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THE CONTROL OF POLLUTION FROM RIVER DISCHARGES IN THE MEDITERRANEAN

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ABSTRACT

The pollution burden of river discharges in the Mediterranean far exceeds all other sources, e.g. land based sources. The main contributors are the Rhone, Po and Ebro. Contributions from the River Nile are expected to be much less than those from rivers in the European continent.

Recent Nile management schemes and irrigation projects in Egypt are posing direct impacts on the Mediterranean. This includes the erosion of the Nile Delta and off-shore pollution due to wastewater discharges. In view of the prevailing circulation patterns in the Mediterranean, these impacts are dominant in the South Levantin region.

Current practices of river management do not necessarily include the protection of marine resources. Similarly, sea protection programs do not include pollution from sources in the river basin. Marine management programs are largely concerned with pollution loads at the points of river discharge.

In the case of a land-locked sea, such as the Mediterranean, it is particularly important to integrate river basin management schemes in the sea protection program. Under a suitable management plan, it could be possible to determine main sources of sea pollution within the river basin. This should serve as the basis for the implementation of control measures, since the problem is not exclusively within the river basin.

INTRODUCTION

The Mediterranean Sea, focal point of cultural development, is threatened by ever increasing pollution and its accompanying public health, social, and economic implications. The Mediterranean has become ever more endangered with increasing population density, industrial development, tourism, and the resultant degradation of sea resources.

Under the auspices of the United Nations Environment Program (UNEP), the Regional Sea Program initiated the Action Plan for the Protection of the Meditarranean in 1975. This has been an exemplary and a most promising effort, which resulted in the establishment of the Coordinated Mediterranean Pollution Monitoring and Research Program, known as MED POL (UNEP 1983). Results from the MED POL program on pollution from land-based sources provided the main impetus for the development and the adoption of a Convention for the Protection of the Mediterranean Sea against pollution from land-based sources (UNEP, 1982).

This paper addresses the problem of pollution resulting from river discharges into the Mediterranean. The main sources of information used in this paper were the MED POL program (UNEP, 1984), and recent studies conducted by the author on the Nile River (Mancy, 1985). The case of the Nile is presented in some details to demonstrate the impacts of river management schemes on the sea. This is used to highlight the necessity to include river basin management in programs for the protection of marine resources.

In this paper, the same convention adopted by UNEP Regional Sea Program for the classification of the Mediterranean in ten regional entities is adopted (UNEP, 1984). This is illustrated in Figure 1.

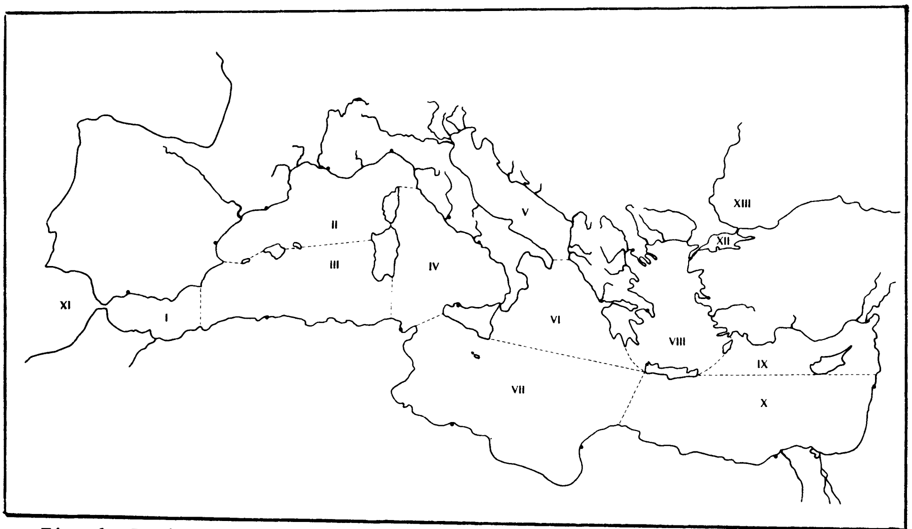

Fig. 1 Regional Entities of the Mediterranean Proper and Adjacent Sea Areas (UNEP, 1984)

MEDITERRANEAN CIRCULATION PATTERNS

The Mediterranean is a land-locked sea, except for the Straits of Gibralter, the Bosphorus Straits, and the Suez Canal. The vast majority of water exchange occurs through the Straits of Gibralter, which is about 12 km wide at its narrowest point. Limited water exchange with the Black Sea occurs through the Bosphorus Straits, which varies from 0.8 to 3 km in width. Insofar as the Suez Canal is concerned, insignificant amounts of water exchange take place.

Evaporation losses in the Mediterranean are hardly compensated for by river input and precipitation. The result is a major flux of water through the Straits of Gibralter. An estimate of the Mediterranean water budget (Kraus, 1972), is shown in Table 1.

TABLE 1 Water Budget of the Mediterranean

Input (m^3/s)		Output (m^3/s)	
From Atlantic Ocean	1,750,000	To Atlantic Ocean	1,680,000
From Black Sea	12,600	To Black Sea	6,100
Precipitation	31,600	Evaporation	115,400
Run-off	7,300		1,801,500
	1,801,500		

The surface circulation patterns in the Mediterranean are largely dominated by the net water influx from the Atlantic and thermo-haline induced convections. A typical surface circulation pattern in summer (Lacombe and Tchernia, 1972), is shown in Figure 2.

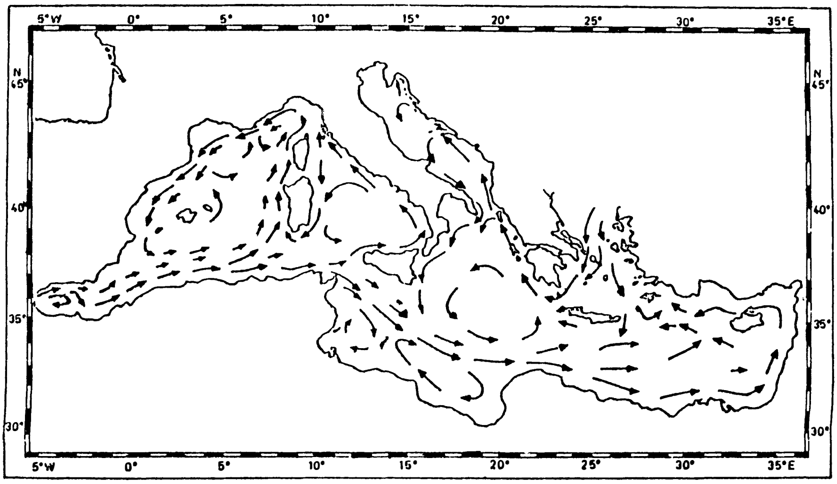

Fig. 2 Prevailing Circulation Patterns in the Mediterranean During the Summer (Lacombe and Tchernia, 1972)

RIVER DISCHARGES IN THE MEDITERRANEAN

A listing of rivers in the pollution source inventory by MED POL includes 81 rivers (UNEP,1984). This listing is given for each regional sector and it includes sea areas, countries, estimates of average river flow, and drainage areas.

Among the 81 rivers listed there are only four major rivers that drain into the Mediterranean. These are the Nile, the Po, the Rhone, and the Ebro. Three of these rivers--the Po, the Rhone, and the Ebro--share the same origin, which is related to the Alpine tectonic events. In contrast, the Nile has origins more closely related to the formation of the Red Sea and the East African rift system. A brief description of these rivers is given in Table 2.

TABLE 2 Major Rivers That Drain in the Mediterranean

River	Country at River Mouth	Drainage Area (km^2)	Maximum Length (km)	Average Annual Discharge (m^3/sec)
Nile	Egypt	3,100,000	6,800	1,584
Po	Italy	70,091	676	1,550
Rhone	France	95,600	812	1,712
Ebro	Spain	84,500	927	550

The Mediterranean catchment area is indicated in Figure 3 by the dotted line which surrounds the coastline. The Nile catchment area is not included in this figure, since it extends to south of the equator and drains about one-tenth of the African continent.

The Po River is the largest river in Italy and it's drainage area almost covers the whole country. The Alps to the north of Italy act as the boundary of its drainage basin. There are about 1,500 lakes in Italy, most of them being alpine lakes. A few of these drain into the Po river by way of six mountain rivers. One of these is the Adige, which is the second largest river in Italy.

The Rhone river in southeastern France drains an area estimated at 98,000 km^2, which is largely a narrow plain between mountains. The peak flow of the Rhone is in the spring and summer, which originates from the snow melt in the Alps. En route, the Rhone receives water from a number of tributaries, i.e., Soane, Isere, Drome, and Durance, in addition to natural drainage from rain water.

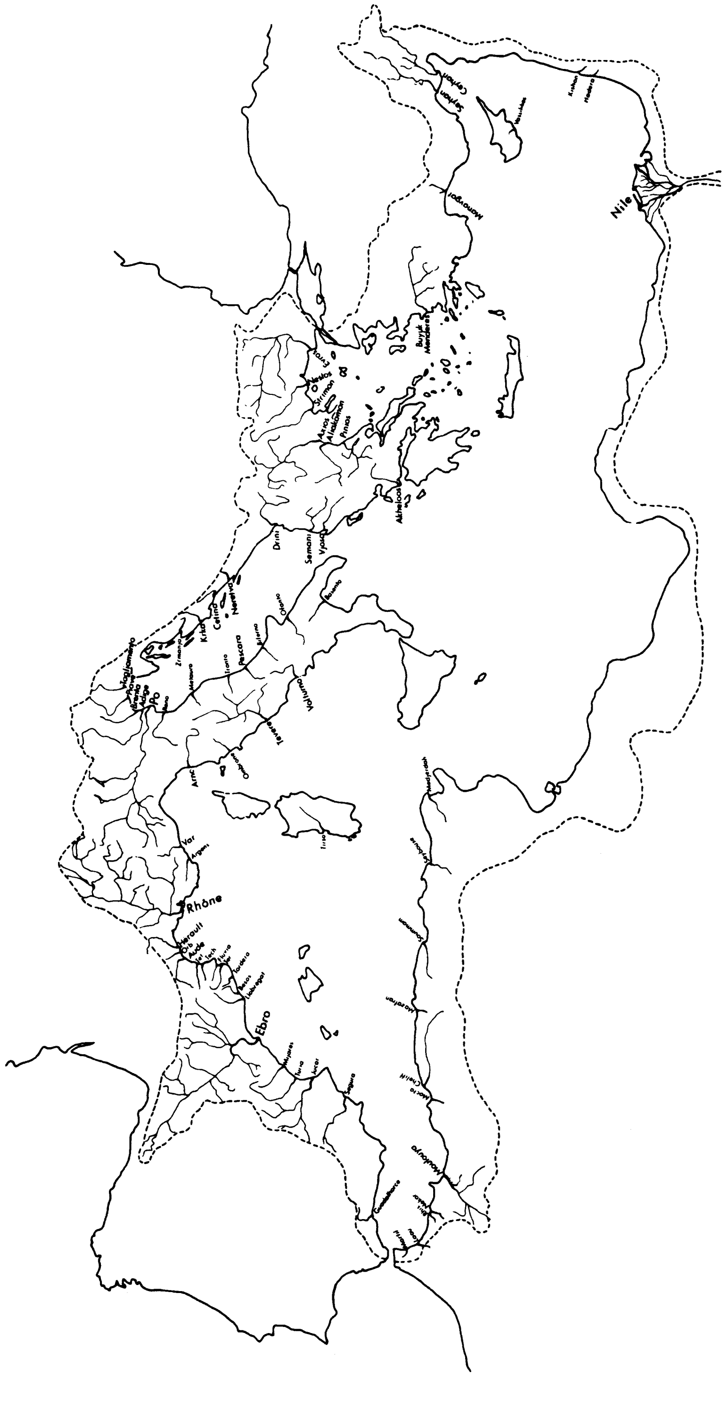

Fig. 3 The Mediterranean Catchment Area and Rivers Included in the MED POL Program (UNEP, 1984)

The Ebro drains an area estimated at 85,997 km^2. The mountains in northern Spain act as a watershed boundary. In the Ebro valley, the climate is dry and it includes extended irrigation schemes. River discharge varies from one season to another. In seasons with low rainfall, droughts occur.

In a dramatic contrast to the above three rivers, the Nile is the longest river in the world, extending for approximately 6,800 km from its remote source in the East African Plateau to the Mediterranean, and thus traversing almost half of the African continent. The Nile basin, shown in Figure 4, is an area of nearly 3,100,000 km^2, occupies one-tenth of the African continent, and is unique among the rivers of the world in that it includes three climatic zones, i.e., tropical, sub-tropical, and arid desert. The Nile Basin extends over ten riparian countries--Burundi, Ruanda, Tanzania, Zaire, Uganda, Kenya, Central African Republic, Ethiopia, Sudan and Egypt.

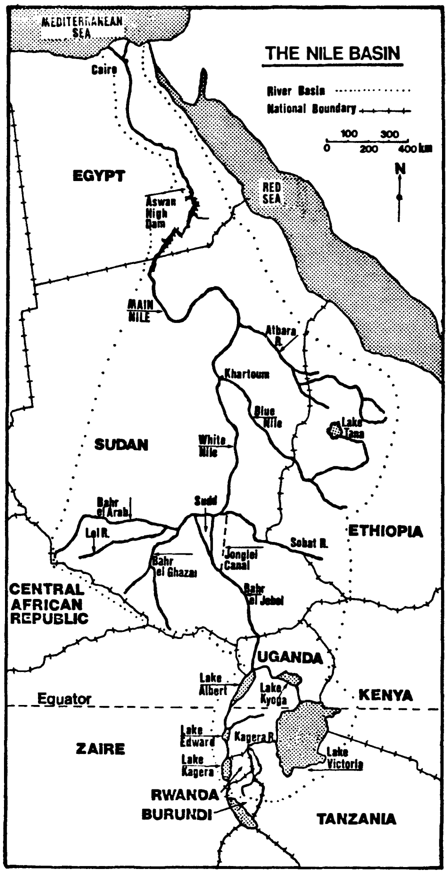

Fig. 4 The Nile Basin

The Nile receives its water from two main watershed areas: the equatorial east African plateau, which feeds the White Nile; and the Ethiopian highlands, which feeds the Sobat, Atbara, and the Blue Nile. The contributions of the White Nile, Blue Nile and the Atbara to the total river discharge (Hurst et al., 1966) are shown in Figure 5. Consequently, the Nile flood which used to reach the Mediterranean before the construction of the Aswan High Dam, occurs during July-October and originates from the Ethiopian Highlands.

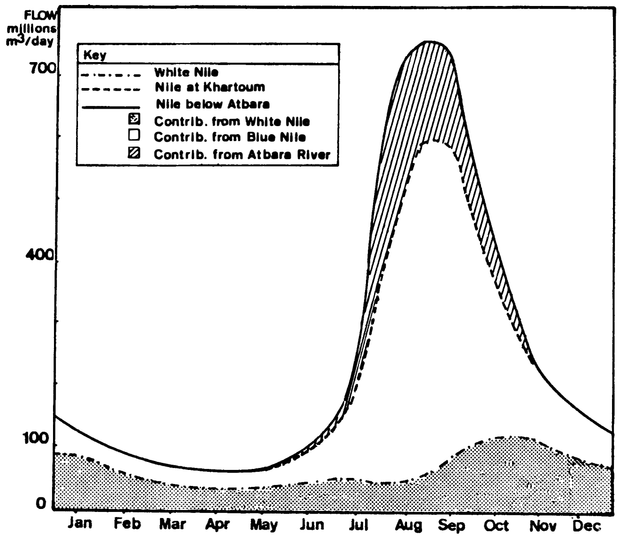

Fig. 5 Main Sources of the Nile

A contrast between the European rivers (Rhone, Ebro, and the Po) and the Nile shows dramatic differences in socioeconomic activities and river use patterns. European river basin countries are highly industrialized and the rivers are extensively used for navigation, hydropower generation, irrigation and waste discharge. In the case of the Nile only Egypt and, to some extent the Sudan, are the main user countries.

Among the Nile riparian countries Egypt has the highest river basin population density and is the most downstream country. Socioeconomic activities and river use patterns in Egypt will have direct impacts on the Mediterranean. The next section of this paper will address the impacts of Nile management and river use patterns on the Mediterranean.

MANAGEMENT OF THE RIVER NILE

The fertile inhabitable land of Egypt is a riverine oasis in the North African Sahara entirely sustained by the Nile. When Napoleon Bonaparte came to Egypt, he said "Si je governais ce pays, pas une goutte d'eau ne se perdrait dans la mer." (from Memoires de Sainte Helene). This statement reflected a basic concept in the economic history of Egypt. Over 5000 years ago Menes, the first Pharoah of a unified Egypt dammed the river and built the city of Memphis (reported by Herodotus: The Persian Wars). Later on in the 20th century before Christ, the Pharoah Amenehmet constructed a dam and a canal for the storage of the Nile flood water in Lake Karoun. Ever since, the Egyptians have been pre-occupied with the control of the Nile, which made the difference between famine and prosperity.

The Nile's annual yield has been subject to great variations from one year to the next. During the 1971-75 period the annual discharge of the Nile at Donkola in Northern Sudan varied from a low of 53,102 million cubic meters in 1972, to a high of almost double that volume, 100,045 million cubic meters in 1975. Seasonal variations of the Nile flow are even more dramatic. More than 80% of the river's total discharge occurs during the flood period (from August to October), and used to be directly discharged into the sea. During the remaining nine months the river carried only 20% of the annual discharge.

Early in the nineteenth century Egypt started large-scale irrigation schemes. This significantly expanded the total farmed area, permitted large-scale cultivation of cotton, and made it possible to harvest two to three crops per year. From 1821 to 1907 the success of the perennial irrigation schemes resulted in a 76% expansion in cultivated land and a 2.5-fold rise in crop production (Hamdan, 1961).

Early in the twentieth century, under British rule, Egypt and Sudan began a systematic river control program which resulted in the construction of six dams, including the Old Aswan Dam (Table 3).

TABLE 3 Water Storage Facilities on the Nile

Facility	Completed	Capacity (billion m^3)	Location
Sennar	1925	0.9	Blue Nile, Sudan
Old Aswan Dam	1902	5.3	Aswan, Egypt
Jebel Auliya	1937	3.5	White Nile, Sudan
Owen Falls Dam	1954	200	Lake Victoria, Uganda
Khashm Al-Girba	1966	1.2	Atbara, Sudan
Roseires	1966	3.0	Blue Nile, Sudan
Aswan High Dam	1970	167	Aswan, Egypt

These dams did not provide sufficient protection against excessive floods or droughts and about 40% of the total annual river flow was still being discharged unused into the sea. In the meantime, Egypt's need for water was rapidly growing. This prompted the Egyptian authorities to build the Aswan High Dam to provide over-year storage of Nile floods. The construction of the Aswan High Dam started in 1964 (river closure), and was finally completed in the mid-1970's. More detailed accounts of the impacts of the Aswan High Dam can be found elsewhere (Mancy 1981, 1985).

The total amount of fresh water supplies available to Egypt are estimated as follows:

1. Nile River allocation at Aswan: $55.5 \times 10^9\ m^3/yr$
2. Drainage water reuse: $7.3 \times 10^9\ m^3/yr$
3. Groundwater: $2.9 \times 10^9\ m^3/yr$

A schematic diagram of water balance for the River Nile throughout Egypt is shown in Figure 6. Water use estimates for the Nile river in Egypt are as follows:

1. Agriculture: $45 \times 10^9\ m^3/yr$
2. Conveyance losses: $8 \times 10^9\ m^3/yr$
3. On-farm losses: $9.3 \times 10^9\ m^3/yr$
4. Municipal/industrial consumption: $1.0 \times 10^9\ m^3/yr$
5. Navigation & Power Releases beyond agricultural demand: $2.5 \times 10^9\ m^3/yr$

The agricultural sector is the main water user in Egypt. It is expected, however, that municipal and industrial water demand will increase to $5 \times 10^9\ m^3/yr$ by the mid-1990's. A complicated irrigation and drainage canal system dominates the Nile Delta. The Damietta Branch is blocked by an earth dam at Faraskour, which does not permit direct river discharge into the Mediterranean. Similarly, the Rosetta Branch is blocked by a barrage at Edfina, which permits the direct release of river water into the Mediterranean mainly during the period from November to February. During that period agricultural water consumption is at a minimum and river discharges are maintained for the purpose of navigation and power production. Monthly river discharges at Edfina are given in Table 4 for the period of November 1978 to October 1979.

TABLE 4 Water Discharge from the Nile Delta

Month	Outflow $10^9\ m^3$	Outflow Rosetta $10^9\ m^3$
November 1978	2.344	0.846
December	3.828	1.824
January 1979	3.383	2.173
February	2.021	0.867
March	1.930	0.438
April	1.664	0.235
May	1.628	0.138
June	1.853	0.017
July	2.193	0.025
August	2.246	0.031
September	2.034	0.024
October	2.062	0.330
Total	26.652	6.948

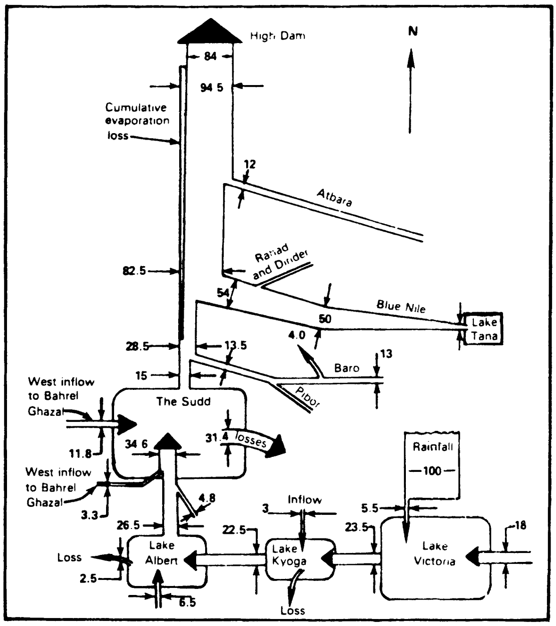

Fig. 6 Inflows and Losses in the Upper Nile Basin (billion m^3)

The irrigation system in the Nile Delta is largely based on water withdrawal from the river upstream from the Delta Barrages, Zifta Barrage, and Edfina Barrage. Drainage water from the irrigated fields are collected in canals which discharge into the Northern Lakes, the Mediterranean, and the Suez Canal.

A comprehensive monitoring program was conducted to assess the distribution and amounts of water discharge from the Nile Delta (Mancy, 1979; Shindy, 1981). This was based on monitoring all known outlets of drainage water which are schematically illustrated in Figure 7. Results from this monitoring program indicate that the total annual water discharge from the Nile Delta is on the order of 26.7×10^9 m^3 for the period of November 1978 to October 1979. Monthly estimates of water discharge are given in Table 4.

The discharged water is largely made of agricultural drainage. It's chemical and bacteriological characteristics vary from one place to another. Discharges from the Nile Delta into the northern lakes (Manzala, Burullus, Edku and Mariut) reach the Mediterranean through sea outlets or seepage. Moreover, discharges in the Suez Canal reach the Mediterranean by currents which prevail from south to north (the flow of water in the Suez Canal is from the Red Sea to the Mediterranean).

IMPACTS OF NILE MANAGEMENT SCHEMES ON THE MEDITERRANEAN

Against an unprecedented amount of controversy concerning its potentially damaging side effects, the Aswan High Dam has been successfully operating for over fifteen yeers, and it has significantly contributed to the economic development of Egypt. The Aswan High Dam was built for the purpose of (a) the storage of Nile flood water which used to be discharged unused into the sea, (b) river flow control, and (c) generation of hydropower. It is evident that these objectives have been fulfilled. Water storage and river flow control were accompanied by increased agricultural production and improved year-round river navigation. Egypt is no longer faced with the threat of high floods, in contrast it could be threatened only by an extended series of low floods.

Environmental impacts of the Aswan High Dam, which have direct effects on the Mediterranean, are largely due to (a) the deposition of the entire Nile sediment load in the Aswan Reservoir, and (b) river controls which dramatically modified the river flow in the Mediterranean.

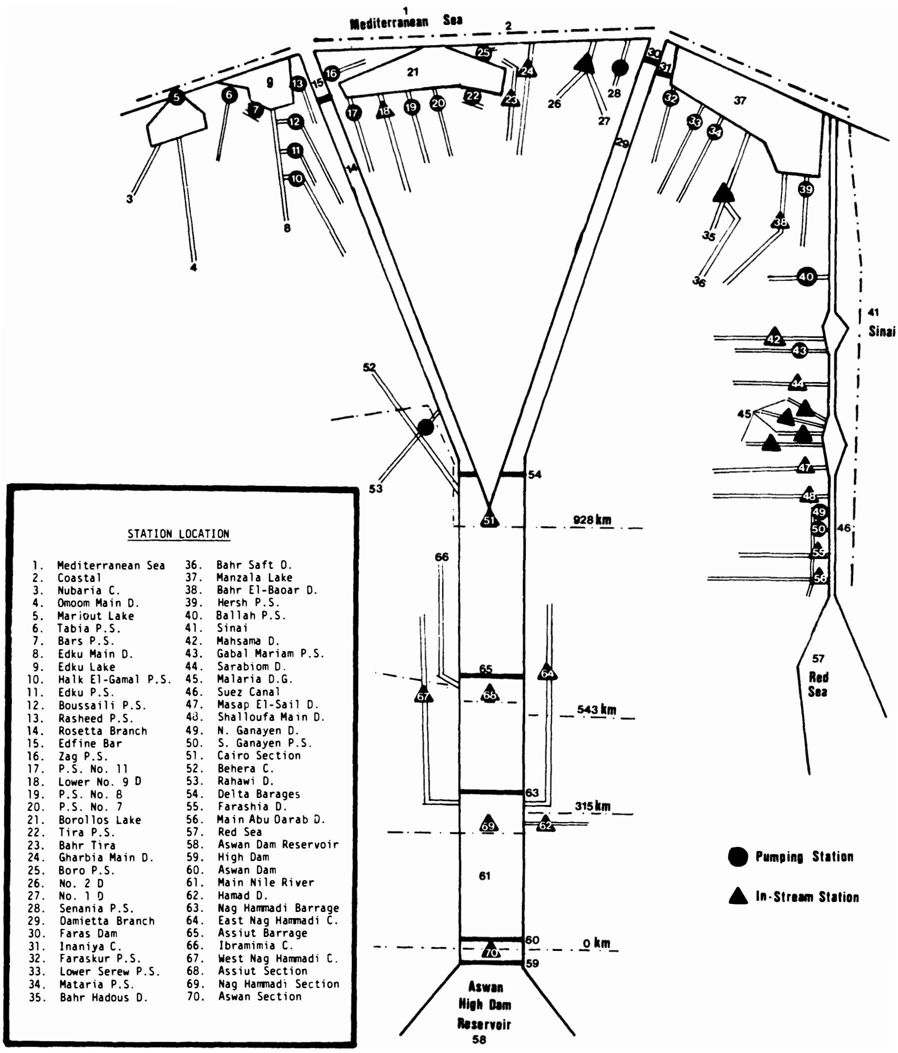

Fig. 7 Schematic Map of Water Quality Monitoring Program: Sampling Locations (Mancy, 1979)

Since the construction of the Aswan High Dam, the Nile sediment does not reach the Mediterranean. Any sediment load in the river north of the dam results from riverbed erosion or agricultural return flows.

The position of the coastline of the Nile Delta is determined by the net effect of two opposing processes. The first is the deposition of sediments carried by the annual Nile floods which builds the Delta seaward. The second process is the erosion of the delta shoreline by the action of waves and sea currents. Before the turn of the century the effect of sediment deposition exceeded shoreline erosion and the delta has been expanding. However, since the construction of the Old Aswan Dam in 1902 and subsequent dams on the upper Nile (see Table 4) there have been significant decreases in the amounts of sediment reaching the Mediterranean. In 1964, river closure for the construction of the Aswan High Dam resulted in a complete loss of sediment in the Nile water reaching the Mediterranean. Since that date, there has been no sediment deposition at the delta shoreline. This was accompanied by significant erosion of the Nile Delta due to the undiminished effects of waves and sea currents (Nielsen, 1977; Khafagy et al., 1981; Inman et al., 1982).

The rate of erosion of the delta coastline varies from one place to another. High rates of erosion seem to occur at promontories at the mouth of the Rosetta and Damietta branches. This is illustrated in Figure 8 which shows periods of accretion and erosion of the Rosetta promontory during the period 1800 to 1982 (Inman and Jenkins, 1984).

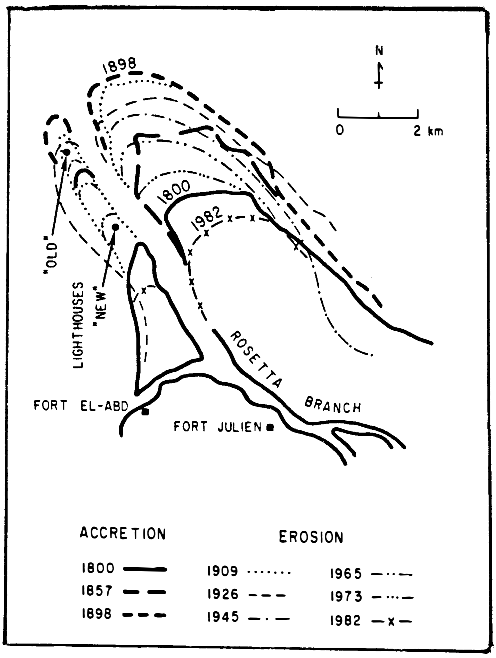

Fig. 8 Historical Shorelines of the Rosetta Promontory (Inman and Jenkins, 1984)

The second main impact of the Aswan High Dam is the modification of river flow patterns. The Aswan High Dam provided the possibility of complete control of river flow and full utilization of the Nile water. As stated earlier, there is no discharge of Nile water from the Damietta Branch. Furthermore, river discharge from the Rosetta Branch is limited to small releases in the order of 12% of the annual Nile yield. River flow in the Delta is sustained by withdrawals for irrigation purposes and recharges using agricultural return flows.

About 85% of the water released from the Delta is discharged in the Northern Lakes and, in particular, Lake Manzala and Lake Burulles (both lakes have outlets to the Mediterranean). The water released from the Delta is essentially agricultural drainage water which contains small concentrations of untreated sewage and industrial waste effluents. The discharge of this wastewater in the lakes resulted in accelerated biological production and the accumulation of pesticides in the sediments (Mancy, 1985).

The water quality characteristics of the Nile system in the Delta, including the Northern Lakes, can be found in reports published by the Egyptian Academy of Scientific Research and Technology (Mancy and Latif, 1982; Lasheen, 1983; Badawi, 1983). Other investigations have also shown that the quality of the northern lakes has been steadily deteriorating (Wahby-Saad, 1978, 1981, 1982; El-Sarraf, 1982; Osman, 1980; Saad, 1981, 1982).

Depending on the type and degree of contamination of these water bodies, the fisheries resources may be adversely affected. For example, fish production in Lake Edku and Lake Mariut has significantly decreased in recent years. In contrast, fish production in Lake Manzalla seems to have significantly increased as a result of fertilization from sewage and drainage water inputs. The effects of water pollution on fish production in Egypt were reported by Badr (1978), Shaheen (1978), and El-Hehawi (1981).

It is important to note here that fish produced from polluted sources may contain infectious agents and toxic substances at levels which may cause public health problems. Bacterial and viral contamination of fish marketed in Egypt have been reported by El-Zanfaly (1982), Farid (1980), and Larsen (1982). Chemical contamination largely due to pesticide residues and toxic metals have been reported by El-Sokkary (1981), Awad (1982), El-Refai (1976), Khattab (1980), and Shehata (1979).

The effect of the discharged wastewaters in the Northern Lakes on the Mediterranean is not well documented at this time. This effect will largely depend on the amount of pollution load ultimately reaching the Mediterranean and the off-shore circulation patterns.

It is expected that a great proportion of the pollution load received by the Northern Lakes does not reach the Mediterranean. In this capacity, these lakes serve to reduce the impact of wastewater discharge on the Mediterranean.

Furthermore, it is important to note that the discharge of these large volumes of wastewater in the Northern Lakes serves to prevent sea water intrusion in the Nile Delta. Sea water intrusions in groundwater will have dramatic effects on the fertility of the agricultural lands in the Northern Delta.

POLLUTION FROM RIVERS IN THE MEDITERRANEAN

It is important in this discussion to assess the relative contribution of rivers versus land-based facilities to the pollution of the Mediterranean. Estimates of annual pollution loads from rivers in the different zones of the Mediterranean are given in Table 5. This includes the percentage of river contribution to the total pollution load. This table was derived from data published by the UNEP Regional Seas Program (UNEP, 1984).

It is interesting to note that river contribution is much larger than land based sources, except for phenols. Both rivers and land based sources almost have equal contributions of organic matter, i.e., BOD and COD. These relative contributions vary from one zone to another.

CONCLUSIONS

River contributions constitute the major source of pollution in the Mediterranean. Current practices of river management do not necessarily include the protection of marine resources. Similarly, sea protection programs do not include pollution from sources in the river basin. Marine management programs are largely concerned with pollution loads at the points of river discharge.

In the case of small seas it is particularly important to include and to integrate river basin management programs. For example, as a start, the Mediterranean protection program should include management programs for the Nile, Po, Rhone and Ebro. Under a suitable management plan it could be possible to determine main sources of sea pollution within the river basin. This should serve as the basis for the implementation of control measures since the problem is not exclusively within the river basin.

TABLE 5 Estimated Annual Pollution Loads from Rivers in the Mediterranean Sea

Zone / Pollutant	I		II		III		IV		V		VI		VII		VIII		IX		X		TOTAL	
Volume	t/a*	%	t/a	%	t/a	%	t/a	%	t/a	%	t/a	%	t/a	%	t/a	%	t/a	%	t/a	%	t/a	%
Total Discharge $10^9\ m^3/a$	6	96	95	96	8.5	96	32	97	150	99	32	99	5	95	46	99	25	100	17	98	417	97
Organic Matter																						
BOD x 10^3	29	35	450	47	35	31	180	49	560	71	130	58	20	30	180	55	100	75	77	54	1,761	54
COD x 10^3	40	15	1,100	46	61	17	480	44	940	57	220	36	35	13	320	35	180	35	140	48	3,516	41
Nutrients																						
Phosphorus	3.4	5.1	115	91	4.8	58	21	72	79	93	18	81	2.8	4.2	25	77	13	69	17	88	299	84
Nitrogen	14	56	340	88	14	51	35	56	250	91	48	78	7.5	38	69	77	36	71	30	65	844	81
Specific Organics																						
Detergents	620	42	8,000	54	860	47	5,100	62	14,000	86	3,200	83	500	41	4,600	77	2,500	93	1,900	54	41.3	69
Phenols	16	1	240	6	20	3	95	9	350	23	90	6	15	2	130	14	70	32	58	16	1,084	9
Mineral Oil	-		-		-		-		-		-		-		-		-		-			
Metals																						
Mercury	1.8	74	30	91	2.5	92	9.5	89	40	99	9.6	98	1.5	88	14	98	7	99	5.6	82	122	93
Lead	42	45	800	59	59	49	230	56	1,300	91	220	95	35	36	320	72	170	95	120	52	3,296	68
Chromium	33	32	540	54	47	39	180	48	82	42	180	87	27	50	250	85	140	96	93	35	1,572	57
Zinc	27	10	2,400	46	380	55	1,400	47	7,900	92	1,400	85	230	50	2,100	84	1,100	96	790	66	17,727	72
Suspended Matter																						
TSS x 10^3	-		-		-		-		-		-		-		-		-		-			
Pesticides																						
Organichloride	6.4	100	14.9	100	10.4	100	12.1	100	14	100	6.1	100	2.9	-	7.4	100	6.7	100	9.1	100	90	100
Radioactivity																						
Tritium Ci/a	-		720	78	-		-		1,060	100	-		-		-		-		-		1,780	72
Other Radio-Nuclides Ci/a	-		6	43	-		-		6	100	-		-		-		-		-		12	32

*t/a: tons per annum

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