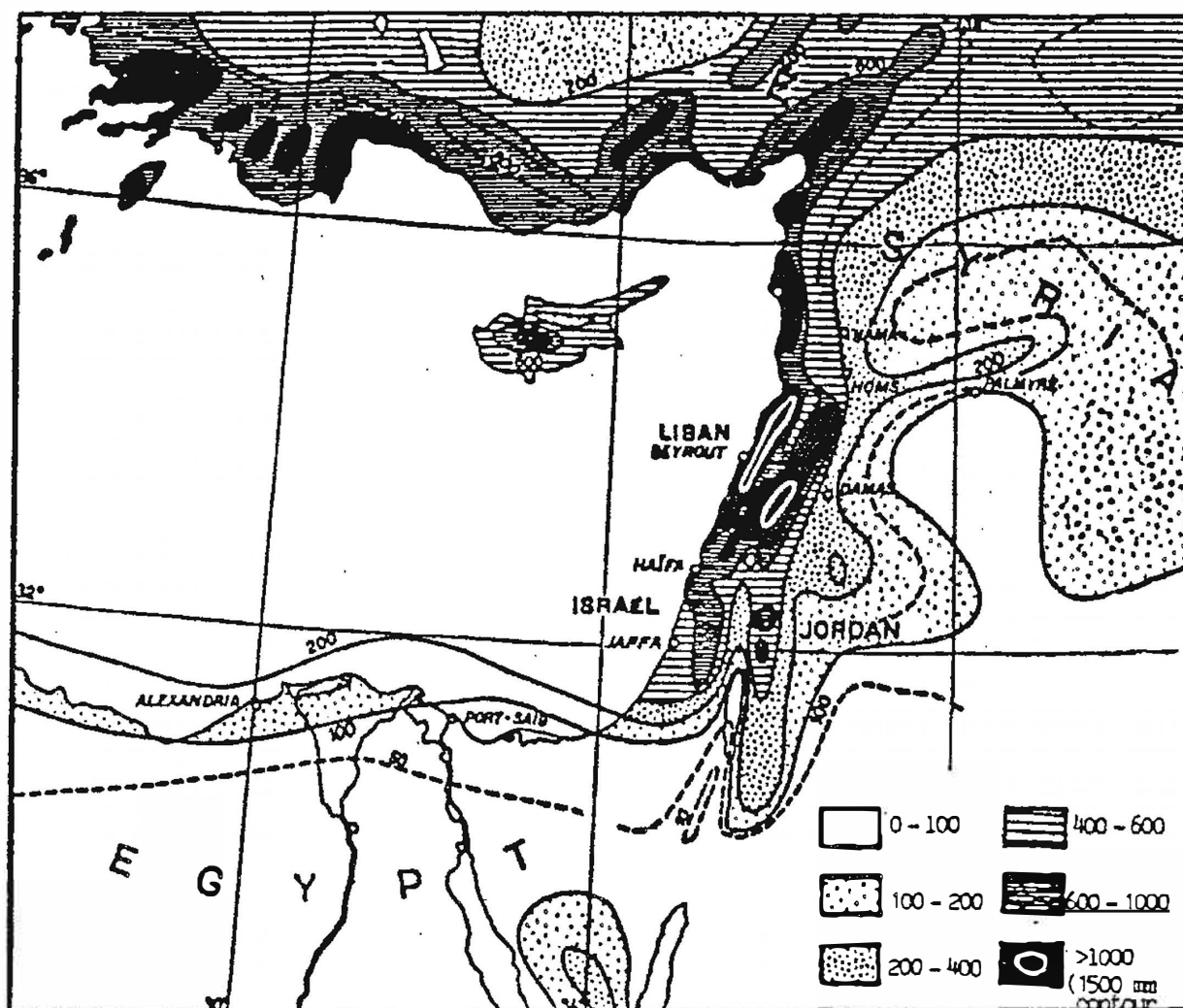


FIG. 3.3

Distribution of rainfall over the Eastern Mediterranean lands (from: Birot & Dretsch- La Mediterranee et le Moyen Orient, 1956)

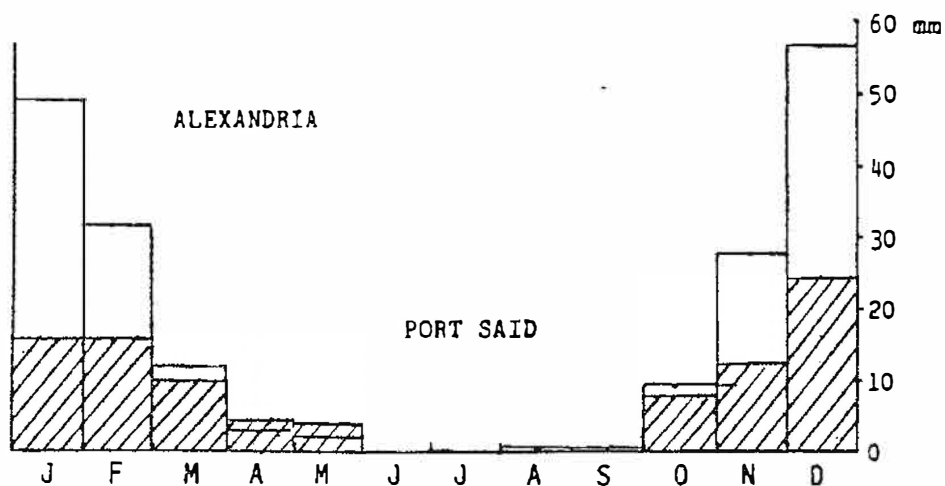


FIG. 3.4

Yearly average distribution of rainfall (1965-1975) at Alexandria and Port Said

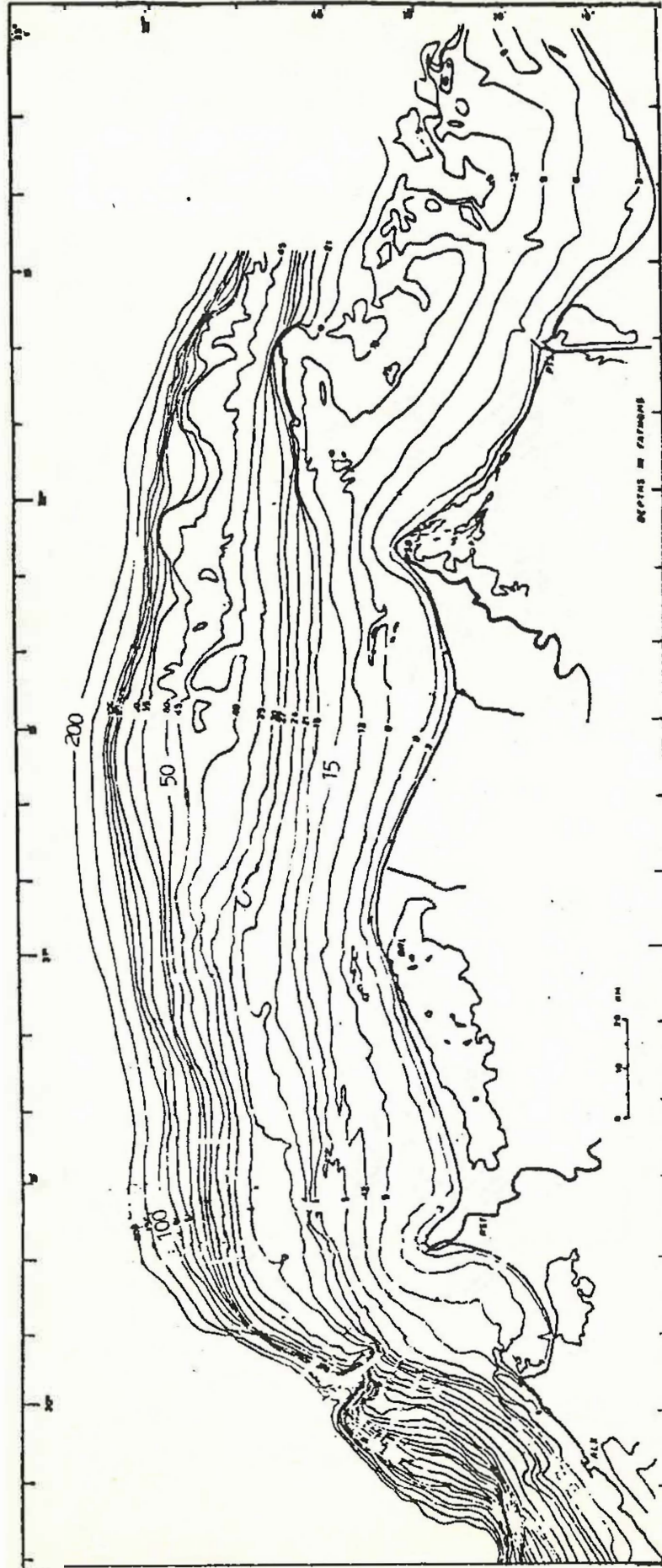


FIG. 3.5

The topography of the Nile Delta continental shelf (UNESCO/ASRT/UNDP 1976)

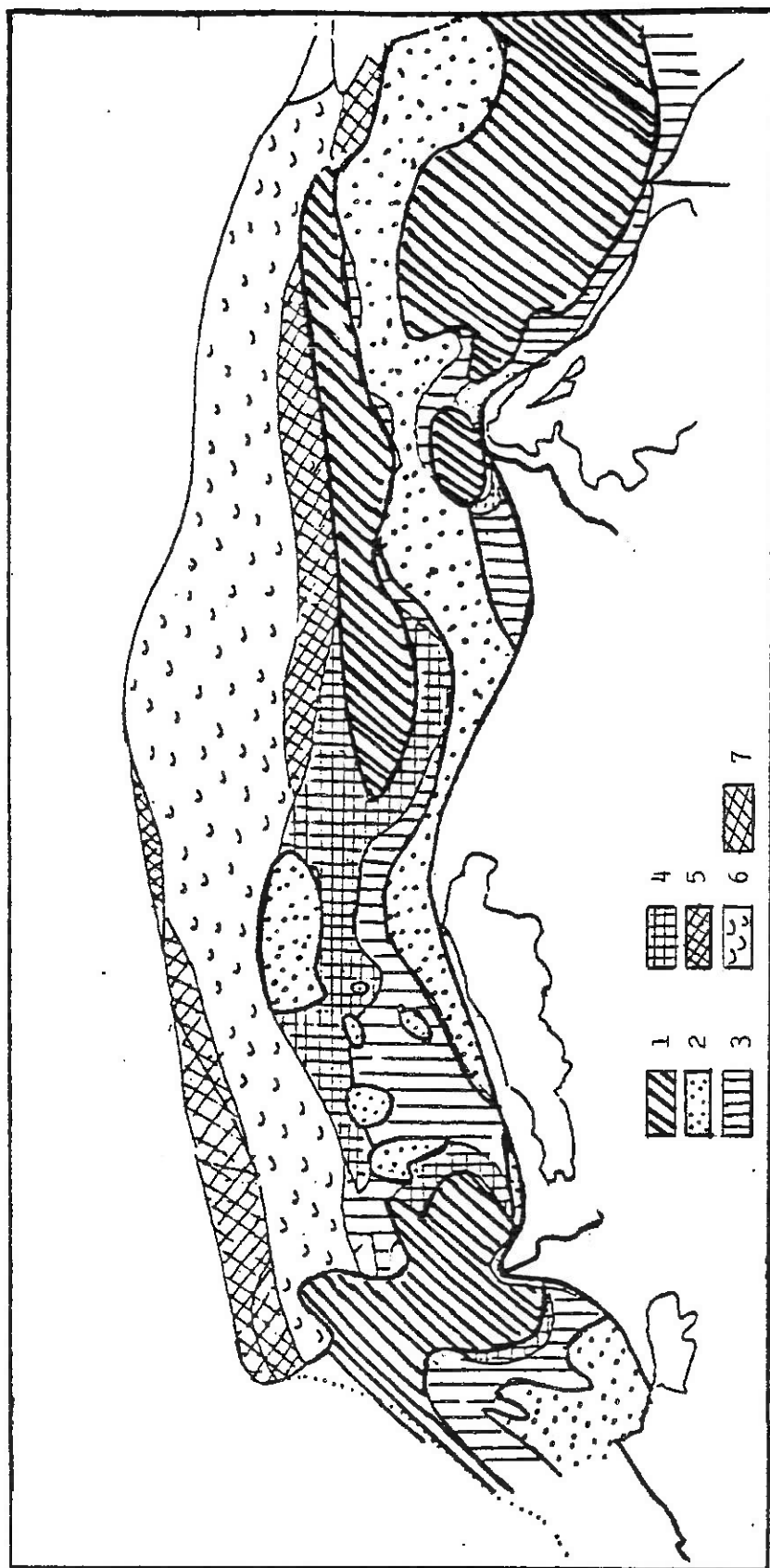


FIG. 3.6

The main sediment types of the continental shelf of the Nile delta (from: Summerhayes et al.1976, and UNESCO/ ASRT/ UNDP 1976). 1. Muds (clayey silt) 2. Sand (clayey silt) 3. Silty sand 4. Sand-silt-clay 5. Sand -silt-clay (bioclastic) 6. Bioclastic-algal sands 7. Foram calcareous muds.

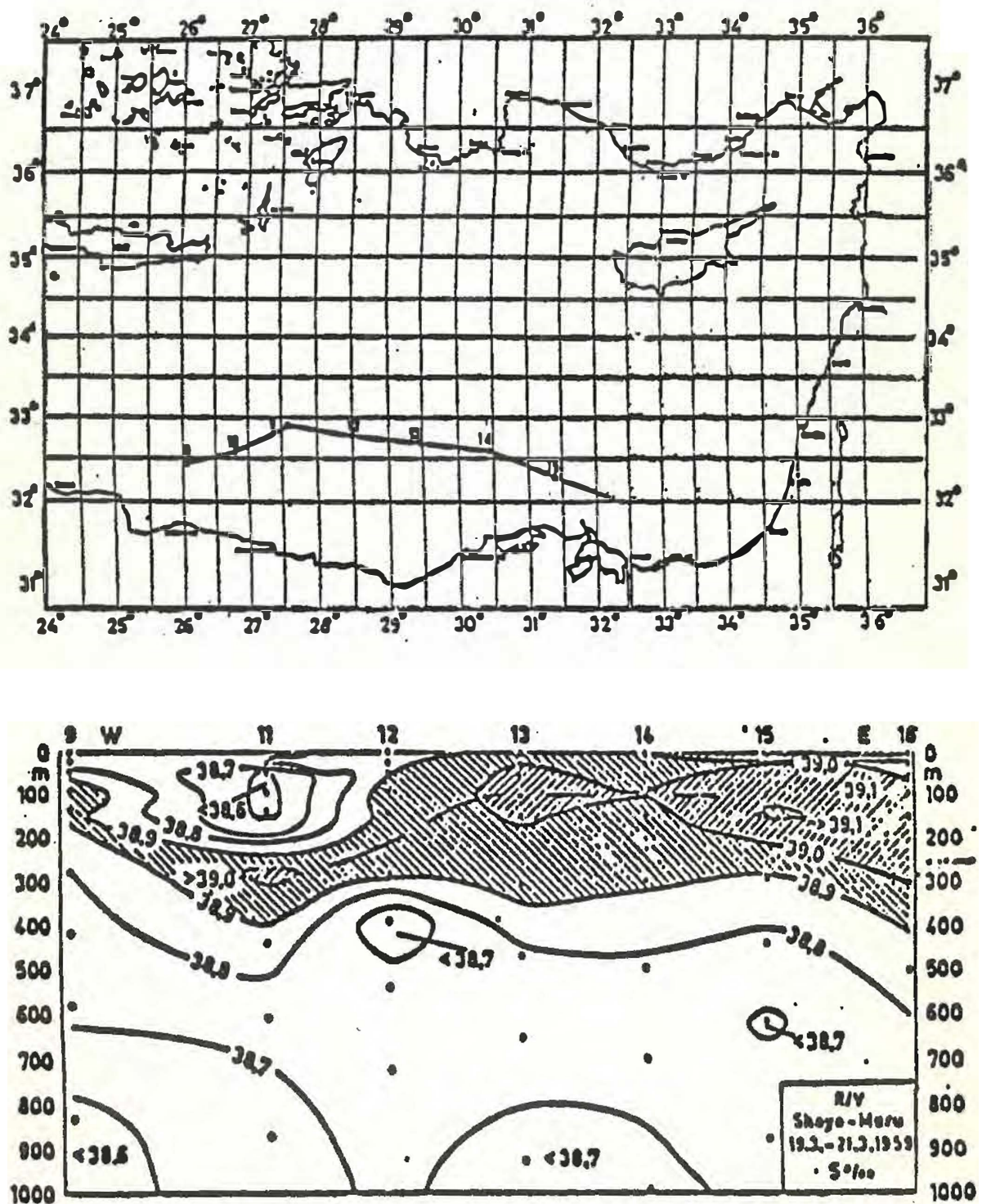


FIG. 3. 7

- a) Salinity transect off Egypt (Morcos 1972). The map above shows the location of the stations.

(a)

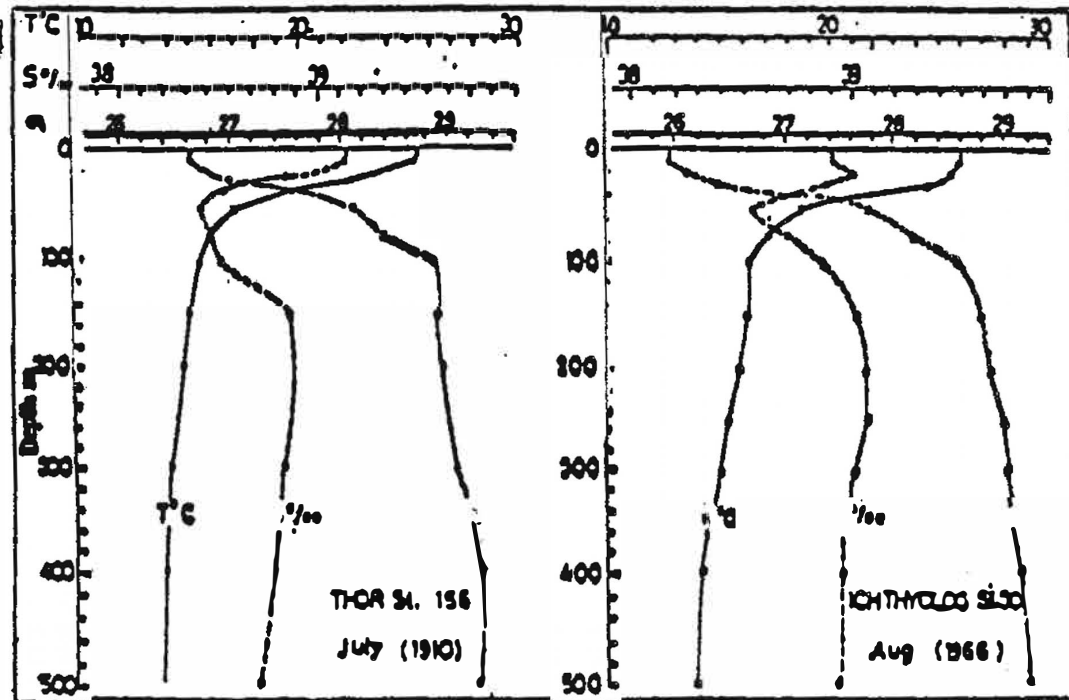
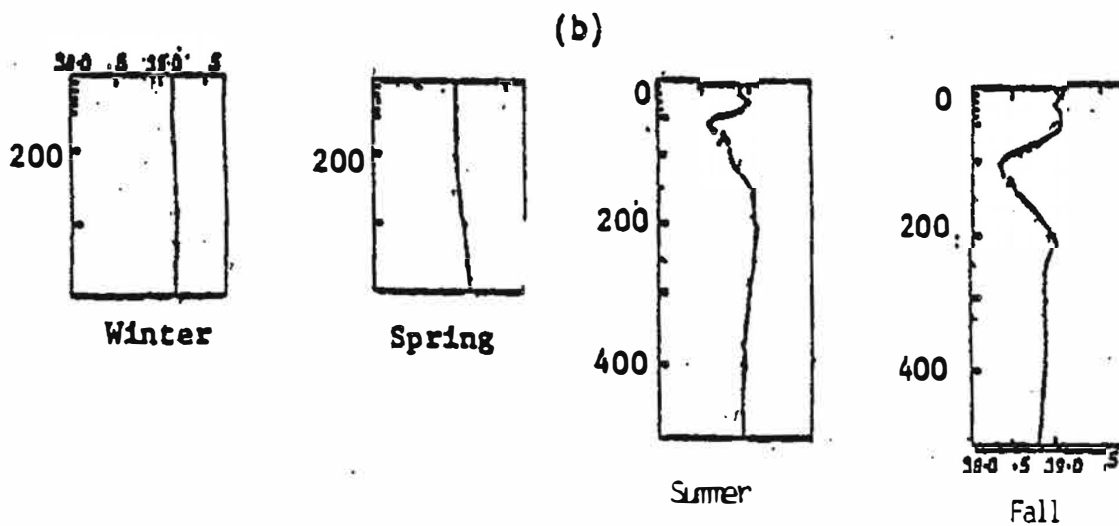
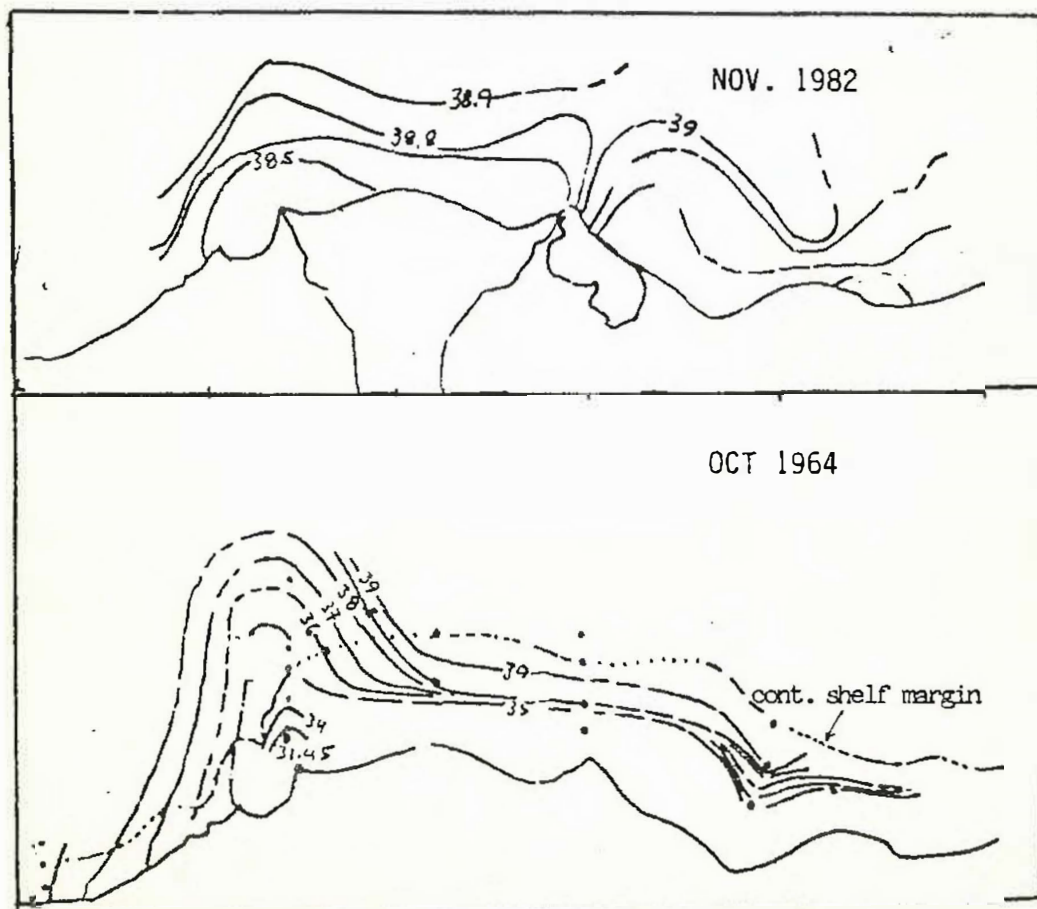
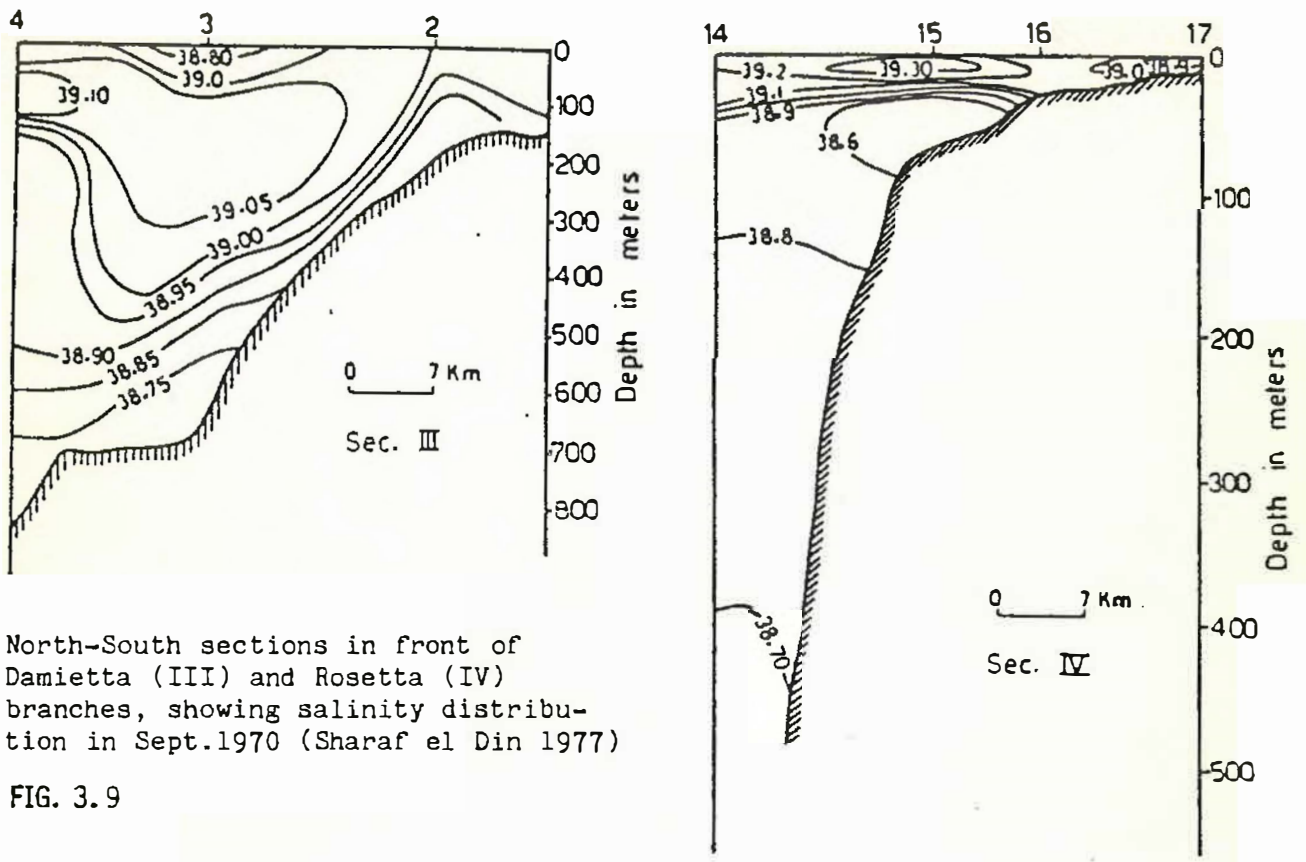
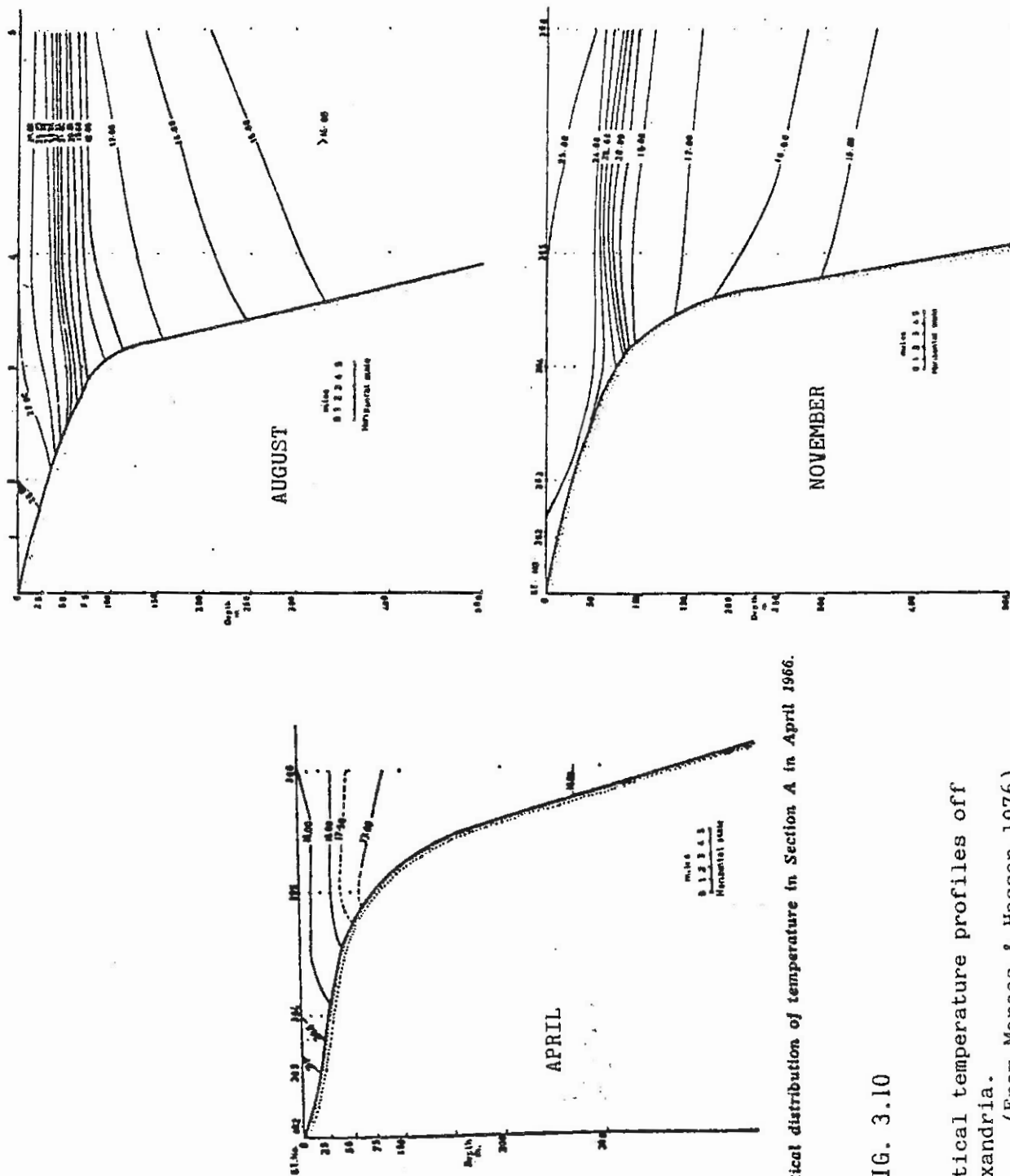


Fig 3.7 Vertical profiles of salinity, temperature and density off Egypt (After Morcos & Hassan 1976)

b) Evolution of the salinity profile at Alexandria





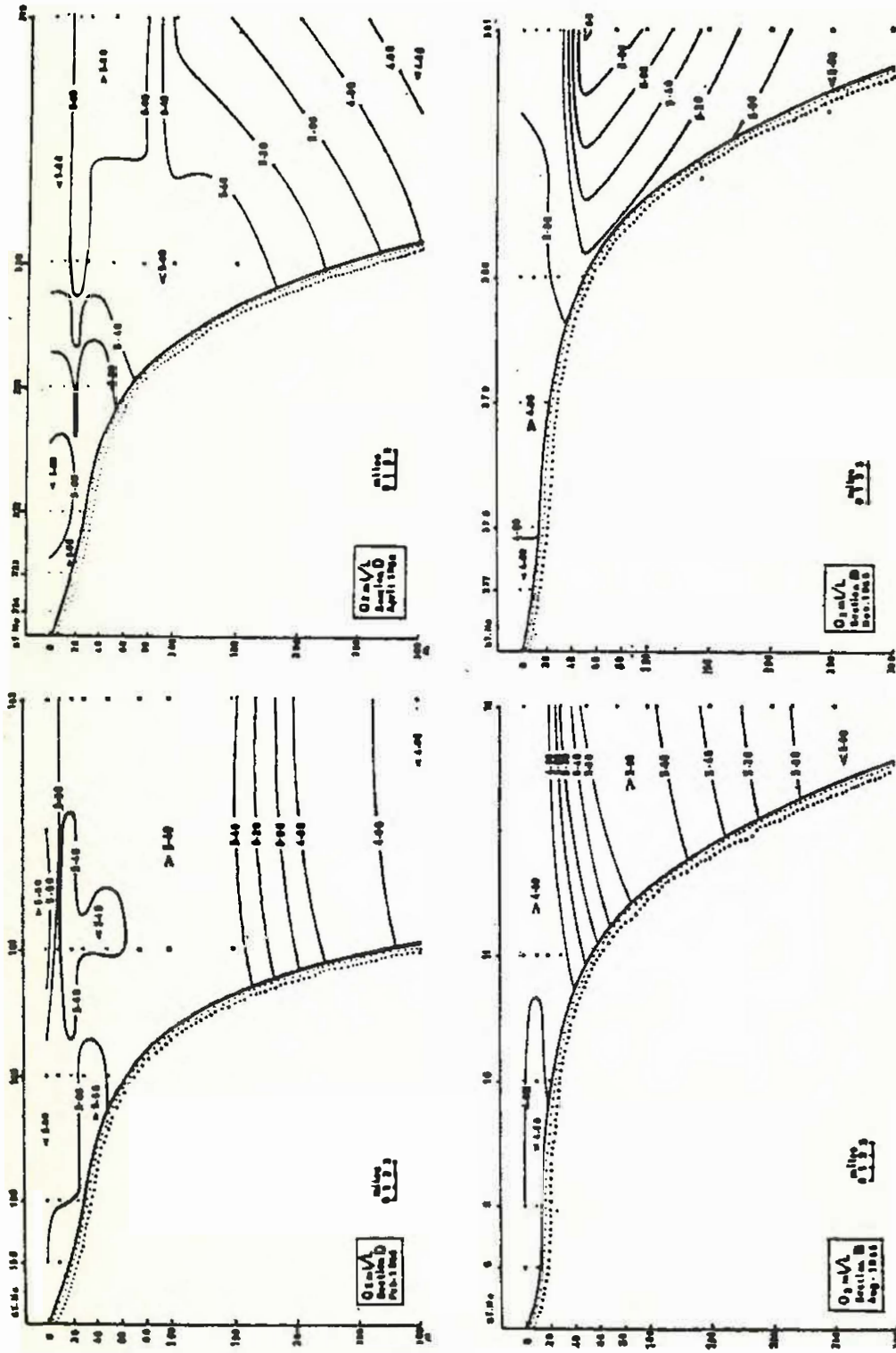


Vertical distribution of temperature in Section A in April 1966.

FIG. 3.10

Vertical temperature profiles off Alexandria.
(From Morcos & Hassan 1976)

Vertical distribution of temperature in Section A in August and November 1966.



North South sections showing the vertical distribution of oxygen (ml/l) in the Egyptian waters

1-a Section D (Brullos ~ 30° 50' E) February 1966.

1-b Section D (Brullos ~ 30° 50' E) April 1966.

1-c Section B (Tina Bay ~ 32° 40' E) August 1966.

1-d Section B (Tina Bay ~ 32° 40' E) November 1966.

FIG. 3.11

(From: Emara et al. 1976)

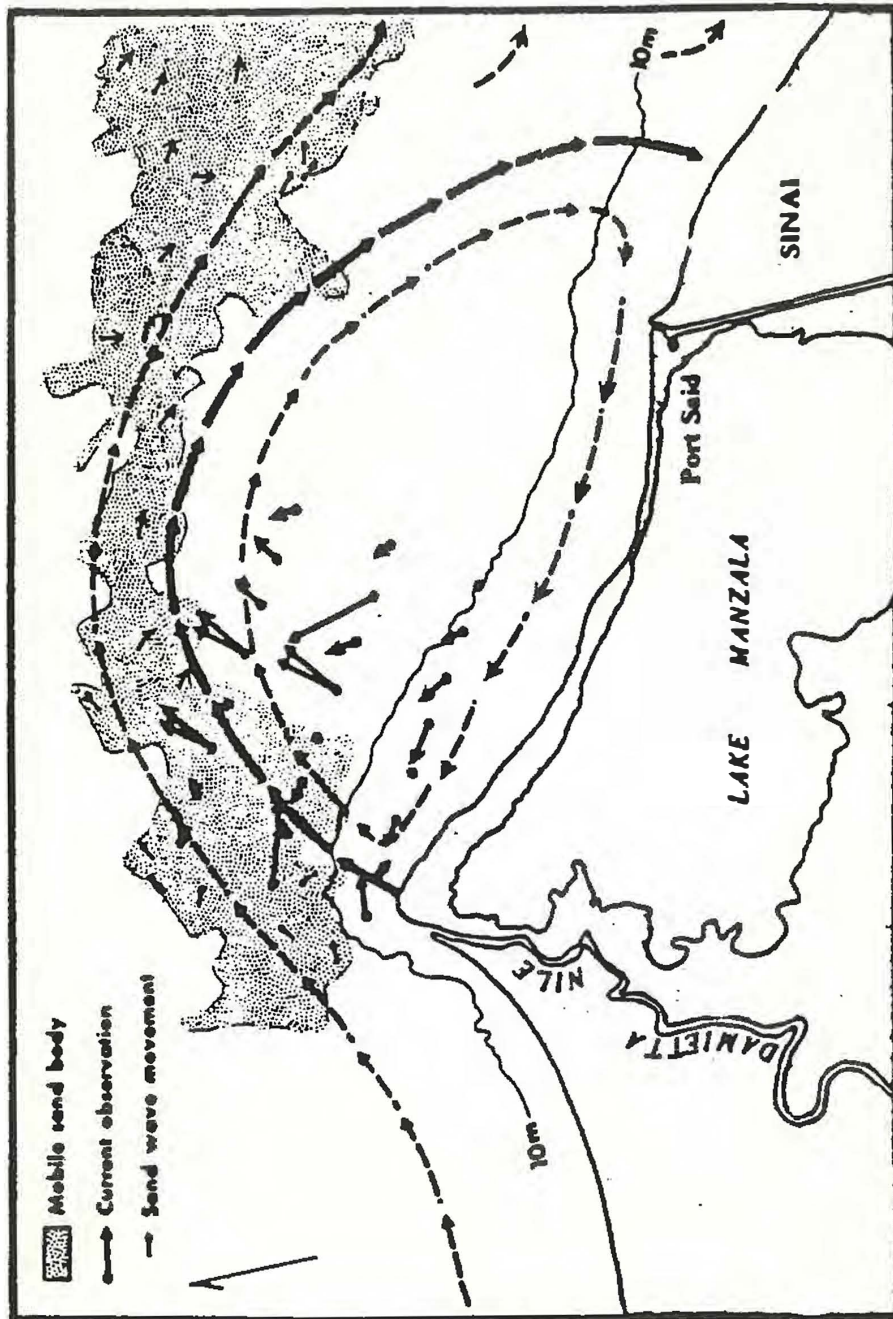


FIG. 3. 13 Observations of currents and sand wave movements compared to the composite model of a trapped eddy (Murray et al. 1981)

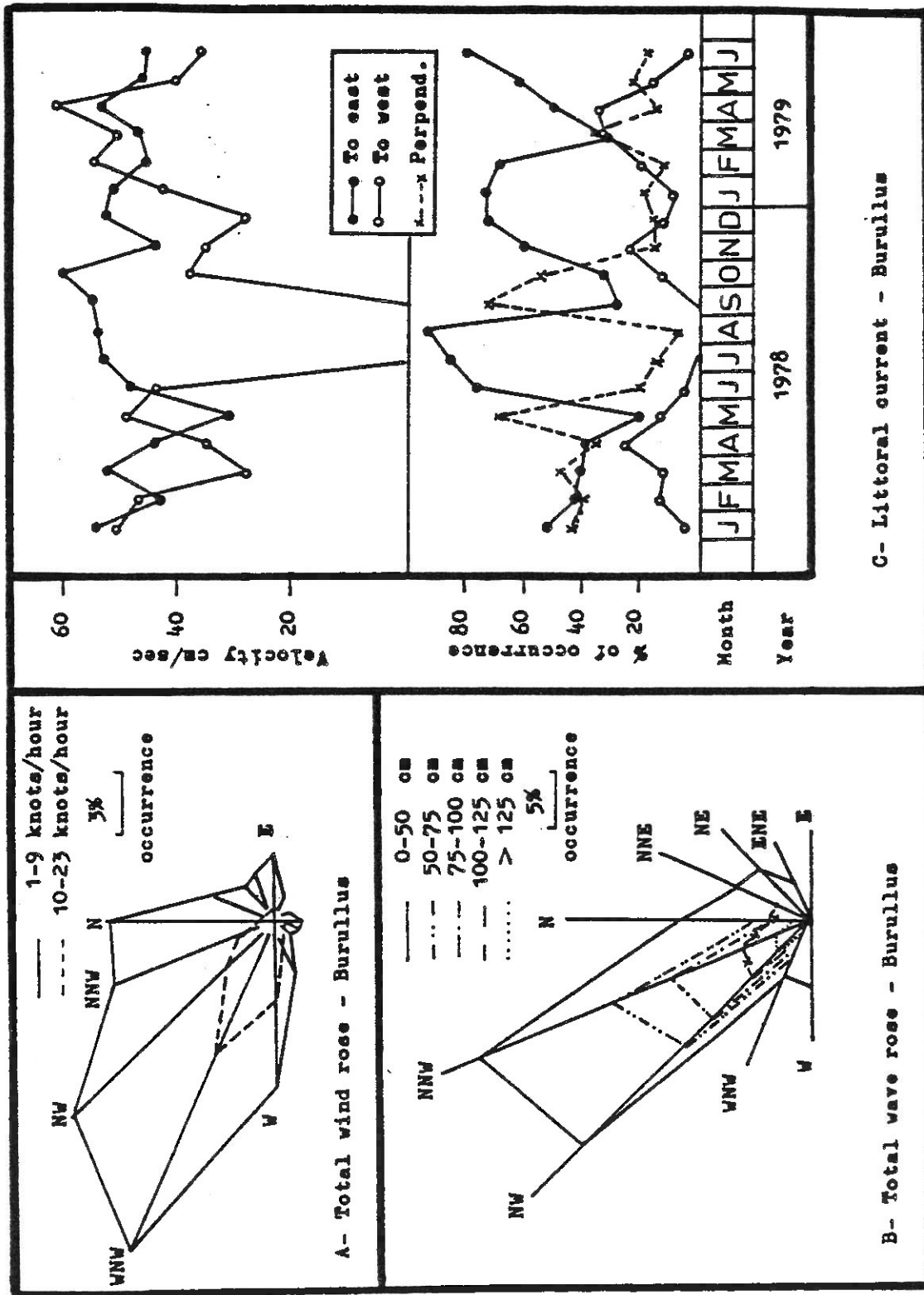


FIG.3. 14 -Dynamic factors affecting the Nile Delta coast : A- Wind B- Wave C- Littoral current
(El Fishawi, 1988)

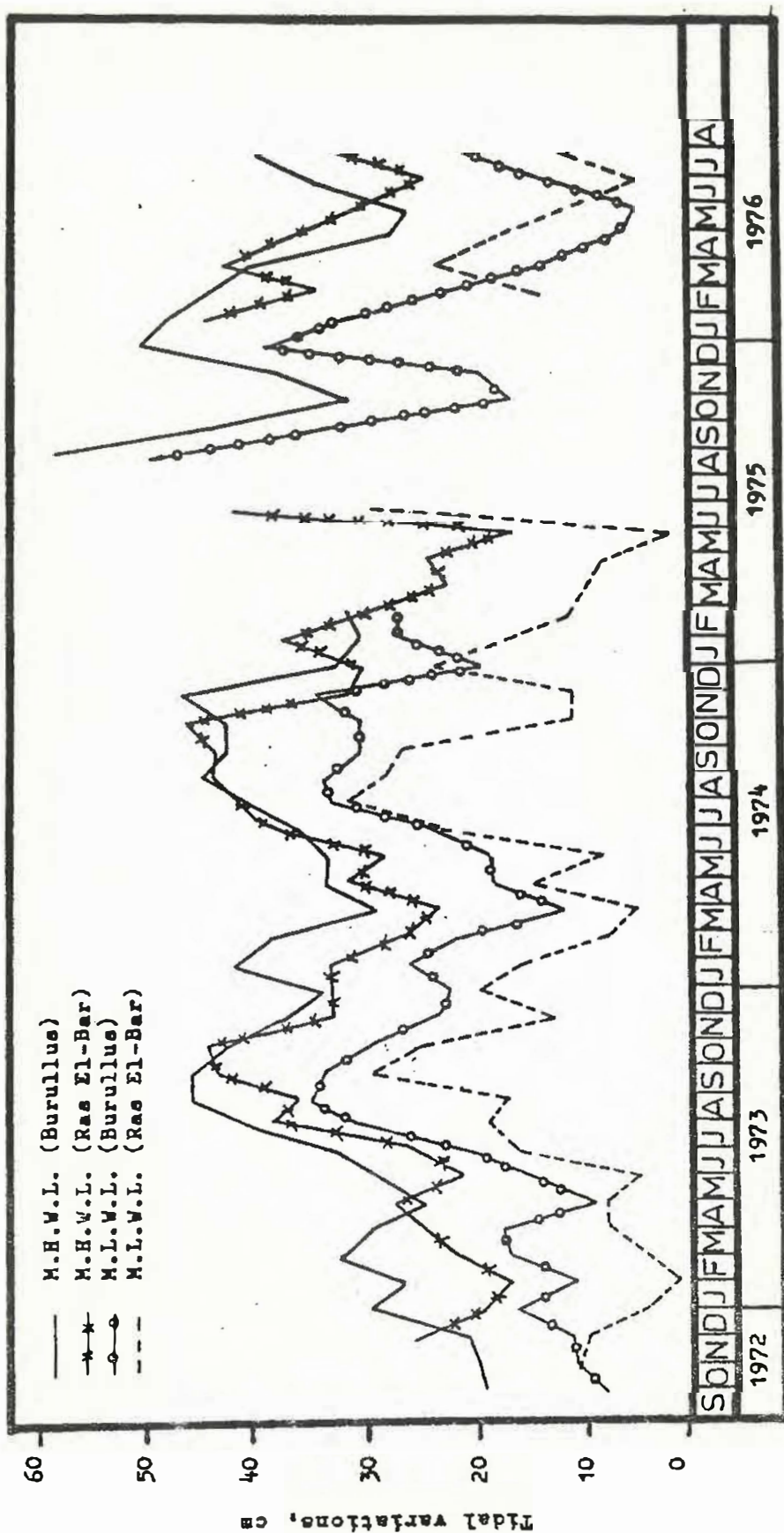


FIG. 3. 15
Tidal variations between Burullus and Ras El-Bar (El Fishawy 1988)

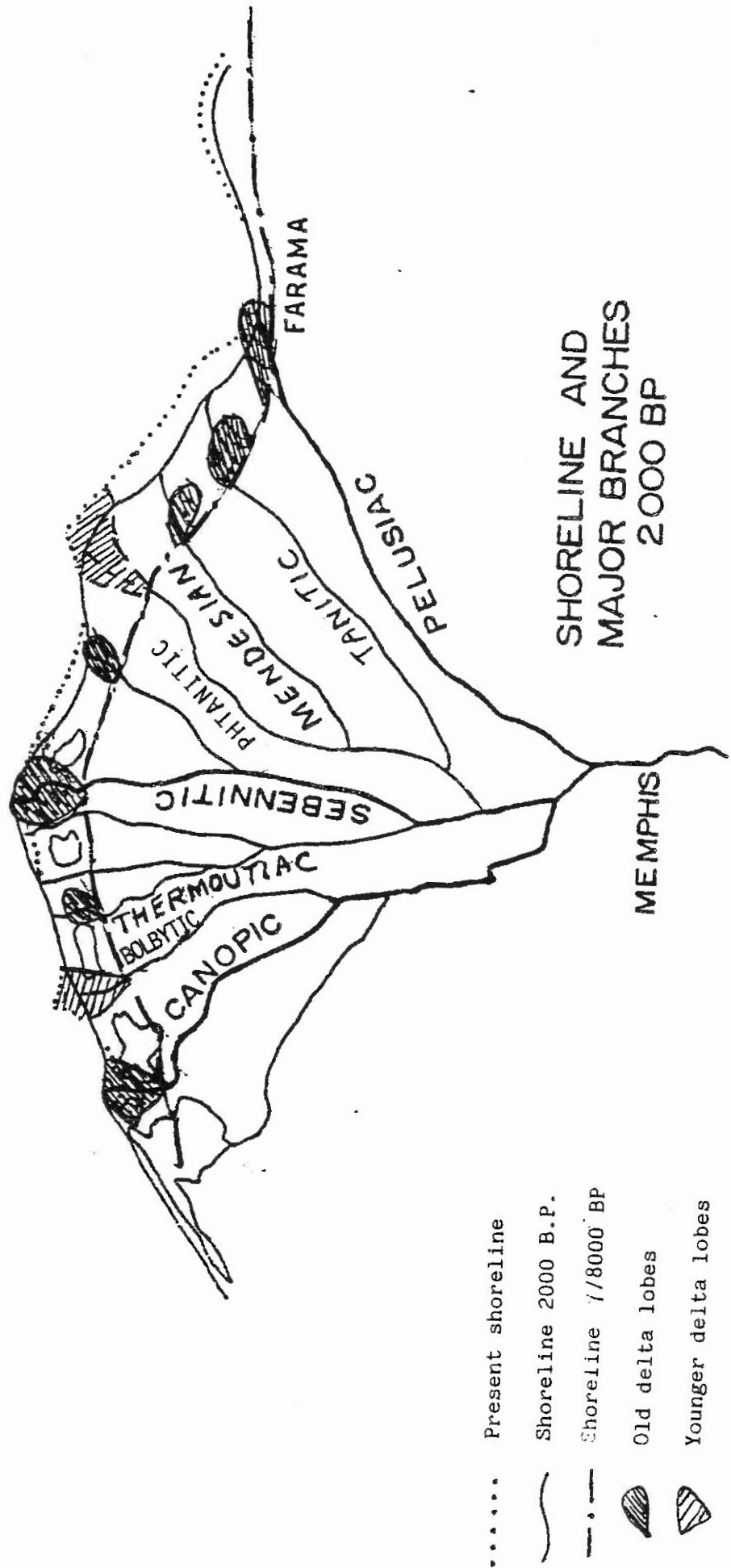
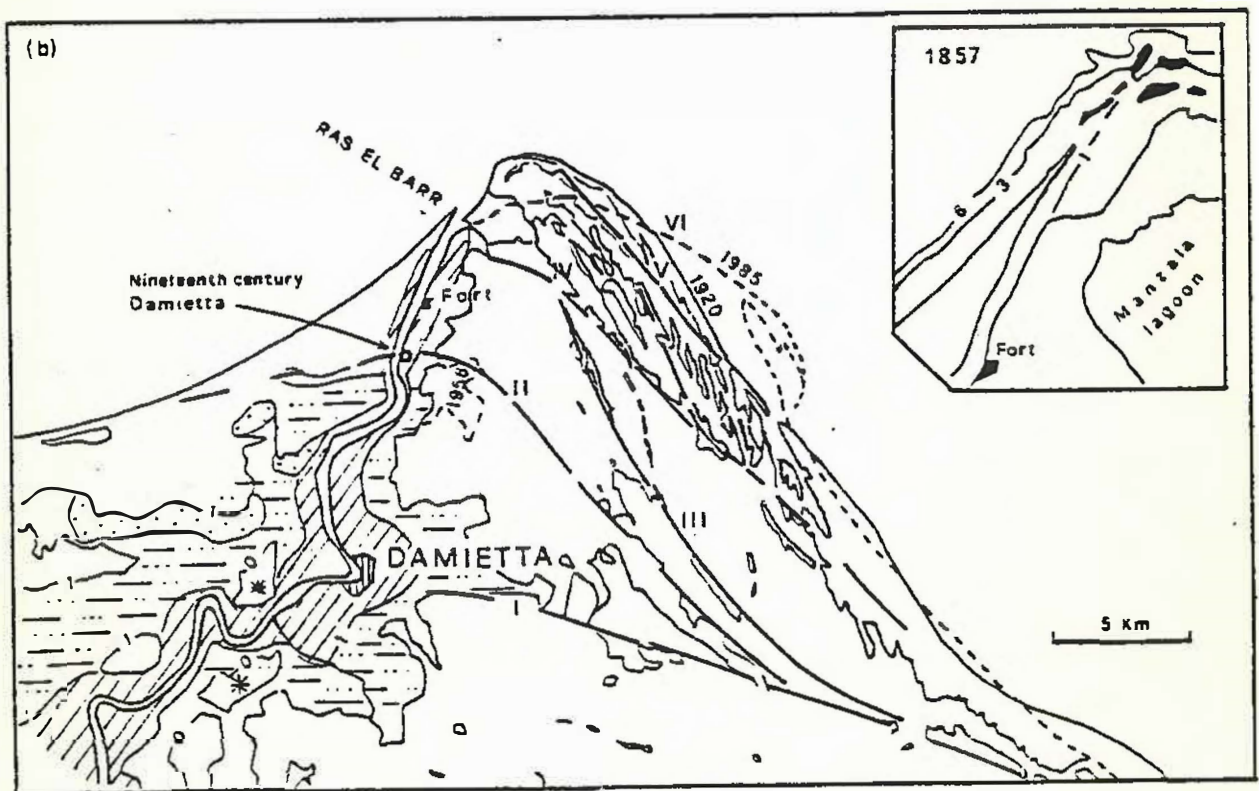
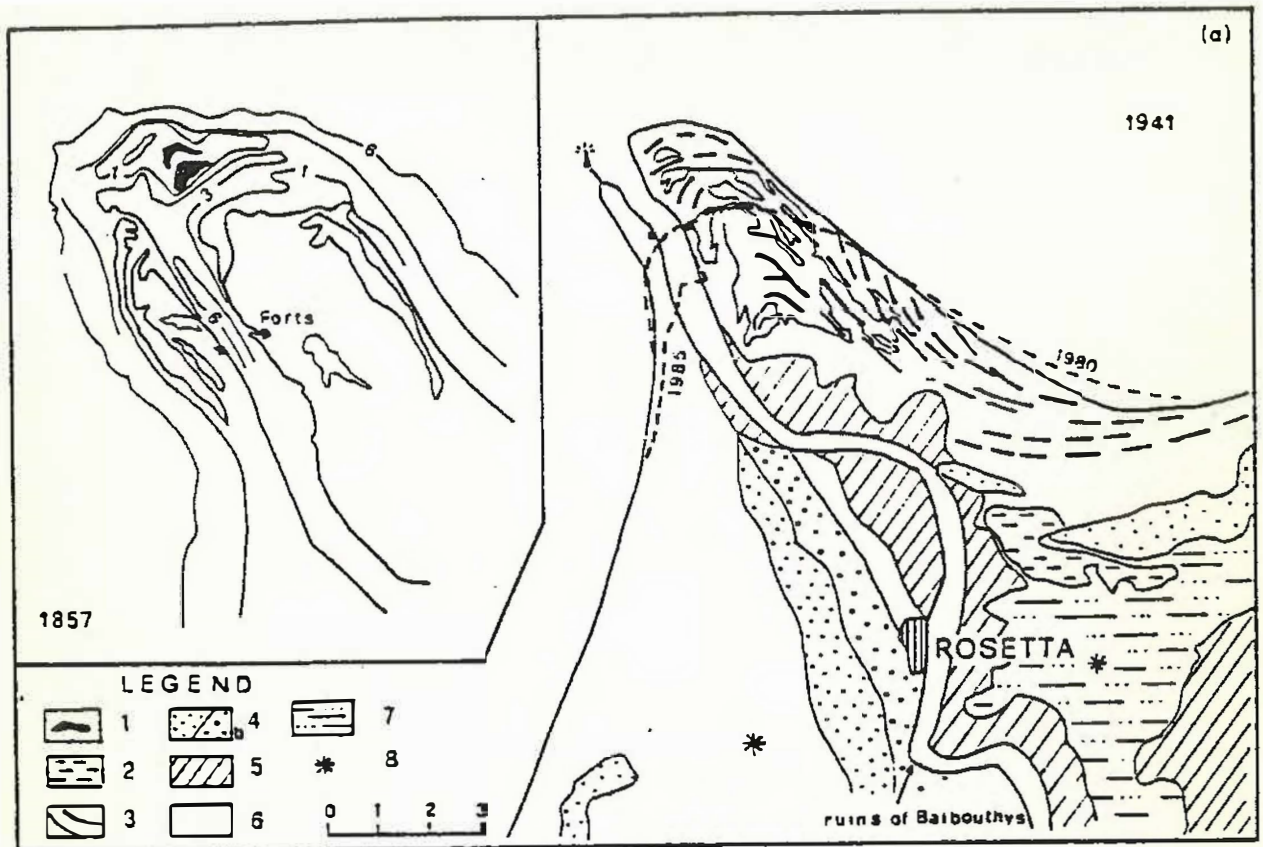
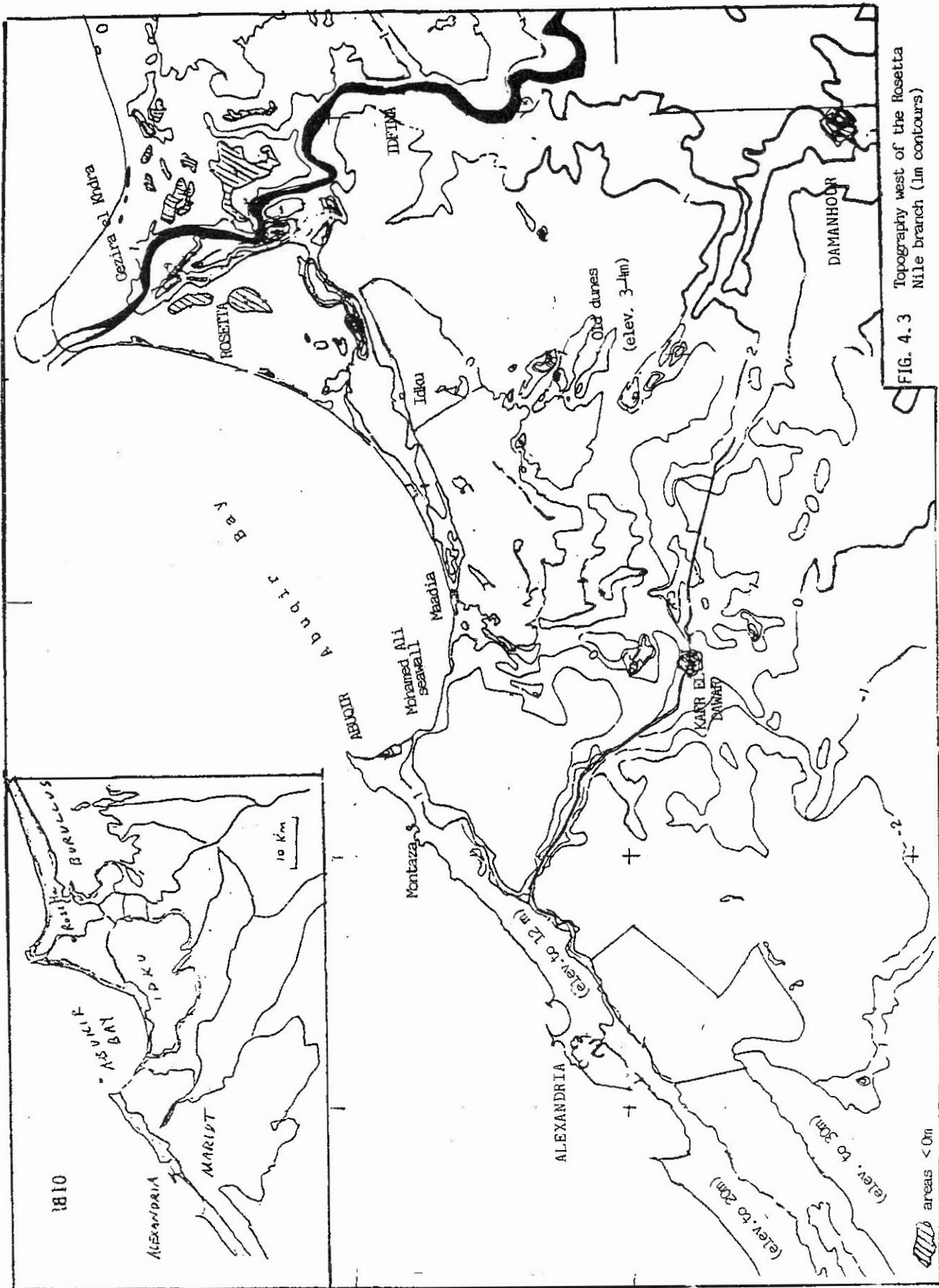


FIG. 4.1



Morphology of the Rosetta and Damietta subdeltas: 1, submerged sand bars; 2, lakes; 3, beach ridges; 4, dunes ($b, > 10$ m); 5, channel-levee complex; 6, backshore plains; 7, flood basins; 8, areas < 0 m; I-VI, stages of shoreline migration (depths in metres). (Sestini, 1988)

FIG. 4.2



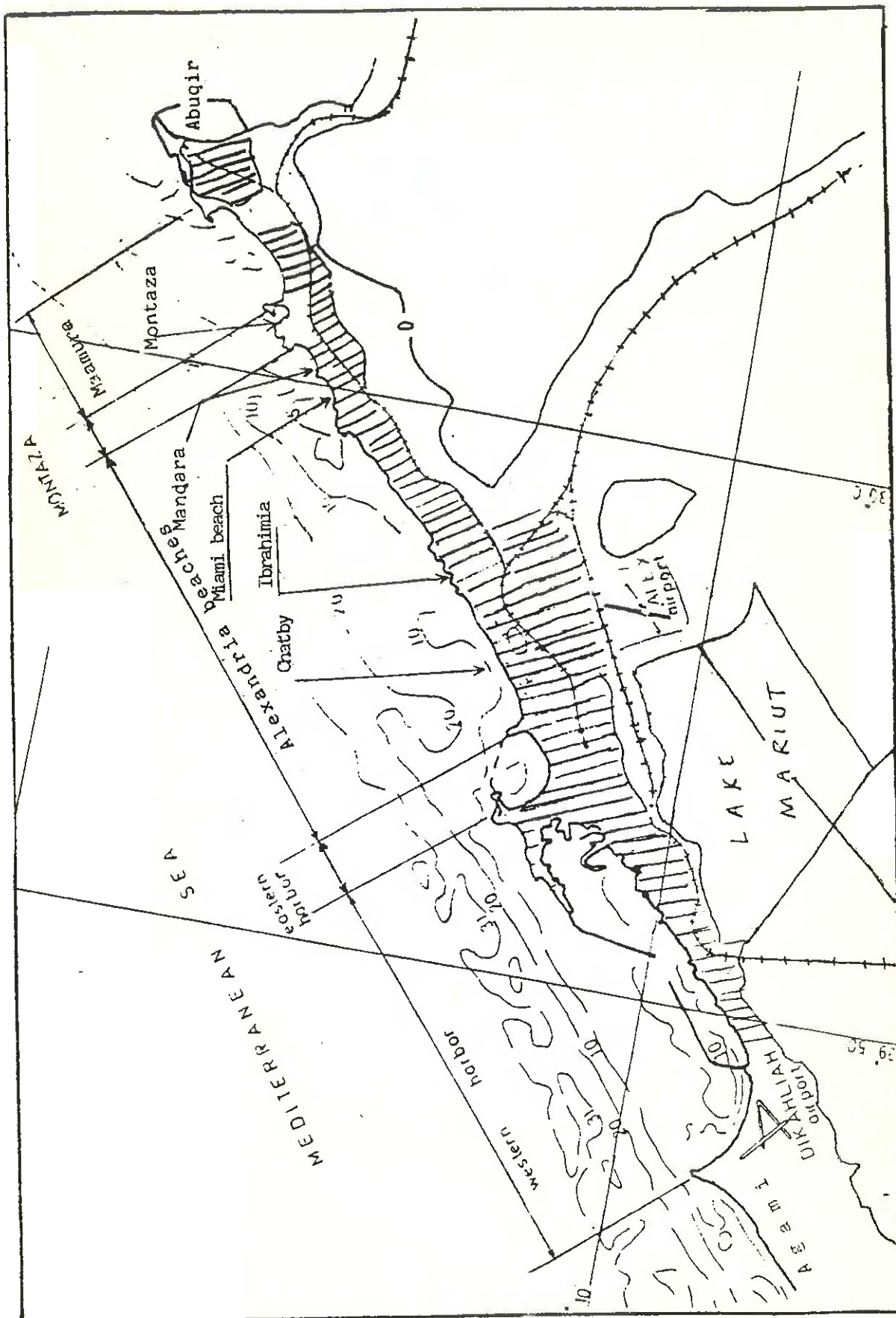


FIG. 4.4
ALEXANDRIA: extent of urban area, harbours and pocket beaches (modified from Tetrattech 1986)

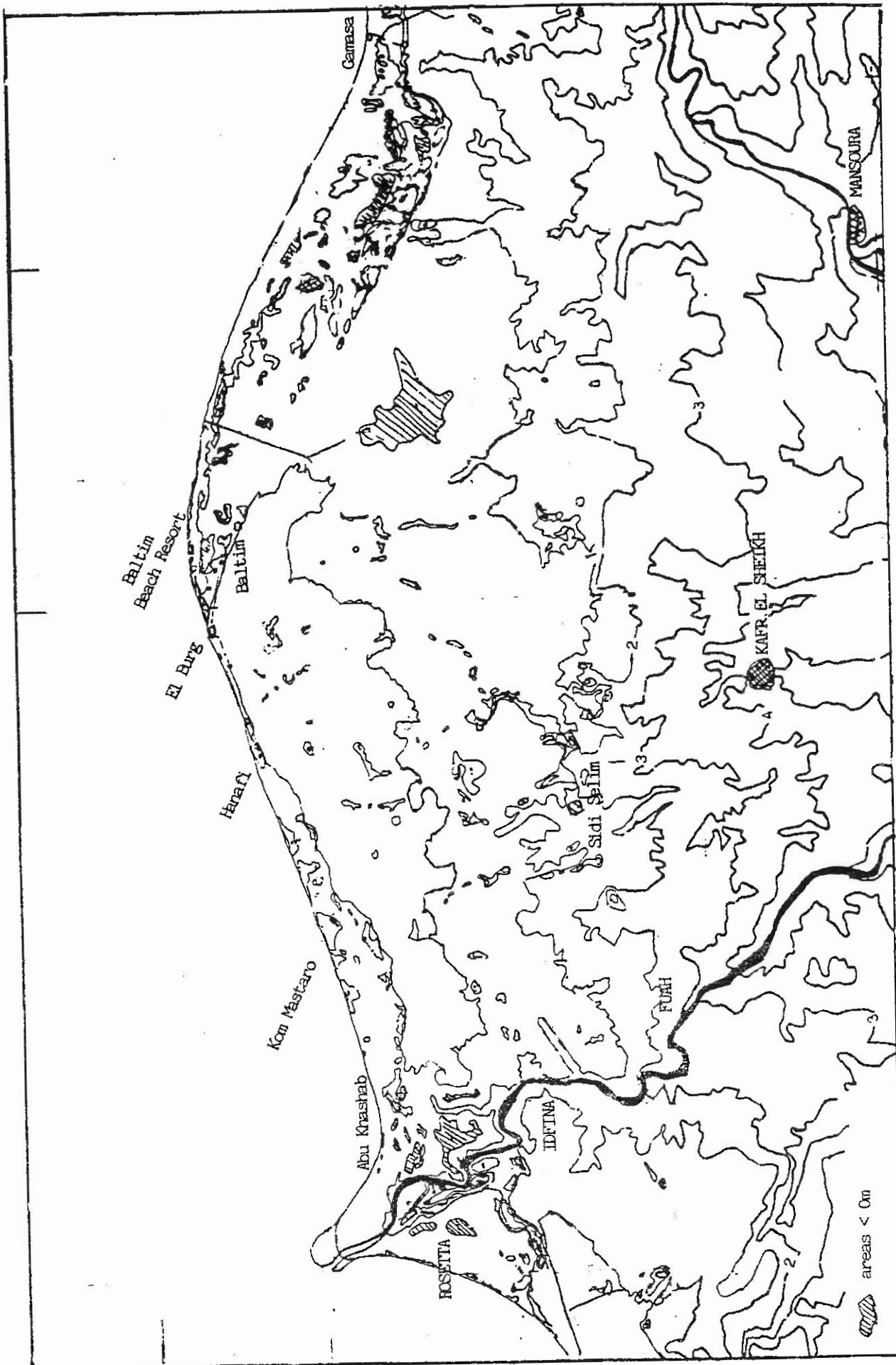
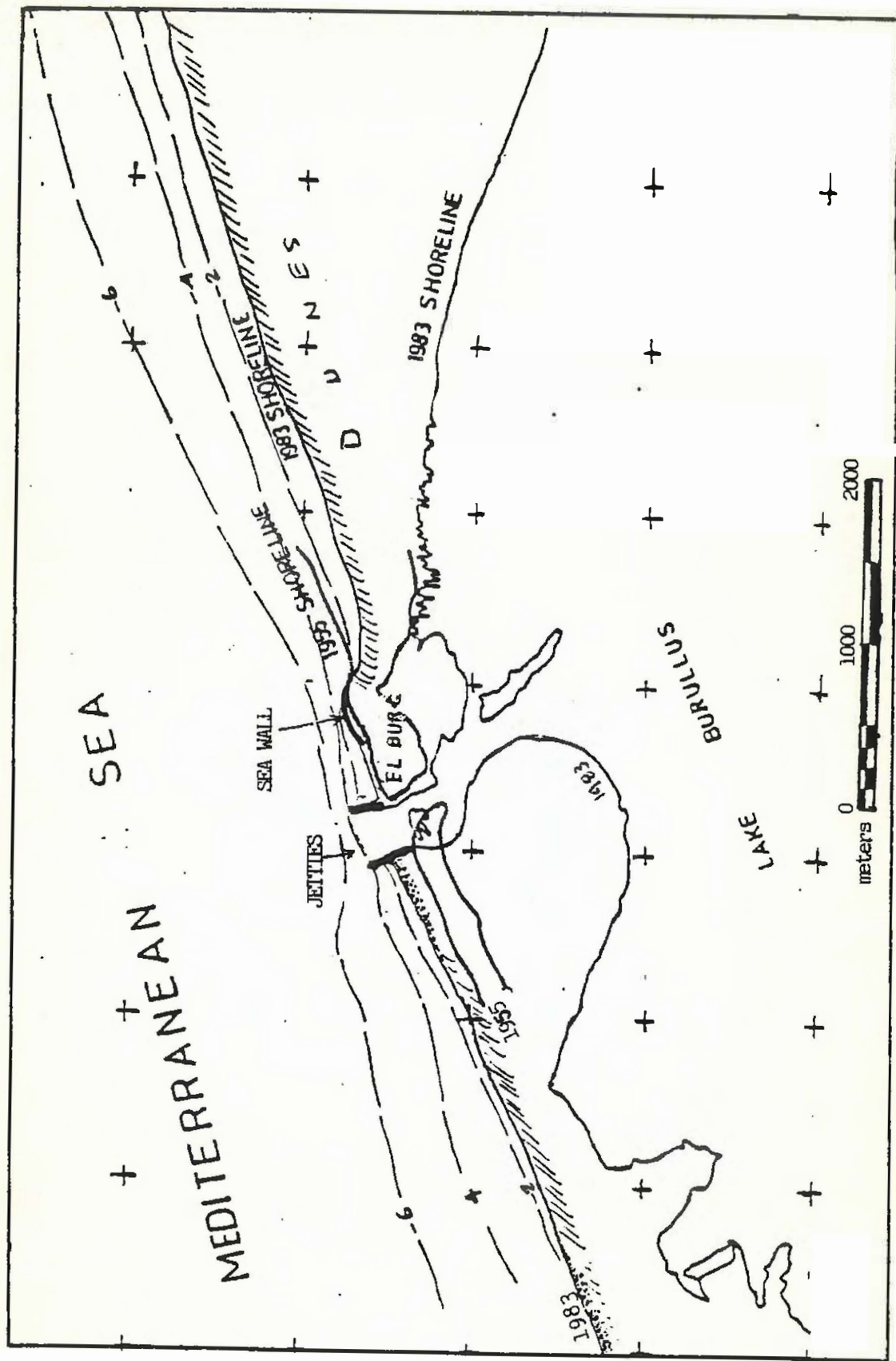


FIG. 4.5 Topography of the lower Nile delta between Rosetta and Gamasa. Contours 1m. From a topographic map, original scale 1:100,000, 1945.



RECENT SHORELINE VARIATIONS
AT THE OUTLET OF THE BURULLUS
LAGOON (From: Tetratich 1986)

FIG. 4. 6

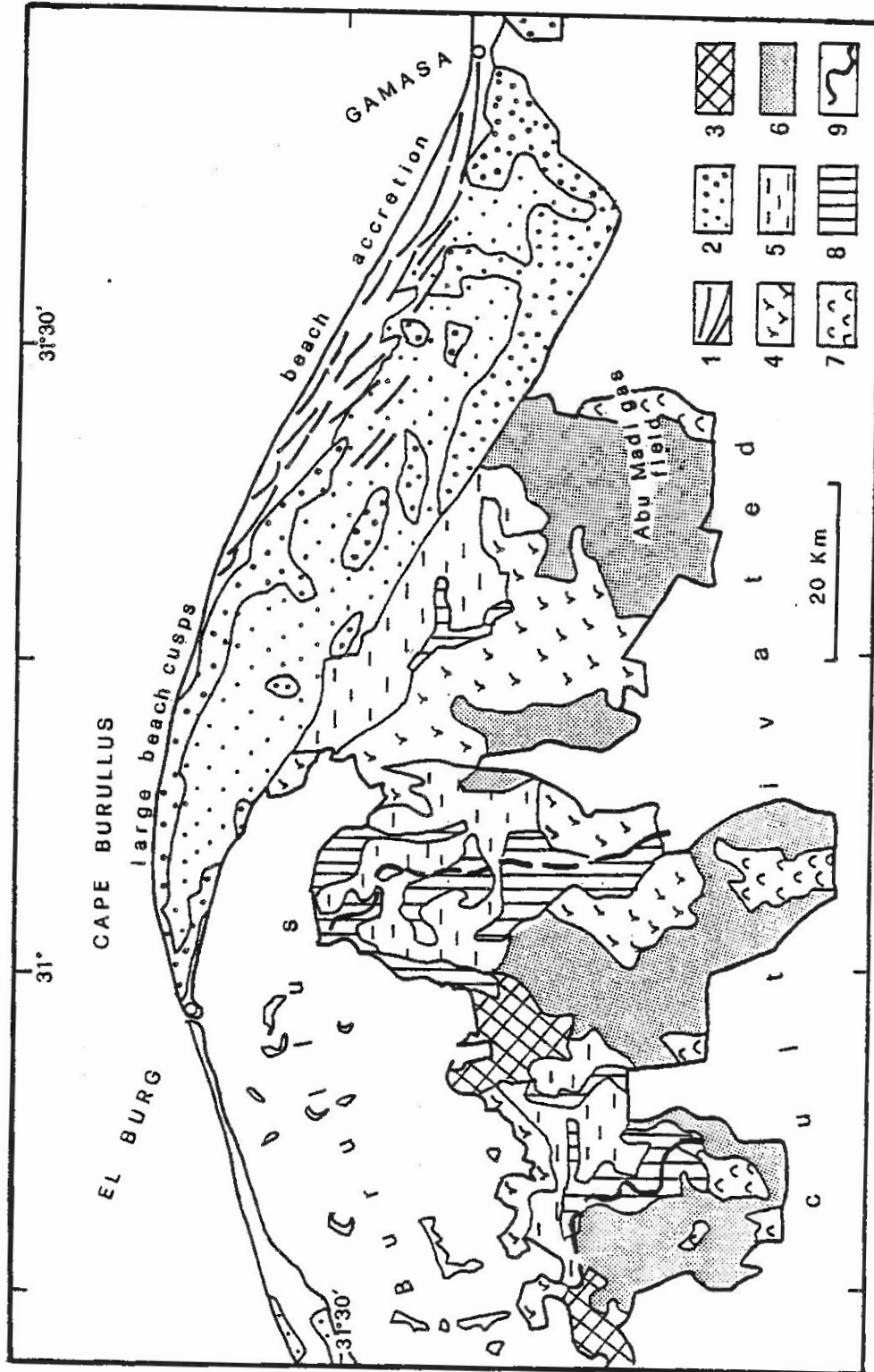
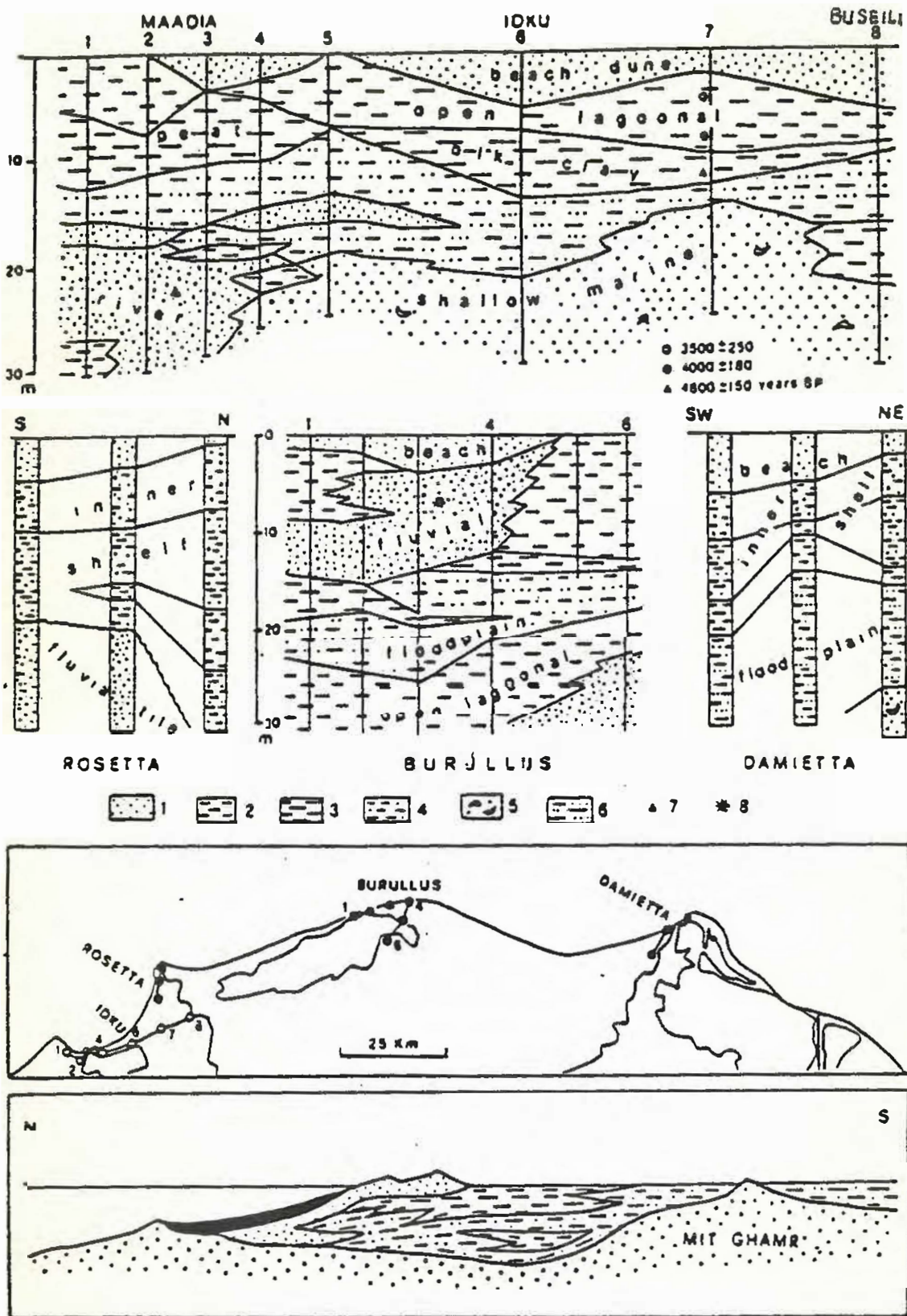


FIG. 4.7

Original sedimentary environments and morphology of the eastern Burullus region (Sestini, 1988).

1. Sandy beach ridges and backshore plains.
2. Windblown sands.
3. Lakes.
4. Areas flooded for several months.
5. Marshes.
6. Silt plains.
7. Silt dunes.
8. Sand-silt elevated areas.
9. Abandoned river channels.



The subsurface Holocene Complex near the coast (based on Sestini 1976; UNESCO/UNDP 1976; Anwar *et al.* 1984): 1, beach-dune complex; 2, open lagoonal deposits; 3, marshy-restricted lagoonal deposits; 4, marine clays and silts; 5, marine sands (medium to fine grained); 6, fluvatile sand-silt-clay; 7, sands of the Canopic distributary channel; 8, sands of the Sebennyitic distributary channel. The schematic model (bottom) shows the regressive inner neritic (mud)-beach-dune-lagoon complex near the Burullus Lagoon.

FIG. 4.8

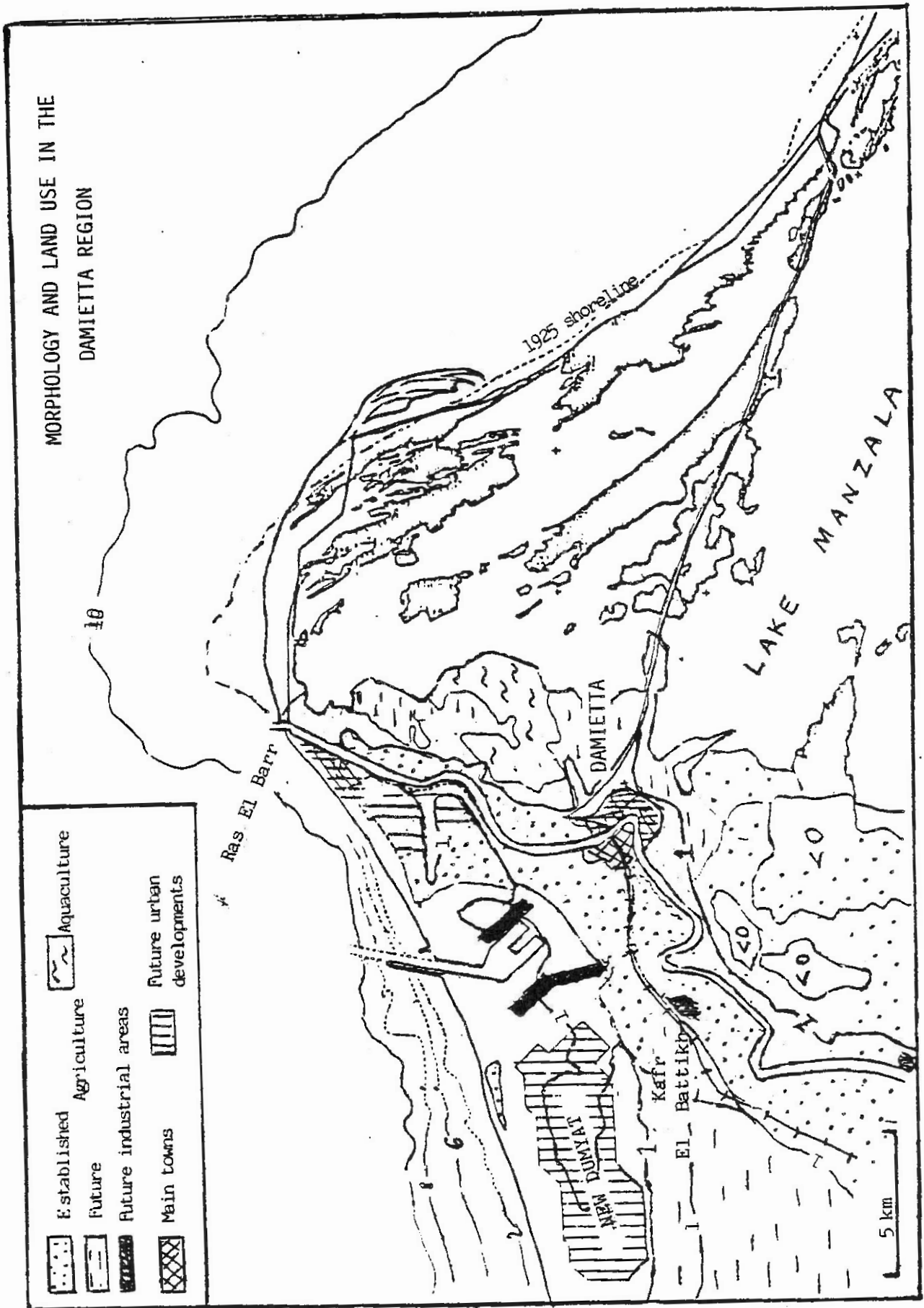


FIG. 4.9

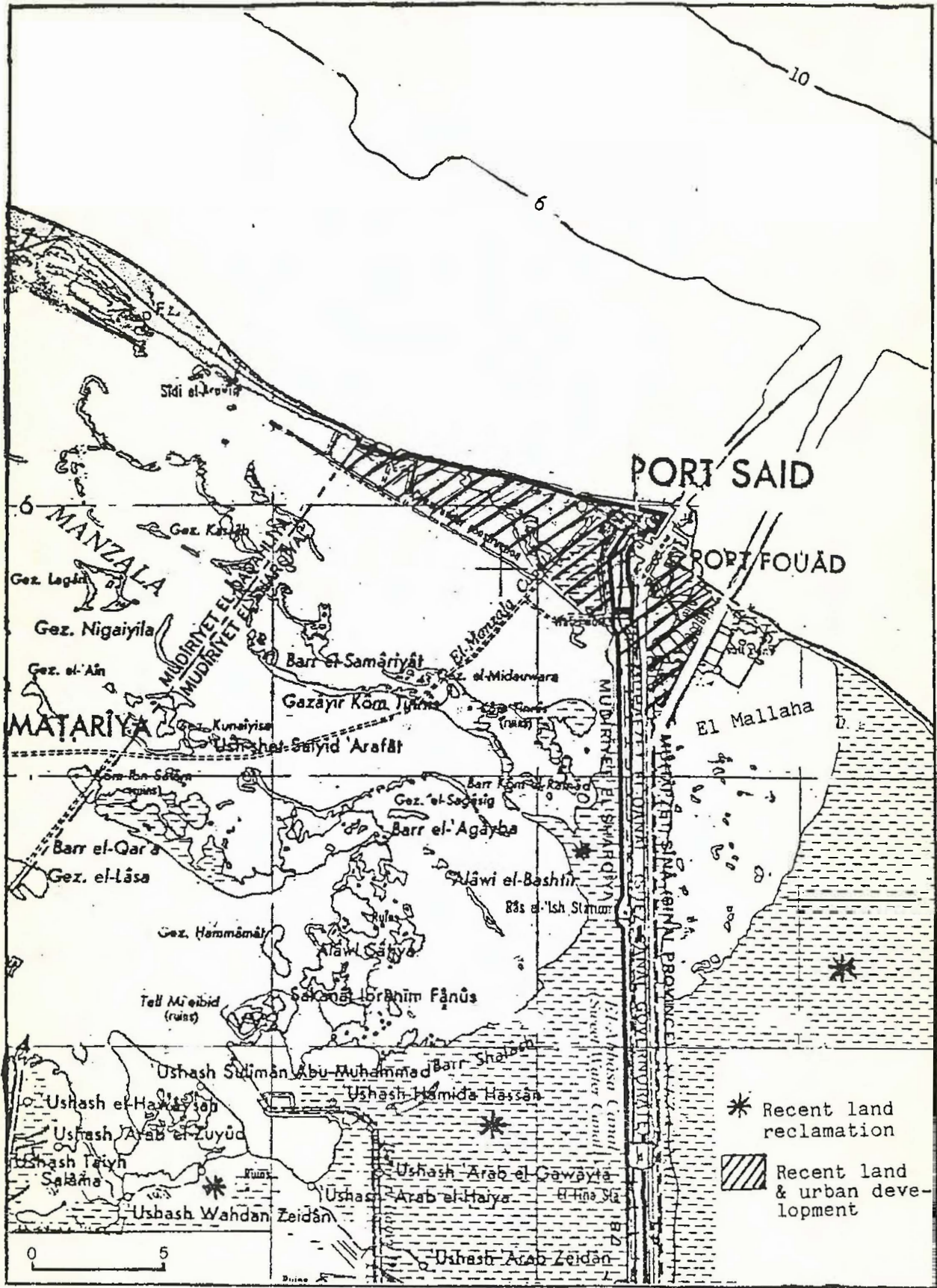


FIG. 4.10

Port Said and the eastern part of Manzala lagoon in 1958 (from a U.S. Army map)

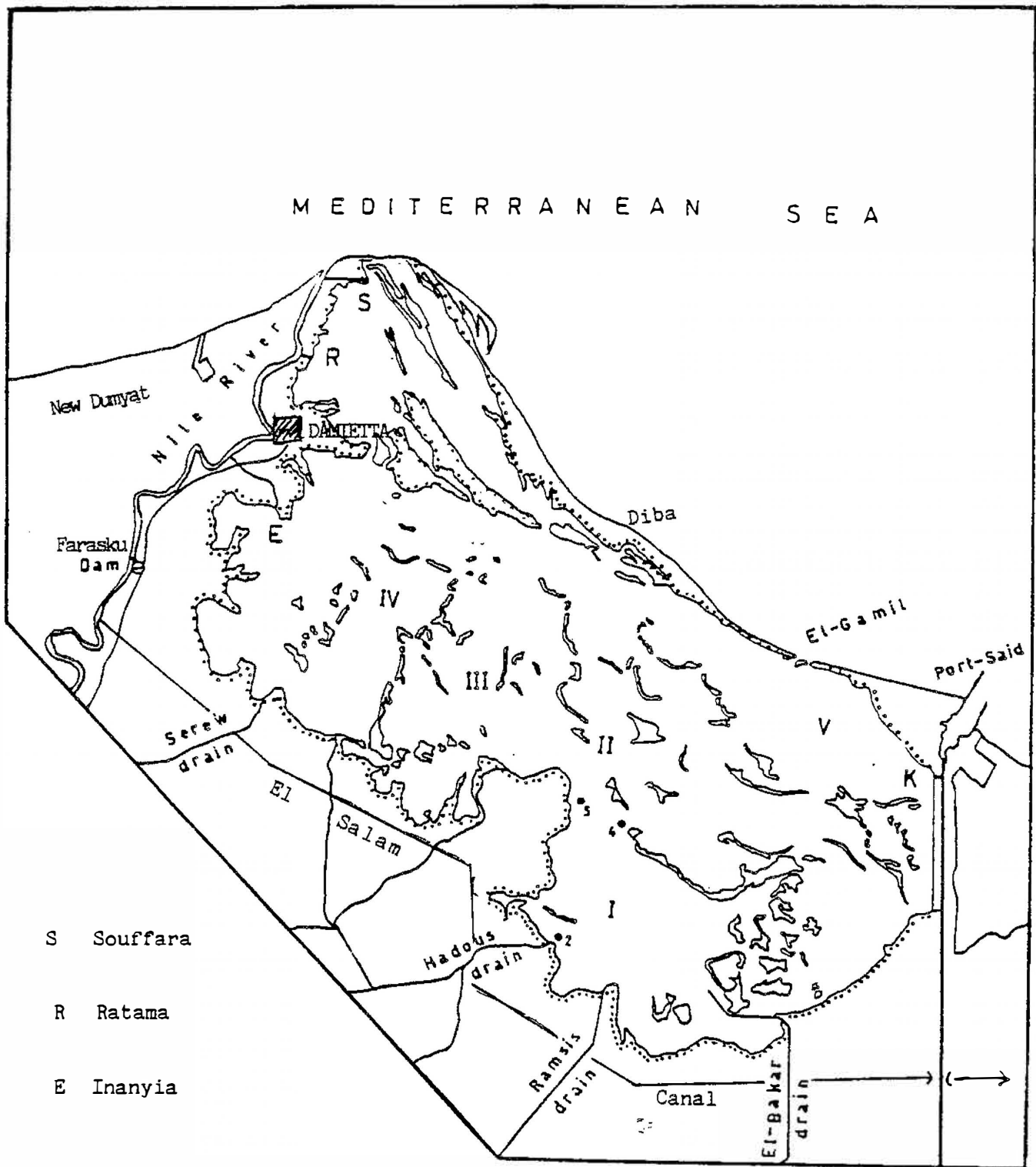


FIG. 4.11

Manzala lagoon subdivisions, drains and canals

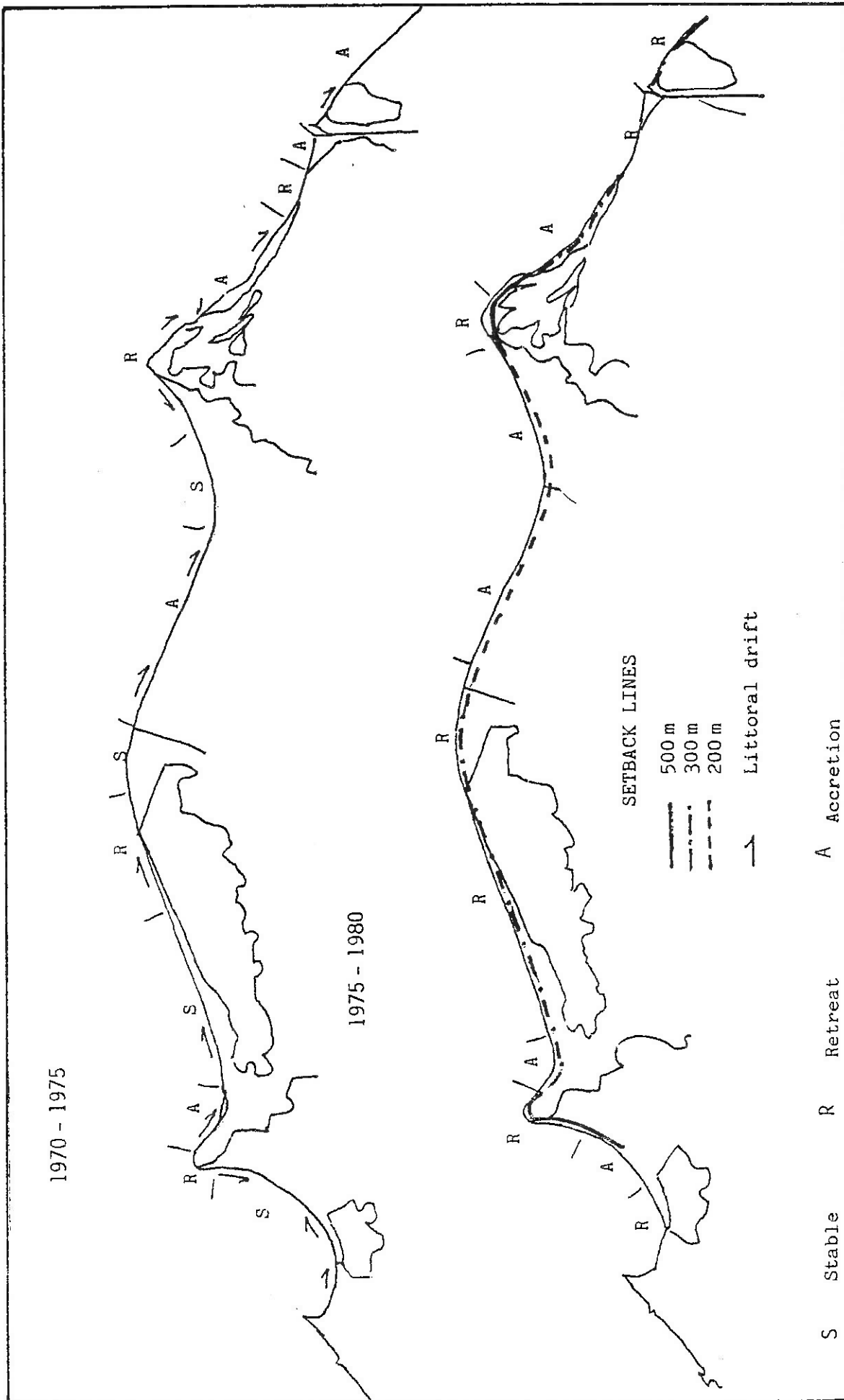


Fig.4.14 Erosion-Accretion state of the Nile Delta shoreline. Top: from UNDP/UNESCO 1978; bottom, from Tetrattech 1986 (based on Coastal Research Institute studies). Proposed setback lines, from Coastal Protection Master Plan.

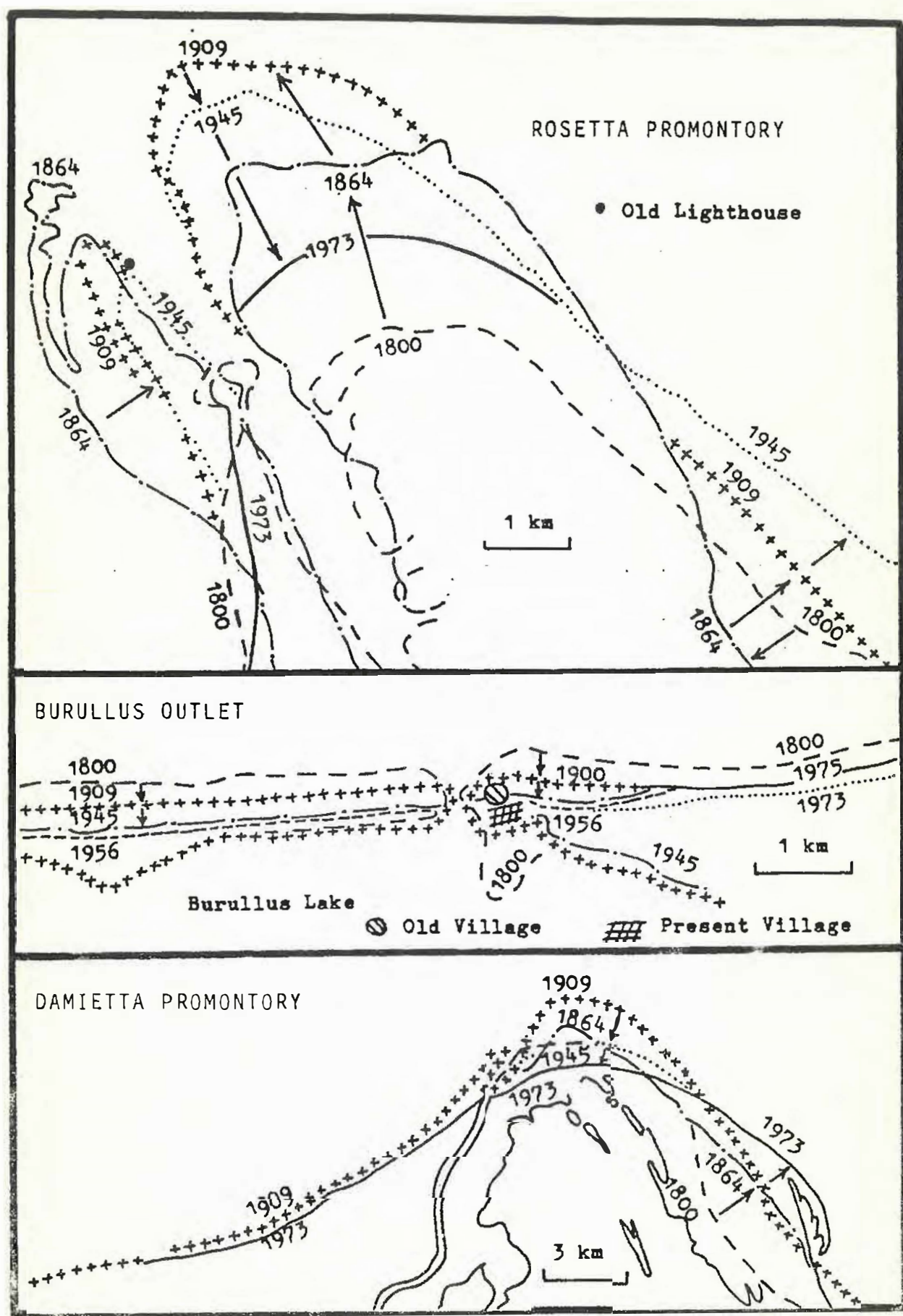


FIG.4.15 Shoreline changes on the Nile Delta coast.
 A- Rosetta B- Burullus C- Damietta (El Fishawy 1988)

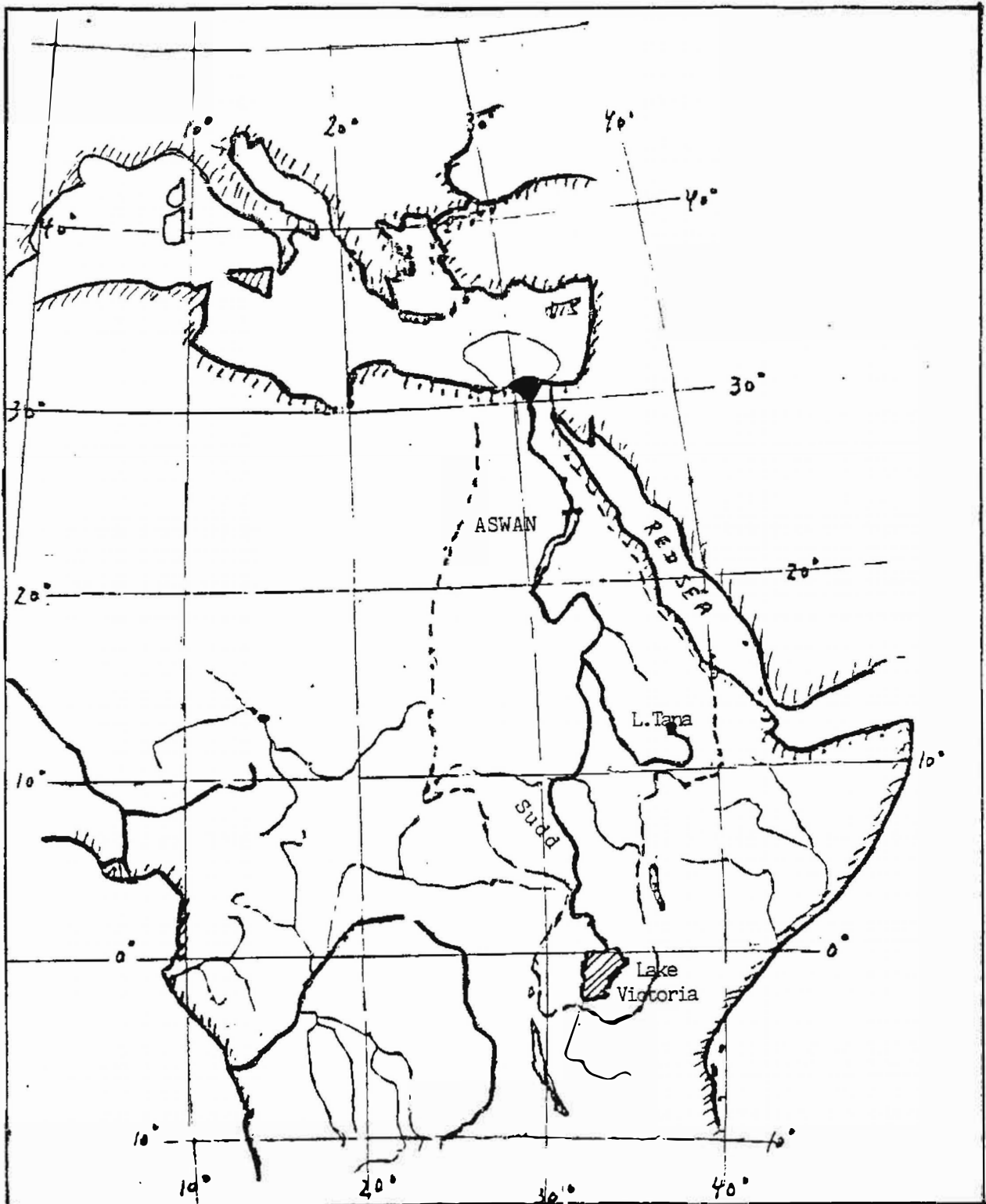
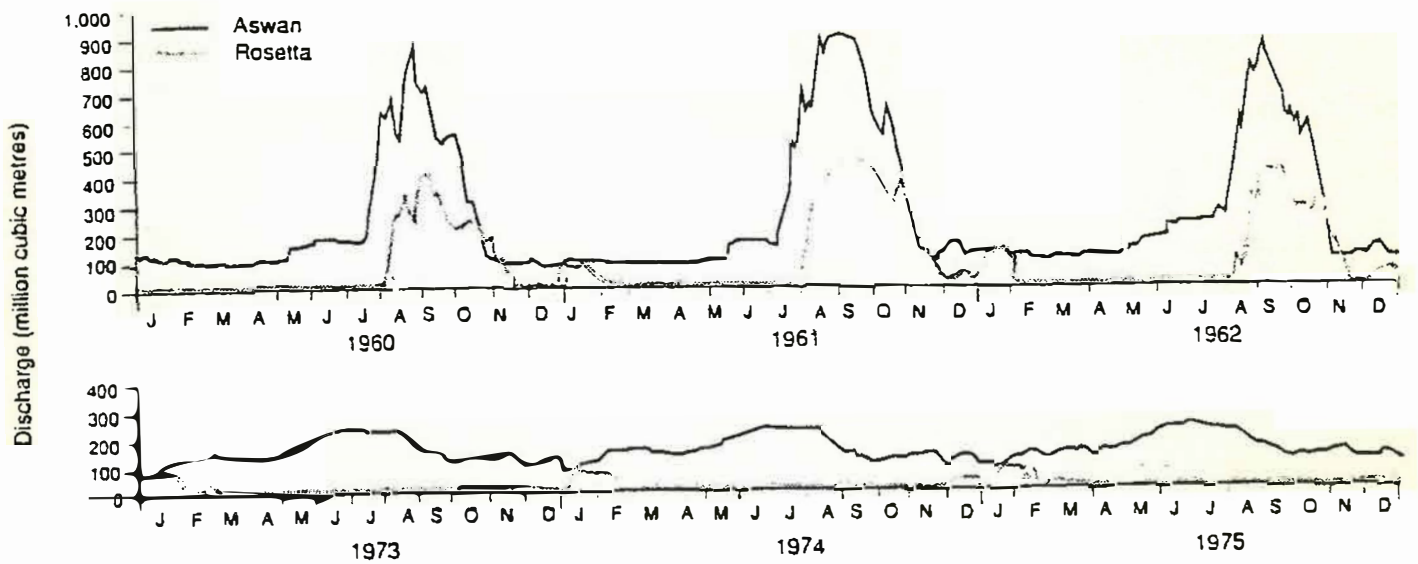
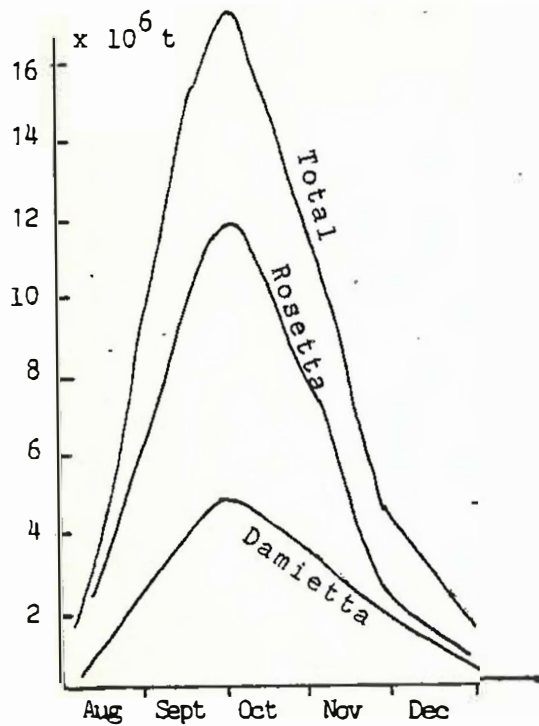


Fig. 5.1

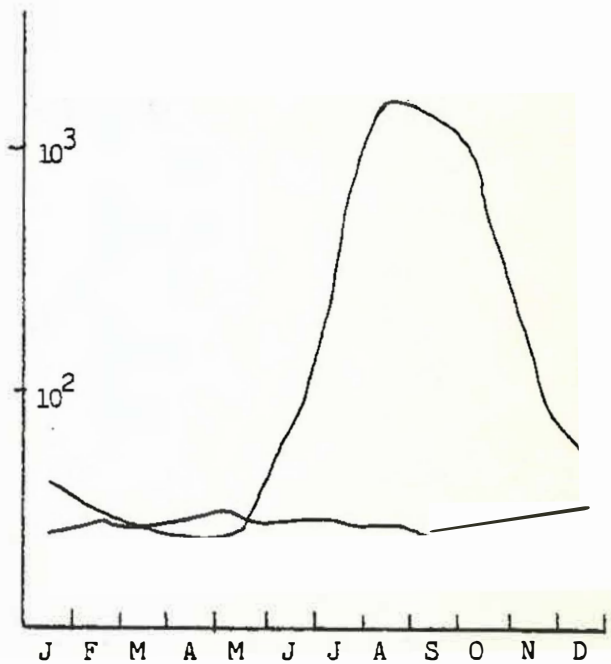
The Nile basin and catchment areas



Daily discharge regime of the Nile before and after the Aswan High Dam (from: Beaumont et al. 1988)



Average monthly discharge of Nile water 1959-1963



Average monthly suspended load downstream of Aswan, pre-'58-63 and in 1968-1975 (ppm)

FIG. 5.2

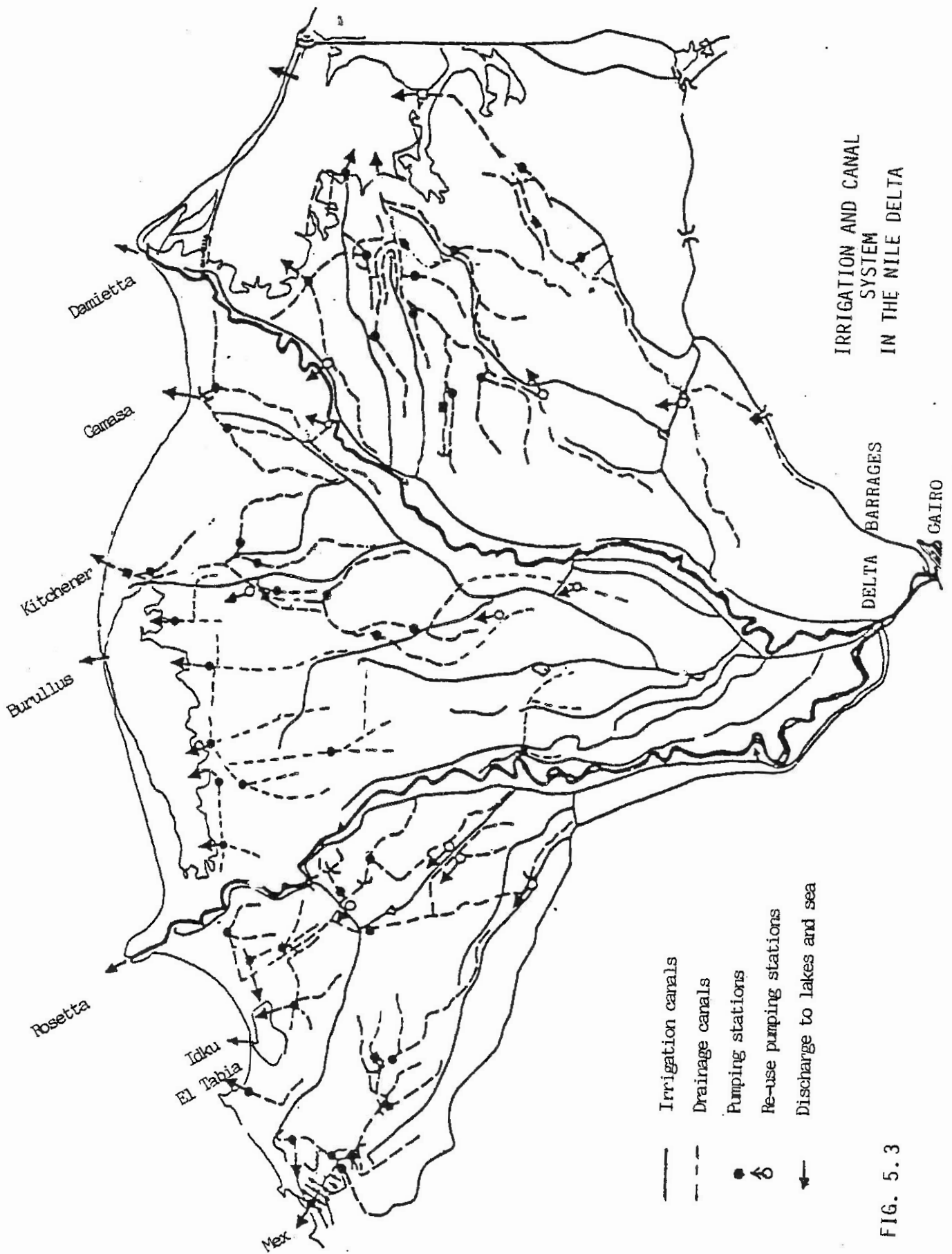


FIG. 5.3

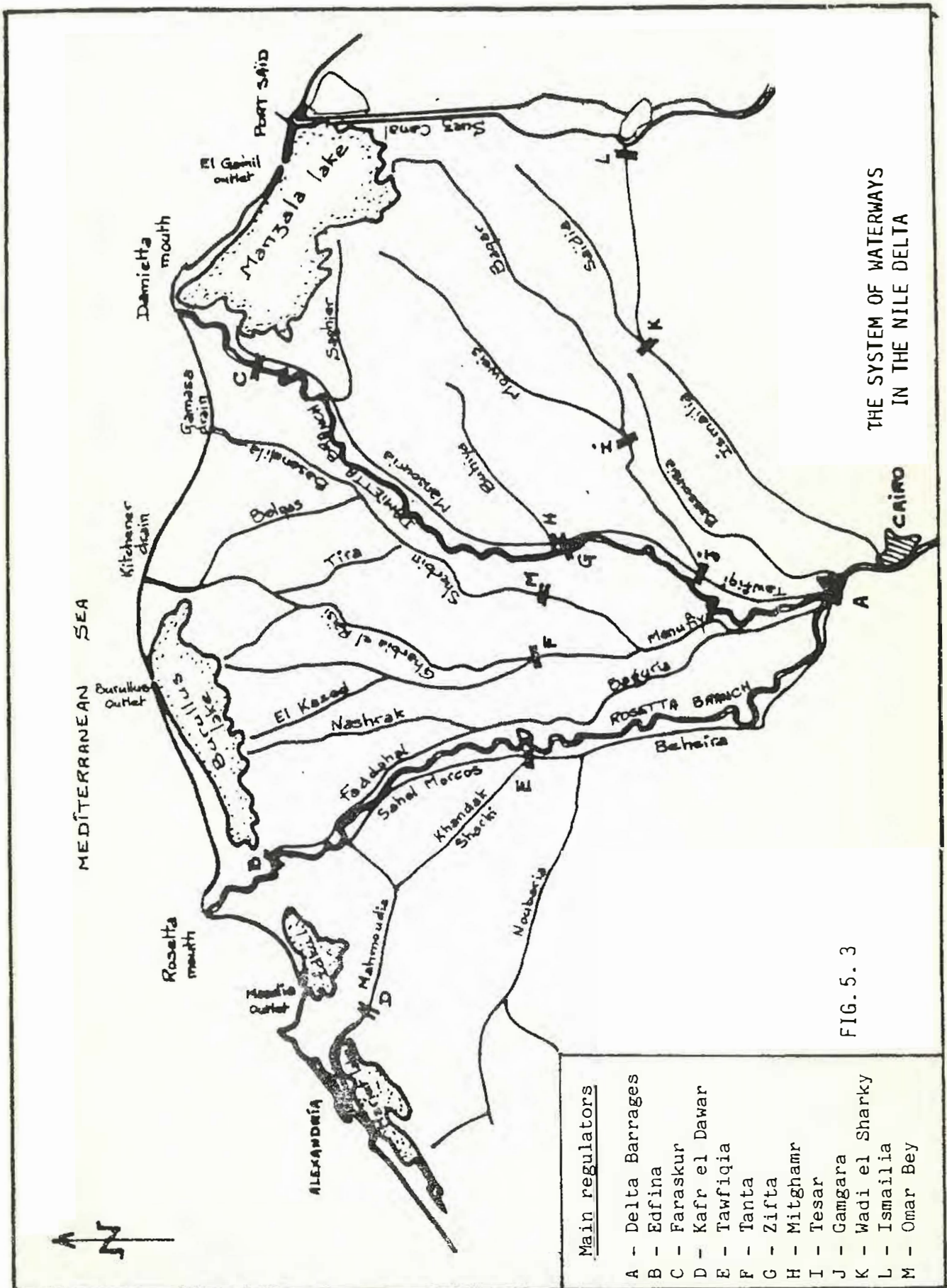
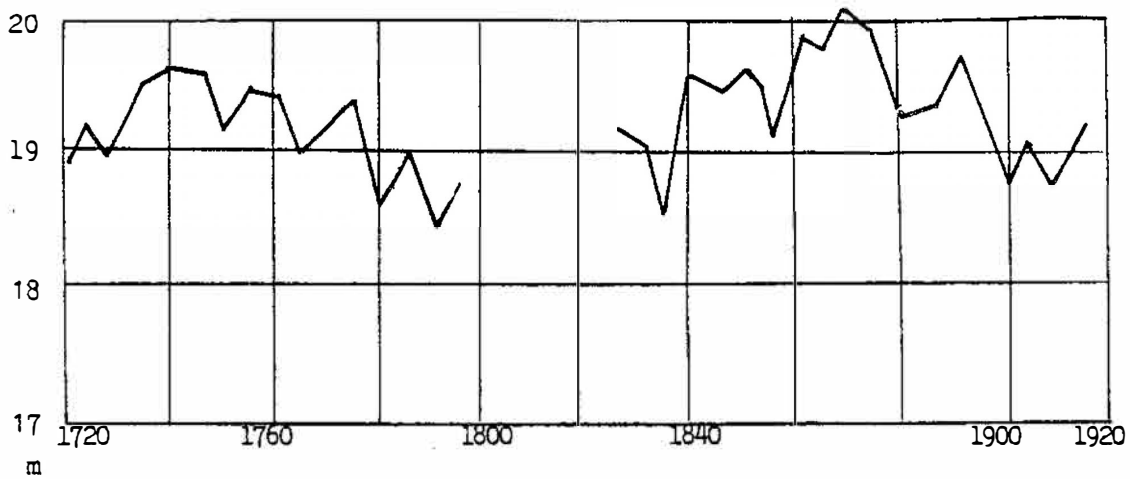
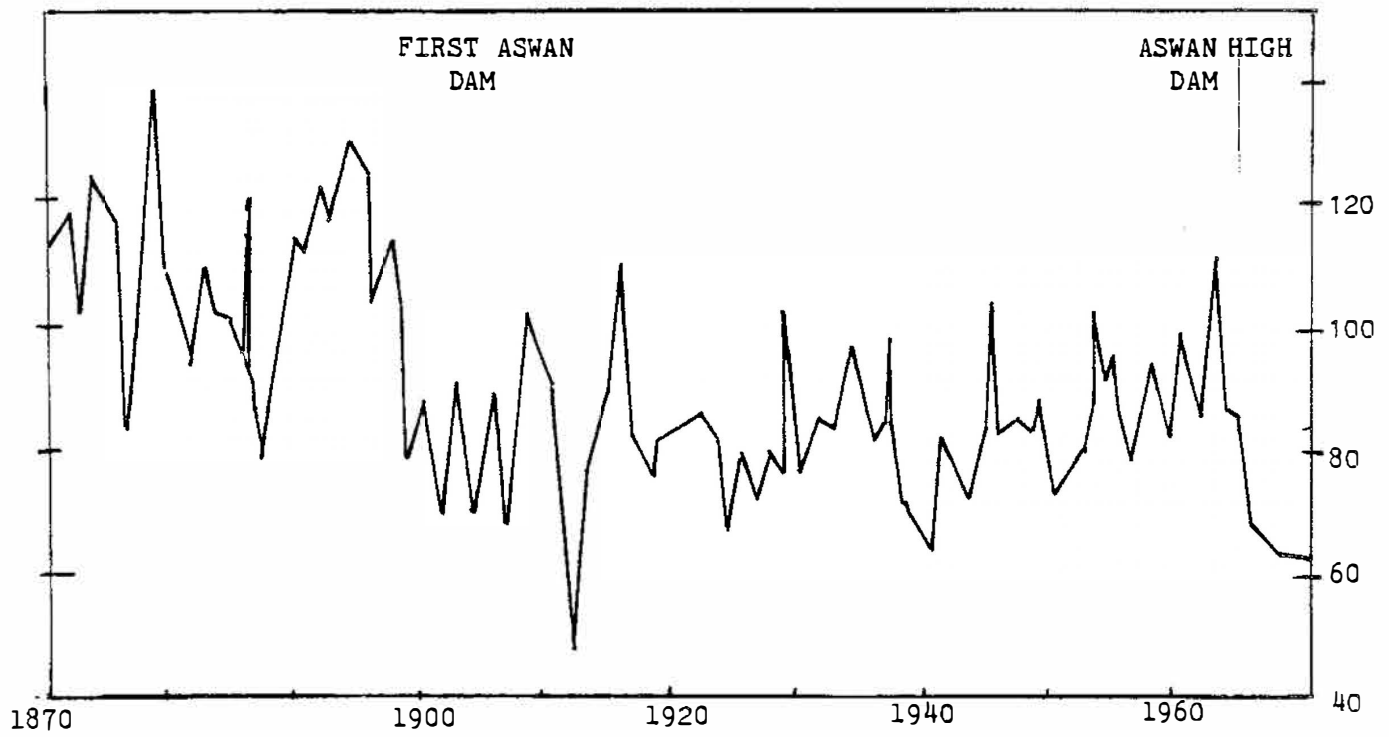
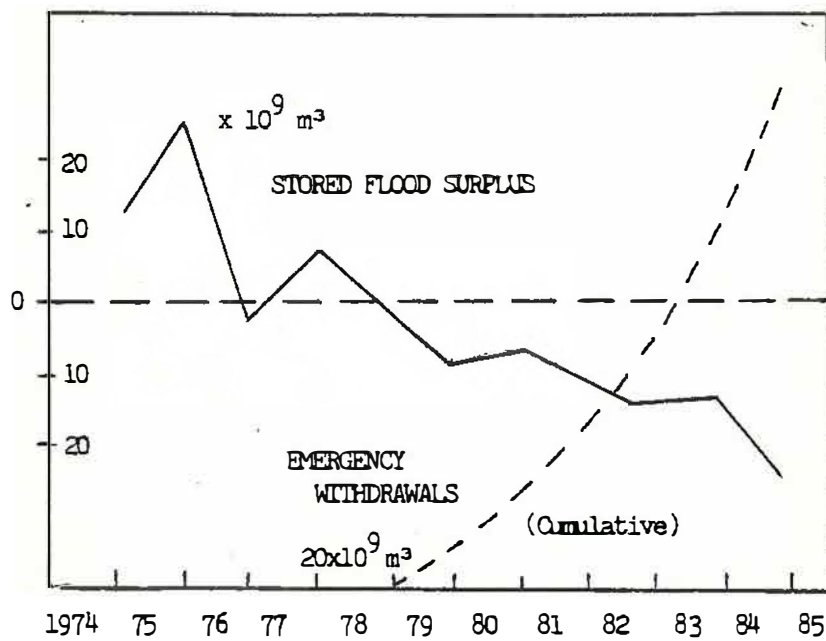
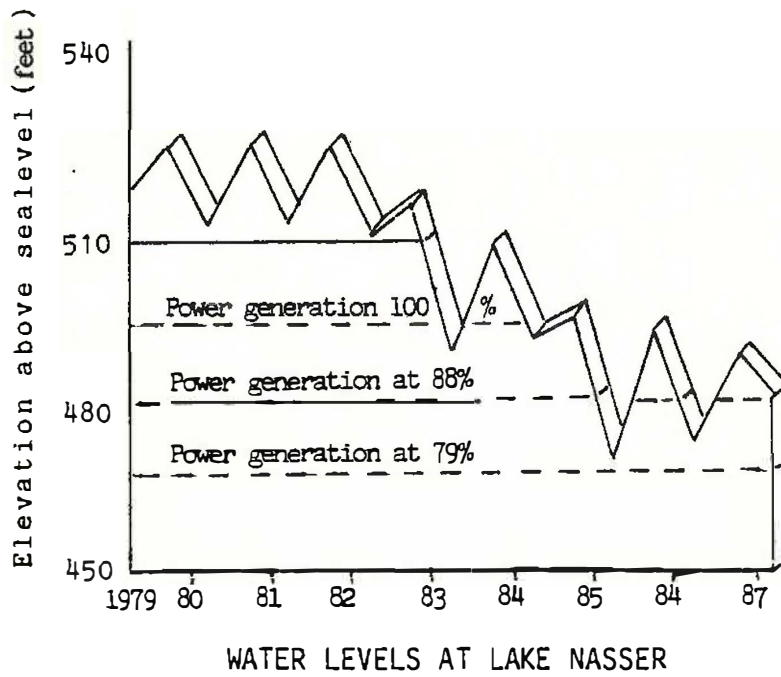


FIG. 5. 3



Variability and cyclicity of Nile discharge
(From: ASRI/UNESCO/UNDP 1976)

FIG. 5.4



STORAGE AND WITHDRAWALS IN LAKE NASSER

FIG. 5.5

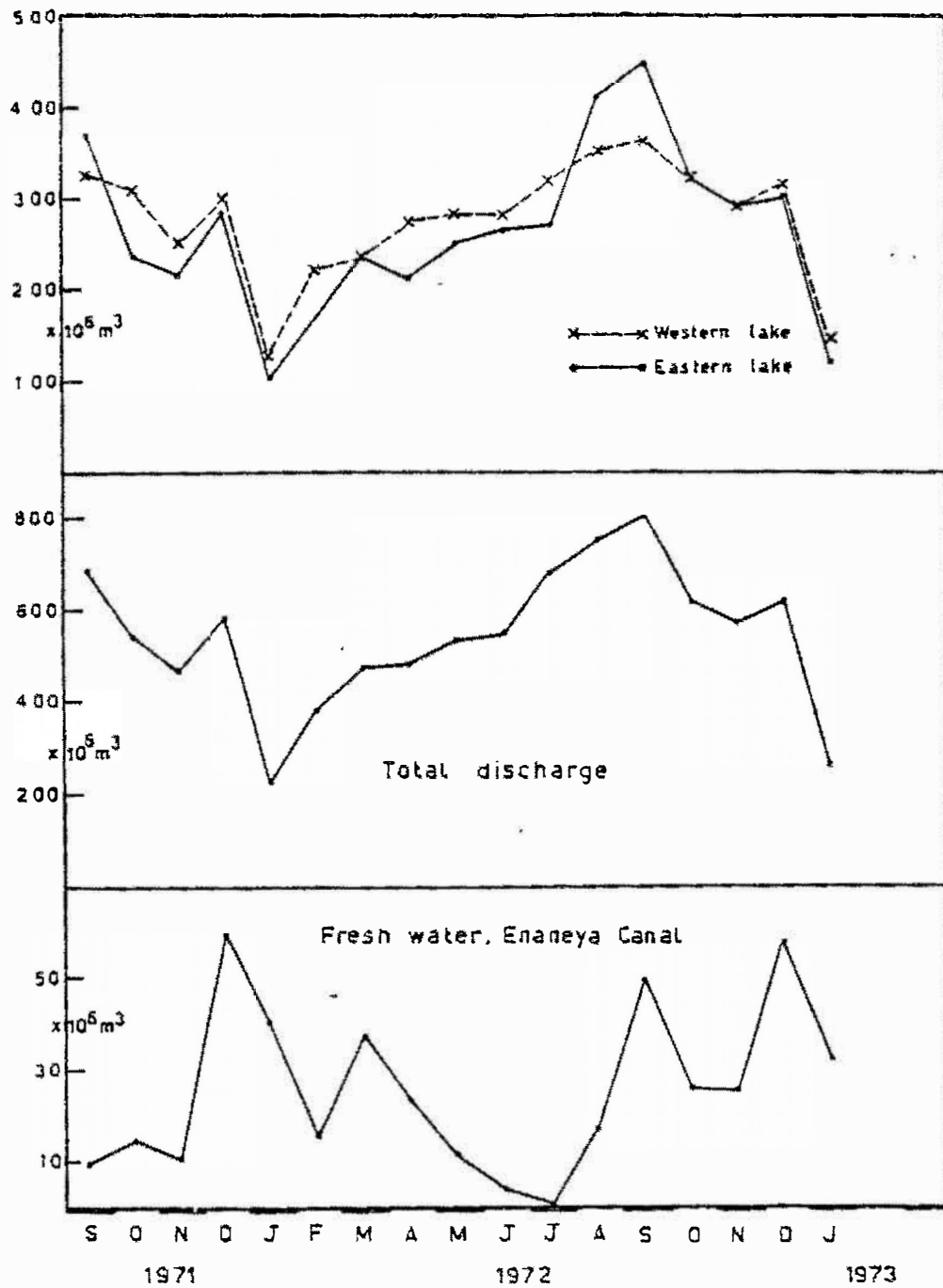


FIG.5. 6 Monthly discharge of drainage and fresh water to Lake Manzala (from Halim and Girgis 1987)

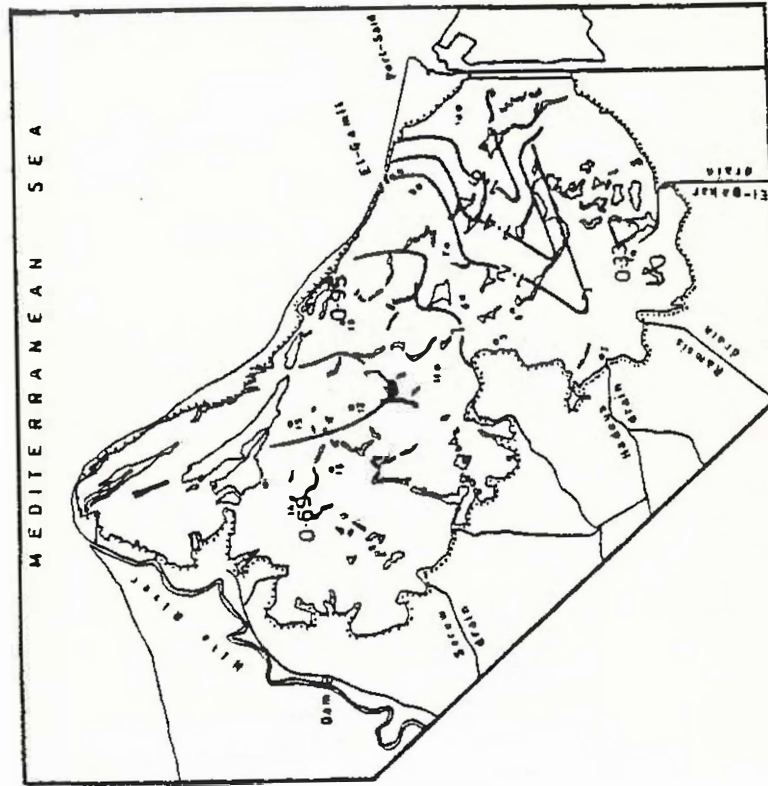
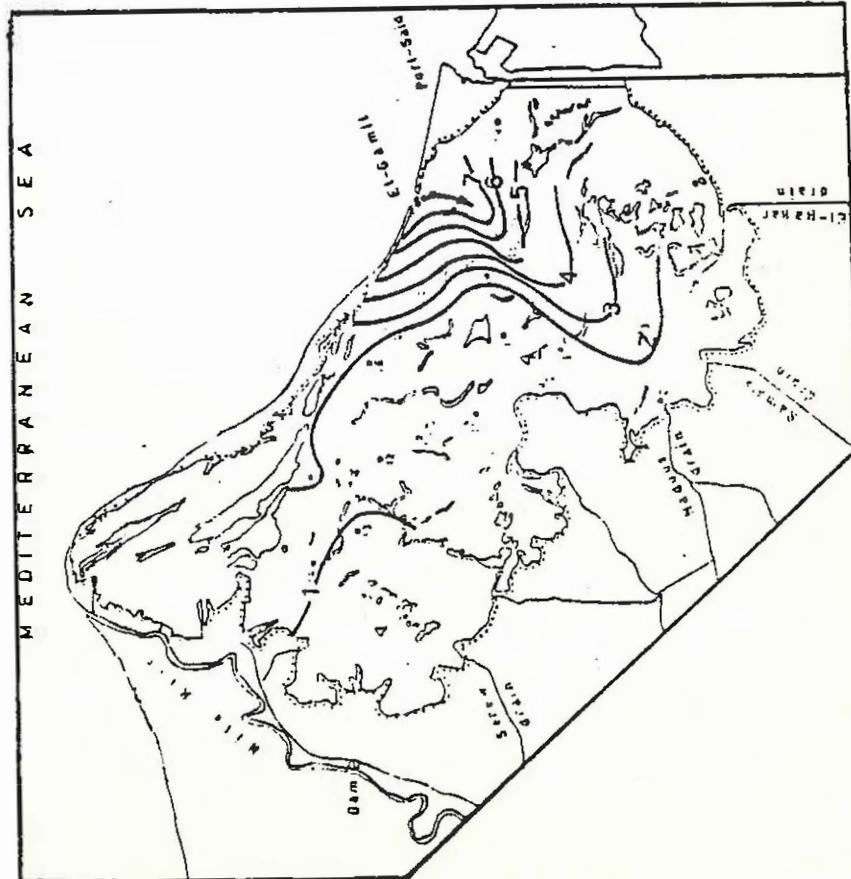


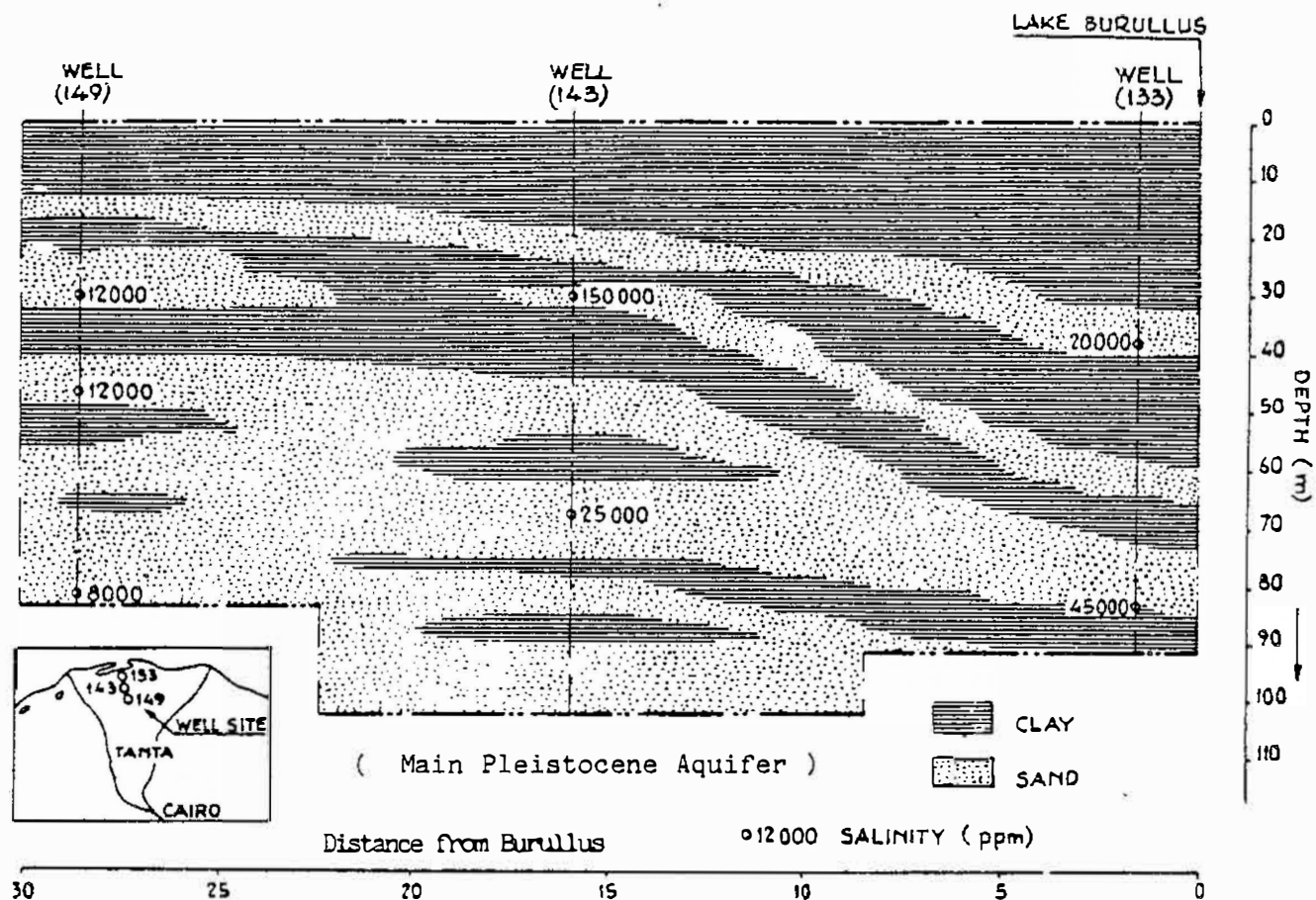
FIG. 5.7

Chlorosity distribution in February
time of minimum drain discharge



Chlorosity distribution in August
at maximum discharge

(Halim and Gerges, 1985)



Subsurface aquifers and aquitards in the northern part of the Nile Delta (From Boumans and Mashali 1983)

FIG. 5.8

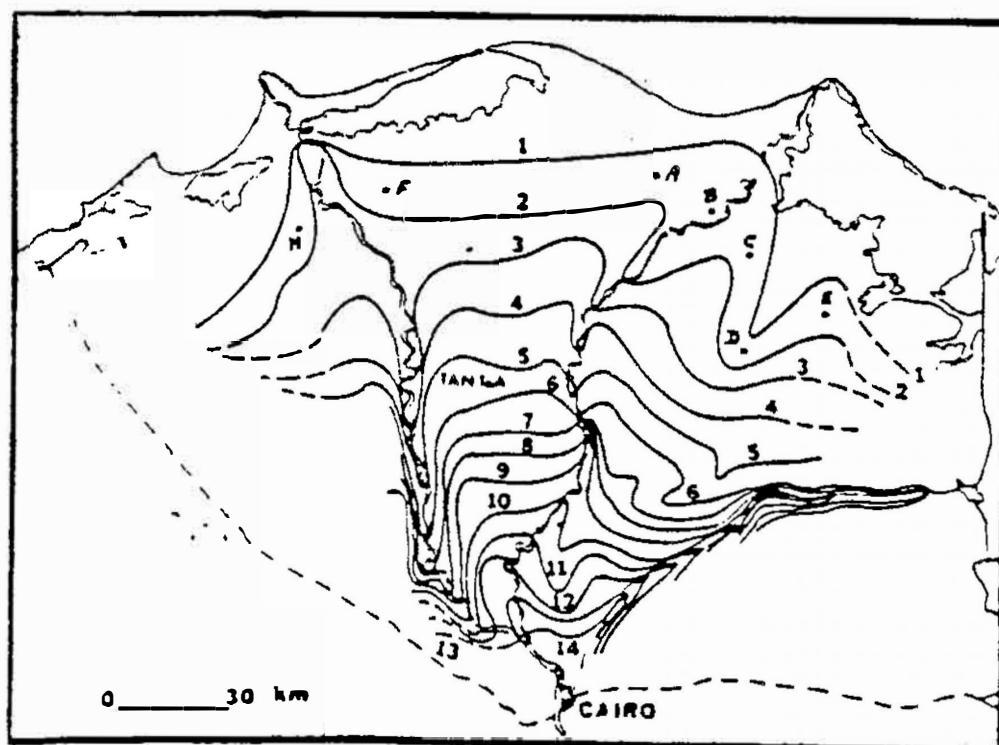


FIG. 5.9

Piezometric contours of the Main Aquifer (from Kashef 1983)

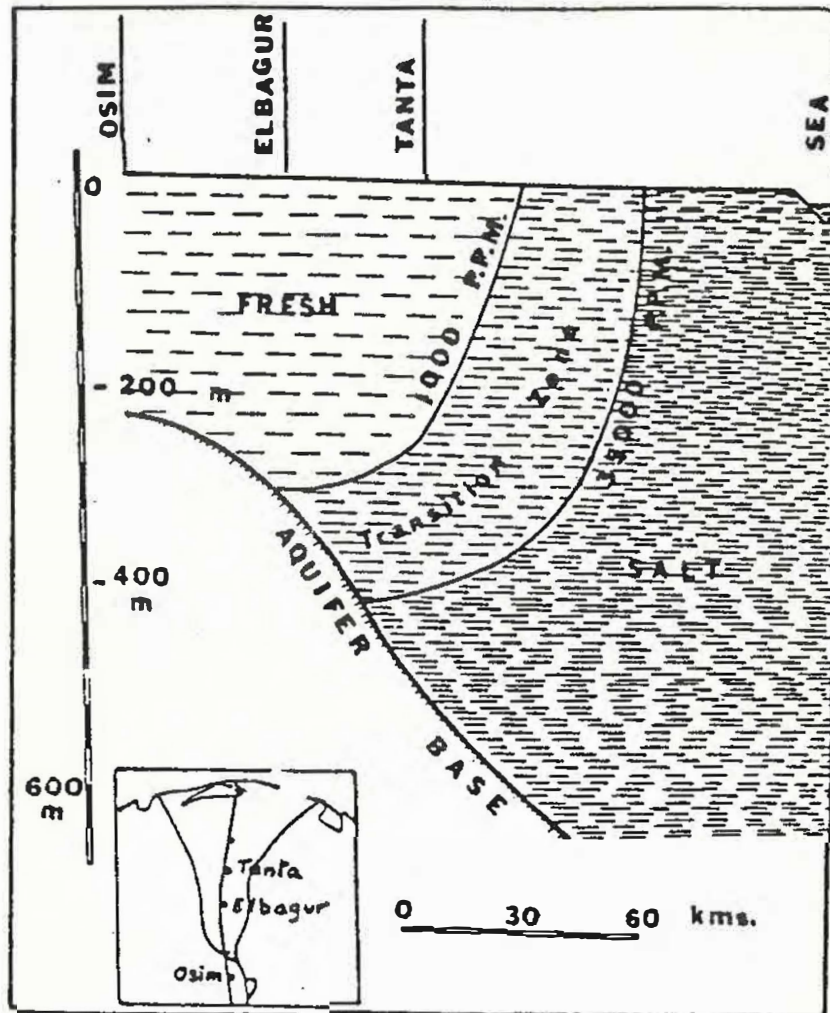


FIG. 5. 10

Distribution of fresh and salt water in the sub-surface of the Nile Delta (From Kashef 1983)

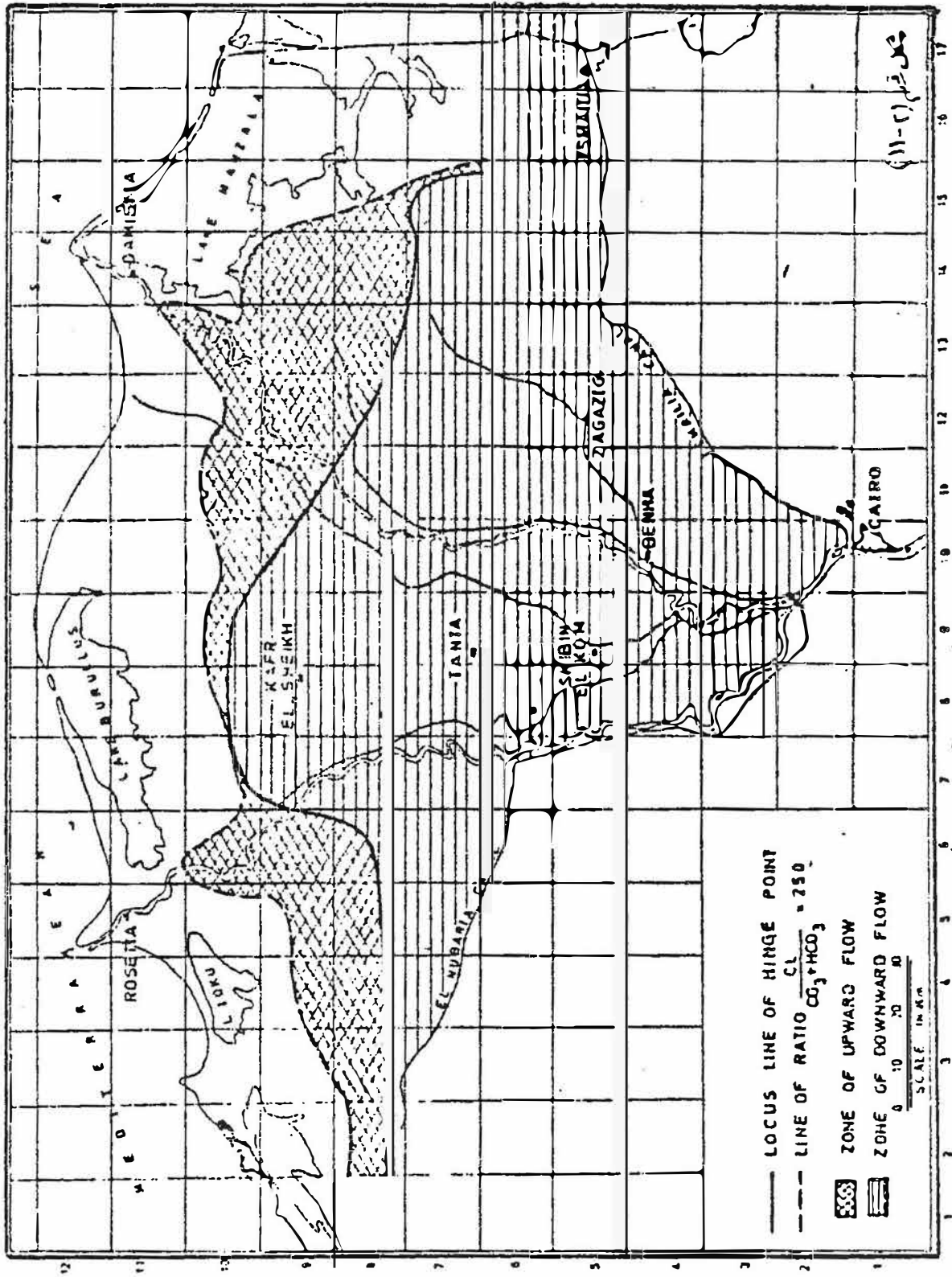


FIG. 5. 11

Areal distribution of upflow of fresh and saltwater

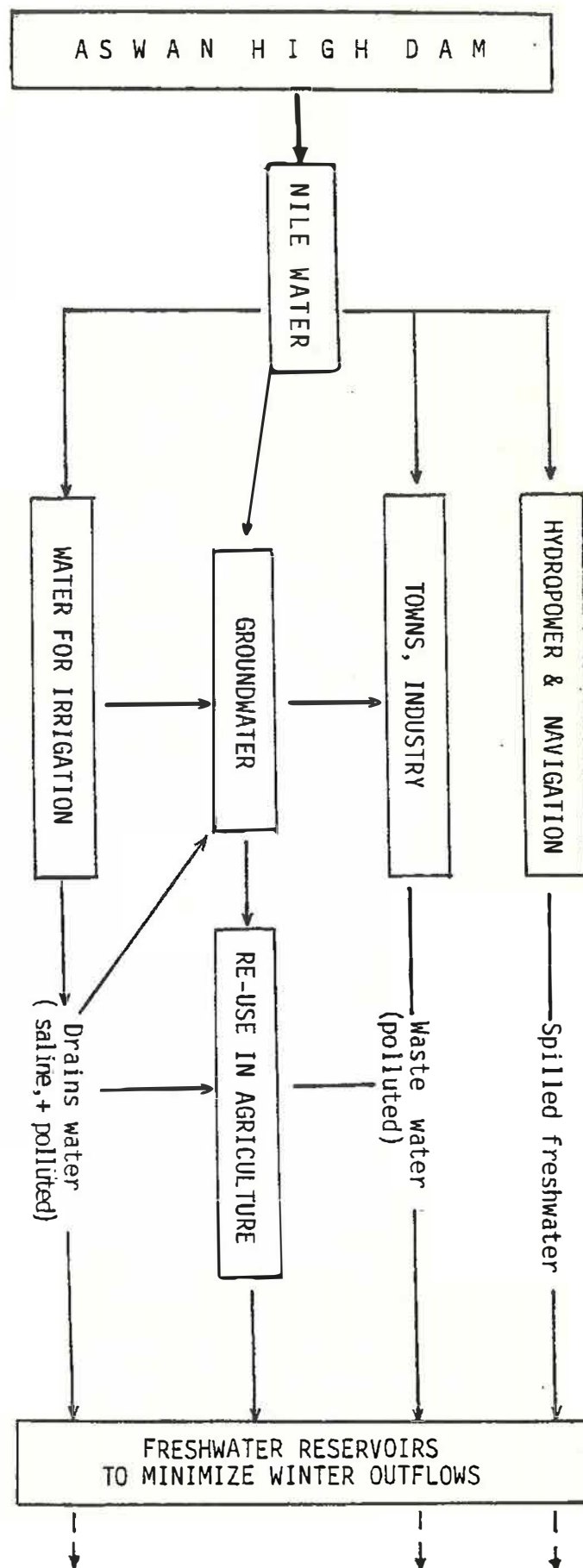


Fig. 5.12

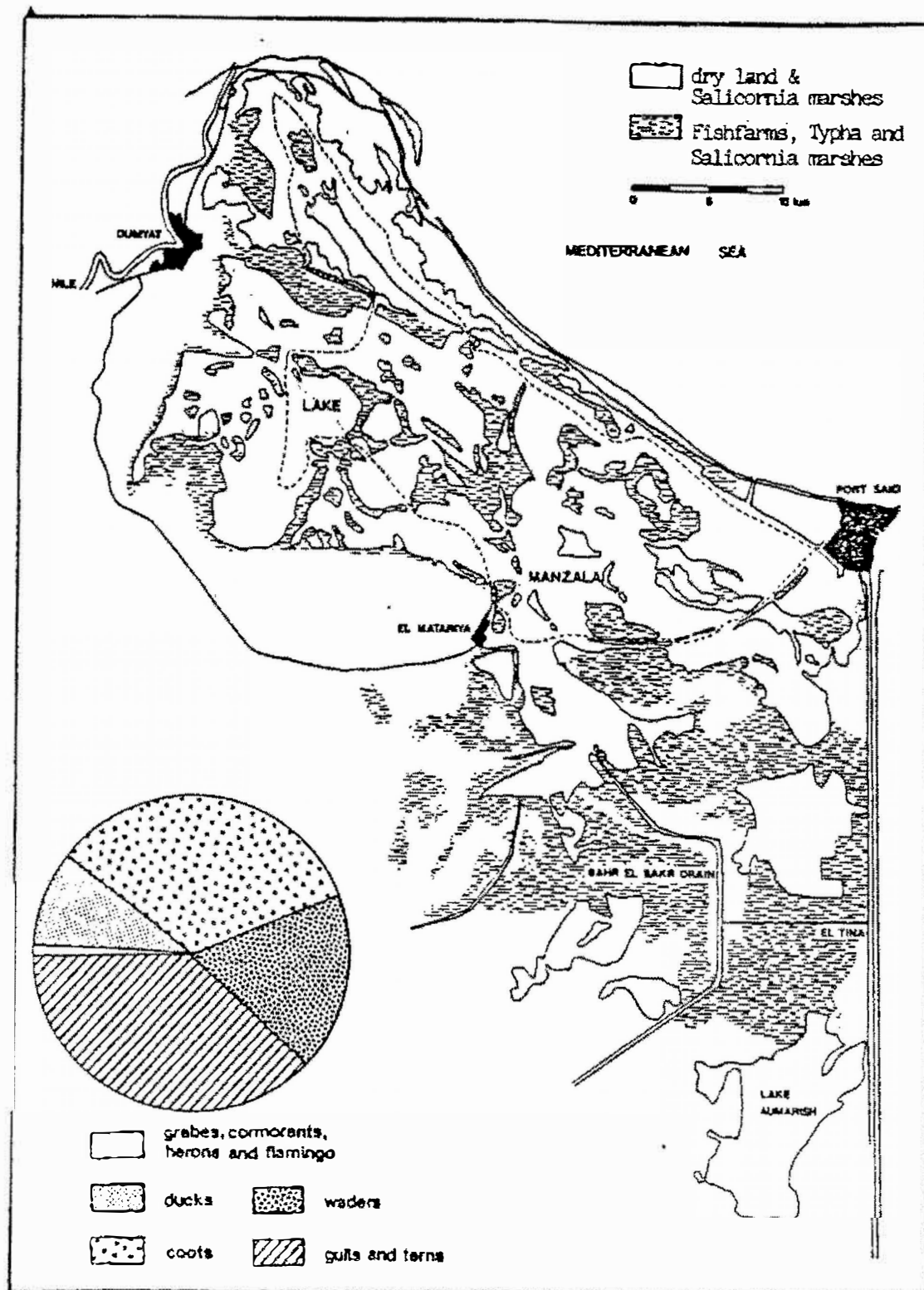


FIG. 6.1

Distribution of vegetation and percentage of wintering bird types in the Manzala lagoon (from Meininger & Mullis 1981)