ESE:SF/UAR 49
Technical Report 2

PREINVESTMENT SURVEY OF THE NORTHWESTERN COASTAL REGION

UNITED ARAB REPUBLIC

PHYSICAL CONDITIONS AND WATER RESOURCES

UNITED NATIONS DEVELOPMENT PROGRAMME
FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

The complete project report consists of:

Technical Report No. 1	Comprehensive Account of the Project
Technical Report No. 2	Physical Conditions and Water Resources
Technical Report No. 3	Agriculture
Technical Report No. 4	Economic Aspects
Technical Report No. 5	Special Studies

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UNITED ARAB REPUBLIC

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Report prepared for
the Government of the United Arab Republic
by
the Food and Agriculture Organization of the United Nations
acting as executing agency for
the United Nations Development Programme

UNITED NATIONS DEVELOPMENT PROGRAMME
FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

Rome, 1970

TABLE OF CONTENTS

LIST OF FIGURES
(in the back pocket)

LIST OF GRAPHS
(in the back pocket)

LIST OF MAPS
(in the back pocket)

Chapter 1

GEOLOGY AND TOPOGRAPHY

1. Geology

The surfacial geology of the region is related to deepseated structural activity, to wind and water erosion and deposition, and to deposition and erosion by the sea. Rocks which outcrop in the area range in age from Miocene to Recent. (see Map 1)

The Recent and Pleistocene sediments which mantle the surface consist primarily of windblown sand and silt and also of alluvial material eroded, transported and deposited by surface water. The active coastal dunes generally consist of loose semi-consolidated limestone grains which have been redeposited in their present highly crossbedded attitude by the wind. The continuous wetting-drying action of water, wind, and sunshine on the limestone has caused a thin, case-hardened upper surface which is irregularly covered by a mantle of loose, shifting sand. Underneath the case-hardened surface the dunes are generally semi-consolidated and highly permeable.

The saline clays and silts deposited behind the coastal dunes, and sometimes between the second and third older consolidated dune ridges, are of both marine and fresh water origin. Material eroded and transported by surface runoff is deposited in temporary lakes and in other areas where the runoff is slowed by a change in topographic gradient or by manmade barriers. In areas where the sea has breached the dunes or where sea water overtops the dunes at times of rough seas or excessively high tides, salts are left after the evaporation of the sea water. The windblown sands and silts which fill the inland depressions are derived from the desert and from loose sands on the coastal dunes. These deposits fill low places in the consolidated rocks and may, along with water-deposited sediments, fill wadis.

The first and second consolidated dune ridges consist of Pleistocene windblown limestone grains formed along ancient shorelines and are similar to, but more consolidated than, the present coastal dunes. The ridges are case-hardened, high cross-bedded and solution riddled.

In some areas these older ridges are well preserved but in other areas they have been reduced or removed by erosion.

Near the coast the Pliocene and Miocene formations consist chiefly of interbedded limestone, marl, and clay with subordinate beds of sandstone, shale and gypsum. Further inland the sandstone and clay beds are more prominent. The limestones are occasionally fossiliferous and cellular, but for the most part are fine textured and compact.

The Miocene rocks are underlain by sediments of Oligocene, Eocene, and possibly Paleocene and Cretaceous age which do not outcrop in the coastal plain. These sediments are not discussed here but are briefly summarized in Table 1.

The rocks in the coastal plain strike in a general east-west direction and dip gently to the north, except where they have been disturbed by structural activity. Variations in the general east-west strike and the northernly dip occur along the plateau in the vicinity of Ras el Hekma where the rocks strike north-south and dip to the east; in the vicinity of Garawla, southeast of Mersa Matruh, where the rocks strike northwest and dip northeast; and southwest of Sidi Barrani where the strike is east-west but the dip is towards the south. Several small structural basins have been detected in the coastal zone, the best known being the synclinal basin at Fuka. Several faults have been mapped in the coastal plain, primarily along the escarpment and near Nogeila between the escarpment and the coast.

Table 1.

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING CHARACTERISTICS, NORTH WESTERN COASTAL REGION, UAR, (ADAPTED FROM EL RAMLY (1965) PETROLEUM EXPLORATION SOCIETY OF LIBYA (1964) AND OTHERS)

Geologic Age		Topographic or Stratigraphic Unit	Approximate thickness (meters)	General Lithologic Character	Water-Bearing Properties
Period	Epoch				
Quaternary	Recent	Coastal Dunes	0-30	Dunes are composed of white, well sorted, limestone grains varying from loose to semi-consolidated; in places highly cross-bedded and capped by a thin case-hardened limestone mantle.	Fresh water lense floats on top of salt water with the thickness of the fresh water zone being controlled by its height above sea level, and by the quality of recharge which enters the dune through direct infiltration of rainfall or from surface water runoff. Chemical quality generally very good but deteriorates rapidly if safe withdrawal rate is exceeded. Yields from galleries have been reported to be as much as 1.19 cubic meters per day per meter of gallery length. However the average yield of the galleries is probably about 0.5 cubic meter per day per meter of gallery length.
		Lagoonal deposits, alluvium, wadi fillings, talus material and windblown deposits.	0-10	Near the coast; calcareous, sandy, loam soil where significantly above sea level; and slight loamy, saline clayey soil where subject to innundation by sea water. Inland: windblown sands fill depressions; wind and water deposited alluvial sandy clays occur	Little to no water except in lagoonal deposits and in alluvian. Thin fresh water lense above saline water where these deposits are above sea level. Water quality brackish to good but deteriorates rapidly if safe withdrawal is exceeded. Quantity adequate for windmill pumpage in many areas. In areas that are very near sea level, the water is commonly more saline than sea water due to concentration by evaporation.

Table 1. (cont.)

Geologic Age: Period	Geologic Age: Epoch	Topographic or Stratigraphic Unit	Approximate thickness (meters)	General Lighologic Character	Water-Bearing Properties
Quaternary				in the wadi channels and near the mouth of most wadis; and talus deposits of sandy clay occur at base of plateau.	
	Pleistocene	Consolidated ridges	0-60	Ridges composed predominantly of tan to white oolitic limestone, medium to massive bedding, cross-bedding common, upper surface commonly case-hardened, lower sections semi-consolidated to consolidated; solutional development common; lower sections interbedded with sandstone and clay layers.	May be a source of ground water from solutionally enlarged openings in limestones. Well at Burg-el-Arab reported to tap this formation has a low porosity but high permeability. Salinity of water at Burg-el-Arab well ranged from 1200-9000 ppm.
Tertiary	Pliocene		0-70	Oolitic limestone and sandy limestone interbedded with sandstone and shale.	Low permeability; very poor water bearing formation; acts as confining bed to water in underlying formations.
	Miocene	Marmarica Limestone	900-1 000	Light colored partly chalky, fossiliferous, limestone interbedded with marl and clay. Limestone becomes progressively sandy from west to east.	Yields relatively large amounts of water from solutionally enlarged fractures and bedding planes. Wells drilled to supply water for oil test holes report yields of more than 10 cubic meters per hour. Chloride content of the water is generally from 3 000-8 000 pmm.
		Moghra Formation		Argillaceous limestone interbedded with sandstone and shale.	
	Oligocene		600	Sandstone interbedded with thick sections of shale, grading downward to marine shales	Not a water-bearing formation
	Eocene	Bartonian Shale	200	Dark greyish-green, silty, glauconitic shale.	Not a water-bearing formation
		Thebes Formation	50-100	White, chalky limestone and chert, fractured and cavernous	Yields highly saline water

Table 1. (cont.)

Geologic Age		Topographic or Stratigraphic Unit	Approximate thickness (meters)	General Lithologic Character	Water-Bearing Properties
Period	Epoch				
Tertiary	Paleo-cene	Esan Shale	?	This unit not reported in literature in the Coastal zone, but it may be present beneath some areas.	Not a water-bearing formation
Cretaceous	Seno-cene		130	Chalk limestone and clay	Some sections yield water that is more saline than sea water.
	Turo-nian		180	Limestone and shale	
	Cenoma-nian		700	Dolomite, shale, and sandstone	
	Lower Cre-taceous	Equivalent to the Nubian sandstone of the Western Desert	1 400+	Calcareous sandstone and dolomite	Excellent water-bearing unit in southern and central part of Western Desert but beneath Coastal Zone yield is less and water is highly saline.

2. Topography

2.1. Introduction

The North Western Coastal Region, as it is defined in the Plan of Operation, is a narrow strip of a width varying from 5 to 40 km, extending 35 km. west of Alexandria to the Libyan boarder - a distance of 480 km. approximately. It is bounded to the north by the Mediterranean sea and to the south by the Libyan Plateau.

The area as defined above presents the following general morphological characteristics:

Almost continuously along the coast, one or more ridges of dunes are formed, the first being the present sand dune and the others the old consolidated dunes. Narrow plains some of which are marshy are found between these ridges.

Behind the ridges of dunes lies the main plain, very variable in width and usually of an even slope. There follows a succession of transitional zones up to the Libyan Plateau. The general slope of the whole area runs roughly south-north.

Besides the above-mentioned main topographical features there are large areas of irregular relief forming series of closed depressions surrounded by low hills.

The western half of the region is cut into by a considerable number of stream beds (wadis) flowing generally south-north. The region can be subdivided into five distinct areas, each with its own particular topographical features. The topography of each of these areas is discussed below.

2.2. Topographical Maps

The following topographical maps were made available to the project:

1. 1:1 000 000 map of the U.A.R.
2. 1:500 000 map of the U.A.R.
3. 1:100 000 map of the North Western Coastal Region
4. 1:25 000 maps of the areas Burg-el-Arab, Hamman, Dabaa and Matruh.
5. 1:10 000 maps of the area between Matruh and Sidi Barrani and the areas of Baqqush and Fuka
6. 1:2 500 maps of the Pilot Project area (Wadi Maguid, Wadi Enthely, Wadi Kharun and Micro-Fuka)

2.3. The area from Sallum to Sidi Barrani

The cliff of the Libyan Plateau starts very close to the sea at the western extremity of the region and, taking up a south-easterly direction, runs inland to a distance of 40 km from the sea. From here, south-west of Sidi Barrani, it turns and runs parallel to the sea in a west-east direction.

A flat coastal band 2 -4 km wide is found behind the ridge of dunes, starting some 10 km east of Sallum.

The area between the coastal band and the plateau has a rather pronounced relief and there are several terraces.

Thereare a few large depressions along the edge of the plateau. Some important streams exist at the escarpment of the plateau, especially south west of Sidi Barrani.

2.4. The area from Sidi Barrani to Ras Abu Laho

This area has very uniform topographical features. The coastal belt of alluvial soil is very narrow and intermittent. South of the coastal belt, a large area of gentle uniform slope extends up to the plateau. This area is traversed by many parallel streams.

There are some important sandy zones inside the area, with undulating relief. The Negeila pilot area is included in this area.

2.5. The area from Ras Abu Laho to Ras el Hekma

The cliff of the Libyan Plateau is very pronounced throughout the area. It runs parallel to the coast at a distance varying from some hundred metres (Ras-el-Hekma) to 25 km (near Matruh).

The discontinuous ridge of dunes develops at a distance varying from 200 metres to 3 km from the coast. A narrow coastal plain of gentle slope is found between the sea and this ridge.

South of the ridge, the main plain slopes evenly up to the escarpment of the plateau. There are some salt lakes in the lower part of the plain, some of them having outlets to the sea. The escarpment of the plateau is deeply cut into by streams, some of which cut into the higher part of the main plain.

The pilot areas of Baqqush and El Qasr are included in this area.

2.6. The area from Ras el Hekma to El Alamein

This area has no dominant topographical features. It consists of an irregular succession of alternating low hills and closed depressions, sloping up from south to north. There is an almost continuous range of dunes along the coast. West of Fuka the cliff along the edge of the Libyan Plateau becomes pronounced.

The pilot areas of Dabaa and Fuka are included in this area.

2.7. The area from El Alamein eastwards

There are three almost parallel ridges of dunes in the area: the present sand dunes ridge, 400 - 600 m wide, and two old consolidated ridges of dunes 20 - 30 m high. The distance between the present sand dunes and the first old consolidated ridge is some hundred metres and the distance between the two old consolidated ridge averages 3 km.

About 5 km to the south of the third ridge there is a very marked relief aligned regularly. Further south the relief shows a slight slope from south to north.

The depressions formed between the ridges are flat and of low altitude, partly covered by the water after heavy rainfalls.

The ridges have a relatively gentle slope and the lower parts of them contain the most important agricultural soils of the area, planted mainly with fig trees.

Chapter 2

CLIMATE

1. Introduction

The following study is based on 30 years of data kindly provided by the Meteorological Department of the U.A.R. Thanks are due to Dr. Fathy Taba, Director of the Meteorological Department of U.A.R. and to Dr. Gidamy and Dr. Harp. New normals were calculated on 30 homogeneous years for the rainfall and 15 years for the other data. All the existing meteorological stations are situated along the coast and, therefore, no data exist about the inland climate. No attempt to define it with the help of the natural vegetation has been made in this report. The relation between vegetation and climate will be ascertained only after some years of observations collected by the new meteorological stations inland.

1.1. The climatological network of the area and the information available to the project.

The north western coast of the U.A.R. has nine meteorological stations between Alexandria and the Libyan border. They form part of an excellent network, well operated by the Meteorological Department of U.A.R. (Ministry of War). Fig. 1 gives their location and Table 2 the number of years of observation.

Most of these stations have been working for more than forty years. The Alexandria station has functioned since 1885, the Mersa Matruh, Sidi Barrani and Sallum stations are more recent and show gaps at each war period. El Dabaa station shows some irregularities for certain years, and Ras-el-Hekma, Dekheila, Mersa Matruh and El Qasr stations have less than 10 years of observations. All the stations are equipped with standardized instruments, on the pattern of the British Meteorological office, consisting of a raingauge, a rainfall recorder, a dry wet temperature recorder, a maximum and minimum thermometer, a dry and wet bulb thermometer, an anemometer, a precision barometer and a barograph, and a Piche evaporometer. The agro-meteorological station of El Qasr possesses a sunshine recorder, a Robitsch radiation recorder, soil thermometers and a USWB class A evaporation pan.

The Nile Control Inspection (Ministry of Public Works) operates 4 rainfall stations. Daily readings are made by the staff of the railway stations of Burg-el-Arab, El Hammam, Fuka and Ras-el-Hekma. Their reliability is doubtful.

A "Daily Weather Report" gives the 0600, 1200 and 1800 U.T. Synoptic observations for all the U.A.R. meteorological stations. A "Monthly Weather Report", describing the general weather conditions of the month and publishing the monthly means, was issued from 1957 to 1961. An "Annual Report" was issued between 1958 and 1961. It is regretable that these two excellent publications have been stopped. The observations made by the agro-meteorological stations were published from 1961 in a stencilled bulletin, "The Agro-Meteorological Monthly Report". The bulletin included monthly data of soil temperature, air temperature and humidity, surface wind speed, total radiation and duration of sunshine and evaporation of a class A pan. Unfortunately, publication stopped in 1966.

As regards the publication of normals, the Meteorological Department issued in 1950 a booklet entitled "Climatological normals for Egypt". The normals referring to the stations of the region were calculated on periods ranging from 5 years to more than 50 years.

Monthly and annual rainfall totals and the number of rainy days were published by the Nile Control Department (Ministry of Public Works) (Hurst, Block, Simaika: The Nile Basin, Vol. VI Supplement 1,2, 3 1943 to 1957). The SOGREAH report (1960) on the hydrology of the north west coast, gives valuable information on rainfall, its intensity and distribution. Many authors include climatic data quoted from the "Climatological Normals" (Atta 1953, Migahid-Ayyad 1959, Aslan 1959, Sherkawy 1961 etc..) In their studies of the region few of them calculated new averages.

Table 2

METEOROLOGICAL NETWORK

Stations	Altitude	Distance to			Kinds of data							
		Sea	Nearest station km	Rainfall	Temp. + humidity	Wind			Evaporation		Sunshine duration	Soil temp.
						Sp.	Din	Roc.	Piche	Class		
Permanent Stations (Daily)	m	(-	-km-	-)								
Alexandria (Airport)	7	-	-	+	+	+	+	+	+	-	+	+
Dekhila	6	0	-	+	+	+	+	+	+			
Burg-el-Arab	10	5	-	+	+	+	+	+	+	+	+	+
El Dabaa	18	6	-	+	+	+	+	+	+			+
Ras el Hekma	40	0	-	+	+	+	+	+	+			+
M. Matruh (Airport)	30	4	-	+	+	+	+	+	+			+
El Qasr	4	1	-	+	+	+	+	+	+	+		+
Sidi Barrani	23	0	-	+	+	+	+	+	+			+
Sallum	6	0	-	+	+	+	+	+	+			
Periodic stations (Weekly records)												
South Dabaa	80	17	16	+	+	+				+		
Abar el Kanayis	200	50	54	+	+	+				+		
Siwa cross road	140	12	12	+	+	+						
Negeila	110	8	60	+	+	+						
Zarraria	80	16	18	+	+	+				+		

Table 2 (cont.)

Stations with rainfall records (Weekly) only	Altitude	Distance to		Rainfall
		Sea	Nearest Station	
	m	(- - - -	-km- - - - - -)	
- 10 km in Siwa road	165	20	20	+
- 10 km east of Siwa road on the railway	140	16	12	+
- Wadi Mahlab	100	6	4	+
- Negeila railway	155	23	58	+
- Fuka	25	3.5	17	+
- Baggush railway	95	2.	22	+
- Wadi km 9	25	1	1	+
- Wadi Ramla (North)	40	6	4	+
- Wadi Mahlab (North)	100	5	25	+
- Wadi Tawila (North)	50	3	50	+
Rain gauge transert (Weekly)				
Siwa road				
1	170	31	30	+
2	200	39	39	
Zarraya road				
1	55	9	9	+
2	80	16	18	+
South Daba				
1	65	14	10	+
2	80	17	20	+

1.2. Work done under the Project:

Calculation of new normals

The existing normals were established either on a small number of years of observation or different years of observation, which precludes any accurate comparison between stations. Thus it seemed that new normals should be calculated to render comparisons more accurate.

A period of time was chosen long enough to calculate significant means and to include the same years of reliable and complete observations for nearly all the stations of the coast. For rainfall, normals need a minimum of 30 years to be reliable. The selected period, 1925 to 1940 and 1951 to 1965, excludes the war years and some post-war years during which the stations were not fully operating. For the other climatic data (air temperature and humidity, wind speed), the between-year variations are rather low and 15 years of observations (1951-1965) were judged to be sufficient.

New climatological network

To discover the best use of rainfall, runoff and groundwater for developing agriculture and improving the grazing capacity of the ranges, isohyets up to about 50 km to the south were sketched and data collected concering frequency, duration and intensity of rainfall in the catchment areas of the wadis.

As shown in Fig. 1, all the existing meteorological stations are situated along the coast or not farther than 10 km from it. Therefore, a network of 5 weekly periodic stations inland, having meteorological equipment standized with those of the Meteorological Department stations, was installed. These stations are operated by the Meteorological Department staff and thus provide reliable data which can be compared to the coastal stations. One daily station belonging to the Meteorological Department Network at Burg-el-Arab was utilized.

Ten rainfall recorders were set up in 4 catchment areas, for hydrological studies. Some raingauges were placed along north-south transect lines, (south of El Daba, south of Matruh along the Siwa Road and south of Sidi Barrani) to assess the decrease of rainfall with distance from the sea. Readings were taken weekly by the Meteorological Department staff.

The maintenance of the weekly meteórlogical stations located inland, however, was difficult. Problems of transportation, personnel, guardianship, and water delayed the beginning or observations. The whole network was ready to work in October 1968. At least 3 years of observations will be necessary to provide a first indication of the water budget of the region.

2. Main Factors Determining the Climate of the Area

Four factors contribute to the climate of the region :

- The situation of the region with regard to the general circulation of the atmosphere.
- The proximity of the Mediterranean sea.
- The orientation of the coast.
- The orography.

There is no doubt that the first factor is the most important one. The North-Western Coastal Region stretches from 31°38 N to about 30°40 N (South of El Hammam) and from 25°11 E (Sallum) to 29°57 W (Alexandria). At this latitude, the weather is controlled in summer by the subtropical high pressure belt and in winter by the cyclone moving eastward with westerlies. The summer situation is characterized by a stationary (or slowly moving eastward) antocyclone on the central Mediterranean Sea and Libya, while deep monsoon lows stay over Iraq and Saudi Arabia. In the region this results in a clear sky, no rain, high solar radiation and relatively weak winds during the summer months (May to September). The situation changes in October because of the weakening of the Mediterranean anticyclone. Cyclones formed over the Atlantic or over certain favourable regions of the Mediterranean Sea (Gulf of Genoa, Cyprus) penetrate eastward with the westerly winds. These cyclones extend sufficiently to affect the region (mainly the Cyprus Low), and account for practically all the winter rainfall. Rainfall occurs as showers associated with cold front cumulus clouds.

The proximity of the sea has a direct effect on the air temperature and humidity, and consequently on evaporation and condensation.

The orientation of the coast with regard to the prevailing winds is probably the main explanation of the difference in the distribution of rainfall along the coast. The parts of the coast directly exposed to the north-west winds (the Western parts of the Delta, Alexandria to Burg-el-Arab) receive more rain than those facing the north-west (Sallum, Fuka).

The role of orography is yet unknown. It will be assessed by the data of the new meteorological station, installed by the project, at Aber El Kanayes, on the 200 m contour line and about 50 km from the coast. It is possible that the altitude has some effect and that the rainfall on the plateau is more abundant than expected.

3. Main Features of the Climate

3.1. Rainfall

The average rainfall and its distribution along the coast.

Table 3 and Fig. 2 show that the average amounts of rainfall observed in eight stations of the North West coast range between 100 and 150 mm. Such a low amount places the zone at the driest limit of the arid climate.

Table 3: Average Monthly and Annual Rainfall

30 years (1925 - 1939, 1951 - 1965)

	J	F	M	A	M	J	J	A	S	O	N	D	Annual
	(- -	- - -	- -	- - -	- -	- mm	- -	- -	- - -	- - -	- -	- -	- - -)
Alexandria	46.4	27.3	8.9	3.0	1.7	0	0	0	0.5	7.8	33.4	51.6	180.6
Burg-el-Arab	42.1	22.1	4.7	4.1	0.6	0	0	0	0.4	13.7	31.4	35.5	156.6
El Hammam	28.5	18.7	5.3	1.5	0.5	0	0	0	3.1	8.9	25.1	28.3	119.9
El Dabaa	32.6	18.1	9.2	2.6	2.6	0	0	0.3	1.0	8.1	29.3	36.8	140.6
Fuka	21.8	18.5	4.8	1.0	1.5	0	0	0	0.8	11.7	19.1	29.2	108.4
Mersa Matruh	36.4	20.3	10.3	3.8	2.2	1.9	0	0.5	0.9	12.1	23.6	35.6	147.6
Sidi Barrani	38.1	19.4	10.2	1.6	2.8	0.1	0	0.1	0.3	14.4	21.9	35.0	143.9
Sallum	21.3	15.8	8.2	1.3	2.8	0	0	0.5	0.1	7.9	19.8	24.5	102.2

Only a small part of the coast, from Alexandria (181 mm) to Burg-el-Arab (157 mm) is a little more favoured.

El Dabaa, Mersa Matruh and Sidi Barrani receive the same amount of precipitation: about 145 mm. The low amount of rainfall at El Hammam (120) cannot at present be explained.

Fuka, protected from the rainywind by the rocky crest of Ras el Hekma, and Sallum on the leeward side of the Libyan plateau, both receive a little more than 100 mm. It must be noted, however, that the data for Fuka and El Hammam are less reliable than other data. It is still difficult on the grounds of these data, collected so very near to the sea (no further than 5 km off the shore), to make any assumption on the inland distribution of the rainfall, or to trace the isohyets.

An attempt to show inland distribution was made, however, by F. Mali (1952) who used the Delta stations (see Fig. 3).

Ismail El Ramly, in a later work (Desert Institute 1966), still unpublished, has also drawn isohyets in a precipitation map of Egypt. These two maps show clearly that the North Western shore of the Delta (Alexandria, Abukir, Rachid and Borollos) is relatively well watered (150 - 200 mm). This is well explained (El Fandy 1946) by the dominance during winter of the cold north west currents on the edge of the Cyprus low.

The 150 mm isohyets seems to follow the coast closely. The 100 mm isohyets cannot be drawn with any confidence solely on the data of Damietta and Damamhour on one side and Sallum on the other side. Such maps have thus a geographical interest but are not accurate enough for technical purposes. The measurement of rainfall in the new inland stations of El Dabaa (south), Mersa Matruh (Aber el Kanayis) and Sidi Barrani (Zarraria) for at least 3 years is the only way to ascertain the position of the 100 mm isohyets. Nevertheless, the first data obtained in hydrological studies on Wadi Ramla (see Economides - Harhash - Interim Report April 1968) indicate that the decrease of the amount of rainfall with the increasing distance from the sea is probably more important than can be predicted by the Delta figures. The rainfall recorded at 12.5 km from the sea at the limit of the catchment area of Wadi Ramla (near Mersa Matruh) was only 58 percent (54 mm) of the rainfall at El Qasr (97 mm), during the winter 67 - 68. This difference could be considered as significant as it was systematic for each month.

Distribution of rainfall during the year

Fig. 4 shows the monthly distribution of rainfall, and Fig. 5 the seasonal distribution in percent. The rainy season begins during the second half of October. Three quarters of the total amount falls from November to February. December and January are the rainiest months with an average of 35 mm per month. Some showers are still observed in March, but the spring is dry and receives only 10 percent of the total.

The dry season lasts 6 - 7 months without precipitation, except for a few stormy rains in April, May and September. This typical winter rainfall regime sets severe conditions for agriculture. The lack of good spring rains and the rather high evaporation in the winter reduce considerably the replenishment of the soil water storage.

The mean annual number of rainy days according to the minimum amount, is given in Tables 4 a, b, c, and d. Of the 42 rainy days per year, only a few bring enough water to moisten the soil. 25 days record rainfalls greater than 1 mm. A rainfall of more than 5 mm is observed 7 days per year. Rainfall of more than 10 mm / day, generally falling with an intensity high enough to fill the wadis, only occurs 3 or 4 times per year, mainly in December and January.

Table 4 a : Mean Number of Rainy Days R / / 0.1 mm. (a)

Year : 1951 - 1965

Stations	J	F	M	A	M	J	J	A	S	O	N	D	Annual Mean
						days							
Alexandria	10.1	7.3	5.3	1.6	1.1	0.0	0.0	0.0	0.3	3.9	7.2	10.9	47.7
Dabaa	5.6	3.7	1.9	0.5	0.5	0	0	0	0.2	3.1	3.7	5.3	24.6
Mersa Matruh	8.0	6.3	4.7	2.7	1.2	0.2	0.0	0.0	0.4	3.7	6.3	8.4	41.9
Sidi Barrani	9.0	5.7	4.8	0.4	1.8	0.2	0.0	0.1	0.3	3.8	4.8	9.3	40.2
Sallum	7.3	4.8	3.7	1.8	1.9	0.2	0	0	0.5	3.2	2.9	5.4	31.7

Table 4 b : Mean Number of Rainy days R / / 1 mm. (b)

Year : 1951 - 1965

Stations	J	F	M	A	M	J	J	A	S	O	N	D	Annual Mean
	(- -	- - -	- - -	- -	- -	days	- -	- -	- -	- -	- -	- -	- -)
Alexandria	6.7	4.8	2.5	0.7	1.1	0.0	0.0	0.0	0.2	2.5	4.3	7.4	30.2
Dabaa	4.4	2.7	1.2	0.2	0.4	0	0	0	0.2	1.9	2.3	3.8	17.1
Mersa Matruh	4.9	3.7	1.8	0.6	0.5	0.1	0.0	0.0	0.2	2.2	3.4	5.7	23.1
Sidi Barrani	6.3	2.8	2.7	0.5	0.7	0.1	0.0	0.1	0.0	2.1	3.4	6.4	25.1
Sallum	3.6	2.1	1.4	0.3	0.7	0.0	0	0	0	1.8	1.0	3.2	14.1

Table 4 c : Mean Number of Rainy days R / / 5 mm. (c)

Year : 1951 - 1965

Stations	J	F	M	A	M	J	J	A	S	O	N	D	Annual Mean
	(- -	- - -	- - -	- -	- -	- - -	days	- - -	- - -	- -	- -	- -	- - -)
Alexandria	2.6	2.0	0.4	0.2	0.0	0.0	0.0	0.0	0.0	0.7	1.9	3.9	11.7
Dabaa	1.7	0.7	1.0	0.1	0.1	0	0	0	0.1	1.2	1.2	1.9	8.0
Mersa Matruh	1.7	0.9	0.6	0.1	0.0	0.1	0.0	0.0	0.1	0.7	1.3	1.9	7.3
Sidi Barrani	3.2	0.5	0.7	0.1	0.0	0.0	0.0	0.0	0.0	1.2	0.8	2.2	8.7
Sallum	0.0	1.0	0.5	0.0	0.2	0	0	0	0	1.3	0	1.2	5.2

Table 4 d : Mean Number of Rainy days R / / 10 mm. (d)

Year : 1951 - 1965

Stations	J	F	M	A	M	J	J	A	S	O	N	D	Annual Mean
	(- -	- - -	- - -	- -	- - -	- - -	days	- - -	- -	- - -	- -	- - -	- - -)
Alexandria	1.4	0.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.8	1.9	5.2
Dabaa	1.0	0.4	0.1	0.1	0.1	0	0	0	0.1	0.4	0.8	1.0	4.0
Mersa Matruh	0.8	0.3	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.5	0.5	0.9	3.1
Sidi Barrani	1.5	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.3	1.2	3.8
Sallum	0.5	0.5	0.2	0	0.1	0	0	0	0	0.6	0	0.6	2.2

Variations of rainfall from year to year

In arid climates, the variation of rainfall from one year to another may be so important that it precludes dry farming agriculture, even if the annual mean seems to allow it.

As the time distribution of the annual amount seldom follows the Gaussian law when the annual amount is low, it is in principle not possible to use the standard deviation as a dispersion parameter. The interannual variability is then used in such a case.

It is calculated on long time records by the formula:

$$I_{av} = \frac{(R_1 - R_2) + (R_2 - R_3) + \_\_\_\_ (R_{n-1} - R_n)}{n - 1}$$

I_{av} = interannual variability

R = annual rainfall (hydrological year June 1 - May 31)

n = number of years of observation

The relative interannual variability (I_{av}) r, is expressed in % of the annual average.

$$(I_{av})\,r = \frac{I_{av}}{R} \times 100$$

R : annual average.

Table 5 shows the interannual variabilities of rainfall observed along the coast.

Table 5.

Interannual Variability of Rainfall along the coast of the North Western Coastal Region

Station	Number of years of observation	Annual average	Interannual Variability I_{av}	Relative I_{av} $(I_{av})r$
	years	mm	mm	%
Alexandria	50	180	57	32
El Dabaa	38	143	57	40
Mersa Matruh	40	145	67	46
Sidi Barrani	35	148	57	37
Sallum	38	106	72	68

It is generally considered that regular dryland farming agriculture is practically impossible with a rainfall which is so scarece and so erratic. The rainfall in Alexandria and surrounding areas is more regular and abundant than in El Dabaa and Mersa Matruh. Sidi Barrani, which has the same annual average as Mersa Matruh, shows less variability. Sallum, on the contrary, has a desert climate with a very high I_{av}.

Comparing these results with those of Perrine Brichambaut and C. Wallen for the Middle East, it appears that the region is quite similar, as far as rainfall is concerned, to the Deir el Zor area in Syria.

The I_{av}, as high as it is, is nevertheless lower than that of many parts of the Middle East, such as Mesopotania, the Iranian South coast, or the Eastern Moroccan plateau.

Frequency of occurrence of dry and rainy years.

The observed values of average annual rainfall, calculated on the basis of hydrological years (June 1 - May 31) were plotted on probit papers (see Graphs A,B,C, D and E). It appears that the observed distribution fits rather well with the normal law except for Sallum. In Alexandria, rainy years with more than 250 mm may occur once or twice in ten years, whereas dry years receiving less than 120 mm are expected once in ten years.

In Matruh, El Dabaa and Sidi Barrani, annual rainfall of more than 250 mm are exceptional. A rainfall of more than 200 mm occurs twice in ten years. Dry years receiving less than 100 mm occur two or three years in ten.

For Sallum, the distribution is highly dissymmetric. Despite the low annual average (102 mm), high annual amounts are sometimes observed, more often than, would be predicted according to the normal law. On the other hand, desert conditions with rainfall less than 50 mm prevail about twice in ten years.

Rainfall Intensity

In 47 years of observation, in Mersa Matruh, which represents the average conditions in the region, a rainfall of more than:

50 mm / day was observed 5 times or 10.6 %
75 mm / day was observed 2 times or 4.3 %
98 mm / day (max) was observed once or 2.1 % (SOGREAH Report)

The maximum rainfall intensity recorded during the last 15 years was 50 mm in one day. On that day, of the 50 mm which fell during 12 hours, 45 mm fell in 6 hours, and 34 mm in one hour.

The distribution of a rainfall intensity of over 2 mm during 1 hour is the following (1951 - 1965) :

more than 2 mm / hr : 100 % of the cases.
more than 5 mm / hr : 85 % of the cases.
more than 10 mm / hr : 30 % of the cases.
more than 20 mm / hr : 15 % of the cases.

3.2. Air temperature

Table 6 indicates the mean monthly maximum and minimum observed during the reference period 1951 - 1956 in five meteorological stations of the regions.

Table 6

	J	F	M	A	M	J	J	A	S	O	N	D	Annual
	(°C)												
Alexandria M	18.9	19.6	21.5	24.2	26.8	28.9	29.8	30.8	29.6	27.9	24.6	20.6	25.3
m	9.2	9.7	11.7	13.7	15.3	20.3	22.8	23.1	21.2	17.7	14.6	10.7	16.1
$\frac{M+m}{2}$	14.1	14.7	16.6	18.1	21.1	24.6	26.3	26.1	25.4	22.9	19.6	15.2	20.3
M - m	9.7	9.9	9.8	10.5	11.5	8.6	7.0	7.7	8.4	10.2	10.0	9.9	9.2
El Dabaa M	18.4	19.1	20.6	22.7	25.3	27.9	29.1	29.8	28.7	27.0	23.6	19.7	24.3
m	7.4	7.9	9.6	12.0	14.7	18.4	21.0	21.3	19.8	17.2	13.4	9.4	14.3
$\frac{M+m}{2}$	12.9	13.5	15.1	17.4	20.0	23.2	25.1	25.6	24.3	22.1	18.5	14.6	19.3
M - m	11.0	11.2	11.0	10.7	10.6	9.5	8.1	8.5	8.9	9.8	10.2	10.3	10.0
Mersa Matruh M	18.2	19.0	20.7	22.9	25.5	28.0	29.2	29.0	28.7	27.1	23.5	19.7	24.4
m	8.4	8.5	10.1	12.1	14.5	18.3	20.4	21.0	19.7	16.9	13.4	10.1	14.4
$\frac{M+m}{2}$	14.8	13.8	15.4	17.1	20.0	23.2	24.8	25.0	24.2	22.0	18.5	14.9	19.4
M - m	9.8	10.5	10.6	10.8	11.3	9.7	8.8	8.0	9.0	10.2	10.1	9.6	10.0
Sidi Barrani M	18.1	18.9	20.3	22.2	24.1	26.9	28.2	29.0	28.1	26.4	23.5	19.7	23.8
m	8.5	9.0	10.6	13.1	15.6	18.3	22.0	22.3	20.4	17.3	13.9	9.4	15.0
$\frac{M+m}{2}$	13.3	13.1	15.5	17.7	19.9	22.6	25.1	25.7	24.3	21.9	18.7	14.6	19.4
M - m	9.6	9.9	9.7	9.1	8.5	8.6	6.2	6.7	7.7	9.1	9.6	10.3	8.8
Sallum M	18.9	19.9	20.4	23.7	26.3	29.5	30.8	31.0	29.2	27.6	24.6	20.4	25.2
m	9.5	10.2	11.5	14.0	16.7	20.2	21.7	22.1	20.6	18.5	15.4	11.5	16.0
$\frac{M+m}{2}$	14.2	15.1	15.1	18.9	21.5	24.9	26.3	26.6	24.9	23.1	20.0	15.1	20.5
M - m	9.4	9.7	8.9	9.7	9.6	9.3	9.1	8.9	8.6	9.1	9.2	8.9	9.2

The mean annual maximum temperature is about 1°C higher and the mean annual minimum 1.5° higher in Alexandria than along the coast westwards. El Dabaa and Mersa Matruh have the same maximum, but El Dabaa has lower night temperatures during winter and spring. The difference is 1.0°C in January, and 0.5°C in March. Sidi Barrani has the most temperate climate of the coast. Maxima are lower and minima higher than in Mersa Matruh. This is probably due to the greater exposure of the northern part of the Sidi Barrani area to maritime effects, and thus cannot be extrapolated to the whole Sidi Barrani area. Once more, temperature data recorded by the Zarraria Meteorological station, 12 km south of Sidi Barrani, will be useful in assessing the extension of sea influence.

At Sallum the summer temperature exceeds that of Matruh by 1.5°C to 2.0°C for the mean maxima. The mean monthly minima are also constantly higher in Sallum than in Matruh or Sidi Barrani (1 or 2°C).

As regards temperature, the region enjoys a typical Mediterranean climate, being strongly influenced by the presence of the sea.

Compares with the Saharian climate prevailing inland, both the maximum and the minimum temperature curves are flattened, but the difference is particularly obvious for the maximum (Fig. 6 : comparison of the air temperatures of the coast to those of Siwa oasis, 300 km away to the South).

The lowest temperatures are observed in January and February : the mean monthly maximum stays around 9°C and the minimum of the night seldom falls below 5°C (absolute minimum 2°C).

No danger of frost, as observed in desert climate, is thus to be feared in the region, but cool nights, characterized by temperatures below 10°C, prevail from the last weeks of December till the middle of March. The day temperature during the winter is rather low and uniform, seldom exceeding 20°C.

Spring begins in the first weeks of March and there is a marked increase of the maximum day temperature (above 20°C). But the nights remain cool and the general trend of increasing temperature is often broken by cold spells lasting 3 or 4 days. April is characterized by frequent "khamsin" winds, bringing the maximum temperature to over 30°C or even 35°C for 2 or 3 days at a time. April nights are still cool (between 10 to 15°C).

The summer lasts over 5 months, from May till the end of October. The day temperature is warm but temperate, fluctuating between 25 and 30°C. The night temperatures are rather high, mainly in August and September (more than 20°C).

Autumn begins with the first rains. Day and night temperatures slowly decrease, dropping to about 20°C (max of the day) and 10°C (min of the night) in mid-December, the beginning of winter.

3.3. <u>Air humidity</u>

Relative humidity at 0600 UT and 1200 UT is given in Tables 7a and 7b, Fig. 7 shows the annual trend of R.H. throughout the year and compares the air humidity along the North West coast with that of a desert station (Helwan).

Table 7a

Mean Relative Humidity % at 0600 UT.

Stations	J	F	M	A	M	J	J	A	S	O	N	D	Annual Mean
	(						%						)
Alexandria	80	77	70	67	65	68	69	70	67	72	76	86	72
Dabaa	72	71	67	63	64	68	71	72	67	69	73	73	69
Mersa Matruh	72	70	67	63	61	65	72	72	63	69	72	74	69
Sidi Barrani	73	63	66	63	59	68	75	74	69	70	74	73	69
Sallum	67	63	61	59	55	50	67	69	68	67	67	69	64

Table 7b

Mean Relative Humidity % at 1200 UT.

Years : 1951 - 1965

Stations	J	F	M	A	M	J	J	A	S	O	N	D	Annual Mean
	(						%						)
Alexandria	54	52	51	49	51	58	61	60	56	54	54	56	55
Dabaa	47	46	46	47	49	55	57	58	55	52	52	51	51
Mersa Matruh	50	47	47	48	52	57	62	60	56	53	53	52	53
Sidi Barrani	54	47	51	53	59	63	70	66	61	58	53	53	57
Sallum	45	45	41	46	48	47	51	52	54	51	46	47	48

For all the stations of the coast, the relative humidity does not vary greatly through the year, staying between 50 to 60 percent at noon and between 60 to 70 percent in the morning (and also in the evening, not shown). The air is markedly drier in Sallum. Compared to Helwan, the air moisture is quite maritime. At noon, the maximum R.H. is observed during August and September. In the desert, minimum R.H. occurs in April - May, as long the North West coast, but a low value persists throughout the summer.

In the morning R.H. is high in Alexandria during winter (about 80 percent); in Matruh and Sidi Barrani it fluctuates around 70 percent.

Saturation deficit, or the difference between the saturated and the actual vapour pressure of the air, is a better way to express the drying power of the air. This concept has a more biological meaning than R.H. Tables 8a and 8b and Fig. 8 show that the combination of a moderate temperature and a fair amount at water vapour in the air makes the Sidi Barrani climate favourable for the vegetative growth of plants. It will not be possible to evaluate how far this action of the sea extends until there are records from the inland meteorological stations.

Table 8a : Saturation deficit mm Hg. at 0600 UT

Stations	J	F	M	A	M	J	J	A	S	O	N	D	Annual Mean
Alexandria	2.0	2.4	3.8	5.2	6.9	7.6	7.7	8.1	8.3	5.8	3.8	1.6	5.2
Dabaa	2.5	2.8	3.9	5.5	6.5	7.8	5.1	7.1	7.7	5.9	3.8	2.8	5.1
Mersa Matruh	2.6	2.9	3.9	5.5	7.2	7.9	6.8	7.0	7.3	5.8	3.9	2.7	5.3
Sidi Barrani	2.5	3.6	4.0	5.4	7.3	7.1	6.0	6.4	6.6	5.4	3.6	2.8	5.1
Sallum	3.1	3.8	4.4	6.1	8.3	9.2	8.2	7.7	6.4	6.2	4.8	3.4	6.0

Table 8b : Saturation deficit mm Hg. at 1200 UT

Year : 1951 - 1965

Stations	J	F	M	A	M	J	J	A	S	O	N	D	Annual Mean
Alexandria	7.0	7.6	8.7	10.5	11.7	11.7	12.1	14.0	13.1	13.1	10.0	7.5	10.6
Dabaa	8.0	8.3	9.1	10.0	11.3	11.4	12.2	13.5	12.3	12.4	9.3	7.9	10.5
Mersa Matruh	7.3	8.1	8.8	9.9	10.5	11.3	11.4	13.1	12.1	12.2	9.5	7.7	10.2
Sidi Barrani	6.7	8.1	8.0	7.8	8.4	8.4	9.3	11.2	10.4	10.0	9.6	7.6	8.8
Sallum	9.4	8.8	8.6	10.7	11.8	13.8	14.9	14.2	12.9	12.4	11.6	8.9	11.5

3.4 Wind speed and direction

In Mersa Matruh and Sidi Barrani, winds blow strongly during winter and early spring, with an average speed of about 20 to 25 km / hr (5.5 to 7 0 m s). Table 9 and Fig. 9 give data on wind speed for the region.

Table 9 : Average wind speed km /hr.

	J	F	M	A	M	J	J	A	S	O	N	D	Annual
						km/	hr						
Alexandria	17.0	17.2	18.2	16.7	15.4	16.5	15.9	15.7	14.4	12.6	13.0	15.9	15.7
El Dabaa	13.1	14.1	15.9	16.3	15.8	16.3	18.0	16.5	13.5	12.8	11.5	14.5	15.0
Mersa Matruh	4.9	23.3	22.8	22.6	20.0	19.3	21.4	18.7	17.8	16.3	17.4	22.0	21.1
Sidi Barrani	20.4	20.2	21.5	20.6	18.2	17.0	20.0	17.2	15.7	15.7	16.5	19.8	19.7
Sallum	15.9	14.5	14.8	13.5	11.9	13.7	15.4	14.1	12.0	11.9	12.8	16.5	17.6

Wind speed decreases in May and June, but July is windy. The end of the summer records many calm days and the average speed drops to 15 km /hr (4 m / s). The wind speed in Alexandria, El Dabaa and Sallum is 25 percent lower.

Maximum wind velocities are expected to occur:

more than 100 km / hr - 2.2 times in ten years
more than 80 km / hr - 18 times in ten years
more than 60 km / hr - 58 times in ten years.

North-West winds prevail with a frequency of 30-40 percent (Fig. 10). South-west winds have some importance in Matruh and Sidi Barrani: 18.6 and 13.5 percent respectively.

3.5. Sunshine duration and Solar radiation

Bright sunshine duration measured in Alexandria, Matruh and Sallum are shown in Table 10, compiled from "Climatological normals" and from the Agro-Met bulletins.

Table 10 : Duration of bright sunshine (% of possible).

	J	F	M	A	M	J	J	A	S	O	N	D	Annual
						%							
Alexandria 1924-45	68	71	75	82	80	84	86	90	90	87	78	66	80
M. Matruh 1964-65	65	71	76	71	79	87	91	90	89	78	70	71	79
Sallum 1932-40	68	68	75	76	72	87	91	92	88	85	69	67	78
Helwan	73	77	78	82	84	91	91	92	90	85	80	75	83

It is clear that there is no great difference in sunshine duration from place to place along the coast, nor from year to year. Cloudiness is greater along the coast than inland (Helwan). The difference is of course more conspicuous during winter and spring (about 10%) but is no more than 5% for the whole year.

The amount of solar energy received per unit of ground area is now generally recognized as the background for any quantitative analysis of most of the micro-climatic phenomena of the low atmosphere. To measure this solar radiation with accuracy, delicate instrumentation is required, such as the Moll thermopile, and only a research institute with scientific staff can afford it. An easy way to obtain a good value of the solar radiation in second class meteorological stations is to measure the sunshine duration and to relate it to solar radiation by appropriate formulae. The checking of the formulae and the adjustment for turbidity and cloud-cover factors can be achieved by some years of observation in a research institute. This has not yet been done in the U.A.R., but some attempts to measure the Linke's sector for turbidity of the atmosphere has been tried at Ras el Hekma (Abd El Salam, A F Nodi 1959). The results indicate that the absorption due to water vapour and dust particles is rather high : nearly 15 percent for an optical mass of 0 and 28 percent for Om = 2. Sun plus sky radiation is about 20 percent less in June at Ras el Hekma than it is at Giza.

In the agro-met station of Matruh El Qasr, direct solar and sky radition have been observed since 1964 by means of a Robitsch bi-metallic radiation recorder. This instrument has a large time response and a rather low accuracy. It is nevertheless useful for estimating (with about 10 to 20 percent relative error) the daily total radiation as shown in Table 11.

Table 11 : Total sun + sky radiation at Mersa Matruh El Qasr

$Cal. cm^{-2} d^{-1}$

	J	F	M	A	M	J	J	A	S	O	N	D	Annual
1964	233	319	420	502	568	600	596	545	464	366	257	205	423
1965	223	320	438	573	580	579	591	560	460	320	228	259	428
1966	245	311	411	479	535	585	590	-	-	-	-	-	

Strong radiation prevails from March till the end of September, with a peak in June - July. In November, December and January, although relatively cloudy months, there is more radiation than there is in temperate Western Europe during the spring.

3.6. Evaporation

Natural evaporation can be measured directly by means of an atmometer or with an evaporation pan, or calculated by more or less empirical climatic formulae. Each method will be discussed here.

Piche evaporimeter

Each meteorological station of the zone is provided with a Piche evaporimeter under meteorological shelter, but the results obtained are not even vaguely related to the evaporation of a water surface or to the loss by transpiration of vegetative cover. They are more or less an expression of the drying power of the air. (See Table 12).

Table 12 : Evaporation (Piche) mm/d^{-1} (1951 - 1965)

	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Alexandria	3.9	4.5	5.1	5.4	5.8	5.5	5.3	5.4	5.7	5.1	4.4	3.9	4.5
El Dabaa	5.1	5.7	6.0	6.6	6.9	6.9	7.4	6.9	7.3	6.5	5.5	5.0	5.9
Mersa Matruh	7.6	9.0	9.1	9.1	8.9	9.0	9.3	9.3	9.4	8.2	7.3	7.5	7.9
Sidi Barrani	5.9	7.3	7.2	7.5	6.3	6.4	6.0	6.3	6.8	6.8	6.4	6.2	6.6
Sallum	7.5	8.3	8.6	9.6	8.7	9.9	10.3	9.2	8.3	7.8	6.9	7.2	8.5

The large divergence observed between Alexandria and Mersa Matruh is mainly due to the nature of the instrument, the Piche evaporimeter being more sensitive to air movement than to heat or radiation. Nevertheless, even if it is not in the proportions indicated by the Piche, evaporation must be somewhat higher in this part of the coast, exposed as it is to the wind. This justifies some protection by windbreak, when possible.

Class A evaporation pan.

Mersa Matruh, El Qasr, is the only station provided with an USWB class A evaporation pan. (see Table 13). Class A is far from being a perfect instrument and has many theoretical flaws, yet it is the easiest way to measure directly evaporation of a water surface, with an accuracy good enough for most practical purposes.

The conversion factor (about 0.7) has been tested in a large variety of environments and is one of the best known. All the meteorological stations of the zone will be eventually equipped with a class A pan .

Calculation by Heat Budget (Penman's formula).

The agro meteorological station of El Qasr collects all the data needed for the calculation of evaporation by heat budget method. The main term, radiation, is measured with a rather crude instrument, but as cloudiness is low the error is probably not more than 10 percent.

The formula of Penman has been applied for a water surface.

$$Vc = \frac{D\,H/_{L} + A\,Va}{D + A}$$

in which

Vc : evaporation of a water surface in mm/d

H : heat budget, or net radiation in cal/cm^{-2}/d^{-1}.

L : latent heat of vaporization = 59 cal. cm^{-2} for 1 mm depth.

$H = R\,(1 - r) - R_b$

with

R : total sun + sky radiations measured with the Robitsch bi-metallic radiation recorder.

r : albedo of a water surface = 0.05

R_b : long wave radiation

$R_b = \sigma T^4$ (0.10 + 0.90 $^n/N$) (0.56 - 0.092 Ve

T : Abs. air temperature in ^oK.

σ : Stefan Holzman constant

$^n/N$: relative sunshine duration

O : vapour tension in mm Hg.

Va : empirical aerodynamic term in mm/d

Va = 0.35 (0.5 + 0.526 U_2) (E - e)

U_2 : wind speed m/s

E - e : saturation deficit in mm Hg.

D : slope of the saturated moisture tension TS temperature curve

A : psychometric constant = 0.5

Evaporation appears to be fairly constant from year to year and amounts to about 1500 mm.

Evaporation rate is high from March to October, with a maximum in July (6.6 mm/d)

Winter evaporation is not neglible (1.7 mm/d in December - January.)

The radiation term accounts for the largest part in the evaporation process, at least in summer. From November to February, the aerodynamic term is 1.5 to 2 times the radiation term. In summer, on the other hand, a complete suppression of the wind will bring only a 25 percent reduction of evaporation.

Table 13 : Evaporation (Mersa Matruh - El Qasr)

1964	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Piche mm/d	5.4	5.7	6.7	7.5	-	-	-	13.4	13.6	4.8	9.0	8.3	
Class A pan mm/d	3.9	5.3	6.4	6.8	6.2	10.0	10.0	10.6	9.6	7.0	5.5	4.2	
0.7 Class A pan mm/d	2.7	3.7	4.5	4.8	4.3	7.0	7.1	7.4	6.7	4.9	3.9	2.9	
0.7 Class A pan mm/mo	84	107	140	144	133	210	220	229	201	152	117	90	1,827
Vc. Penman mm/d	1.7	2.7	3.8	4.8	5.5	6.2	6.6	6.4	5.1	3.3	2.4	1.7	
Vc. Penman mm/mo	53	77	116	145	171	185	204	199	152	101	71	53	1,526
Rainfall	72	29	12	8	1	0	0	0	3	0	29	63	217
Deficit (or Excess) (R-Vc)	+19	-48	-104	-136	-170	-185	-204	-199	-149	-101	-42	+10	-1,299
Piche mm/d	8.4	12.8	17.6	17.1	12.2	12.1	12.3	12.1	10.7	11.8	9.7	10.9	
Class A pan mm/d	4.5	6.4	6.7	9.2	9.6	10.2	11.4	10.5	8.2	7.6	4.5	5.1	
0.7 Class A mm/d	3.2	4.5	4.7	6.4	6.7	7.1	8.0	7.4	5.7	5.3	3.6	3.2	
0.7 Class A mm/mo	99	126	146	192	208	217	248	229	171	164	108	99	2,008
Vc. Penman mm/d	1.8	2.9	3.9	5.0	5.5	6.3	6.7	6.3	4.7	3.3	1.8	1.9	
Vc. Penman mm/mo	56	81	121	150	171	189	208	195	141	102	54	59	1,527
Rainfall	54	5	6	6	0	21	0	0	0	68	9	8	207
Deficit	-2	-76	-115	-144	-171	-168	-208	-195	-141	-134	-45	-51	-1,300

Dew

Loss of calories by long wave radiation occurs at the same rate throughout the year (between 150 to 180 cal. cm^2 d^{-1}). This cooling is partly accountable for dew deposits, but, as it is deducted from global radiation, evaporation is implicitly reduced by this quantity. A more accurate way of determining the daily amount of dew would be to calculate day evaporation and night evaporation separately. This has not yet been done, but A.M. Migahid and M.A. Ayyad measured dewfall by means of a Dudvedani dew gauge for the period June 1955 - July 1956 in Ras el Hekma. However, the same criticism raised against the Piche evaporimeter can be raised against the Dudvedani dew gauge. The total amount of dew collected by this instrument is too strongly affected by its physical properties to be truly representative. Nevertheless, it provides useful information when conditions for dew deposit are met.

From the data, it appears that dew was precipitated on 102 nights of the period, giving a total depth of 11.5 mm of water. This amount is stated to be considerable, but it seems probable that a greater amount is collected by isolated plants. These are, on the other hand, also submitted to a higher evaporation during the day.

On these 102 nights, 20 nights receive more than 0.2 mm/d, 1 more that 0.3 mm/d. These quantities of dew fall when air moisture remains high the day before and when wind velocity is low.

The region is neither more nor less favoured as regard dews than other Mediterranean coasts. For instance, amounts are quite similar to those observed at Montpellier (France).

4. Soil Temperature

Annual trend of soil temperature up to 2m depth is given in Fig. 11 for the year 1965 in Mersa Matruh El Qasr.

No great variations from year to year and from place to place occur and these temperature profiles can be considered as average for the coast for a first approximation.

5. Climatic Indexes and Homoclimates

Two climatic indexes have been calculated (see Table 14):

The Gorszinsky index of continentality in percent based on the difference between the average maximum temperature of the hottest month (August) and the average minimum of the coldest month (January) and corrected for latitude.

$$C = \frac{1.3\ (m - m)}{\text{Sin}} - 36.3$$

The Emberger quotient (see Fig. 12) combining annual amount of rainfall P, annual thermal amplitude M - m and mean temperature $\frac{M + m}{2}$

$$Q = \frac{1000\ P}{\frac{(M + m)}{2}\ (M - m)}$$

Table 14 : Climatic indexes

	P mm/y	M $^{\circ}$C	m $^{\circ}$C	Gorszinsky	Emberger
Alexandria	181	30.8	9.2	17.7	29
El Dabaa	141	29.8	7.4	19.7	21
Mersa Matruh	148	29.0	8.4	15.2	24
Sidi Barrani	144	29.0	8.5	15.2	23
Sallum	102	31.0	9.5	17.3	16

The climate prevailing along the N.W. coast of Egypt can be qualified as "arid Mediterranean with mild winters".

With regard to temperature and rainfall this climate is the same as that of the Cyrenaican coast around Tobruk and of the Tripolitanian coast along the gulf of Sirte. It seems, nevertheless, that rainfall is more irregular in Cyrenaica. Tobruk, with 141 mm of annual average, has recorded a maximum of 326 mm and a minimum of 48 mm. The moderating effect of the sea on temperature is also strong there - the mean maximum of the hottest month (August) is $28^{\circ}3$, the mean minimum of the coldest month (January) is $8^{\circ}9$.

The climate of the North West coast of Egypt is similar, but not quite identical, to the climate of the southern coast of Tunisia, along the Gulf of Gabès. Gabès receives the same amount of rainfall as Alexandria, 175 mm, but the temperature range between the hottest and coldest month is rather bigger - $32^{\circ}7$ down to, $5^{\circ}9$ as opposed $32^{\circ}8$ down to $9^{\circ}2$ in Alessandria. Houmt Souk, in the Djerba Island enjoys the same mild winters and warm temperate summer but is more watered (207 mm). Moreover, the Matmatas, south of Gabès, receives from 200 to 250 mm of rain, whereas rainfall rapidly decreases inland from the Egyptian coast. Elsewhere, the Mediterranean coast is more favoured with regard to rainfall, but not with regard to temperature. At Almeria, in Spain, for instance, summer is a little more temperate (Max. $28^{\circ}9$) and winter is the same (Min. $8^{\circ}2$). But rainfall amounts to 255 mm, with a better distribution, which extends into the late spring. Klaver, in South Africa, is another example of buffered maritime Mediterranean climate with low rainfall (174 mm) well distributed throughout the year. The mean maximum temperature of February is $31^{\circ}6$; the mean minimum of July is $8^{\circ}1$. Most of the time, low amounts of rainfall, as observed along the Egyptian coast, are associated with continental climates. Shafter, in California, records 158 mm of rain, but the rainfall is more abundant in spring. Summer temperatures are higher (Max $37^{\circ}6$) and winter temperatures lower ($1^{\circ}8$). Mafraq, in Jordan, gets 173 mm of water, mostly in winter but some in March. Summer temperatures are not high ($34^{\circ}0$) but winter temperatures are cold ($2^{\circ}1$). Palmyre and Deir el Zer, in Syria, both receive about 150 mm of rainfall and are definitely drier and more continental, with hot summer ($38^{\circ}9$ and $40^{\circ}6$) and cold winter ($2^{\circ}6$ and $1^{\circ}9$). In Iraq, the climate of Basrah is somewhat like that of the Egyptian coast : 158 mm of rain falling late in winter, mild winter (minimum of January : $7^{\circ}1$) and hot summers (maximum : $41^{\circ}9$).

In conclusion, the climate of the North Western Coastal Region is one of the mildest of the Mediterranean sea. Winter temperatures are higher than in any other part of the Mediterranean coast, frosts are not to be feared and mean minimum temperatures remain constantly above the level of temperature requirement for the growth of temperate species. Summer temperature never exceeds critical values. Evaporation is reduced by the fact that summer is not too hot and by the rather high content of moisture in the air. All these favourable conditions are unfortunately offset by the scarcity of rainfall that places the region at the limit of the Saharian climate.

Chapter 3

SOILS

1. Introduction

1.1. Available information

When the project was started not much information was available about the soils in the area, specially not about the distribution of soils and their potential value for agriculture.

The following publications and unpublished data were used during the preparations of the reconnaissance maps and the maps of the pilot areas:

A.G. Abdel Samie: "Soil survey and classification of the Fuka - Ras el Hekma area " (in "Publication de l'Institut du desèrt d'Egypte, 1959", No. 12).

H . Abdel Hakim: "Some studies related to the formation and distribution of soils at the Baqqush Area of the Mediterranean Coastal Zone" (1961).

M.A. Hammad : Relationship between geomorphology and land use in the Mediterranean Coastal Littoral of the U.A.R." (in "Publication de l'Institut du desêrt d'Egypt, 1965").

U.A.R. High Dam Soil Survey Project, Sheet VIII 1964.

1.2. Work done under the Project 1/

During the six months (June - December 1968) that the FAO soil survey expert worked on the project a soil map and a potentiality map, scale 1:50 000, were prepared of the following areas:

a - Negeila Pilot area	51 350	feddans
b - El Qasr Pilot Area	67 575	"
c - Baqqush Pilot Area	22 610	"
d - Fuka Pilot Area	62 425	"
e - El Dabaa Pilot Area	62 900	"
Total :	266 860	"

During this period also a reconnaissance survey was carried out for the Coastal Zone from Alexandria to Sidi Barrani. Five soil maps and soil potentiality maps on scale 1:100 000 were prepared:

Sheet I	Burg el Arab - El Alamein	409 400 feddans
Sheet II	El Alamein - El Dabaa	406 675 feddans
Sheet III	Baqqush - Gallal	517 175 feddans
Sheet IV	Mersa Matruh Area	641 950 feddans
Sheet V	Sidi Barrani Area	377 600 feddans
	Total :	2352 800 feddans

1/ See Appendix I for working methods, terminology and abbreviations.

The soil map and the soil potentiality map of Sheet I were mainly prepared from maps of the U.A.R. High Dam Soil Survey Project (Sheet VIII).

The photo interpretation on the whole area was carried out by J.J. Vleeshouwer, the fieldwork mainly by J.J. Vleeshouwer, A. El Gamal, M. Sidhom and A. Khafaga.

2. The Process of Soil Formation and Main Pedogenetic Classification Units

2.1. General

The soils in the North Western Coastal Region are almost all alluvial soils (rockland is here for convenience sake not considered to be soil). They are mainly sedimented by water action (alluvial material of the fans and out wash plains) but in some areas by wind (coastal dunes and inland dunes). Probably only the subsurface layers of the limited deep alluvial fans on the Miocene plateau are formed in situ and therefore partly derived directly from the limestone bedrock. Striking in the whole area is the absence of gravel and sand layers in the alluvial deposits. Even the alluvial fans at the mouth of the big wadis do not contain considerable quantities of coarse material. Because all alluvial soils in this area are directly or indirectly derived from limestone, they are all rich in $CaCO_3$.

2.2. The pedogenetic processes

The pedogenetic processes in the soils of the zone with its semi-desert climate are slow and on many places not very pronounced. Horizons with an accumulation of organic matter are very weakly developed and obscure, distinct A_2 horizons are not present. The only well developed horizons are accumulation horizons of $CaCO_3$ in many well drained soils, and of NaCl in the poorly drained soils. Another process of soil formation is the cementation of oolitic sand in the dunes along the coast and the weathering of oolitic sand of the inland dunes. Last but not least the formation of man-made soils (ancient agriculture fields) should be mentioned.

Accumulation of $CaCO_3$

Accumulation of $CaCO_3$ occurs only in the well-drained soils. Apparently under the climatologic conditions of the region and/or in soils so rich in $CaCO_3$, as here, an A_2 horizon can never be formed in which the lime is completely removed. Almost everywhere the topsoil still contains more than 10 to 15 percent $CaCO_3$. $CaCO_3$ accumulation horizons (caliche) are mainly found in the soils of the alluvial fans and outwash plains and only locally i.e. in the surroundings of Dabaa in the former beach plains. A caliche horizon can be composed of soft, dusty $CaCO_3$, and be well permeable, but can also be very hard and indurated and therefore very slowly permeable for water. On small scale maps (1:50 000 and smaller) it was not possible to draw reliable boundaries between soft caliche and indurated caliche (croute calcaire). It was noticed in the field that the strongest developed caliche horizons often occur on sloping areas and not in depressions as one would expect. A reasonable explanation for this phenomena cannot be given, because no further investigations were performed. It was also noticed that the areas with a shallow caliche horizon often have a moderately saline or saline topsoil.

Accumulation of NaCl

In the poorly drained beach plain soils along the Mediterranean Coast a very strong accumulation of salts can be observed. Depending on the depth of the ground water this accumulation takes place on, in or under the topsoil. The lowest areas with the highest ground water table are in winter often covered with (salt) water. In summer, a white saltcrush can be found on top of the soils. These areas mostly do not carry a vegetation; the profiles contain, in many places, thick layers of coarse salt crystals, often mixed with gypsum crystals and nodules. The somewhat higher areas are not covered with a saltcrust, carry a scattered salt-tolerant vegetation and have a fluffy topsoil. Probably because of capillary action salts accumulate in the top 20 to 30 cm of the profiles and form there, by coagulation of clay particles, a very saline, loose and more or less granular topsoil in which many small salt crystals can be observed. These small soil particles - 0.5 to 3mm in diameter - can easily be blown away by wind in dry seasons. They accumulate after some distance behind vegetation and form there small hummocky clay or loam dunes, which are, of course, also very saline.

On the highest parts of the poorly drained beach plains - these parts are often also covered with hummocky dunes - the salts accumulate directly under the topsoil.

Cementation and weathering of oolitic sand

In the coastal strip deposits of oolitic sand are found as coastal dunes and as inland dunes. There is a remarkable difference in soil formation in the two deposits. In the coastal dunes the loose oolitic sand grains are cemented and become ultimately even lime stone rock (rocky dunes). In the inland oolitic dunes, however, the sand is weathered and becomes more or less loamy. Only locally in the deep subsoil some cementation can be observed.

Man-made soils

Scattered over the whole region thousands of ancient agriculture fields are found. They all have deep, very homogeneous "clean" soils, without gravels or grit and even without concretions. A caliche horizon is never found within 1.2 m. Mostly the ancient agriculture fields are found in areas where there is "soil". Sometimes, however, the deep soils of the ancient fields are situated directly beside very shallow or even rocky soils, the end of the field forming a very sharp boundary. It is therefore believed that the soils in the ancient agriculture fields are collected from the surroundings and, after the removal of gravels, stones etc. brought to the field.

2.3. The main classification units

According to the supplement to the 7th Approximation of the American System of Soil Classification (March 1967) the mapping units of the reconnaissance maps can be classified on subgroup level as follows:

D Windblown soils

Do Coastal dunes

Do1 Typic Torripsamment
Do2 Typic Torripsamment
Do3 Typic Torripsamment
Do4 Typic Torripsamment and Typic Calciorthid

Ds Inland dunes

Ds1 Typic Torripsamment
Ds2 Calsy Torripsamment
Ds3 Calsy Torripsamment
Ds4 Calsy Torripsamment
Ds5 Calsy Torripsamment
Ds6 Typic Torripsamment
Ds7 Typic Torripsamment
Ds8 Typic Torripsamment

B Soils in the former beach plains and dune depressions

B1 Typic Torriorthent
B2 Typic Torriorthent
B3 Typic Calci/Paleorthid
B4 Typic Calci/Paleorthid
B4d Typic Torriorthent
Bp Typic Salorthid

P Soils of the elongated depressions in the plateau

P1 Typic Torriorthent
Pp Typic Salorthid

F Soils of the alluvial fans and out wash plains

F1 Typic Torriorthent
F1e Typic Paleorthid
F2 Typic Calci/Paleorthid
F3 Typic Torriorthent
F4 Typic Calci/Paleorthid

W Soils of the wadis

Wb Typic Torriorthent
Ww Typic Torriorthent

3. The reconnaissance Maps

3.1. General

The reconnaissance soil maps and the reconnaissance potentiality maps prepared in the last semester of 1968 and the first semester of 1968 and the first semester of 1969. The photo interpretation of the whole area was carried out by J.J. Vleeshouwer. During the field work he was assisted on Sheet II and III by Mr. A. Khafaga, on Sheet IV by Mr. A. El Gamal. The field work of Sheet V was done by Mr. M. Sidhom, Mr. M. Dessouki and Mr. M.A. El Fattah. Analysis on chemical and physical properties of collected soil samples were made in the laboratories of EGDDO in Cairo.

Data of previous investigations in the areas around Dabaa, Ras el Hekma, Baqqush and part of the Mersa Matruh plain were partly used in preparing the reconnaissance soil maps and reconnaissance potentiality maps. Sheet I, covering the area Burg el Arab - El Alamein, is a revised version of the reconnaissance soil map of the U.A.R./High Dam Soil Survey Project (Sheet VIII). The legends of the soil map and the potentiality map of this area are adopted to those of the other maps of the Coastal Zone.

3.2. Details and reliability of small scale maps

On small scale maps like the reconnaisaance map here presented many details cannot be indicated. For example, very clear, high rock outcrops that can be recognized in the field already from a far distance, but that cover only a small area, are not represented on the map. On other places soil boundaries are generalized or small differences grouped together.

The boundaries between the different units are in general correct and reliable, but it is of no use enlarging the maps because no more information or detail will be obtained. A reconnaissance map is made for explanatory purposes, to outline areas with soils suitable for more intensive development. The reconnaissance maps can therefore never be used for detailed planning.

3.3. The reconnaissance map and saline soils

Special attention should be given to the fact that the reconnaissance soil maps give no information about the salinity of soils (except for the poorly drained beach plain soils, which are very saline). This data could not be given, firstly because it would need the collecting and analysis of numerous soil samples, and secondly because the well drained moderately saline and saline soils often cover only small scattered areas which cannot be indicated on these small scale maps. Therefore, on the potentiality map the soils are clissified as if they were not saline. In the table summarizing the potentiality classes of the reconnaisaance maps, however, an attempt is made to give a rough estimation of the saline soils that can be expected in each potentiality class. It should be stressed that this is only a rough estimation and that locally big differences may occur.

3.4. The reconnaissance soil potentiality maps

The suitability of the soils distinguished on the reconnaissance maps is based on the assumption that sufficient fresh water is available for crops to grow. Very saline soils like the poorly drained beach plain soils (mapping unit Bp) are classified as not suitable because leaching of these soils requires big quantities of fresh water and generally these are not locally available. If however the areas can be drained and leaching is possible, for instance with Nile water, most of the soils will become suitable for the cultivation of almost all crops. Wind blown sand soils are considered to be unsuitable for agriculture because of the big quantities of water that are required for the cultivation of crops.

4. Description of the Mapping Units of the Reconnaissance Soil Map and Their Potentiality for Agriculture.

A summary of characteristics of the distinguished mapping units is given in Table 15. Table 16 gives the areas of the different potentiality classes. In Table 17 the mapping units that occur in each potentiality class are listed and in Table 18 some physical and chemical properties of distinguished mapping units are shown.

4.1. Windblown soils

The windblown soils in the area are divided in coastal dunes and inland dunes. The first are found in a rather narrow strip along the Mediterranean Sea, the latter in big areas south of Hamam - El Dabaa and south east of Sidi Barrani. Both are subdivided according to differences in topography, parent material and soil formation.

Do Coastal dunes

The coastal dunes all consist of oolitic sand that is very rich in $CaCO_3$ (more than 80 percent).

The following mapping units are distinguished:-

Do_1 Shifting oolitic sand dunes: cemented oolitic sand and/or rock may occur in maximum 60 percent of the area.

These soils are found in relatively small, scattered areas along the coast. They consist of loose, oolitic sand grains and have predominantly a typical dune topography. The soils are in general deep and very rich in $CaCO_3$ (see Table 18, No.1). In the areas where the dunes are not high, cemented oolitic sand and/or rock (derived from former oolitic dunes) may occur in maximum 60 percent of the area. This is specially the case in the depressions between the dunes.

Where these soils are bordering cultivated land they often are a thread, because the shifting sand very gradually covers it. Only dune fixation can put an end to this slow but disastrous process.

Potentiality for agriculture

The potential value of the soils of this mapping unit is limited to local cultivation of only figs. Local, because they can only grow where rock and cemented oolitic sand is present at considerable depth and where moreover there is some accumulation of fresh water (i.e. in depressions).

Do2 Cemented oolitic sand dunes: locally sheets of shifting oolitc sand and/or rock may occur.

The majority of the coastal dunes consist of cemented oolitic sand. These soils are older than the shifting oolitic dunes, were therefore subject longer to soil formation and consequently the loose grains became cemented in the course of time.

The $CaCO_3$ content is still high, but lower than that of the shifting oolitic dunes (see Table 18, No.2). Though older, the dune topography is still present in most places and the lamination typical for wind blown deposits can be recognized almost everywhere.

In general the cemented oolitic dunes are highest where the strip is wide and low where it is narrow.

Potentiality for agriculture

Not suitable for agriculture, because the soils are too hard to be penetrated by roots.

Do3 More or less parallel ridges of cemented oolitic sand with thin sheets of slightly loamy, loose oolitic sand in the depressions

Only one area of this mapping unit is distinguished. It is found near Um el Rakham. west of Mersa Matruh and consists, of more or less parallel ridges of cemented oolitic sand, 1 to 2 m high. In the strips between the ridges less than 30 cm somewhat weathered and therefore slightly loamy, oolitic sand occurs on top of the cemented oolitic sand.

Potentiality for agriculture

Not suitable.

Do4 Like Do3, but with moderately deep loamy sand to loam soils in the depressions

This mapping unit is also found in only one area near Umm-el-Rakham. In between the ridges the soils are deeper (50 to 100 cm) and consist of loamy sand to loam. Probably this material is a mixture of marine deposits and weathered wind blown oolitic sand.

Potentiality for agriculture

The ridges are not suitable for agriculture. In the depressions vegetables, field crops and moderately deep rooted crops can be cultivated.

Ds Inland Dunes

The inland dunes of the region are mainly divided according to differences in topography. Moreover, the kind of sand (oolitic or quartz sand) is distinguished. The last division is made in order to separate the sands with a high $CaCO_3$ content from those with a low $CaCO_3$ content. It should however not be forgotten that, especially in the transition, there has been a mixing of both sands. The boundary between the mapping units with quartz sand and those with oolitic sand is therefore rather arbitrary.

The following mapping units are distinguished:

Ds 1 Low dunes of quartz sand: many rock outcrops

These soils are found in big areas between El Dabaa and Burg el Arab, in a small area south east of Mersa Matruh on both sides of the asphalt road and south of Sidi Barrani. In the area near Mersa Matruh high hummocks of quartz sand are included in this mapping unit. Part of the dunes are stabilized by natural vegetation but in many places the sand is still shifting..

Most soils are deep and loose and consist of slightly loamy, moderately fine sand. Locally, at a depth of 70 to 120 cm, a weakly developed, rather soft caliche horizon can be observed.

Scattered over the areas low rock outcrops can be recognized easily because they are 50 cm to 2 m higher than the surroundings, do not carry vegetation and are not covered with sand.

Potentiality for agriculture

Not suitable.

Ds2 Moderately high and low dunes of weathered oolitic sand

The soils of this mapping unit are situated south of El Dabaa and between Sidi Abd el Rahman and El Alamein.

The areas have an irregular topography (dunes of 3 to 8 m high), and are covered with a rather dense natural vegetation that stops the shifting of the sand. Locally, on the top of the dunes, the vegetation is absent and the sand still shifting.

The soils of this mapping unit have a high lime content, but it is considerably lower than that of the coastal oolitic dunes. Most remarkable, however, is the difference in silt and clay content. For reasons not yet understood, the inland oolitic dunes do not cement or scarcely cement, but because of weathering become loamy (see Table 18 No. 3).

Caliche horizons are seldom found; locally in some depressions a weakly-developed not very compact lime accumulation horizon can be observed.

Description of a representative profile (see Table 18, No. 3)

0 - 25 cm	loamy medium fine sand, rather loose, many roots.
25 - 75 cm	medium fine sandy loam, somewhat compact, some roots.
75 -120 cm	rather compact medium fine sandy loam, no roots, weakly developed lime accumulation horizon.

Potentiality for agriculture

Not suitable for agriculture. However the soils have a high value for grazing because of the rather dense natural vegetation.

Ds3 Thick local layers of low dunes of weathered oolitic sand

The soils of this mapping unit are found in large areas south eastof El Dabaa. The topography is rather level, though locally some low dunes stick out above the general landscape.

Also locally some outcrops of rocky dunes (mapping unit Rd) may be found. All areas are covered with a rather dense natural vegetation and consequently the windblown sand is stabilized.

The soils consist in general of more than 60 cm, locally more than 100 cm loamy medium fine sand (weathered oolitic sand) with 50 to 70 percent $CaCo_3$, overlying rocky material or former beach plain soils. Locally a weakly developed caliche horizon or cemented oolitic sand can be observed in the subsoil.

Potentiality for agriculture

Not suitable, but the areas have a significant value as range land because of the dense natural vegetation.

Ds4 Thin layers of weathered oolitic sand, predominantly over rock: locally low rock outcrops.

These soils are found in large areas south of El Dabaa - El Alamein. They generally consist of 5 to 50 cm loamy to slightly loamy medium fine (oolitic) sand over rock. The soils of this unit form the transition to the areas where windblown quartz sand is deposited and therefore the weathered oolitic sand is mixed with a varying percentage of quartz sand. Consequently the $CaCO_3$ content is lower than that of the more northerly oolitic sands (see Table 18, No.7).

The areas have a rather level topography but locally some low outcrops of rocky dunes occur. The vegetation is rather dense but scattered and restricted to the areas where the sheets of oolitic sand are present.

Potentiality for agriculture

Not suitable.

Ds5 Dune - depressions: predominantly less than 60 cm weathered oolitic sand over caliche

Scattered over the area with inland oolitic sand deposits between El Dabaa and El Alamein rather level depressions are found which are filled up with less than 60 cm loamy to slightly loamy medium fine weathered oolitic sand. Mostly the subsoil contains a rather soft caliche horizon which forms the transition between the weathered oolitic sand and a subsoil of rock or loamy fine sand to fine sandy loam. This last material is the original deposit in the former beach plains.

The soils of dune-depressions are predominantly cultivated with barley.

Potentiality for agriculture

Suitable for shallow rooted crops only.

Ds6 Thin sheets of quartz sand, predominantly over rock

The soils of this mapping unit are present in the area south of El Dabaa - Burg el Arab and south of Sidi Barrani. They look very much like those of mapping unit Ds4 but the sand is mainly quartz sand, containing only about 5 to 10 percent $CaCO_3$. Moreover, part of this still rather high lime content is caused by the snail remnants present in the sand.

The areas have a more or less level topography and are covered with a rather dense natural vegetation, especially south of Sidi Barrani.

Potentiality for agriculture

Not suitable; the soils have however a high value as range land because of the dense natural vegetation.

Ds7 Thick sheets of quartz sand, predominantly over caliche or rock

This mapping unit is distinguished in big areas south of El Alamein-Hammam and south-east of Sidi Barrani. In both areas the soils are covered with a dense natural vegetation and the topography is almost level. Only locally some low rocks crop out. In these last places the sand cover is thin or even absent and the vegetation more scarce.

The sheets of sand are in general 150 m thick and usually lie on rock. Sometimes, however, loam or sandy loam from the former beach plains can be found in the subsoil.

Potentiality for agriculture

The soils are classified as not suitable for agriculture because they need big quantities of fresh water (which is not available at reasonable costs) to grow crops. Because of the dense natural vegetation the areas have a high value for grazing. Trees would grow very well on these soils, even without irrigation.

Ds8 High and moderately high dunes of quartz sand

These 5 to 10 m high dunes are only found in three areas east and south-east of Sidi Barrani. They are mainly composed of quartz sand in which there is still a rather high $CaCO_3$ content (10 to 20 percent) (See also Table 18, No.11). Most of the areas are covered with a dense natural vegetation which fixed the windblown sand, but locally some shifting dunes without vegetation can be observed.

Potentiality for agriculture

Not suitable for agriculture; the dense natural vegetation give the areas however a high value for grazing.

4.2. Soils in the former beach plains and dune-depressions

These soils are found in the whole region in a rather narrow strip close to the Mediterranean sea. They are deposited in the former beach plains and former dune-depressions and consist of alluvial and colluvial material washed down from the higher neighbouring rocky beach ridges and rocky dunes (mapping unit Rd). In the subsoil, however, probably also material of marine origin is sedimented, especially in the former beach plains.

The subdivision of the soils of this main soil group is based on differences in depth of the profiles, differences in texture and differences in natural drainage.

B1 Deep sandy loam to loam or clay loam soils

The soils of this mapping unit are found in large areas near Burg el Arab, Hammam, El Dabaa, Mersa Matruh and Sidi Barrani. (In the surroundings of the first two places they are being reclaimed and irrigated by Nile water). Small areas and pockets are scattered over the entire region.

All soils of this unit consist of more than 90 cm sandy loam to loam or clay loam; layers of silty loam may occur locally. The topography is in general level, (only on the transition to the neighbouring rocky areas slightly sloping strips are present) and the areas are well drained.

Description of a representative profile near Sidi Barrani (see Table 18, No.12)

0 - 30 cm Sandy loam, friable, many roots, many pores
30 - 60 cm Loam, rather compact when dry, sub-angular blocky, some small and big roots, some pores
60 -120 cm Loam, compact when dry, compactness increases with depth, some small lime concretions,no roots, some small pores.

Potentiality for agriculture

Though now almost exclusively used for the cultivation of barley, these soils are suitable for the cultivation of all crops. They are the most promising soils of the whole region. However, it should not be forgotten that the soils in the depressions are surrounded by higher elevated rock land and that the deep subsoil consists of impermeable rock. When used intensively there is the chance that the depressional soils gradually become saline.

B2 Deep loamy sand to slightly loamy sand soils

These soils are distinguished in only very few areas west of Mersa Matruh and east of Sidi Barrani. Some former beach plains are here filled up with a mixture of loamy colluvial material from the neighbouring rockland and oolitic sand from the coastal dunes. The soils have a level topography and consist of more than 90 cm loamy medium fine sand to slighly loamy medium fine sand with a high lime content. In the subsoil locally fine sandy loam to loam can be found.

Potentiality for agriculture

Suitable for all crops, though the high lime content may be a limitation for some deep rooted crops like olives.

B3 Limited and moderately deep sandy loam to loam soils over caliche or rock

In almost all areas where beach plain soils are distinguished these soils are found. In general they are situated somewhat higher than the soils of mapping unit B1 or they form the transition to the surrounding rockland.

The soils consist of 30 to 90 cm fine sandy loam to loam (a further subdivision was not possible during the reconnaissance survey) predominantly overlying a caliche horizon, only locally overlying rock. In the surroundings of oolitic sand deposits the top soil may be covered in many spots with a thin layer of oolitic sand. In the subsoil here and there a horizon of clay loam can be observed.

Potentiality for agriculture

Depending on the depth at which the caliche horizon starts, these soils are suitable for shallow rooted crops or also for moderately deep rooted crops. Most of the soils are, however, moderately deep and therfore suitable for shallow and moderately deep rooted crops.

B4 Limited and moderately deep loamy sand to slightly loamy sand over caliche or rock: locally rock in the surface: sloping and gullied

Only some areas of this mapping unit are distinguished. They are found at the northern slope of rocky dune ridges (unit Rd) north west of El Dabaa and between Sidi Abd el Rahman and Hammam.

The soils are probably composed of a mixture of colluvial material (washed down from the slopes of the rocks) and weathered oolitic sand. The areas are sloping and, because no erosion control measures have been taken, many erosion gullies continue to form and widen. Especially on the southern side of this mapping unit outcrops of rock are found.

Potentiality for agriculture

Depending on the depth at which the caliche or the rock starts, these soils are suitable for shallow rooted crops and moderately deep rooted crops. In case of intensified cultivation, erosion control measures are necessary, i.e. contour ploughing and terracing.

B4d Like B4, but deep and locally with loam subsoil

These soils are found in three elongated areas north of Burg-el-Arab - Hammam, on the slopes of two rocky dune ridges (mapping unit Rd). The profiles look very much like those of mapping unit B4, but the caliche or the rock starts in general at more than 90 cm depth. Besides, 20 to 30 or even 40 cm loam can be found between the topsoil and the caliche or the rock subsoil.

Potentiality for agriculture

Suitable for all crops but only after erosion control measures have been taken, i.e. terracing.

Bp Poorly drained and very saline soils: variable in texture

Along the whole Mediterranean coast, in many places just south of the coastal dunes, elongated salt marches are found. These poorly drained and very saline soils are mostly covered with a salt tolerant vegetation. Only the parts that are covered with water in winter carry no vegetation. The topsoil of these lowest areas often have a thin whitish salt crust. In the somewhat higher areas a 20 to 25 cm thick, very saline fluffy topsoil is present. The 0.5 to 3 mm big loam or clay loam particles of this fluffy topsoil can be blown away by wind and often accumulate behind or around vegetation. In this way hummocks are formed on many, somewhat dryer parts of the poorly-drained beach plains.

The soils of the poorly drained beach plains are variable in texture; slightly loamy sand soils as well as clay loam soils may occur. They have in common that they are all very saline and often contain thick layers of coarse salt crystals, locally mixed with gypsum crystals. In general the soils are deep (more than 120 cm) and only locally limited deep or moderately deep profiles are present.

Potentiality for agriculture

Not suitable because of very high salinity.

4.3. Soils of the elongated depressions in the plateau

These soils are only distinguished in some rather small areas south east of Mersa Matruh. They are found in steep depression 5 - 15 m deep in Miocene rockland. The subdivision within this group of soils is based on differences in natural drainage and consequently on differences in salinity.

P_1 Deep loam to clay loam soils overlain by 20 to 60 cm sand

The three areas of this mapping unit have a level topography, are in winter mostly cultivated with barley and consist mainly of deep soils. In most places the top 20 to 60 cm is formed by sand to loamy sand, probably weathered oolitic sand. The subsoil consists of loam to clay loam.

Potentiality for agriculture

Suitable for the cultivation of all crops.

Pp Like P_1, but poorly drained and very saline

These soils look very much like those of mapping unit Bp. They are also poorly drained, contain often thick layers of coarse salt cystals and are in many places covered with hummocks.

Potentiality for agriculture

Not suitable because of very high salinity and high saline ground water table.

4.4. Soils of the alluvial fans and outwash plains

These soils are composed of alluvial material transported by runoff water from the neighbouring rocklands. They have in general a slightly sloping to nearly level topography and are, unlike the soils in the former beach plains, not found in depressions. Very locally (i.e. on the Miocene plateau south of Negeila and south east of Sidi Barrani) these units are found in a very shallow depressional situation.

During rain periods the surface runoff passes over these soils and therefore in many places gullies and even shallow wadis can be observed.

A subdivision is made according to differences in depth of the profiles and differences in texture.

F_1 Limited deep sandy loam to loam soils over caliche or rock

The soils of this mapping occur in vast areas on the Miocene plateau between Sidi Barrani and Baqqush. They are found in places where accumulation of erosion material was possible i.e. where drainage gradient decreases and in very shallow depressions. The soils have a nearly level to slightly sloping topography and are in many places bordered by somewhat higher, rocky and very shallow soils.

The profiles consist in general of 30 to 60 cm medium fine sandy loam to loam over an indurated caliche horizon, locally directly over rock. Mostly the soils do not contain many gravels, but where they are deposited in front of a wadi gravels may occur on the surface or throughout the profile.

Almost all soils of this mapping unit are in winter cultivated with barley.

Description of a representative profile south east of Sidi Barrani (see Table 18, No. 19)

0 - 30 cm	Sandy loam, friable, many small pores, many small and some big roots, some crotovina, some snail remnants.
30 - 55 cm	Loam, rather compact, compactness increases with depth, many small pores, decreasing with depth, some hard lime concretions.
55 cm -	Indurated caliche.

Potentiality for agriculture

Suitable for the cultivation of shallow rooted crops only

F_{1e} Like F_1, but shallow; eroded phase

The soils of this mapping unit are only found south and south west of Mersa Matruh in slightly sloping areas. They were probably formed by erosion of limited deep soils. The topsoil was completely or partly washed away and now the indurated caliche horizon is on the surface or only covered with some 5 to 20 cm sandy loam to loam.

These areas are another example of the drastic consequences of erosion.

Potentiality for agriculture

Not suitable.

F2 Moderately deep sandy loam to loam, locally clay loam soils over caliche or rock

These soils are only distinguished in some scattered areas south east of Mersa Matruh. Mostly they are slightly sloping to the north but east of Garawla the outwash material is accumulated in depressions behind rocky dunes (mapping unit Rd).

The soils consist of 60 to 90 cm medium fine sandy loam to loam. However, in the areas between Mersa Matruh and Garawla, also layers of clay loam can be found, especially in the subsoil.

Potentiality for agriculture

Suitable for vegetables, field crops and moderately deep rooted crops only.

F3 Deep sandy loam to loam or clay loam soils

Scattered in the area between Fuka and El Mathaney, close to the coast as well as further inland, the soils of this mapping unit are present. Especially near Sunniyat, El Qasr and Baqqush, they cover promising areas. The topography is uniform with a slight upward slope to the north. In many places shallow gullies and small wadis are eroded in the soils (except in El Qasr plain).

The profiles are deep and consist in general of more than 90 cm sandy loam to loam. Locally, however, also layers of clay loam or even whole profiles of clay loam are found. In the deep subsoil a predominantly soft caliche horizon is formed.

Areas with a whitish, crusty topsoil and with a scarce vegetation are probably all saline in the top 20 to 40 cm.

Though now almost exclusively used for the cultivation of barley, these soils belong, together with those of mapping unit B1, to the most promising of the whole region. However, detailed investigations on salinity are required before further agricultural development plans are made.

Description of a representative profile near Baqqush (Table 18, No.21)

0 - 15 cm	Fine sandy loam with a whitish, crusty surface, friable, few small roots, many small pores.
15 - 30 cm	Fine sandy loam, friable, some small roots, many small pores, some grits many soft $CaCO_3$ concretions.
30 - 100 cm	Loam, rather compact, compactness increases with depth, many hard and some soft $CaCO_3$ concretions.
100 - 130 cm	Silty loam, compact, many soft $CaCO_3$ concretions.

Potentiality for agriculture

Suitable for the cultivation of all crops.

F4 Limited deep and moderately deep sandy loam to loam soils over caliche or rock

These soils are found at the foot of the Miocene Plateau in the Mersa Matruh plain, in the surroundings of Baqqush and west of Fuka. The areas have a slightly sloping topography. Close to the plateau, where the slope is greater, many shallow gullies are found.

In general the shallow soils are situated close to the plateau. Here they overlie a predominantly indurated caliche horizon and often contain some gravels. More to the north the profiles are deeper and gravels are absent.

Most of the soils of this mapping unit have a saline to moderately saline topsoil.

Potentiality for agriculture

If not saline the soils are suitable for shallow rooted crops when the caliche horizon starts between 30 to 60 cm depth and suitable for moderately deep rooted crops when the impermeable subsoil starts between 60 and 90 cm. Most soils are however saline.

4.5. Soils of the wadis

These soils are only found in the Mersa Matruh plain, near Baqqush and west of Fuka. They occur in the places where the greater part of the runoff water is transported. Therefore the soils are not heavy textured and in most places are laminated with sand and gravel layers. Two mapping units are distinguished:

Wb Wadi bottom soils; deep sandy loam to loam soils with sand and gravel layers

The soils of this mapping unit are distinguished in the Mersa Matruh plain and in the surroundings of Baqqush. They have a slightly sloping topography and are mostly dissected by one om two steeply incised erosion gullies, the major drainage ways. Most of the runoff water is transported over these soils and therefore they are mostly not saline.

Potentiality for agriculture

Suitable for the cultivation of all crops. It should however not be forgotten that during the wet season much rainwater runs over these soils, which can cause damage to cultivated crops.

Ww <u>Wadi wash soils; deep sandy loam to loam soils; locally with sand layers</u>

This mapping unit is only found in the area west of Fuka. The soils occur at the mouth of many wadis coming from the Miocene plateau. The areas look therefore much like those of the fans and outwash plains (the topography is also nearly level to slightly sloping) but the soils are more coarse textured and contain even locally layers of coarse sand.

<u>Potentiality for agriculture</u>

Suitable for all crops.

4.6. <u>Miscellaneous land types</u>

The miscellaneous land types distinguished on the reconnaissance soil maps include only rockland. The profiles consist of less than 30 cm soil over rock and are therefore not suitable for the cultivation of agricultural crops, but they do have value as range land.

Based on differences in morphologic features the following subdivision was introduced:—

Rp <u>Plateau land</u>

The greater part of the areas surveyed during the reconnaissance consists of this mapping unit. The land is mainly Upper Miocene and Middle Miocene rockland and has a rather level topography with a very gentle slope to the north. Only locally some narrow strips with a steeper gradient occur, i.e. south of Dabaa and south of Sidi Barrani.

Rh <u>Like Rp, but with sink holes</u>

This mapping unit is found south of the areas indicated with Rp. The areas are also predominantly level but many scattered, small, shallow and more or less round depressions can be observed. These are mostly filled up with more than 50, often with more than 100,cm fine sandy loam to silty loam. Because of the depressional situation rain water accumulates and consequently the depressions carry a much more dense vegetation than the surrounding rocklands.

Rr <u>Denuded rockland; smoothed relief</u>

These areas are situated north of the plateau land (unit Rp) and consist predominantly of Middle Miocene rock. They are slightly sloping to gently sloping to the north and in many places wadis occur, but they are not steeply incised.

Rs <u>Dissected rockland with more or less parallel ridges.</u>

South of Fuka and south-east of Mersa Matruh severely eroded rockland occurs in which more or less parallel ridges are most striking. At first sight they resemble former shore lines but probably they are folded and partly eroded Miocene deposits.

Rg <u>Severely dissected rockland</u>

This mapping unit is distinguished south and south-east Mersa Matruh. Here severely eroded and dissected rockland with many steeply incised wadis occurs. The areas have a very rough topography and consist mainly of rock. Only at the bottom of the wadis some coarse sandy to very gravely soils can be found.

Rf Foot slopes; gullied and sloping

North of the Miocene plateau land, at the foot of the escarpment between Fuka and El Methaney, sloping areas are found that consist mainly of very shallow soils over rock. In many places the surface is covered with gravels and often not very deep gullies occur.

Rd Former coastal dunes and dune ridges

This type of rockland includes the former oolitic dunes and dune ridges that by certain processes were gradually transformed into rock. They are of Pleistocene to Pliocene age and are partly developed as beach ridges (Burg el Arab, Hammam and Fuka), partly as dunes with the typical haphazard form (El Dabaa, El Galal and Sidi Barrani). The youngest, found close to the coast, consist of rather soft limestone rock, the older ones are situated more inland and are harder.

In many places the boundary between this mapping unit and the bordering rockland of unit Rr and Rp is rather arbitrary, because in the transitions thin layers of Rd are deposited on the Miocene rock.

Rdg Like Rd, but sloping and dissected

This mapping unit is distinguished in only two areas. One is found near Ras el Hekma, the other south of Burg el Arab. The first area has a rather rough topography is incised with many steep erosion gullies, and slopes up to the north. On the slopes the rocky dunes are eroded in many places and there the Miocene rock is found on the surface.

In the second area the topography is less rough, the erosion gullies are not so steeply incised and the slope to the north is less steep.

Rde Like Rd, but locally with less than 50 cm loamy sand to sandy loam

On top of the former coastal dunes and dune ridges between El Alamein and El Dabaa locally some soil is deposited. In gneral this cover is not thicker than 50 cm and consists of loamy medium fine sand, sometimes of medium fine sandy loam. Moreover the areas with soils are very scattered, always elevated and mostly saline to moderately saline.

Rt Terrace remnants

South west of Fuka some rocky areas with a remarkable level surface are found. Originally they formed a single area but because of erosion they were cut into several separate ones. Probably they are all remnants of a former terrace.

4.7. Complex areas

Under this head the areas with a complicated soil pattern are grouped. It was not possible to indicate the differences separately on a map scale 1:100 000, but on maps with a larger scale (1:10 000 or 1:25 000) this can probably be done.

C_1 Complex of rock and shallow to moderately deep sandy loam to loam soils over caliche or rock

This mapping unit is found in many areas, predominantly close to the coast. The rockland may consist of Miocene rock as well as of former coastal dunes. In general the sandy loam to loam soils are found at a somewhat lower level than the rockland. They have a slightly sloping to gently sloping topography and are locally incised with gullies and shallow wadis.

C2 Complex of rock and deep sandy loam to loam soils in depressions

The areas of this mapping unit are found south of Burg el Arab, near Ras el Hekma and south east of Mersa Matruh. They consist mainly of rockland. The areas with soils are rather small and always located in depressions.

C3 Complex of rock and deep loamy oolitic sand soils

Only one area is distinguished. It is found west of Mersa Matruh near Abu Laho. Here deep weathered oolitic sand soils consisting of loamy medium fine sand occur between slightly elevated rocks.

C4 Complex of cemented oolitic sand dunes and poorly drained, very saline beach plain soils

Three areas with this mapping unit are found between El Alamein and El Dabaa. They consist of poorly drained, very saline soils and slightly elevated areas of cemented oolitic sand. The last areas can easily be recognized in the field because of their white colour.

4.8. Additions

Additions are soil characteristics that occur in many mapping units. They are grouped under the head "Addition" in order to reduce the number of mapping units, not because these characteristics are less important.

Hummocky dunes

Scattered over the entire region, along the Mediterranean Sea as well as far inland, big areas are covered with hummocky dunes. These 20 to 60 cm high hummocks have formed in places where windblown material could accumulate behind the natural obstacles, such as vegetation, etc. In fact, two kinds of hummocks can be distinguished, one composed of loam or clay loam and one composed of predominantly sand. The first kind is always found in the surrounding salt marshes (poorly drained beach plain soils) and is formed of the windblown particles of fluffy topsoil that occurs in the salt marshes. The second kind consists of sand and is always found further inland.

Locally thin sheets of sand

Where there is transition from areas with windblown deposits to neighbouring rockland or areas of different soils, thin sheets of sand occur. In general these thin sheets are only locally deposited and not more than 10 to 20 cm thick. In the surroundings of the oolitic sand deposits they consist mainly of oolitic sand, in the other areas predominantly of quartz sand.

4.9. Topographic features

Most of the topographic features indicated on the maps do not need any explanation. They are distinguished to make orientation in the field possible. Special attention should be paid, however, to the karms and the ancient settlement fields. Thousands of these ancient agricultural fields are spread all over the region. They are proof that the area was rather densely populated in the past and that the farmers practised agriculture by using special methods. If it could be discovered what these methods were and why they were used, possibly they could be adopted again, and agriculture in the region be improved at low costs.

Karms are ancient agricultured fields, found predominantly in areas where deep and moderately deep soils are present. They also occur locally on the plateau land.

The karms are surrounded by 1 to 5 m high "dykes" of predominantly very saline soils (see Table 18, No.26). The soils within the "dykes" are always clean, i.e. they do not contain gravels, grits, etc. Many theories about the meaning of the karms fields and karmwalls exist. According to some the dykes were built to create a micro climate, according to others, to collect rain water. Most probably however the karmwalls consist of topsoil material from the karm field that became too saline and therefore was removed and stored on the side of the field (see Fig. 13A).

Ancient agricultural fields are found mostly on the plateau, i.e. in places where there is not much soil. They consist of numerous, small parcels with a rather irregular form, and each of them were originally surrounded by a 1 to 1.5 m high wall of stones. The walls tumbled down and now only a straight line of rubble is found on the spot.

The fields themselves contain always more than 1 m soil. It is believed this soil was transferred to the agricultural fields from elsewhere by man. (see Fig. 13B).

5. Soil and Water Conservation

Soil erosion by wind and water is one of the most important phenomena in this region, calling for action at Government and farmers' level. Because of the undulating topography, the lack of soil structure, the rather light soil texture, the sparsity of vegetative covering, the torrential character of rains and strong winds, erosion is very quick. As a result, the region is now in an advanced stage of erosion. For instance, the Libyan plateau to the south is for the most part entirely eroded, with very shallow soils and rock outcrops, and the escarpment also is severely eroded in the upper two-thirds, with rocks exposed at the surface.

The soil brought by runoff and wind is partly transported and deposited downstream of the wadis, forming a narrow strip of alluvial soil. The rest is transported further and is lost in the sea. On the other hand, the shifting sand from the northern side of the maritime sand dunes tends to cover this narrow strip of good alluvial soils.

Erosion even disintegrates the rocks, and their products, such as sand and pebbles, are transported by runoff and gradually cover the good alluvial soil downstream. Thus uncontrolled erosion could steadily transform the entire region into unproductive land.

Although no special quantitative measurements for soil erosion were made, it was seen that, after a rainfall of more than 7 to 10 mm, a large amount of soil had been carried from the slopes and deposited on depressions, flat lands and even on the roads.

The main soil conservation measures should be established in the beds of wadis, the lower slope of the escarpment (downstream) and on the coastal plains. In order to avoid obstructing the passage of water needed for irrigation, erosion control works should be closely connected with water conservation works and consist of dykes, terraces, canals, a special contour ploughing system, the establishment of windbreaks, shelterbelts and special crop protection.

For sand dune fixation the measures consist of the mechanical device of hedges of reeds or other materials and afforestation.

Soil conservation measures having no direct connection with the various production schemes recommended under the project should be decided upon at national level and within the national development policy. The overall problem of soil conservation can only be solved completely through a long term integrated approach aiming at the preservation of the production potential of the region. In this respect it must be emphasized that soil erosion is an irreversible process. The soil, as a production factor, cannot be replaced once it is lost.

Table 15

SUMMARY OF MAIN CHARACTERISTICS OF DISTINGUISHED MAPPING UNITS OF THE RECONNAISSANCE SURVEY.

Mapping Unit	Depth of soil in cm	Main texture	Permeability	Topography	Potentiality for Agriculture	Remarks
Do1	-	Oolitic sand	Moderately rapid to rapid	Irregular	Locally suitable for figs only	Shifting dunes
Do2	-	Cemented oolitic sand	Slow	Irregular	Not suitable	Cemented dunes
Do3	<50	In depressions slightly loamy sand	Slow	Irregular	Not suitable	Cemented dunes with shallow depressions
Do4	>50	ls to l in depressions	Moderate in the soils	Irregular	Not suitable and moderately suitable	Cemented dunes with depressions
Ds1	—	s to ls	Moderate rapid to moderate	Irregular	Not suitable	Low dunes
Ds2		s to sl	Moderate rapid to moderately slow	Irregular	Not suitable	Moderately high and low dunes
Ds3	—	s to sl	Moderately rapid to moderately slow	Rather level	Not suitable	Some low rock out crops
Ds4		s to sl	Moderately rapid to moderately slow	Rather level	Not suitable	Shallow over rock
Ds5	ca 60	ls to sl	Moderate to moderately slow	Level	Suitable for vegetables, field crops and moderately deep rooted crops	
Ds6	—	s	Rapid to moderately rapid	Rather level	Not suitable	Shallow over rock

Table 15 (cont.)

Mapping Unit	Depth of soil in cm	Main texture	Permeability	Topography	Potentiality for Agriculture	Remarks
Ds7	—	s	Rapid to moderately rapid	Rather level	Not suitable	Some rock outcrops
Ds8	—	s	Rapid to moderately rapid	Irregular	Not suitable	Dunes
B_1	>90	sl to l or cl	Moderate to moderately slow	Level	Suitable for all crops	Locally in depressions surrounded by rockland
B2	>90	ls to slightly ls	Moderate to moderately rapid	Level to nearly level	Suitable for all crops	
B3	30–90	sl to l or cl	Moderate to moderately slow	Level to nearly level	Suitable for moderately deep rooted crops, locally for shallow rooted crops only	
B4	30–90	ls to slightly ls	Moderate to moderately rapid	Sloping and gullied	Suitable for moderately deep rooted crops; locally of shallow rooted crops only	
B4d	>90	ls to slightly ls	Moderate to moderately rapid	Sloping and gullied	Suitable for all crops	Terracing and erosion control is needed
Bp	mostly >90	s to cl		Level	Not suitable	Very saline
P_1	>90	l to cl	Moderately slow	Level	Suitable for all crops	Surrounded bv rockland

Table 15 (cont.)

Mapping Unit	Depth of soil in cm	Main texture	Permeability	Topography	Potentiality for Agriculture	Remarks
Pp	mostly >90	s to cl		Level	Not suitable	Very saline; surrounded by rockland
F_1	30-60	sl to l	Moderate	Nearly level to slightly sloping	Suitable for vegetables, field crops and other shallow rooted crops	Locally with gravels
F_{1e}	<30	sl to l	Moderate	Nearly level to slightly sloping	Only locally suitable for shallow rooted crops	Many areas not suitable
F2	60-90	sl - l	Moderate	Nearly level to slightly sloping	Suitable for vegetables, field crops and moderately deep rooted crops	Locally in depressions.
F4	30-90	sl to l	Moderate	Slightly sloping to gently sloping	Predominantly not suitable	Most soils are saline; locally gravels
Wb	>90	sl to l	Moderate	Slightly sloping	Suitable for all crops	Terracing is needed; risk of damage by runoff water
Wp	>90	sl to l	Moderate	Nearly level to slightly sloping	Suitable for all crops	

N.B. All mapping units of the miscellaneous landtypes consist of rockland with less than 30 cm soil. They are not suitable for agriculture but have value as range land.

Table 16

SUMMARY OF THE POTENTIALITY CLASSES OF THE RECONNAISSANCE MAPS, THEIR AREAS AND A ROUGH ESTIMATION OF THE SALINE SOILS IN EACH CLASS

Potentiality class		Sheet I		Sheet II		Sheet III		Sheet IV		Sheet V		Total		Rough estimation of saline soils percent
Code	Short Description	Feddan	percent	Feddan	percent	Feddan	percent	Feddan	percent	Feddan	percent	Feddan	percent	
I	Suitable for all crops	94.725	23.14	24.525	6.27	67.600	13.07	11.675	1.82	5.350	1.42	204.875	8.78	5
IIa	Suitable for moderately deep rooted crops							2.200	0.34			2.200	0.09	10
IIb	Like IIa, but locally only suitable for shallow rooted crops	600	0.15	11.075	2.72	6.425	1.24			16.550	4.38	34.650	1.47	10
III	Suitable for shallow rooted crops only			6.450	1.71	15.350	2.97	67.125	10.45	50.450	13.36	139.375	5.92	On plateau 10 : North of plateau 60
IVa	Locally suitable for figs only			300	0.07	1.425	0.28	2.850	0.44			4.575	0.20	5
IVb	Locally suitable for shallow rooted crops only							6.025	0.94			6.025	0.26	50
Va	Not suitable: rocky	130.525	31.88	240.975	59.18	400.675	77.47	529.850	82.47	236.225	62.57	1 538.260	65.35	-
Vb	Not suitable: very saline	32.725	7.99	7.025	1.73	1.200	0.23	6.475	1.01	125	0.03	47.550	2.02	100

Table 16 (cont.)

Potentiality class		Sheet I		Sheet II		Sheet III		Sheet IV		Sheet V		Total		Rough estimation of saline soils percent
Code	Short Description	Feddan	percent	Feddan	percent	Feddan	percent	Feddan	percent	Feddan	percent	Feddan	percent	
Vc	Not suitable: inland dunes	95.075	23.22	109.250	26.83	2.975	0.58	600	0.09	54.150	14.34	262.050	11.13	
Va/I	Complex of class Va and class I	52.00	12.72			11.775	2.28	5.450	0.93			69.225	2.94	5 of class I
Va/IIb	Complex of class Va and class IIb			600	0.15	9.750	1.89			14.750	3.9	25.100	1.07	20 of class IIb
Va/III IIa	Complex of class Va, class III and class IIa							9.225	1.44			9.225	0.38	15 of class III and IIa
Va/Vb	Complex of class Va and class Vb			5.475	0.35							5.475	0.23	
Va/Vc	Complex of class Va and Vc	3.750	0.91					475	0.07			4.225	0.18	
	T O T A L +)	409.400	100.01	406.675	100.01	517.175	100.01	641.950	100.00	377.600	100.00	2 352.800	100.02	

+) water excluded

Table 17

SUMMARY OF THE POTENTIALITY CLASSES OF THE RECONNAISSANCE MAPS AND THE MAPPING UNITS OCCURRING IN EACH CLASS

Potentiality class		Mapping Units				
Code	Short description	Sheet I	Sheet II	Sheet III	Sheet IV	Sheet V
I	Suitable for all crops	B_1, B_4d	B_1	B_1, F_3, Wb, Ww	B_1, B_2, P_1, F_3, Wb	B_1, B_2
IIa	Suitable for moderately deep rooted crops				F_2	
IIb	Like IIa, but locally only suitable for shallow rooted crops	B_4	B_3, B_4	B_3, F_4		B_3
III	Suitable for shallow rooted crops only		Ds5	Ds5, F_1	F_1, F_4	F_1
IVa	Locally suitable for figs only		Do_1	Do_1	Do_1	
IVb	Locally suitable for shallow rooted crops only				Fie	
Va	Not suitable - rocky	Do2, Ds4, Ds6 Rp, Rd, Rde, Rdg	Do_2, Rp, Rr, Rd, Rde, Ds_4, Ds_6	Do_2, Ds_4, Rp, Rh, Rr, Rs, Rf, Rd, Rdg Rde, Rt	Do_2, Do_3, Rp, Rh, Rr, Rs, Rg, Rf, Rd.	Do_2, Ds_6 Rp, Rd, Rr, Rh
Vb	Not suitable - very saline	Bp	Bp	Bp	Bp, Pp	Bp

Table 17 (cont.)

Potentiality class		Mapping Units				
Code	Short description	Sheet I	Sheet II	Sheet III	Sheet IV	Sheet V
Vc	Not suitable - inland dunes	Ds_1, Ds_7	Ds_1, Ds_2, Ds_3	Ds_1	Ds_1	Ds_7, Ds_8
Va/I	Complex of class Va and class 1	C_2		C_2	C_2	
Va/IIa	Complex of Va/IIa				Do_4	
Va/IIb	Complex of class Va and class IIb		C_1	C_1		C_1
Va/Vb	Complex of class Va and class Vb		C_4			
Va/Vc	Complex of class Va and class Vc	C_3			C_3	
Va/III/IIa	Complex of class Va, class III and class IIa				C_1	

Table 18

PHYSICAL AND CHEMICAL PROPERTIES OF SOILS DISTINGUISHED ON THE RECONNAISSANCE SOIL MAP

No.	Area	Mapping Unit	Depth cm	Physical Properties		Mechanical Composition			Texture	EC mm Hos/cm	$CaCO_3$	pH	Chemical Analysis						
													Cations				Anions		
				Permeability cm/hour	Field capacity	Clay	silt	sand			percent		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Cl'	HCO'_3	SO4'
1	Mersa-Matruh	Do_1	0-30 30-60 60-120							1.0 1.7 1.9	86.9 98.8 97.9								
2	Mersa-Matruh	Do_2	surface	5.7	19.5	0.5	0.5	99.0	s.	2.7	80.4		4.8	5.7	15.0	0.7	12.6	0.3	5.6
3	Dabaa	Ds_2	0-25 25-75 75-120	2.1 0.3 0.4	12 16 16.5	4.5 14.5 12.5	13 22 16	82.5 63.5 71.5	l.s s.l s.l	1.9 1.6 2.8	60.8 47.1 52.3		4.0 3.7 3.9	3.9 1.4 1.2	14.0 6.5 9.5	0.8 0.9 0.4	14.3 9.8 20.5	0.4 0.5 0.6	3.6 4.6 4.3
4	Dabaa	Ds_2	surface	18.8	12.5	0.5	1.0	98.5	s.	3.3	66.0		7.8	5.1	17	1.0	24.1	0.3	6.5
5	Alamein	Ds_3	0-30 30-60	2.4 1.0	13.0 16.5	1.5 13.5	19.0 23.0	79.5 63.5	l.s s.l	4.6 5.0	52.9 40.3		8.2 12.8	5.7 5.4	35.0 36	0.9 1.2	18.8 35.7	0.3 0.2	30.6 19.4
6	Dabaa	Ds_3	0-30 30-60	4.3 2.2	13.5 12.0	7.5 3.5	23.0 31.0	62.5 65.5	l.s s.l	6 38	58.9 42.0		5.8 6.8	4.5 61.0	18.1 75.0	1.3 2.3	20.5 120.5	0.3 0.3	8.7 24.5
7	Dabaa	Ds_4	0-30	3.2	14.5	7.5	21.0	71.5	l.s	29	40.7		51.8	56.2	25.5	3.7	360.0	0.31	5.6
8	Dabaa	Ds_5	0-30 30-60 60-90 90-120	2.8 2.9 3.7 5.4	13.5 14 12 18	5 5 8 17	23 22 24 22	72 73 78 61	s.l s.l s.l s.l	1.5 2.4 2.6 4.5	57.8 56.5 84.4 63.3		6.4 6.4 5.4 11.9	3.1 2.7 4.4 7.6	6 11 17 55	0.7 0.8 0.7 1.3	10.7 12.5 14.3 54.5	0.3 0.4 0.5 0.3	5.2 8.0 12.8 18.9

Table 18 (cont.)

No.	Area	Mapping Unit	Depth cm	Physical Properties: Permeability cm/hour	Physical Properties: Field capacity	Mechanical Composition: Clay	Mechanical Composition: silt	Mechanical Composition: sand	Texture	EC mm Hos/cm	$CaCO_3$ percent	pH	Chemical Analysis, Cations: Ca^{++}	Cations: Mg^{++}	Cations: Na^{+}	Cations: K^{+}	Anions: Cl'	Anions: HCO'_3	Anions: SO4'
9	Barrani	Ds_6	0-30	6.4	12.0	2	3	95	s.	0.8	7.5		5.5	1	3.7	0.3	6.1	0.2	4.2
10	Barrani	Ds_7	0-60	7.6	10	-	8	92	s.	1.2	12.5		3.4	4.7	4.6	0.3	4.0	0.2	7.3
11	Barrani	Ds_8	0-60 60-120	9.1 5.9	11 12.5	- 3	12 11	88 86	s. s.	1.3 0.8	13.0 20		5.9 3.6	2.2 0.9	6.3 4.7	0.5 0.3	8.5 6.5	0.2 0.3	6.2 2.7
12	Barrani	B_1	0-30 30-60 60-120	1.2 1.1 0.8	15.5 17.0 16.5	9 14 16	37 42 34	55 44 50	s.1 1 1	1.1 0.9 0.8	12.8 12.0 31		5.6 4.8 3.9	2.3 1.5 2.8	5.9 4.8 4.5	0.5 0.4 0.3	8.1 6.5 6.1	0.2 0.2 0.2	6.1 4.9 4.2
13	Fuka	B_1	0-25 25-60 60-90 90-120	5.7 6.6 3.2 1.2	12 12.5 13.5 14	9 16 28 34	21 18 28 24	70 66 44 42	s.1 s.1 1 c.1	2.7 1.4 2.4 0.7	11.2 23.1 21 21.4		7.7 7.9 10.7 3.0	6.2 10.2 10.7 3.4	12 3 9 24	0.8 1.1 1.0 0.4	22 7.5 19 6	4.0 2.7 2.2 2.1	1.9 2.8 10.0 1.7
14	Qasr	B_2	0-40 40-80 80-100	7.1 1.6 7.1	14 15 13.5	2 4 10	20 22 12	78 64 78	l.s l.s l.s	1.8 1.5 1.7	29.6 51.8 59.4		8.7 8.4 3.1	5.1 1.5 0.9	4.6 50 6.1	2.1 1.3 0.2	13.9 7.5 4.7	0.8 0.7 0.5	0.8 7.9 5.1
15	Barrani	B_2	0-30 30-60 60-90	3.5 4.2 3.4	12 13.5 14	0 3 4	14 15 14	86 82 82	l.s l.s l.s	1.0 1.1 1.1	20 16.4 18.4		5.6 9.3 5.4	2.5 1.6 5.6	5.4 5.5 4.5	0.3 0.3 0.3	6.7 8.1 8.4	0.3 0.2 0.1	6.8 8.4 7.2
16	Barrani	B_3	0-30	1.3	15.5	14	32	54	s.1	1.3	14.4		6	1.5	8	0.6	6.1	0.3	9.8
17	Dabaa	B_4	0-30 30-60	2.4 1.3	13.5 14	2 3	18 22	80 75	l.s l.s	1.0 0.8	8.0 15.0		3.9 4.5	1.1 1.5	3.3 4	0.2 0.3	5.7 5.7	0.3 0.3	2.5 4.4

Table 18 (cont.)

No.	Area	Mapping Unit	Depth cm	Physical Properties: Permeability cm/hour	Physical Properties: Field capacity	Mechanical Composition: Clay	Mechanical Composition: silt	Mechanical Composition: sand	Texture	EC mm Hos/cm	$CaCO_3$ percent	pH	Chemical Analysis – Cations: Ca^{++}	Cations: Mg^{++}	Cations: Na^{+}	Cations: K^{+}	Anions: Cl'	Anions: HCO'_3	Anions: SO4''
18	Fuka	B_p	0-40 40-80 80-120	 - -	17.0 19.5 19.5	21 29 32	30 36 34	49 35 34	l. cl.l cl.l	60 64 69	32.3 27.9 20.2		215.0 198.3 202.0	244 293.3 198.9	492 360 440	1.5 1.2 1.2	948.2 1031.0 1075.8	3.5 2.7 2.7	1.2 - -
19	Barrani	F_1	0-30 30-55	1.4 0.9	13.5 18	10 16	32 34	58 50	s.l. l.	0.8 1.1	12.0 17.0		4.2 7.1	2.6 0.5	3.5 8.7	0.3 0.4	6.1 7.2	0.2 0.3	4.3 6.5
20	Garawla	F_2	0-20 20-60 60-85	1.6 2.9 0.9	13.5 14.5 18.0	11 14 24	24 33 45	65 63 31	s.l. s.l. l	0.8 1.0 21	16 24 26		4.2 3.5 5.0	2.6 1.5 4.4	3.5 6.5 12.1	0.3 0.3 0.7	6.1 8.1 18.2	0.2 0.2 0.2	4.3 3.5 3.8
21	Baqqush	F_3	0-15 15-30 30-100 100-130	2.9 4.8 1.1 2.0	16 15.5 16 17.5	11 9 10 9	26 37 41 53	62 54 49 38	s.l. s.l. l. sil	11.25 21.5 0.9 11.0	24.9 26.2 42.2 40.1		9.8 14.9 3.8 25.8	11.8 10.5 0.3 16.9	129.7 172.5 4.4 57.5	4.5 6.5 0.5 1.1	140.7 179.7 6.7 86.6	0.3 0.3 0.3 0.2	13.1 24.3 1.9 14.5
22	Baqqush	Wb	0-20 20-60 60-120	7.4 3.4 2.8	13.2 12.5 13.5	6 8 23	15 13 26	79 79 51	l.s. l.s. s.cl.	0.6 0.8 0.7	34 28 18		5.5 4.3 3.2	1.3 4.7 3.5	2.3 3.4 3.4	0.8 5.1 6.7	2.0 4.9 3.1	4.3 4.1 3.7	3.5 5.1 4.1
23	Fuka	Ww	0-30 30-60		13.5 17.5	20 21	41 43	39 36	l. s.l.	1.4 1.6	26.8 36.8		6.9 7.1	4.6 3.9	4.9 5.7	1.2 0.9	13.5 10.6	0.3 0.3	2.3 6.5
24	Negeila	Settlement field	0-30 30-60 60-90	2.8 2.7 0.2	15.5 15.5 16	14 11 17	48 47 45	38 42 38	l. l. l.	1.4 20.4 29.0	37.8 10.3 12.0		5.3 32.3 51.5	1.8 33.1 61.1	12.8 131.3 188.8	0.7 0.7 1.7	12.9 169 259	3.0 1.7 2.3	4.5 26.3 42.7

<u>Table 18 (cont.)</u>

No.	Area	Mapping Unit	Depth cm	Physical Properties		Mechanical Composition			Texture	EC mm Hos/cm	$CaCO_3$	pH	Chemical Analysis						
													Cations				Anions		
				Permeability cm/hour	Field capacity	Clay	silt	sand			percent		Ca^{++}	Mg^{++}	Na^+	K^+	Cl'	HCO'_3	SO4'
25	Dabaa	Karm	0-20	0.3	19	28.5	34.0	37.5	cl.l.	4.6	24.5		13.9	8.0	22	1.4	35.7	0.4	9.2
			20-60	0.6	21.5	26.5	32.0	41.5	l.	4.2	23.4		11.5	8.5	36	1.2	33.0	0.3	23.8
			60-100	1.5	21.0	32.5	30.0	37.5	cl.l.	3.8	29.5		10.1	7.5	15	1.0	30.4	0.3	2.9
26	Dabaa	Karm wall	0-40	3.5	16.5	14.5	36	49.5	l.	45	20.9		96.1	146.1	350	0.3	452.8	0.4	139.4
			40-80	1.9	16.5	8.5	30	61.5	l.s	59	26.6		112.8	225.8	500	5.7	637.6	0.4	206.5
			80-100		18.0	8.5	30	61.5	l.s	64	28.7		116.5	225.2	450	6.0	718.9	0.4	78.5

Chapter 4

WATER RESOURCES

1. Introduction

1.1. Previous investigations

Previous surface-water investigations in the region are limited. The following summarize the available data :

- Survey of Wadi Kharruba by John Ball (1937) published under the title "The Water Supply of Mersa Matruh". Based on observations of runoff in Wadi Kharruba, the author assumed that the runoff, when daily rainfall equalled or exceeded 10 mm, could be derived by the formula :

  $$r = 0.75\ (R - 8)$$

  where r = amount of runoff in mm
  R = amount of runoff in mm

- Measurements of rainfall and runoff in Wadi Kilo 9 near Ras el Hekma during January - February 1959, by Salah Shafei and Abdel Hamid el Tody. Their results confirmed the Ball formula.

- Measurements of rainfall and runoff in Wadi Kilo 9 during December 1959 - May 1960. The results, published by Sogreah (Reconnaissance Survey of the Western Desert Coastal Zone, "Appendix"), are different from those obtained during January - February 1959.

- Water supply survey of the Baqqush area by Salah Shafei.

These hydrological investigations are insufficient for estimating the frequency and quantity of runoff of the wadis because of the short duration of the measurements and the conflicting results.

The first recorded work related to ground water in the Coastal Zone was Dr. John Ball's paper, "The Qattara Depression of the Libyan Desert" (1933), which contained references to a series of boreholes between El Alamein and the Qattara Depression. During World War II, the northwestern Coastal Zone became important because of the demand for water to supply the Allied and Axis soldiers. From late 1940 until the summer of 1943, geological and geophysical investigations, test drilling, and gallery development were undertaken by the British Commonwealth Army. Accounts of these investigations and developments were published by Shotton (1944 and 1946) and by Addison and Shotton (1946). The Italian and German Armies also constructed collecting galleries and drilled boreholes, but accounts of their work are not published.

A study by Paver and Pretories (1954) summed up ground water data available from previous investigations and made electrical resistivity investigations of some areas of the region. From 1954 to 1961, several investigators reported on general geology and groundwater conditions : Attia (1954) published a report entitled "Ground Water in Egypt" in which he included a general discussion of the region's hydrology; Kaddah (1954) described ground-water conditions in the vicinity of the Burg el Arab experimental farm; Shata (1955) reported on the northern portion of the Western Desert including a discussion of regional geologic features affecting the region; Shata (1957) reported on the soil and water supplies of the Ras el Hekma area; and Sogreah (Société Grenobloise d'Etudes et d'Applications Hydrauliques) published a report in 1961 concerning the land development of the region which included a discussion of the water supplies.

More recent reports concerning the hydrogeology of the region include a portion of a doctoral dissertation by Saad (1964) evaluating the ground water reservoir at Fuka, and a doctoral dissertation by Shazly (1964) describing the geology and hydrology in the Mersa Matruh area. Several recent investigators have dealt with the water supply problems and potential in the Burg el Arab area. These include Saad and El Ramly (1964), El Ramly (1965), and Hassan and Meghath (1965). Sharkawi (1964) reported on the ground water in the region and (1965) recommended areas for agricultural expansion along the northwestern coast by using groundwater. The Baqqush area was described in reports by Bowser (1959) and El Shafei (undated), the Magid Valley area near Mersa Matruh was described by Harhash (undated) and the groundwater conditions at Ras el Hekma were described by Hassan and El Ramly (1966). In 1965-66, the REGWA Company prepared geologic and soil maps of the northwestern Coastal Zone.

The above summary constitutes the major works dealing with the hydrogeology and hydrology of the northwestern Coastal Zone. Other corollary studies and reports in the field of agricultural development are included in the "List of References".

1.2. Work done under the project

The surface water investigations included a hydrographical survey, and a drainage map was prepared by EGDDO, at the request of the surface water conservation expert, to show the catchment area, length and average slope of the wadis. Six wadis were selected for runoff measurements, rain gauges were installed on them and weirs constructed and equipped with water-level recorders. A small basin in Fuka which drains into a cistern was selected for measurement of the runoff coefficient. Two special studies were made on the intensity and inland distribution of rainfall. Studies of the present use of water resources (runoff of wadis, cisterns, galleries and wells) dealt with the amount of water used for irrigation, the water distribution systems, and the means of lifting water.

Basic hydrologic data relating to the occurrence, availability and chemical quality of groundwater were collected, and an inventory made showing the location, depth to water, and mean sea level altitude of representative wells throughout the project area, and of all wells, collecting galleries and other watering points in the five pilot areas. Key wells were then selected for periodic and continuous water-level observations in the various hydrogeological environments in each of the five pilot areas. To provide a seasonal picture of the groundwater table and of the chemical quality of the groundwater in the areas, water-level measurements and chemical analyses were made in all wells in April and October. The hydraulic properties of representative wells in these hydrogeological environments were also determined and the data used to determine the hydrologic balance for the pilot areas. Outside the pilot areas, wells were selected to provide data for interpretation between them.

Water-level measurements were made once each month in 60 observation wells in all, and charts were changed periodically on 13 observation wells equipped with automatic water-level recorders. Water-use data were collected to relate water-table fluctuations to man made causes. All data were tabulated on standard forms and systematically plotted on maps and graphs.

Geophysical investigations, undertaken by the Geophysica Company of Zagreb, Yugoslavia, and completed in November 1968, are reported on more fully elsewhere. Briefly, they consisted of electrical resistivity surveys carried out in two areas, one of about 250 km^2 around Qataf-Gabal and another of about 30 km^2 around Fuka, to attempt to detect small subsurface geologic features which might be a source of fresh groundwater. Test holes will be drilled by the Government to check the accuracy of the geophysics. It is hoped that by proceeding in this manner it can be determined whether the electrical resistivity method is a reliable tool for prospecting for groundwater in the project area without an extensive supporting test drilling programme.

2. Hydrography

2.1. Introduction

There is a network of wadis in the project area from the western border of the country up to Fuka. These wadis are listed in Appendix 2.

The sizes given for the catchment areas of the wadis are approximate, since the boundaries defined by the stereoscope from the aerial photographs were sometimes ill-defined, especially to the South, because of the even slope of the plateau. On the original hydrographical map some boundaries showed as a belt of land of variable width. In these cases a line was traced on the map through the middle of the belt. Where the side boundaries did not reach the belt, they were extended to it on the map. The geological features of the catchment areas were taken from the 1:50 000 geological maps of the pilot areas made under the project, and, for the areas which these maps do not cover, from the REGWA reconnaissance geological map at 1:100 000.

2.2. General hydrographical features of the project area

The project area, from the hydrographical point of view, can be divided in two parts: the western part, from Sallum to Fuka, which comprises a considerable number of wadis in a hydrographic network more or less distinctly organized, and the eastern part, east of Fuka, where there is no evidence of a runoff network.

There are 218 wadis in all, with catchment areas varying from less than 1 km^2 to 240 km^2. Some of them are in reality groups of small wadis. Table 19 shows their classification by size of catchment areas.

In general the runoff network starts from the plateau, not far from the escarpment, and both the plateau and the escarpment are deeply cut into by the beds of the wadis. Sudden drops of 2–5 m are typical in the escarpment area.

Loose stones and large boulders from the calcareous foundation are often found in the beds downstream from the drops. Except for those in the escarpment, the water courses have an even longitudinal slope, seldom exceeding one percent. The wadis, after running some kilometres in the transition zone, either peter out in the depressions and plains or spread out behind the ridge of dunes. In some cases, however, they reach the sea.

It seems that the beds of the wadis in their present form do not result solely from the action of water erosion but were developed over a period when the climate of the area was not the semi-arid climate it is now.

Most catchment areas are underlain by hard limestones of Miocene age, with the Quaternary alluvium being found only in the immediate vicinity of the spreading areas. Hard Pliocene limestones are found, however, in the lower part of the catchment areas of the wadis east of Matruh.

Table 19 Number of Wadis in the Coastal Region

	Size of Catchment Area								Total Number of Wadis
	5	5-10	10-20	20-30	30-40	40-50	50-100	100	
	km^2								
Sallum - Sidi Barrani	33	12	22	5	6	1	2	2	83
East of Barrani - Mersa Asi	19	18	21	6	4	2	3	-	73
Um el Rakhem - Matruh	5	3	2	3	2	4	7	1	27
East of Matruh - Ras el Hekma	3	1	7	4	3	1	2	3	24
Ras el Hekma - Fuka	2	-	2	4	1	-	-	2	11
Total	62	34	54	22	16	8	14	8	218

2.3. The Sallum - Sidi Barrani Area (Wadis 1 - 83)

Many of the wadis, originating in the plateau, have cut deep into the escarpment, which, starting very close to the sea near Sallum, runs in a south-easterly direction inland up to a distance of 40 km southwest of Sidi Barrani.

Wadis 1 - 14 are short and reach the sea. As the escarpment runs inland, the length of the wadis increases, but they do not reach the sea, petering out in the plain which extends downstream from the cliff of the plateau.

Southwest of Sidi Barrani the escarpment is more even. Here there are three of the biggest wadis of the project area, the Wadi El Khur, with two main branches, El Magran and El Kabah, the Wadi El Kharuba, and Wadi 83. Their catchment areas are 239, 82, and 164 km^2 respectively, and they receive enough rain water to flow 2-4 times a year. The runoff is spread on the permeable soils downstream and probably enriches the underground aquifers.

2.4. The Area between Sidi-Barrani and Mersa Asi (Wadis 84 - 156)

The escarpment in this area of uniform topographical features runs parallel to the seashore. The 73 wadis are of medium size and run from south to north at a distance of 1 - 3 km from one another. Their catchment areas are generally a narrow strip 12 - 20 km long and 1 - 4 km wide. The runoffs are spread on the narrow belt of alluvial soil near the coast or reach the sea through the openings between the sand dunes. These wadis seem to carry water several times each year.

2.5. The Area Um el Rakham and Matruh (Wadis 157 - 183)

The wadis in this area are larger, some of them being the most important wadis of the project area. Six of them (including Wadi Ashtan, Wadi Maguid, Wadi Madwar, Wadi Ramla) reach the plain of El Qasr. All the wadis have well developed ramifications and deep cut beds. Some of them, near Mersa Asi, have a big drop of more than 10 m just before the plain. Because of their large catchment areas and dense ramifications, the peak discharge of the larger wadis is very high.

The wadis of this area do not reach the sea directly but spread out over the alluvial plains behind the sand dunes, or reach the lagoon west of Mersa Matruh.

2.6. The Area East of Matruh to Ras el Hekma (Wadis 184 - 207)

There are some important wadis, also highly ramified, in this area (Wadi Naghamish, Wadi Zarga, Wadi Kassaba). As the annual rainfall is low, they carry less water than those west of Matruh. The high cliff of Baqqush, which rises sharply some 4 or 5 km inland, has been cut into by a certain number of wadis, four of which reach the Baqqush plain.

The escarpment east of Ras el Hekma runs parallel to the shore and very close to it, facing east. It has been cut into by a few very short wadis which are not included in the hydrogeological survey. One of these wadis is Wadi Kilo 9, in which some runoff measurements were made prior to and under the project.

2.7. The Area Between Ras el Hekma and Fuka (Wadis 208- 218)

The wadis of this area are of medium size and run from west to east. Some of them are well ramified but carry very little water, since the area receives in general less rainfall. They all peter out in the plain of Fuka some 5-10 km from the sea.

2.8. The Area east of Fuka

This area does not have any wadis worth mentioning. There is a considerable number of closed depressions in it on which the runoff of the surrounding slopes converges, only to disappear quickly through evaporation and infiltration.

3. Hydrology

3.1. Hydrological investigations

3.1.1. Introduction

The hydrological investigations in the project area aimed to establish:

a) the correlation between rainfall and runoff in the catchment area of each wadi;

b) the frequency curve of the runoff in each wadi;

c) the correlation between the amount of rainfall and the surface runoff (runoff coefficient) under different conditions of slope, intensity of rainfall, soil, etc.

There was insufficient time under the project, however, to do more than establish the methods of investigation, define the difficulties and the means of overcoming them, and reach some preliminary conclusions about the general conditions of flow in the wadis.

3.1.2. Methods

3.1.2.1. Measurements of the runoff of wadis

As it was not possible to take measurements in all the wadis of the area, six representative wadis were selected and weirs constructed on them by EGDDO in preparation for the work of the surface water conservation expert. The selection was based on the following criteria:

a) the wadis were to be of different sizes and located in various regions to cover the whole area from Ras el Hekma to Sallum;

b) preference was to be given to wadis where the runoff could be used downstream for winter watering of land suitable for cultivation;

c) the wadis were to have a drop in altitude where a weir, accesible by car, could be constructed.

Table 20 shows the wadis selected and their characteristics.

Table 20 Wadis selected for Hydrological Investigations

Name of Wadi	Region	Size of Catchment Area	Average Slope	Total Length
		km^2		km
Kilo 9	Ras el Hekma	4.25	0.035	2.0
Kharun	Baqqush	13.50	0.0018	6.0
Ramla	El Qasr	117.50	0.0047	18.5
Mahlab	Um el Rakham	18.20	0.0038	16.8
Tawila	El Negeila	29.20	0.0042	23.0
Akrab	Sallum	34.25	0.0056	7.9

The short duration of flow, its unforeseen time of occurrence and the relatively limited discharges called for the use of weirs as the surest way to measure runoff on the selected wadis. The weirs constructed were rectangular, with large crests, and the downstream face of the bulkhead at a slope of 1:2. This type of weir has been studied by the Research Experimental Station of the Ministry of Irrigation of UAR and tables, giving the relation between head and discharge, have been drawn up.

The measurement of the head of water in the weirs was made by water level recorders installed upstream at a distance not less than four times the maximum head expected to run over the crest.

The dimensions of the weirs were calculated by empirical methods, the sizes of the catchment areas being taken into account. An enlargement of the weirs proved necessary in Wadi Ramla and Wadi Mahlab.

One or two rain recorders were installed in each catchment area for determining, if possible, rainfall/runoff correlation. Unfortunately, the "unit hydrograph" method of determining the correlation could not be used, since there were insufficient hyetographs and hydrographs of individual storms. Moreover, since rainfall in the area is widely dispersed, the number of rain recorders proved insufficient for registering with precision the rainfall in the single catchment areas. Therefore a tentative estimate of the rainfall/runoff correlation is given for some of the wadis by admitting a simple linear relation.

3.1.2.2. Measurement of the surface runoff (sheet sunoff)

Cisterns, of which there are a considerable number in the project area, were used for the measurement of surface runoff. They are generally excavated in rock and are lined with cement, and water can flow into them from the surrounding area. As this makes a catchment not usually more than one square kilometre in size, one rain recorder is sufficient to measure the amount of rainfall in it. By comparing tha amount of rainfall and the additional volume of water collected in the cistern (measured by installing a water-level recorder), a rough estimate of the surface runoff can be made. To reach safe conclusions about the runoff coefficient, measurements of surface runoff should be taken for several years in a number of cisterns, distributed throughout the coastal region under different soil and slope conditions. However, measurements could only be taken in one cistern, located in Fuka. They started in February 1968 and the results obtained were insignificant because no rainfall occurred after February in the Fuka area.

3.1.3. Difficulties encountered

Many difficulties were encountered in obtaining measurements, and the value of the results is thereby lessened. The water-level recorders and rain recorders did not arrive until February 1967, the end of the 1966/67 rainy season. Apart from a few measurements of runoff taken in the Ramla and Tawila wadis with two old water-level recorders provided by the Government, measurements of runoff did not start until 1967/68. It is clear that sure conclusions about the flow in the wadis cannot be arrived at on the basis of measurements over so short a period of time.

As the equipment installed was often damaged by intruders and animals, each instrument required fencing with barbed wire and permanent guarding. In the meantime some important measurements were lost or were not to be relied on. Measurements were also lost because charts were not changed on the instruments on the fixed day. The assistant engineer from Matruh charged with changing weekly the charts of the 6 water-level recorders and 8 rain recorders scattered throughout the project area from Fuka to Sallum, often failed to perform his task through sickness or because his car was not working.

The dry sandwinds - "Khamsin" - caused damage to installed equipment several times. Th sand, entering the rain-recorders and water-level recorders, stopped the watch mechanism or dried the ink of the pen. Thus the rainfalls and runoff that often follow sandwinds were not recorded.

Notwithstanding these difficulties in measuring the conditions of flow of the wadis in the project area, the experience obtained was of a great value for any further hydrological study.

3.2. Selected Wadis

3.2.1. Wadi Kilo 9 (Ras el Hekma)

The main reason for selecting this small wadi for hydrological study was that the Desert Institute had previously investigated it and some measurements of runoff had been taken in 1958-59 and 1959-60.

General description of the Wadi

The catchment area of Wadi Kilo 9, determined on the basis of the 1:10 000 map recently provided by the Government, is 4.25 km^2, (see Fig. 14). This area is divided in two parts (the eastern part 2.56 km^2 and the western 1.69 km^2) by the asphalt road which goes to Ras el Hekma. Owing to its irregular topography and to the presence of the road, the western part of the catchment area makes by far the lesser contribution to the runoff of the wadi.

The catchment area is composed of 45 percent bare oolitic limestone, steeply sloping; 40 percent alluvial bench lands (sandy loam to silt loam, highly calcareous, level to gently sloping, partially cultivated); 10 percent talus slope and mixed rock, and 5 percent bench lands mixed with rock outcrops, gently sloping.

The wadi has well developed ramifications and a deep-cut bed. Its total length is approximately 2 km and its average slope 0.035.

The cliff of the plateau in this region runs very close to the coast; thus, as there is no plain, the wadi reaches the sea directly and the runoff is completely lost.

Observation methods

A weir was constructed by the Desert Institute in 1958 at the outlet of the wadi, where there is a natural fall of two metres. Its width is 3 m, its height one metre above the crest, and its maximum discharge, calculated according to the tables given by the Research Hydraulic Station of the Ministry of Irrigation, is :

$$Q = 4.3218\ H^{1.52}$$
$$\text{for } H = 1.00\ m$$
$$Q\ max = 4.3218\ m^3/s.$$

A water-level recorder was installed by the weir and a rain recorder 500 m upstream. The charts of the two instruments were changed weekly. The data of the rain gauge installed at the meteorological station of Ras el Hekma, some 8 km north of the wadi, were also taken into consideration.

Results

Table 21 shows the results obtained both from previous investigations and under the project.

Table 21 Runoff and rainfall measurements in Wadi Kilo 9

Date	Runoff	Rainfall		Rainfall	Remarks
		Rain gauge near the weir	Rain gauge of Ras el Hekma		
	m^3	mm		days	
18-19.1.59	314	14.0	9.5	2	Measurements taken by Salah Shafik and Abdel Hamid el Tady
30.1.59	2 041	10.7	0.0	1	
12-16.2.59	15 657	35.5	32.3	5	
Total	18,012				
26-27.12.59	34	15.8	18.8	2	Measurements reported in the Reconnaissance Survey of the N.W. Coastal Zone by SOGREAH
30-31.12.59	794	0.0	24.5	2	
1-2 .1.60	7 525	55.6	19.2	2	
7.1.60	6 619	15.2	6.5	1	
23.1.60	355	7.7	15.3	1	
10.3.60	24	5.0	0.0	1	
Total	15 351				
6.12.67	1 000	7.2	17.7	1	Measurements taken under the project
14. 1.68	?	8.0	13.8	1	
29. 3.68	600	6.0	5.8	1	

The following points about the above data deserve mention :

- The runoff of 26-27.12.59 seems very low in relation to the rainfall (15.8 mm near the weir and 18.8 mm in Ras el Hekma). This is probably the result of the dispersion of rainfall in the catchment area and of the high capacity of retention of the dry soil at this first rainfall of the year.

- A runoff of 794 m^3 was recorded on 30-31.12.59 without any rainfall being recorded near the weir. This is also accounted for by the dispersion of rainfall.

- The runoff of 1-2.1.60 is low in proportion to the very high amount of rainfall recorded near the weir. Excluding the case of error, the fact could also be explained by the dispersion of rainfall.

- The runoff of 14.1.68 was not recorded because of damage to the rain recorder.

Rainfall/runoff correlation

Excluding the above-mentioned abnormal cases and considering the amount of rainfall recorded only in the rain gauge near the weir, data can be tabulated as shown in Table 22.

Table 22 Selected data on runoff, rainfall and duration of rainfall in Wadi Kilo 9

Date	Runoff (R)	Rainfall	
		Amount (h)	Duration (T)
	m^3	mm	days
18-19. 1.59	314	14.0	2
30. 1.59	2 041	10.7	1
12-16. 2.59	15 657	35.5	5
7. 1.60	6 619	15.2	1
23. 1.60	355	7.7	1
6.12.67	1 000	7.2	1
29. 3.68	600	6.0	1

The rainfall figures given by the rain recorder certainly do not represent the average amount of rainfall in the catchment area because of the dispersion of rainfall. However, a tentative estimate of the rainfall/runoff correlation can be made by admitting a simple linear relation between rainfall and runoff of the form:

$$R = b_1 + b_2h + b_3T \qquad (1)$$

Where R = amount of runoff
h = amount or rainfall
T = duration of rainfall

The parameters b_1, b_2, b_3 can be calculated by the analystical method using the following formulas :

$$b_2\Sigma(\Delta x_2)^2 + b_3\Sigma(\Delta x_2\Delta x_3) = \Sigma(\Delta x_1\Delta x_2)$$
$$b_2\Sigma(\Delta x_2\Delta x_3) + b_3 \ (\Delta x_3)^2 = \Sigma(\Delta x_1\Delta x_3) \qquad (2)$$
$$b_1 = x_1 - b_2x_2 - b_3x_3$$

With the data of Table 22 and the calculations shown in the Appendix 3, the following values of the three parameters were obtained :

$$b_1 = 3922$$
$$b_2 = 800$$
$$b_3 = 1923$$

Thus, the formula (1) can be written :

$$R = 800h - 1923T - 3922 \qquad (3)$$

Taking into consideration the size of the catchment area of Wadi Kilo 9 (4.25 km^2), we can generalize formula (3) as follows :

$$\boxed{R = \left[0.19\ (h - 4.9) - 0.45T\right] 1000\ S} \qquad (4)$$

Where R = runoff in m^3
h = average rain fallen in the catchment area in mm
T = duration of rainfall in days
S = size of catchment area in km^2

Again it is to be noticed that formula (4) is only a first approach, or a tentative estimate of the correlation between rainfall and runoff. A more accurate correlation could only be arrived at after some years of measurements. Moreover, the formula can be applied only in Wadi Kilo 9 or other wadis presenting the same characteristics i.e. small catchment area (4-5 km^2) and relatively steep slope (0.035).

Frequency of annual runoff

It is also premature to make any assumption concerning the frequency of the annual runoff of the wadi, the only available date being the following :

Table 23 Annual Runoff in Wadi Kilo 9

Year	Annual Runoff	Annual Rainfall		
		Matruh (airport)	Ras el Hekma	El Daba
	m^3	mm	mm	mm
1958-59	18 012	143.9	79.8	105.1
1959-60	15 351	79.9	92.6	
1967-68	2 150 (1)	83.5	97.5	71.6

(1) Annual runoff for this year was taken as the total measured runoff (1 600 m^3) plus 550 m^3. This is the runoff, calculated by formula (4), corresponding to the rainfall of 14.1.68

It is to be noted that, during the three years of observation, the rainfall in Ras el Hekma and in most of the neighbouring stations was definitely lower than the average annual rainfall. Taking this into account the following very rough estimate of the annual runoff and its frequency can be made :

Frequency	Total annual runoff	Specific runoff
0.50 (average)	15 000 m^3	3 500 m^3/km^2
0.60 - 0.70	10 000 m^3	2 300 m^3/km^2

3.2.2. Wadi Kharun

General description

Wadi Kharun is one of the four wadis which reach the Baqqush plain. It cuts deeply into the high cliff of Baqqush, which rises sharply some 5 km inland, and peters out in the plain.

The catchment area of the wadi (Fig. 15), determined from a 1:10 000 topographical map, is 13.5 km^2. It is 6 km long approximately and has an average slope of 0.0018. It is crossed by the railway and the Alexandria - Matruh road. To obtain a better spreading of the runoff of the wadi, a number of dykes have been constructed by EGDDO in its catchment area, upstream and downstream from the road. The existence in the catchment area of the road, the railway and dykes parallel to the contour certainly has a retaining effect on the runoff of the wadi, diminishing its "sensibility". On the other hand it seems that, owing to the low annual rainfall of the region of Baqqush, the wadi carries less water than other wadis of the Coastal Region.

Observation methods

The same principles of observation were applied as in the case of Wadi Kilo 9. A rectangular weir 3.00 m wide and 1.50 m high was constructed upstream from a natural fall at a distance of 1800 m from the sea. A water level recorder was installed close to the weir and a rain recorder near the railway. The charts of both instruments were changed weekly. Observations started in September 1967.

Results

Owing to the dryness of the year 1967-68, especially in the area of Baqqush, no significant results on runoff were obtained. A small runoff of 500 m^3 was the only one that occurred, corresponding to a rainfall of 5.8 mm recorded by the rain recorder (see Fig. 16).

3.2.3. Wadi Ramla

General description

Wadi Ramla, the most important wadi in El Qasr region, has well developed ramifications and a deep cut bed starting immediately south of the railway. Its catchment area, a great part of which is in the plateau (see Fig 17), was determined from aerial photos at 117.5 km^2. This figure is approximate, since the boundaries of the area are difficult to define. The wadi is 18.5 km long and its average slope is 0.0047. Most of the catchment area belongs to the Tertiary Miocene, Recent Quaternary being found only in the spreading area.

After a course of 12 km in the plateau and the transition zone, the wadi reaches the plain, where it peters out. A dyke constructed by EGDDO prevents the flow of the runoff to the salt lake of Matruh. Because of the large catchment area, the peak discharge seems to be very high.

Observation methods

A large weir 6.00 m wide and 2.00 m high was constructed on the wadi 5.5 km from the sea, and a water level recorder was installed close to it. The maximum capacity of the weir is 27 m^3/sec. Because of shortage of equipment, only two rain recorders were installed in the catchment area, one 6.75 km from the sea and the other 12.5 km from the sea at the junction of the Siwa road with the Alexandria-Sallum road. Given the size of the catchment area of the wadi and the dispersion of rainfall in the Coastal Region, two rain recorders are certainly insufficient to measure the rainfall in the catchment area. Observation on the runoff of the wadi started in Séptember 1966 when an old water level recorder was installed. Observation on the rainfall started only in February 1967, upon the arrival of the rain recorders from Rome.

Results

Figure 18 shows the hydrographs obtained, and Table 24 the runoff and rainfall measured during the two years of observation. The following should be noted :

- During the year 1966-67, seven flows occurred in Wadi Ramla, only three of which were measured. Acording to local information, the flows of 23.1.1967 and 4.3.1967 were very small.

- During the year 1967-68 six flows occurred, four of which were measured. The flows of 14.1.68 and 24.1.68 were insignificant.

Table 24 Runoff and Rainfall measurements in Wadi Ramla

Date	Runoff	Maximum discharge	Total Rainfall		
			Wadi Ramla rain recorder No. 1	Wadi Ramla rain recorder No. 2	Matruh Station (airport)
	m^3	m^3/s	mm	mm	mm
28.9.66	7 900	0.884	recorder not installed		7.0
24.10.66	49 000	6 547	"	"	6.0
9-10.11.66	375 000	20 000	"	"	41.6
17-20.11.66	?		"	"	16.1
17-20.1.67	?		"	"	10.8
23.1.67	?		5.2	2.4	8.7
4.3.67	?		5.0	4.3	1.2
Total, 1966-67	431 900				126.0
2.11.67	32 000	3.255	3.8	no record	7.7
15.11.67	43 900	5.293	15.3	9.8	21.1
17.11.67	25 000	3.572	19.1	6.6	2.2
17.11.67	2 000	0.210	1.7	1.4	0.0
14.1.68	?				6.0
24.1.68	?		4.4	1.2	6.6
Total 1967-68	102 900				83.5

Applying Thiessen's principle, rain recorder No. 1 shows rainfall over 17 percent, and rain recorder No. 2 over 83 percent, of the catchment area. This explains the apparent discrepancies in the table.

Rainfall/Runoff correlation

As the table above shows, data on runoff and rainfall are complete only for the flows of 15.11.67, 16.11.67 and 17.11.67.

A tentative estimate of the rainfall/runoff correlation can be made by using the same simple formula used for Wadi Kilo 9 :

$$R = b_1 + b_2h + b_3T \qquad (1)$$

The data of Table 25 below were used :

Table 25 Complete data on runoff, rainfall and duration of rainfall. Wadi Ramla

Date	Amount of runoff (R)	Effective Rainfall			Duration of Rainfall (T)		
		Rain Recorder No. 1	Rain Recorder No.2	Average (1)	Rain Recorder No. 1	Rain Recorder No. 2	Average (1)
	mm	mm	mm	mm	hours	hours	hours
15.11.67	43 900	14.0 2/	7.2 2/	8.4	6.0	5.0	5.2
16.11.67	25 000	18.7 2/	4.8 2/	7.2	17.0	11.5	12.0
17.11.67	2 000	1.7	1.4	1.5	0.5	0.5	0.5

(1) The average rainfall and its duration were calculated on the basis of the Thiessen principle.

2/ Only the rainfall before and during the flow of the wadi has been taken into consideration.

On the basis of the calculation shown in Appendix 3, the following formula was obtained :

$$R = 7110h - 7930 - 1520T \quad (2)$$

Taking into consideration the size of the catchment area of Wadi Ramla (117.5 km^2), we can generalize formula (2) as follows :

$$\boxed{R = \left[0.06\ (h - 1.12) - 0.013T\right] 1000\ S} \qquad (3)$$

Where
- R = runoff in m^3
- h = average rainfall in the catchment area in mm
- T = duration of rainfall in hours
- S = size of catchment area in km^2

Apart from the reserve put on the use of the above type of formula (see under Wadi Kilo 9) and the insufficiency of the number of rain recorders, the fact that only three flows were used for the calculation of formula (3) and that these flows were successive, limits the value of the formula.

But, as it is absolutely necessary to make an estimate of the runoff of the wadis, expecially in the highly interesting El Qasr area, the formula was used as the best obtainable on the basis of existing data.

Frequency of annual runoff

There were only two years of observation on which to estimate annual runoff :

Table 26 Observation of Runoff in Wadi Ramla

Year	Annual Runoff		
	Measured	Estimated missed flows	Total
	m^3	m^3	m^3
1966-67	431 900	48 100	480.000
1967-68	102 900	37 100	140 000

The annual rainfall in 1966-67 was lower than the average annual rainfall in the Matruh and El Qasr stations. The year 1967-68 was a dry year with an 82 percent probability of its rainfall being exceeded. Taking these facts into account, the annual runoff and its frequency were roughly estimated as follows :

Frequency	Total annual runoff	Specific runoff
0.50 (average)	500 000 m^3	4 250 m^3/km^2
0.60 - 0.70	275 000 m^3	2 300 m^3/km^2

3.2.4. Wadi Mahlab

General description

Wadi Mahlab, also called Wadi Ibeitir, is located in Um el Rakham, between Ras Abu Laho and Mersa el Asi, approximately 35 km west of Matruh.

It runs, with very few ramifications, for 2 km in the plateau in a deeply cut bed and, after a very steep drop of more than 30 m, reaches the plain of Suiniyyat. This plain receives the runoff of 15 wadis in all.

The catchment area, a great part of which is in the plateau, is a narrow strip 16.8 km long and 18.2 km^2 in area and has an average slope of 0.0038 (Fig. 19). It belongs to the Tertiary Miocene.

Observation methods

A weir 3.00 m wide and 1.50 m high, with a maximum capacity of approximately 8 m^3/s, was constructed just upstream from the fall and a water level recorder was installed close to it. A rain recorder was installed 2 km south of the weir. Observation on the runoff and rainfall began in September 1967.

Results

Fig. 20 shows the hydrographs obtained and Table 27 the runoff and rainfall measured in 1967/68.

Table 27 Runoff and Rainfall Measurements in Wadi Mahlab

Date	Runoff	Maximum discharge	Rainfall		
			Wadi Mahlab		Matruh Station (airport)
			Amount	Duration	
	m^3	m^3/s	mm	hours	mm
2.11.67	80		6.2	5	7.7
15.11.67	68 400	5.728	36.6	11	21.1
6.12.67	2 000	0.233	12.4	5	9.9
14.1.68	?		9.6	10	6.0
Total for the year 1967-68	70 480				

As the table shows, only one important flow occurred in 1967/68. The simple method used in cases of Wadi Kilo 9 and Wadi Ramla to determine annual runoff cannot be applied because of the great variability in runoff measured, and it is also very difficult to estimate the frequency of the annual runoff on data from only one year of observation. However, some indication of the annual runoff and its frequency can be obtained on the following basis :

a) the total rainfall in the area of Wadi Mahlab in 1967/68 was 92.1 mm, considerably less than the average rainfall at the station of Matruh (138.2) and in Sidi Barrani (147.5);

b) the rainfall of 15.11.67 (36.6 mm, duration 11 hours), to which the runoff of 68 400 m^3 corresponds, could be considered as an exceptional rainfall which, according to a special study on the rainfall of Matruh, recurs every 8 years. Thus the runoff of the wadi in 1967/68 was the result of a storm of high intensity, which occurs once every 8 years, and of a low annual rainfall.

Thus the annual runoff and its frequency can be estimated as follows :

Frequency	Total annual runoff	Specific runoff
0.50 (average)	55.000 m^3	3 000 m^3/km^2
0.60 - 0.70	35 000 m^3	2 000 m^3/km^2

3.2.5. Wadi Tawila

General description

Wadi Tawila, which is located in the Negeila area some 1-2 km east of El Negeila village, is one of the medium size wadis which run from south to north and whose runoff is spread on the narrow belt of alluvial soil near the coast. Its catchment area is 34.62 km^2 and its shape a narrow strip 23 km long and 1-1.5 km wide. Most of this area belongs to the Tertiary Miocene, the Quaternary being found only near the estuary of the wadi (Fig. 21).

The average slope of the catchment area is 0.0042. The well-defined bed of the wadi starts north of the Matruh-Sallum road, 9 km from the sea. The two main branches join at a point 800 m from the shore. For hydrological observation, only the eastern branch, which has a catchment area of 29,2 km^2, was used.

Observation methods

A weir 3.00 m wide and 1.50 m high with a maximum capacity of 8 m^3/s, was constructed upstream of a natural fall 2.5 km from the coast. A water level recorder was installed close to it and a rain recorder 1.5 km south of it. As a new meteorological station was erected in September 1967 at El Negeila village, very close to the Matruh-Sallum road, data from this station were to be used for the rainfall in the catchment area, but unfortunately the station did not operate regularly in 1967-68 and therefore no data became available.

Observation of the runoff of the wadi began in September 1966; observation of the rainfall in September 1967.

Results

Fig. 22 shows the hydrographs obtained and Table 28 the runoff and rainfall measured during two years of observation.

Table 28 Runoff and Rainfall Measurements in Wadi Tawila

Date	Runoff	Maximum discharge	Total Rainfall			
			Wadi Tawila		Negeila Station	Matruh Station
			Amount	Duration		
	m^3	m^3/s	mm	hours	mm	mm
9.11.66	18 700	1.390				33.5
10.11.66	8 400	0.970				8.1
14.11.66	14 400	2.213				0.0
28.12.66	15 400	0.893				2.2
20. 1.67	6 500	0.709				5.1
Total of the year 1966-67	63 400					
2.11.67	2 000	0.255	7.7	4		7.0
15.11.67	13 700	1.858	18.2	12		21.1
16.11.67	500	0.117	3.4	1		2.2
21.11.67	500	0.072	1.2	1		1.8
6.12.67	?		10.1	4		9.9
14. 1.68	5 300	0.855				6.0
24. 1.68	?				5.0	4.6
29. 3.68	50 700	3.643	2.0	0.3		7.7
30-31.3.68	60 000	4.500				0.2
Total of the year 1967-68	132 700					

According to local information, the flows of 6.12.67 and 24.1.68 were moderate. It seems that the important flow of 29.3.68 was caused by rainfall in the southern part of the catchment area. The rainfall recorded by the instrument installed near the weir - 2 mm - is very low in proportion to the amount of runoff. Rainfall data are lacking for the second important flow, that of 30-31.3.68, because of damage to the rain recorder.

Rainfall/Runoff correlation

Excluding the flow of 21.11.67 (insignificant amount of rainfall) and that of 29.3.68 (abnormal case due to dispersion of rainfall), the rainfall/runoff correlation can be based on the data shown in Table 29:

Table 29 Complete Data on Runoff, Rainfall and Duration of Rainfall in Wadi Tawila

Date	Runoff	Effective Rainfall	Duration of rainfall
	mm	mm	hours
2.11.67	2 000	7.7	4
15.11.67	12 700	15.0 1/	5
16.11.67	500	3.4	1

1/ Only the rainfall before and during the flow of the wadi is taken into consideration.

Applying with the same reserves the simple method used in the cases of the other wadis, the calculations shown in Appendix 3 give the following formula:-

$$R = 1907h - 3765 - 2230T$$

Taking into consideration the size of the catchment area of wadi Tawila (29.2 km²), we can generalize the formula as follows :

$$R = \left[0.065\ (h - 1.97) - 0.08T\right] 1000\ S$$

Where R = runoff in m^3
h = rain fallen in the catchment area in mm
T = duration of rainfall in hours
S = size of catchment area in km^2

Frequency of the annual runoff

There are two years of observation for the estimate of annual runoff :

Table 30 Observation of Runoff in Wadi Tawila

Year	Annual Runoff		
	Measured	Estimates of the missed flows	Total
	m^3	m^3	m^3
1966-67	63 400	-	63 400
1967-68	132 700	7.300	140 000

Annual rainfall data has to be taken from Sidi Barrani, and Matruh stations, as there is no station at El Negeila. The years 1966-67 and 1967-68 can be considered as normal years for Sidi Barrani, the two annual rainfalls being only slightly different from the average annual rainfall. In Matruh, the rainfall in 1967-68 was lower than the average (61 percent probability of being exceeded) and the year 1967-68 was a dry year (82 percent probability of being exceeded). Thus, the heavy rainfalls which occurred on 29 and 30-31 March 1968 in the southern area of El Negeila, causing the two important runoffs of the same dates, may be considered as uncommon cases.

Accordingly, only the following very rough estimate of the annual runoff and its frequency can be given.

Frequency	Total annual runoff	Specific runoff
0.50 (average)	85 000 m^3	3 000 m^3/km^2
0.60 - 0.70	60 000 m^3	2 000 m^3/km^2

3.2.6. Wadi Akrab

General description

Wadi Akrab, which is located close to the town of El Sallum, originates in the plateau, cuts deep into the escarpment, which is very close to the coast, and reaches the sea. It has well developed ramifications.

The catchment area of the wadi is 34.25 km^2 and its shape is almost circular. It is 7.9 km long and has an average slope of 0.0056. (Fig. 23).

Observation methods

A weir 3.00 m wide and 1.50 m high was constructed upstream of a natural fall, some 1,5 km from the coast. A monthly water level recorder was installed close to the weir. As a meteorological station, equipped with rain recorder, is in operation in El Sallum, no additional rain recorders were installed. Observation started in September 1967.

Results

In 1967-68 the total rainfall in El Sallum was only 70.6 mm - much lower than the average - and no significant runoff occurred in the wadi.

3.3. The applicability of the hydrological data to the rest of the region

While estimates of annual runoff for the whole region are needed for defining the scope for development, extrapolations of the results obtained from the hydrological investigations is hazardous in a region where there is so much variability in the factors influencing wadi runoff. This must be borne in mind for the very rough estimates made below, which, in addition, had to be based on the results of a mere year or two of hydrological investigations and on some general information about the flow of wadis and the climate and soil conditions of each area.

3.3.1. Estimate of the annual runoff of the main wadis in the Coastal Region

With all the reserves expressed in section 3.1. above, we can recapitulate as follows :

Table 31 Recapitulation of the obtained results from the hydrological studies of wadis

Wadi	Region	Size of catchment area	Rainfall/runoff correlation R = f (h.T)	Specific annual runoff	
				Frequency 0.50	Frequency 0.65
		km²		m³	km²
Kilo 9	Ras el Hekma	4.25	R=0.19(h-4.9)-0.45T	3 500	2 300
Kharun	Baqqush	13.50			
Ramla	El Qasr	117.50	R=0.06(h-1.12)-0.013T	4 250	2 300
Mahlab	Um el Rakham	18.20		3 000	2 000
Tawila	El Negeila	29.20	R=0.065(h-1.97)-0.08T	3 000	2 000
Akrab	Sallum	34.25			

The following general information is also to be taken into consideration.

- The area of Fuka, protected from the rainy winds by the rocky crest of Ras el Hekma, and the area of Sallum on the leeward side of the Libyan plateau, each receive less water than the rest of the Coastal Region.
- Most of the wadis of the Sidi Barrani area are located inland at a distance of 20 to 50 km from the coast. Rainfall decreases in relation to the increasing distance from the sea in the Coastal Region. It is estimated that these wadis receive only 35-40 percent of the quantity of rain received near the coast at the meteorological station of Sidi Barrani.
- According to local information the wadis east of Matruh carry less water than those west of Matruh (El Qasr). This is due probably to the more permeable soils of their catchment area.
- According to local information the wadis of Baqqush carry less water than other wadis in the Coastal Region. This is due to the lower rainfall of the area. In fact the rainfall recorded by the rain recorder of Wadi Kharun during a certain period of the year 1967-68 was 13.0 mm, while for the same period the rainfall in Matruh was 54.4 mm and in Ras el Hekma 57.9 mm.

On the basis of the data of Table 31 and the information above, the annual runoff of the main wadis in the Coastal Region was roughly estimated as shown in Table 32.

Table 32 Rough estimation of the annual runoff of the main wadis in the Coastal Region (frequency 0.65)

Region	Number of wadis of a catchment area more than 10 km²	Catchment area		Estimated specific annual runoff	Total annual runoff
		Total	Average per wadi		
		km²	km²	m³/km²	m³
Sallum	14	328.11	23.44	1 300	426 000
Sidi Barrani	24	932.59	38.86	1 000	932 000
Sidi Barrani East	14	227.74	16.27	2 000	455 000
El Negeila	22	584.70	26.58	2 000	1 169 000
Um el Rakham	12	535.73	44.64	2 000	1 071 000
El Qasr	7	419.20	59.88	2 300	964 000
Matruh	14	697.02	49.79	1 800	1 254 000
Baqqush	7	155.22	22.17	1 300	201 000
Fuka	9	446.99	49.67	900	402 000
Total	123	4 327.30 Av	35.18 Av	1 588	6 874 000
Total for wadis with catchment areas of less than 10 km²					626 000
GRAND TOTAL					7 500 000
GRAND TOTAL (frequency 0.65)					11 000 000

3.3.2. Maximum runoff of wadis

To design hydraulic works for the wadis of the Coastal Region, their maximum discharge must be known. As the measurements of the discharge taken in some wadis are very few, it is necessary to have recourse to formulae by which the maximum discharge of a wadi can be calculated on the basis of its physiographic characteristics and the maximum expected depth of precipitations during the "time of concentration".

The characteristics of wadis (size and length of catchment area, average slope) can be determined with a certain accuracy from the existing maps and aerial photos. These characteristics are given in the tables of the hydrographical survey of the Coastal Region (see Appendix 2) . The maximum depth of precipitation-duration curves has been calculated in an interim report 1/ on the basis of the rainfall data of the Matruh meteorological stations, covering the period 1951-1965.

1/ P. Economides - I. Harbash : "Maximum depths of precipitation in accordance to the duration of rainfall and the recurrence interval" Alexandria, October 1967.

Thus, for the calculation of the maximum discharge of a wadi with a determined recurrence interval we can use the following method :

a) Calculation of the "time of concentration" Tc

The following simple formula of Passini can be used :

$$Tc = \frac{0.108 \sqrt[3]{LS}}{\sqrt{Im}} \qquad (1)$$

Where : Tc = time of concentration in hours
L = length of catchment area in km
S = Size of catchment area in km^2
Im = average slope of the wadi

b) Maximum expected depth of precipitation during the "time of concentration"

For the calculation of the maximum expected rainfall during the "time of concentration" we can use the formulae given in the above-mentioned interim report for the maximum depths of precipitation for durations of rainfall. To a recurrence interval of 10 years, which is considered reasonable for small works, the following formula corresponds :

$$h_c = 26.5 \ Tc^{0.159} \qquad (2)$$

where : h_c = maximum expected depth of precipitation in mm with a recurrence interval of 10 years during the time Tc

Tc = time of concentration in hours

c) Maximum discharge of wadis

The following formula of Turazza can be used :

$$Qmax = \frac{1.5 \times C \times S \times hc}{3.6 \times (Tc + Tr)} \qquad (3)$$

Where Qmax = maximum discharge in m^3/s
C = instantaneous runoff coefficient (C=0.70)
S = size of catchment area in km^2
hc = maximum expected depth of precipitation during the time Tc
Tr = duration of rainfall. The maximum discharge occurs when Tr = Tc.

In Table 33 the calculated maximum discharges of the wadis selected for hydrological investigation are given. The same method can be applied for the rest of the wadis in the Coastal Region.

Table 33 Maximum discharge of the wadis in the Coastal Region selected for hydrological investigation

	Physiographic characteristics			Time of concentration Tc	Maximum expected depth of precipitation during the time Tc	Maximum discharge	
	S catchment area	L length of wadi	I slope			Calculated with a recurrence interval of 10 years	Measured during the period of the hydrological investigations
	km^2	km		hours	mm	m^3/s	m^3/s
Kilo 9	4.25	2	0.035	1.22	27	13.72	
Kharun	13.50	6	0.0018	11.09	37	6.57	
Ramla	117.50	18.5	0.0047	20.26	43	36.35	20.000
Mahlab	18.2	16.8	0.0038	11.75	38	8.58	5.728
Tawila	29.2	23.0	0.004	15.00	41	11.65	4.500
Akrab	34.25	7.9	0.0056	9.33	36	19.34	

4. Hydrogeology

4.1. Hydrogeological investigations

The potential for agricultural development on the project area is limited by the lack of usable water. Neither surface nor groundwater is available for large scale agricultural development projects or even to support large domestic settlements. But what there is should be developed, if only for the purpose of settling the Bedouin tribes into villages relying upon agriculture.

The hydrogeological investigations under the project could not be based on existing knowledge of the geological conditions, the rainfall and the climatic features, and runoff and groundwater variations over a long period, since, except for some geology and a few long-term precipitation records, data on these matters do not exist. Predictions of water occurrence and availability were therefore very difficult. Since surface geological mapping in the project area is very difficult because the bedrock formations are generally buried and individual beds of limestone, clay and sandstone are similar in appearance, surface geological investigations and mapping were undertaken only in the selected areas El Qasr, Dabaa, Fuka, Negeila and Baqqush. The maps show outcrops, structural features, geologic sections, and generalized geologic columns with lithology and approximate thickness of units. In addition, a 400 km^2 area southwest of Sidi Barrani was investigated by the Geological Survey of Egypt, and an interpretative report and maps on it submitted to the project as part of the Government's participation.

A test drilling programme to provide subsurface geologic data and additional hydrologic data in the detailed study areas and in certain other selected areas was undertaken by Government personnel with Government equipment in cooperation with the hydrogeologist. Drilling was supervised by the Egyptian counterpart staff. Twenty-nine test holes were dug by hand and twenty-four holes were drilled by percussion equipment. Rock and water samples were collected from each hole. Electrical resistivity surveys were carried out in two areas in an attempt to detect structurally perched groundwater bodies. An area of about 250 km^2 around Qataf-Gabal and an area of about 30 km^2 around Fuka were chosen for the purpose.

The groundwater study of the project area was carried out in two phases. The first phase included a description of the groundwater reservoir, its geology, water-bearing zones and position, the extent of the water table in relation to varying seasons, and the changes in the chemical quality of the water in response to fluctuations in the water table. The geologic formations and their water-bearing characteristics are given in Table 34. The second phase included the quantitative assessment of the groundwater conditions, aquifer tests to determine the coefficients of transmissibility (the rate at which the aquifer will yield water) and the storage coefficients (the amount of water which can be stored in the aquifer). These data were then used to estimate the total amount of water available in selected areas, the pumping rates necessary to prevent the intrusion of saline water, and the proper well spacing for eliminating interference between pumping wells.

As a first step in describing the groundwater situation in the area, an attempt was made to inventory all the existing wells, collecting galleries, and other watering points in the five detailed study areas, and many wells throughout the remainder of the project area. This inventory includes information on location, depth to water, mean sea level altitude, and other basic data on the watering points, and the chemical analysis of water samples. After completion of the inventory, sixty periodic and 13 recording observation wells were monitored to determine seasonal and cyclic fluctuations of the water table. Twice yearly water levels were recorded to determine high and low water level, and chemical analyses were made for corresponding periods.

Preliminary quantitative studies were made to determine a hydrologic balance for the five detailed study areas. These provide some indication of the "safe yield", or the amount of water which can be taken from the basin without producing an undesired result.

4.2. Main features of groundwater in the region

Groundwater in the region occurs under both artesian and non-artesian conditions; however, all the groundwater suitable for agricultural and domestic uses occurs in relatively shallow non-artesian aquifers or in small shallow semi-perched aquifers with slight artesian pressure. Relatively large quantities of groundwater are found at depth in rocks ranging in age from Cretaceous to Miocene, but the quality of the water is brackish to highly saline and the water is not usable for the purposes of this project.

The non-artesian aquifers in the coastal plain occur in Miocene, Pliocene, Pleistocene, and Recent deposits which crop out at land surface and are recharged directly by rainfall and by the infiltration of surface runoff. In the sandy coastal dunes there is very little runoff, as a large part of the precipitation enters the soil. Inland, the soils are less permeable and water tends to run off to lower areas or to stand on the surface, where it rapidly evaporates. Consequently, southward from the coast, smaller amounts of water are recharged into the groundwater reservoir.

Non-artesian groundwater in the coastal plain can be found as the main water table, the coastal dunes water table, and as semi-perched water tables in structural basins (see Fig. 24).

Main water table. The main water table aquifer is composed primarily of relatively fine-grained marly limestone, but near the coast it is composed of alluvial silt and sand. The aquifer is present throughout the coastal plain.

The surface of the main water table is at or near mean sea level throughout most of the area. The surface of the water table is near mean sea level along the coast; however, in some areas, such as El Qasr, the water table rises so that 18 km from the coast it is about 100 m above mean sea level. In other areas, such as El Dabaa, the water table is only about 1 m above mean sea level 12 km south of the coast. The

Table 34

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING CHARACTERISTICS, NORTH WESTERN COASTAL REGION, U.A.R, (ADAPTED FROM EL RAMLY (1965) PETROLEUM EXPLORATION SOCIETY OF LIBYA (1964) AND OTHERS)

Geologic Age		Topographic or Stratigraphic Unit	Approximate Thickness	General Lithologic Character	Water-Bearing Properties
Period	Epoch				
			metres		
Quaternary	Recent	Coastal Dunes	0-30	Dunes are composed of white, well-sorted, limestone grains varying from loose to semi-consolidated; in places highly cross-bedded and capped by a thin case-hardened mantle.	Fresh water lense floats on top of salt water with the thickness of the fresh water zone being controlled by its height above sea level, and by the quantity of recharge which enters the dune through direct infiltration of rainfall or from surface-water runoff. Chemical quality generally very good but deteriorates rapidly if safe withdrawal rate is exceeded. Yields from galleries have been reported to be as much as 1.19 cubic metres per day per metre of gallery length. However the average yield of the galleries is probably about 0.5 cubic metre per day per metre of gallery length.
		Lagoonal deposits, alluvium, wadi fillings, talus material and windblown deposits	0-10	Near the coast:calcareous, sandy loam soil where significantly above sea level; and slightly loamy, saline clayey soil where subject to innundation by sea water. Inland: windblown sands fill depressions; wind and water deposited alluvial sandy clays occur in the wadi channels and near the mouth of most wadis; and talus deposits of sandy clays occur at base of plateau.	Little to no water except in lagoonal deposits and in alluvian. Thin fresh water lense above saline water where these deposits are above sea level. Water quality brackish to good but deteriotates rapidly if safe withdrawal rate is exceeded. Quantity adequate for windmill pumpage in many areas. In areas that are very near sea level, the water is commonly more saline than sea water due to concentration by evaporation.

Table 34 (cont.)

Geologic Age		Topographic or Stratigraphic Unit	Approximate Thickness	General Lithologic Character	Water-Bearing Properties
Period	Epoch				
			metres		
	Pleis-tocene	Consolidated dune ridges	0-60	Ridges composed predominantly of tan to white limestone grains, medium to massive bedding, cross-bedding common, upper surface commonly case-hardened, lower sections semi-consolidated to consolidated; solutional development common; lower sections interbedded with sandstone and clay layers.	May be a source of ground water from solutionally enlarged openings in limestones. Well at Burg-el-Arab reported to tap this formation has a low porosity but high permeability. Salinity of water at Burg-el-Arab well ranged from 1200-9000 ppm.
Tertiary	Plio-cene		0-70	Oolitic limestone and sandy limestone interbedded with sandstone and shale	Low permeability; very poor water-bearing formation; acts as confining bed to water in underlying formation
	Miocene	Marmarica Limestone	900-1 000	Light coloured, partly chalky, fossiliferous, limestone interbedded with marl and clay. Limestone becomes progressively sandy from west to east.	Yields relatively large amounts of water from solutionally enlarged fractures and bedding planes. Well drilled to supply water for oil test holes report yields of more than cubic meters per hour. Chloride content of the water is generally 3 000-8 000 ppm
		Moghra Formation		Argillaceous limestone interbedded with sandstone and shale	
	Oligo-cene		600	Sandstone interbedded with thick sections of shale, grading downward to marine shales	Not a water-bearing formation
	Eocene	Bartonian Shale	200	Dark greyish-green, silty, glauconitic shale	Not a water-bearing formation
		Thebes Formation	50-100	White, chalky limestone and chert, fractured and cavernous	Yields highly saline water

Table 34 (cont.)

Geologic Age		Topographic or Stratigraphic Unit	Approximate Thickness	General Lithologic Character	Water-Bearing Properties
Period	Epoch		metres		
Tertiary	Paleocene	Esna Shale	?	This unit not reported in literature in the Coastal zone, but it may be present beneath some areas.	Not a water-bearing formation
Cretaceous	Senonian		130	Chalk, limestone and clay	Some section yield water that is more saline than sea water
	Turonian		180	Limestone and shale	
	Cenomanian		700	Dolomite, shale and sandstone	
	Lower Cretaceous	Equivalent to the Nubian sandstone of the Western Desert	1400+	Calcareous sandstone and dolomite	Excellent water-bearing unit in southern and central part of Western Desert but beneath Coastal Region yield is less and water is highly saline.

relatively low water table gradient implies very slow movement of groundwater towards the sea and this slow movement results in the solution of relatively large amounts of soluble salts from the Miocene limestones. This, along with the proximity to the sea, largely accounts for the salinity of water in the aquifer.

Recharge to the main water table occurs through direct infiltration of precipitation and through infiltration of surface runoff, particularly near the coast, where water ponds form after heavy rains. Discharge occurs through extraction from shallow wells, evapotranspiration where the water level is near the surface, and subsurface outflow to the sea.

There is little uniformity of water quality or yield from wells tapping the main water table, except near the coast in the alluvial sediments. The lack of uniformity is undoubtedly related to the secondary porosity of the aquifer which is developed by solutionally enlarged openings along joints and bedding planes. Where relatively fresher water is encountered, it is related to vertical and lateral porosity which allows more rapid movement of water to and within the aquifer, to topographical conditions favourable for internal drainage, and to geological conditions favoring the accumulation of ground water. In all instances, fresher water floats on more saline water and the thickness of the fresh water zone is related to the amount of recharge reaching the aquifer and to the altitude of the water level above mean sea level. Near the coast in the alluvial sediments, the water quality is more uniform and the fresh water layer is generally thicker because the water table is near the surface and receives substantial amounts of recharge by direct infiltration of rainfall and surface runoff.

Yields of wells tapping the main water table are generally adequate to support a windmill if the water quality is satisfactory. However, excessive pumping causes rapid deterioration in the water quality. In many areas the upper relatively fresh water zone is so thin that it is not possible to develop any fresh water.

Coastal dunes water table. The coastal dunes are a prominent feature throughout much of the project area. From Alexandria to near El Alamein the dunes are very prominent, between El Alamein and El Dabaa they are less conspicuous, and from El Dabaa and Fuka they are only locally developed. Near Ras el Hekma the dunes are prominent and very well developed to about 40 km west of Mersa Matruh. East of Negeila they are cut by wadis which extend to the sea, and from Negeila to Sidi Barrani they are well developed in some areas and absent in others. West of Sidi Barrani they are well developed to near Sallum.

Recharge to the water table in the coastal dunes occurs through infiltration of precipitation, through lateral seepage of accumulated surface runoff behind the dunes in areas of favorable inland drainage, and through subsurface seepage from the main water table when it is higher than the water table in the dunes.

Discharge of water from the dunes occurs through collection galleries and wells, through subsurface seepage to the sea and inland to the lagoonal areas when the water level in the dunes is relatively high, and through transpiration by plants along the fringes of the dunes, and occasionally by deep-rooted plants on the dunes.

The position of the water table in the dunes is related to the balance between recharge and discharge, to topography, and to the hydraulic properties of the dunes. In areas where there is significant recharge from the various sources and little discharge, the water level may be a metre or more above sea level. In other areas where there is less recharge or more discharge, the water level may be only a few centimetres above sea level. The water table is somewhat above sea level and will generally be highest under the highest dunes, except where manmade effects disturb the natural conditions.

Where the dunes are well developed and receive substantial recharge, the water quality is very good, commonly less than 1 000 ppm total dissolved solids. Due to the limited recharge, however, the quality deteriorates rapidly if pumpage is excessive. Therefore, to extract substantial amounts of water from the dunes, it is necessary to carefully control the pumping and to monitor the changes in water quality. The quality of the water in the dunes is also related to the proximity and size of salt marshes. As a part of the recharge to the dunes is from seepage of ponded surface water, a salt marsh immediately behind the dunes causes recharge water to become saline before entering the dunes.

Synclinal basin water tables. In some areas in the coastal zone the interbedded limestones and clays have been folded into gentle synclinal (basin-like) structures. Where the relatively impermeable clay in such a basin is overlaid by limestone and where the basin lies above sea level, conditions are favourable for the development of groundwater. Such basins are recharged by rainfall, runoff or by subsurface inflow. The salinity of the water in the structural basins is lower than that of the main water table. Detailed test drilling by the British Commonwealth Army proved the existence of a synclinal basin at Fuka and less extensive drilling near Qataf-Gabal, and Hatowa indicated deviations from the normal geological structure which might be similar to the Fuka structure.

Where these structurally perched aquifers occur they supply good, though probably limited, supplies of groundwater. At Fuka, for instance, the synclinal basin has yielded water with a salinity of less than 1 000 ppm total dissolved solids for 25 years. The results of quantitative studies indicate that the synclinal basin at Fuka has the potential to yield more water than is presently being developed from properly located and pumped wells without excessive mutual interference or serious depletion of ground water in storage. Wells tapping the perched aquifers at Qataf-Gabal and Ras-el-Husan commonly produce water with less than 500 ppm total dissolved solids.

Locally perched water tables sometimes occur in wadis where there is an impermeable clay layer relatively near the surface. Where this condition has been observed in the project area, there is no potential for development because of the limited quantity of water and its high salinity. The high salinity of the water indicates that the flooding of the wadis is not frequent enough to flush the salts from the aquifer.

Depth of the water table. The depth of the water table in the project area varies from less than a metre to more than 50 metres, depending upon the relationship of topography to hydrology and upon the season of the year. Highest water levels occur from February to April, depending upon the length of the rainy season, and lowest water levels occur from October to November, depending upon the beginning of the rainy season. To the south of the area, wells with water deeper than 50 metres are utilized by the Bedouins; nearer the coast, the water table is, of course, closer to the land surface.

In the interdunal plain behind the coastal dunes, the water table is generally less than 5 metres below land surface. In the coastal dunes the water table generally ranges from 5 to 10 metres below the surface, depending upon the height of the dunes.

The depth to the water table in the structural basins varies according to topography and the depth to the subsurface confining layers. At Fuka, the semi-perched water table is between 13 and 14 metres below land surface. In the Qataf-Gabal area the water table is between 11 and 14 metres below land surface and at Ras-el-Husan it is about 45 metres below land surface.

Where locally perched water tables occur in wadis, the depth to water is generally less than 10 metres.

Quality of the water. The quality of the water encountered in the several aquifers in the area varies widely. Depending upon the hydrogeological conditions, the total dissolved solids content may vary from a few hundred to several thousand parts per million. Water quality also varies with seasons, being best immediately after the winter rains, and worst in the late autumn before the beginning of the rainy season. Water from the main water table aquifer may contain as much as 20 000 ppm total dissolved solids or less than 1 000 ppm.

In the alluvial sediments near the coast, the water quality is more uniform and the total dissolved solids are commonly less than 3 000 ppm.

In the coastal dunes the water often contains less than 1 000 ppm. Water from the structural basin aquifers is commonly good, but the locally perched aquifers in the wadis commonly contain water high in total dissolved solids.

5. The Present Use of Water Resources

5.1. Surface water

The available surface water resources in the region are:

(i) The surface runoff (sheet runoff).
(ii) The runoff of wadis.
(iii) The Nile water destined for the irrigation of the Extension Mariut Project.
(iv) The water carried out by the pipeline Alexandria - Mersa Matruh

The water carried by the pipeline is exclusively for drinking, and the Nile water concerns only the area of the Mariut Extension project. Thus surface water resources for agriculture in the rest of the region are the surface runoff and the runoff of wadis, both of which are a direct result of rainfall and depend on the total amount of it, its annual distribution and its intensity.

5.1.1. Natural winter watering

Natural watering of land in winter takes place in :

(a) the depressions, where the topographical situation favours the accumulation of the runoff of wadis or the surface runoff from the higher-lying area;

(b) the water spreading zones, where the runoff of wadis is spread freely following the slope and accumulating behind the natural obstacles (sandy dunes or rocky hills).

As the two processes are accompanied by a sedimentation of the fine materials, the depressions and part of the spreading areas usually contain deep alluvial soils.

In the areas of an undulating relief, (Dabaa, Fuka) most of the areas cultivated with barley receive additional water from the surface runoff of the surrounding higher areas. Farmers know by experience the locations where surface runoff accumulates and these locations are the first to be ploughed for barley cultivation. On the other hand the runoff of wadis is naturally spread in the coastal plains and especially in those where no outlet to the sea exists. Most of the flooded areas are cultivated with trees or vegetables.

But this natural watering is very irregular, depending mainly on the topography. The low flat areas, upstream the natural obstacles, receive too much water which cannot be retained by the soil and is lost by infiltration to the deeper layers.

Owing to the irregular depth of flooding, the beneficiary area by natural spreading in the plains is very limited. Following heavy spring rainfalls, the depth of water in these low areas is excessive, preventing the timely preparation of the land for cultivation of spring crops (vegetables).

5.1.2. Artificial winter watering

Artificial watering is done on a small scale by:

a. constructing dykes to prevent the flow of the runoff of wadis to the sea;

b. constructing dykes, in the spreading zones, diverting the runoff of the wadis. In some cases spreading is facilitated by the opening of small channels by which the runoff water reaches some isolated fields;

c. constructing transversal stone or earth barrages in the beds of the small wadis to facilitate sedimentation and create terraces which in general receive abundant runoff from the wadis;

d. constructing small dykes parallel to the contour lines to retain the surface runoff.

To prevent the flow of wadi runoff from reaching the sea and to facilitate the natural winter watering in the spreading zones, EGDDO has constructed a certain number of dykes. The first objective was reached: by closing the mouths of the wadis with earth dykes, runoff water is kept away from the sea and the areas immediately upstream from the dykes are flooded during the spates. In some cases an enrichment of the ground water is also obtained. The second objective was not truly reached because, owing to the slope of the spreading areas, the runoff of wadis finds channels to follow in them and consequently only a very limited area upstream the constructed dykes is flooded.

Some small artificial winter watering works have also been constructed by individual farmers. The results are more or less favorable. Good examples of successful works are some farms planted with olive trees in the El Qasr area, the barrages constructed in the bed of Wadi Halazin, etc.

The construction of the above works by individual farmers shows that the importance of the winter watering has been well understood. Table 35 shows the dykes constructed by EGDDO and other government organizations.

Table 35

DYKES CONSTRUCTED IN THE COASTAL REGION BY EGDDO AND OTHER GOVERNMENTAL ORGANIZATIONS

Region	Number of Dykes	Total length	Approximate Volume	Purpose of Dykes
		m	m^3	
Sidi Barrani	8	3 700	55 500	To prevent the flow to the sea
"	12	2 100	99 500	To spread the runoff
Negeila	4	1 500	30 000	To prevent the flow to the sea
"	27	4 600	21 000	To spread the runoff
Abu-Laho	11	1 740	11 000	To spread the runoff
Um el Rakham	1	600	3 000	To spread the runoff

Table 35 (cont.)

Region	Number of Dykes	Total length	Approximate Volume	Purpose of Dykes
		m	m^3	
Mersa Matruh	2	2 700	63 000	To prevent the flow to the sea
	20	2 800	11 000	To spread the runoff
Garawla	3	2 800	16 000	To spread the runoff
Baqqush	1	460	12 400	To prevent the flow to the sea
	8	6 400	7 700	To spread the runoff
Fuka	19	15 000	60 000	To spread the runoff
T O T A L	116	44 400	300 100	

5.1.3 Cisterns

More than 3 000 cisterns dating back to the Roman period exist in the Coastal Region. Some of them (approximately 30%) have been cleaned and repaired by EGDDO and the farmers during the last years. They are the main drinking supply for the people and the animals inland.

The cisterns have been excavated in the rock and their capacity varies from 100 to 3 000 m^3. Dykes or channels constructed to facilitate the accumulation of the runoff in the cistern are sometimes found. Table 36 shows the cisterns in operation after cleaning by EGDDO and their capacity.

Table 36

CISTERNS IN OPERATION IN THE COASTAL REGION AFTER CLEANING BY EGDDO

Region	Number of Cisterns	Capacity	
		Total	Average
		m^3	
Burg el Arab - Hammam	15	2 000	133
Dabaa - Fuka	104	30 000	288
Mersa Matruh - Negeila	229	120 000	524
Sidi Barrani - Sallum	138	63 000	456
T O T A L	486	215 000	442

5.2. Groundwater.

5.2.1. Types of supply

Drilled wells

At present there are six drilled wells tapping the limestone aquifer at Fuka. All wells were originally equipped with turbine pumps but in March 1968 only three of the pumps were operative. The pumps are capable of producing about 25 m^3/hour, but generally no more than two of the wells are in working order simultaneously and these are operated no more than four hours each day during the irrigation season. During the non-irrigation season, the pumps are operated much less as they only supply water for Fuka village. The total annual withdrawal from the drilled wells is estimated to be about 48 000 m^3 although in some years the pumpage is much greater.

There are six drilled wells at Hatowa near Mersa Matruh which were drilled during World War II. These wells were used to supplement the Mersa Matruh municipal water system for several years but have not been used since about 1964. The wells are out of operation because of faulty pumps and poor water quality.

Twenty-four wells drilled during the UNDP/SF project were primarily for geologic and hydrologic data, and are not used for water supply.

Wells were drilled in several locations during World War II but, except for the wells at Fuka and Hatowa, all have been destroyed or abandoned.

Dug wells

The total number of dug wells in the region is not accurately known. There are about 1 040 dug wells equipped with windmills; many with some primitive mechanical arrangement for raising the water and many where the water is raised simply by bucket and rope.

The largest concentration of dug wells with windmills is in the Burg el Arab area where there are 526 windmills; however only about 200 of the windmills are in operation. The total annual estimated withdrawal by the windmills is 90 000 m^3. At El Qasr, there are about 110 wells with windmills and about 50 wells with shadoofs or buckets and rope. The total estimated annual withdrawal of ground water from the dug wells is 75 000 m^3. There are about 130 dug wells with windmills at El Dabaa with an estimated annual yield of 20 000 m^3. There are about 25 dug wells with windmills at Fuka with an estimated annual yield of about 5 000 m^3. There are about 20 dug wells with windmills in the Negeila area but due to lack of maintenance of the wells or windmills and because of saline water in some wells the groundwater extraction in that area is negligible. There are 34 dug wells equipped with windmills and 6 wells equipped with shadoofs in the Baqqush-Burbeita area. The estimated annual groundwater withdrawal in the area in 12 000 m^3. In other areas of the coastal zone there are about 215 windmills and an undetermined number of wells with shadoofs or buckets and ropes. The estimated annual withdrawal of water from these wells is 75 000 m^3.

A rough estimate of ground water developed from dug wells annually is 275 000 m^3.

Collecting galleries

The most extensive gallery development is at El Qasr, where there are 10 different galleries with a total developed length of about 11.5 km. The total annual withdrawal of water from collecting galleries in the El Qasr area is estimated to be 250 000 to 300 000 m^3, or 0.056 to 0.071 m^3 of water per metre of gallery per day.

Extensive gallery systems were developed during World War II in the Baqqush-Burbeita area. These galleries were reported to have produced 290 m^3 per day without over pumping. Unfortunately, these gallery systems have been allowed to deteriorate and in 1967 the only water taken from the galleries was with buckets from holes dug along the old gallery alignments.

Galleries less successful than those at Baqqush and Burbeita were constructed at Buqbuq, Zaqya, and Kilo 96 during World War II. All these galleries have been destroyed.

5.2.2. Means of lifting of water

Windmills

Windmills are the most common means in the project area of lifting water from wells, since winds blow fairly constantly with an average speed of 15-20 km/h and thus favour their use. According to the existing meteorological data it seems reasonable to assume that the average daily operation of the windmills is about 12 to 14 hours.

By the initiative of EGDDO, 1 041 windmills have been installed in the area from Sallum to Burg el Arab in a period of five years. However, many of these have been removed or are out of order. In the Burg el Arab area, water is now available through the Extension Irrigation project; elsewhere water may be scarce or highly saline or there may be mechanical troubles with the windmill. Finally, many farmers show a lack of interest in utilization of the groundwater.

Stone storage tanks of a capacity varying from 2.5 to 12 m^3 are constructed close to the windmills. With a few exceptions, these tanks are excavated and their level does not permit use of the water for irrigation by gravity.

The discharge of the windmills depends on the depth of water and on the wind speed. According to sporadic measurements made during the project, it varies from 0.2 to 0.8 m^3/h, with an average of 0.4 m^3/h.

Data on the windmills in the project area are shown in Table 37.

Table 37

WINDMILLS IN THE COASTAL REGION

Locality	Number of windmills installed	Number of windmills in operation	Average capacity of storage tanks	Irrigated areas		Amount of water used yearly	
				Trees	Vegetables	Per windmill	Total
			m3	number	feddans	m3	m3
Burg el Arab	526	200	3.5	40 000	15	450	90 000
Dabaa	190	190	3.5	15 000	8	150	28 500
Mersa Matruh	311	276	8.0	70 000	12	480	132 500
Sidi Barrani	14	14	3.5	(for drinking only)		100	1 400
Totals	1 041	680		125 000	35	Av. 370	252 400

Mechanically driven pumps

Mechanically driven pumps are used for lifting water from the galleries of El Qasr and from the drilled wells at Fuka. In the galleries, centrifugal pumps driven by diesel motors of 6-12 hp are used; in the drilled wells at Fuka, turbine pumps driven by electrical motors are used. Data on the pumps is shown in Table 38.

Table 38

MECHANICALLY-DRIVEN PUMPS USED FOR IRRIGATION IN THE COASTAL REGION

Locality	Pumping Unit	Type of motor	Horse-power	Dis-charge	Average amount of water pumped daily	Number of farmers using the water	Irrigated areas		
							Tree-plantations	Vege-tables	Total
			hp	m3/h	m3			feddans	
El Qasr	No 1	Diesel	8	25	100	Experi-			
"	No 2	"	10	30	120	mental	5	5	10
"	No 3	"	12	30	120	Farm			
"	No 4	"	10	30	120	8	30	20	50
"	No 5	"	10	30	120	9	20	40	60
"	No 6	"	10	30	120	21	20	33	53
"	No 7	"	10	30	120	8	-	35	35
"	No 8	"	10	30	120	23	35	75	110
"	No 9	"	8	20	80	6	6	24	30
"	No 10	"	6	15	60	7	1	10	11
	Omda El Qasr	"	6	25	100	1	18	(5)	18
Baqqush	Senussi	"	6	15	15	1	16	-	16
Fuka	No 1	Electrical	5	-	100	Experimental Station Fuka	38	2	40
"	No 2	"	5	20					
"	No 3	"	5	20					
"	No 4	"	5	20					
"	No 5	"	5	20					
"	No 6	"	5	-					
Burg el Arab		Diesel	22	25	150	Expermental farm	14	-	14
Total	19		158		1 445	87	203	244	447

5.2.3. Distribution and utilization of groundwater

Areas irrigated and amount of water used

Water from wells equipped with windmills is generally used to irrigate tree-plantations and some very small plots of vegetables. In the case of trees, the water is usually applied only during the dry season and mainly to young trees. The amount of water per tree, applied at intervals of 15 - 20 days, seldom exceeds 40-50 litres per application. In the case of vegetables, irrigation is applied more systematically, and 100-150 m3 of water per feddan are usually applied at intervals of 4-6 days.

Distribution systems

A sample-survey was made of 60 wells in the project area equipped with windmills.

In 51 percent of the cases, water is distributed from the storage tank to the trees by buckets carried by hand, in 32 percent of the cases there is a distribution system consisting of earth ditches, and in 17 percent of the cases water is conveyed to the trees by combination of earth ditches and buckets.

Having to carry the water in buckets, sometimes for several hundred metres, discouraged the farmers from taking full advantage of the wells. Thus, in general, the amount of water used for irrigation is much lower than the potentiality of the well. The total amount of irrigation water carried in buckets hardly exceeds 60 m3 per well, which is on average only 0.1 of its annual capacity.

On the other hand, the conveyance of the water in very small streams through earth ditches results in considerable losses from evaporation and infiltration. According to observations made on a farm in Burg el Arab, these losses amount to 50 percent of all the water lifted. Nevertheless, better use of the well is made under this method of conveyance, since the amount of water lifted approaches its maximum capacity. The farmer's choice of one of the above-mentioned systems depends mainly on the level of the water tank and on the topography of the soil. Where water is stored in excavated tanks, no other system of distribution is possible.

Water from galleries in the Qasr plain is conveyed to the head of the irrigation area through fixed iron pipes. It is then distributed over the area through earth ditches.

5.3. Other water resources

5.3.1. Nile Water

Mariout Extension Irrigation project

The Mariout Extension Irrigation project lies within the project area, starting approximately 10 km west of the desert road Alexandria-Cairo and extending 55 km parallel to the coast to a point 20 km west of Hammam. The gross area of the project is 30 000 feddans, and works have been completed on 18 000 feddans.

The main objective of the project is to apply an intensive agricultural plan through irrigation. The Nubaria canal (Nile water) and the Main Drain of the Behera region are used as sources of water, with a ratio of 6 parts of Nile water to 1 part of drainage water. Four successive pumping stations lift the water 30.5 m, to the maximum height of the land under irrigation.

The main canal is 70 km long. Secondary canals have been constructed at a distance between them of 2 km and tertiary canals at a distance between them of 150 m.

With very few exceptions all these are open earth canals, most of them being higher than the surrounding natural land. The water is distributed in the network by manually operated control structures. A dense system of open earth drains, approximately 1 m deep, runs parallel to the canals. Drainage water flows away under gravity.

The dimensions of the plot units are 150 x 75 m, or 2.7 feddans.

Levelling has generally been applied, involving an average volume of 250 m3 per feddan of earth moved.

Furrow irrigation is employed, the length of the furrows being 75 m and the admitted maximum longitudinal slope 0.5 percent. The depth of water applied per irrigation varies from 60 to 100 mm, according to the crops.

The water requirements of the crops have been calculated at 6 000 m^3 per feddan yearly. The irrigation efficiency (ratio between amount of water applied in the field to the amount of water delivered at the head of the main canal) is expected to be 0.60.

Dabaa irrigation project

The Dabaa irrigation project, the execution of which is still under study, concerns the reclamation through Nile water of an area of 60 000 feddans located entirely in the project area and comprising the areas west of El Alamein and Dabaa. Water will be taken from the main canal of the 210 000 feddans of the West Nubaria project, which is situated east of Dabaa and is now under construction. The main canal of the Dabaa project, which will be 80 km long, will start from pumping station No. 5 of the West Nubaria project at a level of 50 m and end at a level of 40 m.

The amount of water needed for the Dabaa project is 1.8 million m3 daily or 21 m3/s, which corresponds to 7.5 mm of depth of water daily.

5.3.2. Water pipeline

A pipeline is used for carrying fresh drinking water to Mersa Matruh and to the villages lying on the road between Alexandria and Mersa Matruh. It consists of iron pipes 8 inches in diameter, dates back to the second world war, and follows the Alexandria-Mersa Matruh road for about 300 km, supplying Nile water from the Nubaria canal. Seven pumping stations, spaced at roughly regular intervals and each of 40 hp, provide the pressure for conveying the water.

Water tanks varying from 400 to 4 000 m3 in capacity have been constructed by the pumping stations to ensure the continuous supply of water in case of damage to the pipeline.

The amount of water reaching Mersa Matruh through the pipeline varies from 300 to 650 m^3 daily. Fresh water is mixed with the gallery water in a ratio of 1:1 to 1:4 (according to the needs) and distributed by the fresh water system of Mersa Matruh. This amount of water hardly suffices to cover the needs of the town during the off season. In the summer time, with the great influx of tourists from Cairo and Alexandria, the shortage of water is great.

The pipeline and the pumping stations are in a bad condition after so many years of continuous operation. A programme of renewal was started in 1967 and part of the pipeline near Mersa Matruh was replaced by asbestos pipes of the same diameter.

The water supply of Mersa Matruh is a very serious problem, the solution of which, while outside the scope of this project, demands special studies and considerable capital investment.

6. The Available Water and the Scope for Development

6.1. Surface water

6.1.1. The runoff of wadis

According to the rough estimate given in Table 32, the available annual runoff (frequency 0.65) of the 123 wadis in the project area having catchment areas of more than 10 km2, is 6 874 000 m3. With the annual runoff of the 95 remaining wadis (catchment area less than 10 km2), total annual runoff amounts to 7 500 000 m3. If a frequency of 0.50 (average) is taken into consideration, the estimated available annual runoff is 11 000 000 m3.

Most of this water is lost to the sea because of the lack of retaining and spreading works. It is estimated that only 20 percent of the total available runoff is profitably used for improving the water conditions of the cultivated lands, either by natural spreading on the depressions and the plains or by the few existing terracing works and diversion dykes.

As wadi runoff is the main water resource of the region, its profitable use is basic for the area's water development. It may be utilized in the following ways:

Storage by retention dams

Storage by retention dams is an attractive method, since the stored water can be used both for supplying the villages with drinking water and for irrigating vegetables and tree plantations during the summer period. However, the following requirements must be met:-

(a) the topography of the stream valley must provide a feasible dam and reservoir site with adequate storage capacity;

(b) there must be certainty that the reservoir will be filled each year;

(c) the geological conditions of the dam and reservoir site must be such that the stability of the dam and the water tightness of the reservoir are assured.

Although, from the topographical point of view, there are some very suitable sites for the construction of retention dams, the hydrological and geological conditions are, in general, unfavourable. In fact, according to hydrological studies carried out under the project, the total annual runoff (frequency 0.65) of Wadi Ramla, which is one of the most important wadis of the region, is not more than 275 000 m3. Also, at least one drought year is to be expected every ten years. Thus it cannot be guaranteed that the necessary amount of water can be stored in the retention dam each year. A retention dam with interannual regulation or connected to neighbouring wadis to increase the amount of annual runoff stored might be a solution, but the cost of the dam would be considerably increased. On the other hand, an electrical resistivity survey carried out at Wadi el Kharruba by the geophysical section of the Desert Institute in 1957 1/ proved the absence of a continuous layer of impermeable material which would prevent the retained water from leaking away.

There are other adverse factors for the construction of retention dams that should also be taken into consideration. They are:-

(a) the high rate of evaporation (1 500 m per year on average). This would diminish the efficiency of the dam, especially if there were interannual regulation;

1/ G.B. Ghazarian "Final Report on the Electrical Resistivity survey carried out at Wadi El Kharruba" March 1957, Scientific papers of the Desert Institute No.10.

(b) the high sedimentation yield of the watersheds due to the high degree of erodibility of the soils. This reduces the storage capacity of the reservoir;

(c) peak discharges necessitating the construction of very costly emergency spillways.

Consequently it is concluded that the construction of retention dams for the utilization of wadi runoff is of doubtful feasibility. However, owing to the scarcity of fresh water in the region, further investigation of the possibility of constructing a retention dam on Wadi Ramla is worthwhile. Not only is this the most favourable case, but it would help solve the water supply problem of Mersa Matruh.

Storage in artificial reservoirs

Wadi runoff could be stored in artificial reservoirs (water tanks), mainly for drinking purposes. Obviously these reservoirs should be covered by concrete slabs to avoid evaporation and pollution, and their cost would be very high. The cost of an artificial reservoir is estimated at approximately £E 10 per m3 of storage capacity, which implies an annual amortization cost (amortization in 30 years with an interest of 5 percent) of £E 0.650 per cubic metre of water. When the cost of maintenance, pumping and transportation of water is added, the total cost will certainly be prohibitive. This solution can be considered only in exceptional cases for drinking purposes, e.g. for four artificial reservoirs of a total capacity of 500 m3 which have been constructed recently by EGDDO at El Sallum to provide the village with drinking water. They are supposed to be filled by the runoff of a small wadi near the village, and they cost £E 6 000, i.e. £E 12 per m3 of storage capacity.

Winter watering of agricultural lands

Winter watering is indubitably the most economical way of utilizing the runoff, and can be done by flooding, by spreading, or by terracing the gently-sloping areas of deep soils for the flash floods of wadis. The water is retained by the soil and rendered to the plants according to their needs. After saturating the root zone, some of the water may penetrate the deeper layers and recharge the underground aquifer. Plants with deep root systems, such as olive trees, vineyards etc. can also take more advantage of the stored water.

The design of winter watering projects for the region should be based on the following general principles:

(a) Since winter watering cannot give the same results as real summer irrigation, the cost of the works should be kept low, expensive lining of canals or levelling of the land being excluded;

(b) since the runoff of the wadis is limited in relation to the area suitable for cultivation, a good distribution system by which uniform spreading of the water can be obtained is essential;

(c) since the time of wadi flows cannot be predicted and their duration is generally very short, automatic systems of water distribution not needing any human intervention are required.

Methods of winter watering

There are several methods of winter watering, which depend on the ratio of the spreading area to the amount of runoff available and to the local soil and topographical conditions. The three methods described below were studied under the project and five detailed schemes for immediate implementation were prepared.

(a) Winter watering by flooding

This method is suggested for gently-sloping areas which are free from gullies or depressions, and when the runoff of the wadi is relatively important. The water is directed by canals to the beneficiary area, which is divided into small basins by dykes. The layout and construction of the basins are such that the entire beneficiary area is submerged. After filling one basin, water passes to the next through pipes or spillways. Examples of this method of winter watering by flooding are the Wadi Maguid and the Wadi Enthely schemes.

(b) Winter watering by spreading

This method is suggested for the more sloping areas and when runoff is not sufficient to submerge the whole beneficiary area. Spreading is based on the construction of two series of dykes, one series running from left to right, and the other from right to left, across the area and down the slope, the dykes being set at a small angle to the contour. After flowing down and across the slope in shallow streams along the length of a dyke of one series, the water flows round the end of it and is picked up by a dyke of the second series, which conducts it further down the slope and across it in the opposite direction. In this way the available runoff is accumulated in narrow strips upstream from the dykes which can be planted with trees or vegetables. The angle to the contour of the dykes is such that the velocity of the water, even in the case of maximum discharge, is kept low, thus avoiding erosion. An example of this method is the Wadi Wakal scheme.

(c) Winter watering by terracing

In the case of wide wadis with even bank-slopes but having land downstream unsuitable for cultivation, terracing can be done, a series of parallel dykes across the channel and along the contour being constructed. This technique is not new in the project area and there are many successful examples of terraces in the channels of wadis, built by the farmers and planted with olive trees.

After filling one terrace the runoff flows to the next through provided side-openings. A gradual silting of the terraces with fine materials can be expected, and the side-openings must be so designed that all the excess water may pass through, rather than flow over the earth dykes. The Wadi Abou Moubarak scheme is an example of winter watering by terracing.

Possibilities of winter watering in the project area.

The above briefly described methods of winter watering can be widely applied in the area, as follows:-

- The flooding method on the plains of El Qasr, Suiniyyat (Abu-Laho), Baqqush, Garawla and several other smaller plains between El Negeila and Mersa-el-Asi.

- The spreading method on several gently sloping areas all along the North Western Coastal Region and particularly in the areas of Ghot-Rabah, Garawla, Abou Laho, El Negeila, the area between Baqqush and Ras el Hekma, and the western part of Fuka.

- The terracing method on all wadis which do not peter out on the cultivable land, i.e. on several wadis in the area between Sidi Barrani and Mersa-el-Asi.

Table 39 gives the roughly estimated total area on which winter watering can be applied.

Table 39

ESTIMATED AREA OF POSSIBLE WINTER WATERING IN THE NORTH WESTERN COASTAL REGION

Type of Winter Watering	Beneficiary areas		Average annual runoff used	
	Gross	Net	Total	per net feddan
	feddans	feddans	m3	m3
Flooding	7 000	6 000	6 000 000	1 000
Spreading	8 000	3 000	1 500 000	500
Terracing	1 500	1 000	2 000 000	2 000
T O T A L	16 500	10 000	9 500 000	950

Recharging of aquifers

Artificial recharge of aquifers may be used successfully where the groundwater supplies are being depleted by increasing pumpage, as is the case in all the aquifers of the North Western Coastal Region. The value of this practice depends on the availability of runoff and the permeability of the soil over which the water will be spread. The basin method of artificial recharge of aquifers appears to be most promising. It consists of impounding the water diverted from the wadis in a series of basins formed by dykes or banks built on the contour. The layout and construction of the basins are such that the entire spreading area is submerged. The main problem of the method is the decrease of the percolation rate during the life of the basin, since water containing silt or other fine materials causes sealing of the surface of the spreading area. Special treatment of the land surface may improve its ability to absorb at good rates for long periods.

As there is no constant annual surplus of runoff in the region which can be used exclusively for recharging aquifers, the recharging has to be part of the winter watering. In the dry years, the limited amount of runoff will be enough for humectation of the superficial layers of soil and will be used directly and more profitably by the plants. In the years of heavier rainfall, the water, after saturation of the superficial layers of soil, will penetrate to the deeper layers and recharge the aquifers. Thus winter watering will,at the same time, recharge the aquifers.

6.1.2. Sheet runoff

Sheet runoff is the surface runoff that flows over the land. Its amount depends on several factors such as rainfall intensity, seasonal occurrence of precipitation, vegetal cover, land scope and soil type. For small basins, the effect of storm rainfall intensity is more influential in precipitation-sheet runoff relationship than the annual precipitation totals alone.

Measurements of sheet runoff begun in February 1968 in the Fuka region did not lead to any result because no significant rainfall occurred there after February. Thus only a very rough estimate of the surface runoff coefficient could be made, based on some general observations in the field. For short courses of water flow (50-100 m), the annual sheet runoff coefficient (relationship between annual rainfall and annual runoff) is estimated to vary from 0.15 to 0.35, depending mainly on the slope of the land, its treatment and the type of soil. For longer courses of water flow, the sheet runoff coefficient must be lower, 0.05 to 0.10. The sheet runoff is the only surface water resource in the cultivated area upstream from the escarpment of the plateau and in a large area between Ras el Hekma and Burg el Arab, where there is no evidence of a hydrographic network.

Sheet runoff in the project area can be utilized either through the construction of water conservation works for its immediate use or by first storing it in the existing cisterns.

Water conservation works for immediate water use.

Water conservation works for immediate use of sheet runoff can be utilized in a very large scale in the North Western Coastal Region, where more efficacious methods of water improvement are not possible.

The main aim of such works is to conduct the sheet runoff on to restricted areas of good soil. By reducing the area which receives the sheet runoff, the amount of water given per surface unit is increased. Besides improving the water conditions of the land, the water conservation works provide effective erosion control.

In areas of uniform slope, water conservation works consist of dykes constructed parallel to the contour lines, the cultivation of winter crops being restricted to narrow strips upstream each dyke, where an accumulation of the sheet runoff will occur. The ratio between non cultivated and cultivated area can be 3:1 or higher. The depth of water that will be received by the cultivated strips is $H = h + CRh$, where h is the annual depth of rainfall, C is the annual sheet runoff coefficient and R is the ratio between non cultivated and cultivated areas. Considering $C = 0.25$ and $R = 3$, the depth of water that will be received by the cultivated strips will be $H = 1.75$ h.

The two demonstration projects in Negeila, one of which is being implemented, are examples of this method of utilizing sheet runoff. Sheet runoff accumulates naturally on the flat lowest-lying land of depressions in the project area, and there farmers have cultivated barley for centuries. But owing to the small catchment area of the depressions, the barley fields receive a very limited amount of water and only once every four or five years is there a satisfactory yield of barley. Also, a progressive degradation of the soils takes place, due to the concentration of salts on the surface of the flat lands, as the soil survey of the area has shown. In such cases, the aim of water conservation works is to accumulate sheet runoff on the edge of the depressions by means of peripheral dykes. The surface water development micro-project of Fuka and most of the Fuka water development plan are based on this principle.

Water conservation works for sheet runoff utilization can be applied progressively to a large part of the agricultural land of the region, i.e. in a gross area of at least 120 000 feddans. It must be emphasized that such works do not only improve the water conditions of the lands, but also give the soils effective protection against erosion, which seriously menaces the cultivated areas of the region.

Storage of sheet runoff in cisterns

Sheet runoff in the region can be stored in the numerous cisterns once they have been cleared and repaired. The stored water can be used for human and animal consumption and, in some cases, for establishing tree plantations, the young trees being given small amounts of water during the dry season.

The catchment area of each cistern should be large enough to provide it with the needed amount of sheet runoff, e.g. for a cistern of a storage capacity of 1 000 m3 the catchment area should be at least 0.5 k^2 (120 feddans) to fill the cistern each year.

Some small earth works (small dykes or ditches) are sometimes necessary to lead the sheet runoff into the cisterns.

According to information given by EGDDO, the cost of cleaning and repairing the cisterns is £E 0.70 per m3 of storage capacity. On this basis, and on the basis of the amortization and maintenance costs, and since the effective storage capacity of cisterns is 70 percent of their total capacity on average, it is estimated that the average cost of water will not exceed £E 0.100 per m3. This is thought to be the lowest cost obtainable at present in the North Western Coastal Region for stored water. It is therefore recommended that the needed number of cisterns be restored as soon as possible to ensure sufficient drinking water for the human and animal population and occasional irrigation to young trees, to keep them alive during the dry season. The total number of cisterns in the region is believed to be some 2 500. Hence it may be assumed that, with an average effective storage capacity of 400 m3 per cistern, the amount of water that can be assured yearly, after all the existing cisterns are cleaned, is 1 000 000 m3.

6.2. Staff requirements and training

A permanent staff for the investigation and evaluation of groundwater resources should be maintained with headquarters in Mersa Matruh. This staff should include as a minimum a senior engineer, geologist and chemist, one of whom is designated as Chief of the Section. The Chief should have the responsibility for planning (in cooperation with his supervisors) and implementing a programme for the systematic collection of basic water resources data, conducting investigations in selected areas, and performing research on specific problems related to the occurrence and development of groundwater. The three senior groundwater specialists should be supported by other well trained professionals as required to properly undertake the planned investigations. A sufficient number of technicians and labourers are essential to carry out routine data collection, laboratory tests, field surveying and other supporting services.

A number of well-trained groundwater engineers, geologists and chemists are available on the staff of EGDDO. These men should be utilized in directing the work in the coastal zone and in training younger personnel in the proper field, laboratory, and office techniques. A number of the senior staff have been trained abroad and this training should continue whenever the opportunities are available. However, it is more important to have a properly developed, continuing, on-the-job training programme for younger professional and technical personnel. Only in this way can the experience and training of those best qualified be transferred to a sufficient number of personnel to cope with the problems in the coastal zone.

Periodically, a consultant from outside the U.A.R. should inspect the work plans, programmes and training to give advice as to where additional emphasis should be concentrated.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

1. Topography and Geology

The Northwestern Coastal Region as defined in this report extends from about 35 kilometres west of Alexandria to the Libyan border, a distance of about 480 kilometres. The area is bounded on the north by the Mediterranean Sea and on the south by the Libyan Plateau and varies in width from 5 to 40 kilometres.

Active sand dunes occur more or less continuously along the coast. Inland from the active dunes there is generally a narrow, flat, interdunal plain succeeded by one or more older consolidated dune ridges associated with ancient shorelines. South of the consolidated ridges there is an alluvial plain which slopes gradually upward to the Libyan Plateau. In some areas a pronounced escarpment occurs between the plain and the plateau and in other areas the transition is gradual. The plateau is generally flat but slopes upward to the south. In addition to the main topographic features there are areas of irregular relief forming hills and depressions of different orientation. The western half of the coastal zone is dissected by numerous wadis which generally are oriented south-north.

Rocks exposed at the surface in the coastal zone range in age from recent sediments along the coast to Miocene limestones in the escarpment and on the plateau. Recent and Pleistocene sediments consist primarily of windblown sand and silt and of alluvian material eroded, transported, and deposited by surface water. The active coastal dunes are generally loose to semi-consolidated limestone grains. Saline clays and silts are often deposited by temporary lakes which form behind the dunes or consolidated ridges after heavy rains. Where these deposits are significantly above sea level, the salts have been leached leaving good soils. The Pleistocene consolidated ridges consist of wind deposited limestone grains which are similar to, but more consolidated than, the active coastal dunes. South of the consolidated ridges the Pliocene and Miocene rocks outcrop. They consist chiefly of interbedded limestones, marls, and clay with some sandstone and shale. The geology of the area is shown in Map 1.

The rocks in the coastal zone strike in a general east-west direction and dip gently to the north except where they have been distributed by structural activity.

2. Climate

The climate of the zone is characterized by a low average rainfall of at best 150 mm per annum on the coast and rapidly decreasing inland. Most of the rain falls in autumn and winter, with about 70 percent of it in the period December-February. No rain falls in summer. The variability of the rainfall from year to year is high, although somewhat lower than in most similar areas. Summers are moderately hot (mean maximum for July 29°C), while winters are relatively mild (mean minimum for January 9°C). Frosts never occur along the coast. The region has a high relative duration of sunshine (80 percent for the whole year) and is subject to high potential evaporation (1 500 mm per annum). While the climate of the region may be classified as arid, measured by the low rainfall and the high radiation, the harsh conditions are somewhat tempered by the maritime influence, which acts favourably on the air moisture and temperature.

3. Soils

Good deep soils that are not saline are found only in small scattered plots in a narrow strip along the Mediterranean Sea. In the surroundings of Daba and Mersa Matruh such soils sometimes cover a sufficient area to make an organized, wide scale plan for development worthwile.

The areas with shallow soils - mainly found on the Miocene Plateau - are suitable for barley cultivation. To improve production, the construction of low dykes for water conservation is recommended.

Most of the project area is rockland suitable only for grazing.

Between El Alamein and Dabaa and south-west of Sidi Barrani, at some 3 to 5 km from the coast, vast dune areas are found. These soils are not suitable for agriculture, but in most areas they carry a natural vegetation with high fodder value.

Special attention should be paid in the whole coastal zone to soil conservation. Very large amounts of soils are lost through erosion by wind or water. Big areas, in the plains as well as on the plateau, that are covered with a thick layer of fertile soil, have in the course of centuries changed into barren land with rock at or close to the surface. This process is continuing. Soil conservation is therefore an urgent necessity in the whole area.

Further soil studies are necessary because the only semi-detailed and reconnaissance soil survey work was done under the project. The studies should be carried out in close cooperation with the Desert Institute, since this Institute has a team of scientifically trained soil surveyors.

The studies and methods recommended are :

1. Research on soil fertility with a view to providing advice on fertilization.

2. Research on the available moisture of the different soils for the purpose of growing the right crop on the right soil.

3. Research on the infiltration rate of the different soils to determine the most economic distribution of the limited amount of water available.

4. Research on the influence of caliche horizons on the growth and production of crops (especially deep-rooted crops).

5. Detailed soil surveys of the areas chosen for further development.

6. The use of aerial photographs and mosaics, as the only way to conduct soil surveys in desert areas.

7. The study of the geomorphologic pattern of the land and the use of photo-interpretation methods to save time and improve the accuracy of the location of the different soils.

8. The granting of fellowships in soil survey, rather than soil chemistry and physics, to Egyptian graduates and post-graduates doing soil survey work.

4. Water Resources

1. Fresh groundwater occurs in the coastal zone under the following conditions: in coastal dunes; in the main water table, and where geologic structure and stratigraphy has formed small synclinal basins which permit the accumulation of fresh water above sea level (as at Fuka).

2. Groundwater in the region occurs in the primary openings of the dune deposits, alluvial material and older limestone and in secondary solution openings in the limestone and consolidated dune deposits. Larger yields of water will be obtained where primary porosity is supplemented by solution development.

3. With proper development and management, greater quantities of groundwater can be extracted from the various sources than are being extracted at present.

4. Groundwater in the coastal dunes, alluvial areas, and limestone ridges where the saturated thickness of fresh water is 3 m or less can be effectively developed from properly spaced wells or galleries generally parallel to the coast. These wells and galleries would enable the capture of fresh water now being lost to the sea. Development must be carried out by carefully planned management systems, which include close monitoring of water levels, water quality and punpage.

5. Sea water intrusion into fresh water zones caused by excessive withdrawals has not taken place and the upcoming of salt water into wells or galleries is moderate and localized.

6. During periods of rainfall, water collects in the drainage basins and discharges through the wadis to the lagoonal and salt marsh areas and to the sea. Under the present hydrologic regimen only a small part of this runoff percolates to the water table and recharges the groundwater reservoirs.

7. In general, the salinity of groundwater increases with depth. Test drilling indicates that the deeper aquifer contains brackish to very saline water except:

a) In the southern part of the Qasr pilot area, where wells 60 m deep penetrate 15 m of relatively fresh water.

b) Where several wells drilled along the southern margin of the project area penetrated water in the Miocene limestone containing 5 000 to 10 000 ppm chlorides. This is a very productive aquifer that could be considered if desalinization becomes practical in the future.

3. Geophysical studies, though helpful, are inconclusive at the time of this writing and must be supported by test drilling before the method can be used effectively for delineating water supplies in the area.

9. Photogeologic work supported by field checking should be carried out to delineate geologic structural patterns, particularly joint systems. Areas of concentrated joints should then be drilled to determine if the photogeologic method can be used as a short cut to define areas of fresh water accumulation.

10. Systematic collection of climatic, hydrologic and geochemical data should continue to enable re-evaluation of quantitative results at the end of a five-year period of record.

Chapter 6

RECOMMENDATIONS FOR FURTHER INVESTIGATIONS

1. Climate

The inland meteorological stations should be kept in activity for the establishment of correlations between rainfall in the catchment areas and wadi flows. A sufficient number of stations now exists.

2. Soils

The study on soils carried out under this project was limited to the preparation of maps on which different kinds of soil are indicated. The compilation of the soil potentiality maps required considerable reliance upon judgment and experience since there was very little data available from experiment and study. Important characteristics and properties of the soils distinguished could not be determined, because the counterpart organisation did not possess the necessary equipment and often there was no time. The soil maps presented in these reports can therefore only be considered as an inventory of the available soil potential in the region. For its preparation of detailed development plans, it will be necessary to:-

(a) prepare detailed soil maps and potentiality maps of the areas chosen for development;

(b) collect data on the infiltration rate of soils. These data are needed for proper distribution of the limited amount of water that is available in most areas. The infiltration rate should be determined in the field on sites with undisturbed soils;

(c) collect data about the water holding capacity of soils, i.e., the moisture content between wilting point and saturation point. These data are needed for drawing up crop patterns and should be determined in undisturbed ring samples;

(d) study the soil fertility with a view to improvement of the soil fertility for specific crops;

(e) study the influence of caliche horizons on the rooting possibilities of crops. Indurated caliche horizons limit the depth of rooting, but the effect of weakly developed and soft caliche is less definite.

(f) study the special methods of agriculture carried out in the past. The remnants of thousands of ancient agriculture fields scattered over the whole region show that the area was rather densely inhabited in the past and that agriculture was carried out by using special methods.

3. Water Resources

3.1 Surface water

Further work and investigation should consist of:-

(a) Continuation of the hydrological investigations in the selected representative wadis to determine with a certain accurcy the rainfall-runoff correlation and to establish the annual runoff frequency curves. Measurements of the rainfall and runoff should be continued for a period of at least five years.

(b) Determination of the rainfall-sheet runoff correlation and establishment of the annual sheet runoff frequency curves under different physical soil conditions (permeability, slope, traitment, etc.). A number of cisterns should be selected for measurement of the rainfall and fluctuation of the water stored, following determination of the catchment area of the cistern.

(c) Implementation of one of each type of surface waterdevelopment projects. Study of the effect of the suggested winter watering and water conservation works on the improvement of the water conditions of the soil (determination of the soil humidity in different depths during a period of 2-3 years with parallel observations on the yield of the crops).

(d) Elaboration of a general plan of surface water development covering the whole Region. Selection on the basis of this plan of some pilot areas and the elaboration of detailed studies of water development in them.

(e) Preliminary study of the possibility of establishing a retention dam in Wadi Ramla for supplying the town of Mersa Matruh and for irrigation purposes. The study should include hydrological and geological investigations.

(f) Study of the feasibility of establishing dessalinization plants to provide the towns and villages with drinking water and eventually to provide irrigation water. Particular emphasis should be given to the feasibility of a dessalinization plant of a daily capacity of 1000 m^3 in the town of Mersa Matruh.

3.2 Groundwater

The following activities are recommended for future groundwater studies:-

(a) Continue data collection programme implemented during the project. This programme includes the periodic collection, analysis and tabulation of water levels and water quality data at about 60 points.

(b) Supplement quantitative tests made during the project with additional tests and re-evaluate all quantitative studies, utilizing the additional basic data collected since the original tests.

(c) Begin detailed water resources studies in areas other than those selected under the project.

(d) Implement a full-scale groundwater development programme in at least one area, as recommended in other sections of this report.

(e) Delineate in detail all coastal sand dune areas not bordered by salt marches or breached. Evaluate the occurrence of fresh ground water in sand dunes, definin[illegible] parameters for full scale development and management.

(f) Investigate areas where fresh groundwater is substantially above sea level; for example, at Qataf-Gabal.

(g) Continue with a more detailed invesgigation of the groundwater possibilities southwest of Sidi Barrani.

(h) Develop or reclaim additional cisterns in the Pleistocene consolidated dune ridges and other favourable areas.

Appendix 1

SOILS: WORKING METHODS AND TERMINOLOGY AND ABBREVIATIONS

Working methods

The use of aerial photographs and aerial photo-mosaics

Aerial photographs and specially aerial photo-mosaics are an indispensable tool for doing field work in and preparing maps of scarsely populated desert areas like the North Western Coastal Region of Egypt. Without them it would have been impossible to produce maps with even one-tenth of the detail or accuracy of the maps presented with this report.

In a semi-detailed survey, and especially in a reconnaissance survey, it is essential to have an understanding of the geomorphology of the area, i.e. the system of soil formation, sedimentation, erosion, etc. Only if the soil surveyor understands the regional distribution of the different soil materials, will he be able to map them intelligently, i.e. to draw the boundaries between the differences in soils correctly. Only then will he be able to set up a proper map legend in which not only the depth and the mechanical composition of the soils are represented, but also a correlation shown with other soil characteristics, such as salinity, $CaCO_3$ content, water holding capacity, water intake rate, topography, etc.

For this reason it is highly recommended that some of the Egyptian engineeers whose job it is to prepare soil maps, should be granted a fellowship in soil survey and/or aerial photo interpretation.

Aerial photo interpretation

Aerial photographs, scale 1:25 000, were studied under the stereoscope, and by interpretation preliminary soil boundaries, topographic features, etc. were drafted in different colours on the photographs. These data were transferred to controlled photo-mosaics scale 1:10 000 (the only ones available) of good quality.

Field work

The photo mosaics were used in the field as field maps. The preliminary soil boundaries obtained by photo interpretation were checked and when necessary corrected. Soil samples were collected for further analysis and sent to the laboratory.

Drafting

After finishing the field work the photo-mosaics were finalized, sometimes after a further study of the pertinent aerial photographs under the stereoscope and prepared with final symbols, names, etc. The boundaries, etc. on the photo-mosaics were reduced by pantograph to scale 1:25 000 for the pilot areas and to 1:100 000 for the reconnaissance survey. For this work three or four mosaics were assembled as one block and then reduced. Several reductions were brought together to form one map. Finally the maps were provided with the legend, helioprinted and coloured. A soil map and a soil potentiality map was prepared for every area.

Laboratory work

All soil samples were analysed in the laboratory of EGGDO in Cairo. The following methods were used in determining the different soil properties.

Physical Analysis

Determination of Saturation Percentage (S.P.)

1) Weighing a certain amount of air-dried soil.

2) Saturate this amount with distilled water and measuring the volume of water added for saturation.

3) $S.P. \frac{(\text{Volume of water added} + \text{moisture}) \times 100}{\text{Oven dried soil}}$

4) Field capacity = approximately $\frac{1}{2}$ S.P.

Permeability Determination

Measuring the volume of water which passes through a certain size of disturbed soil in a certain time.

Calculations:

$$\text{Permeability } (cm^3/\text{hour}) = \frac{\text{Volume of water} \times \text{hydraulic head} \times}{\text{Time} \times \text{hydraulic head} + \text{depth of soil}}$$

$$\frac{I}{\text{Area of the cylinder section}}$$

Mechanical determinations

Hydrometer method: using sodium hexametaphosphate 5 percent as a dispersion solution. The first reading after 40 seconds to determine clay and silt. The second reading after one hour to determine clay. These readings should be corrected to be under optimum temperature (20°C). The U.S. salinity laboratory tables were used to determine the texture.

Calcium carbonate percentage determination

Using calcimeter apparatus. Adding the suitable amount of hydrolic acid (1:3) on a certain weight of soil sample. Measuring the volume of CO_2, under a certain atmospheric pressure and temperature, and then calculating the calcium carbonate contents percentage.

Chemical Analysis

Salinity

Determination of the total soluble salts, using solu-bridge conductivity apparatus, by measuring the electrical conductivity of the soil saturation extract, in millimhos/cm^3.

Cations determinations

Calcium and Magnesium

1) By Versinate titration, using ammonium hydroxide and ammonium chloride (as a buffer solution), and erio-chrome black T. (as indicator).

2) By Versinato titration using NaOH, as a buffer solution, and ammonium purpurate as indicator.

Sodium and Potassium

Direct reading by Flame Photometer apparatus.

Anions determinations

Chloride

By titration with silver nitrate 0.005 N., using Potassium chromate 5 percent solution as indicator.

Carbonate and Bicarbonate

By titration with sulfuric acid (0.01.N), using phenolphthalein indicator for CO_3, and methyl orange for HCO_3.

Terminology and abbreviations

The terminology used in the legend, the soil descriptions and the tables is in general in accordance with that recommended for international use in the "Soil Survey Manual" (Hand Book No. 18, US Dept. of Agric.). With respect to the depth of soils, minor changes have been introduced.

1 - Soil depth

Very shallow	less than ca 30 cm
Limited deep	30 - 60 cm
Moderately deep	60 - 90 cm
Deep	More than 90 cm.

This nomenclature is not completely in accordance with the American classification but is adapted to the classification generally used by EGDDO in the region. It should be noticed that the nomenclature describes the thickness of a certain soil horizon, layer or solum, not only over rock but also over any other soil material that limits the rooting possibilities of plants (i.e. a caliche horizon).

2 - Mechanical composition

Every soil is composed of particles of different size; they are called soil separates.

The following size limits of the various soil separates can be distinguished:-

	Name	Abbreviation	Size limits (mm dia)
Gravel	Coarse gravel fine gravel grit	c.gr f.gr gt	Bigger than 40 4 to 40 2 to 4
Coarse Sand	Extremely coarse sand very coarse sand medium coarse sand	e.c.s. v c.s. m.c.s.	2 to 1 1 to 0.40 0.40 to 0.20
Fine sand	medium fine sand very fine sand extremely fine sand	m.f.s. v.f.s. e.f.s.	0.20 to 0.15 0.15 to 0.10 0.10 to 0.05
Silt	coarse silt fine silt	c.si f.si	0.05 to 0.02 0.02 to 0.002
Clay	clay	c	smaller than 0.002

Note: The different separates of analysed soil samples of this project were determined without removing the $CaCO_3$. Removal of $CaCO_3$ before determining the separates will probably result in less clay, less silt and more sand.

The texture of a soil is defined by the distribution or ratio of the different separates. Many soil properties (e.g. water holding capacity, permeability) are often correlated with the texture and therefore it is one of the most important characteristics of a profile.

The texture classification and nomenclature are derived from the American texture triangle, based on the percentage of clay (smaller than 0.002 mm), silt (0.002 to 0.05 mm) and sand ($<$0.05 mm). (See Fig. 1 of this appendix).

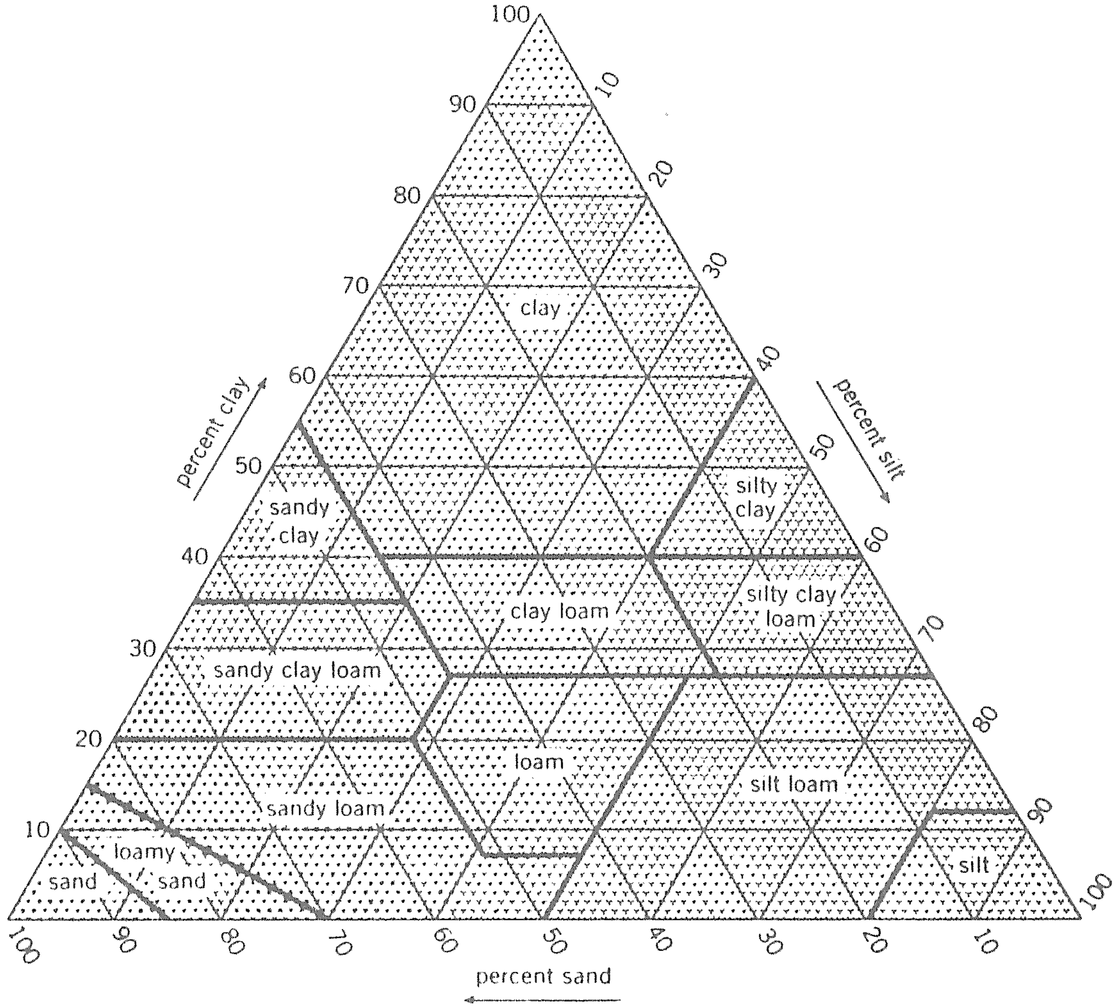
Appendix 1

FIGURE 1

U. S. Department of Agriculture, Bureau of Plant Industry, Soils, and Agricultural Engineering

GUIDE FOR TEXTURAL CLASSIFICATION

May 1, 1950



A subdivision of the names used in this classification is made with respect to the size of the sand where this is 50 percent or more of the soil material.

Basic textural class		Subdivision	General terms	
Sand Loamy sand	(s) (ls)	Coarse sand fine sand loamy coarse sand loamy fine sand	Coarse textured soil	sandy soil
Sandy loam	(sl)	coarse sandy loam fine sandy loam	moderately coarse textured soil	
Loam Silt loam silt	(l) (sil) (si)	- - -	medium textured soil	Loamy soil
Clay loam Sandy clay loam Silty clay loam	(cl) (scl) (sicl)	- - -	moderately fine textured soil	
Sandy clay Silty clay Clay Heavy clay	(sc) (sic) (c) (hc)	- -	fine textured soil	clay soil

3) Lime content

All soils in the North Western Coastal Region have a high percentage of $CaCO_3$ (more than 10 to 20 percent) and therefore no subdivision is introduced.

4) Salinity

Degrees of salinity are classified according to the following criteria:

Salinity class	E.C. of extract mmhos/cm (25°C)
Not saline	0 - 4
Slightly saline	4 - 8
Moderately saline	8 - 15
Saline and very saline	above 15

5) Soil permeability

Soil permeability was determined in disturbed samples in the laboratory and can be classified by the following criteria:-

Classes	Rates in cm/hour
Slow	
1) Very slow	less than 0.15
2) Slow	0.15 to 0.5
Moderate	
3) Moderately slow	0.5 to 1.0
4) Moderate	1.0 to 6.5
5) Moderately rapid	6.5 to 12.5
Rapid	
6) Rapid	12.5 to 25
7) Very rapid	over 25

6) Field capacity

Field capacity is the moisture content of a soil that, after complete saturation, has been drained freely for some days. In the field this situation will be reached after some days of excessive irrigation. The field capacity is a good approximation of the upper limit of the amount of moisture that is present in a soil and that can be consumed by plants. The lower limit of this amount is the wilting point. The difference between field capacity and wilting point is the amount of water that is really available for a crop. It is therefore important to know not only the field capacity of a soil, but also the wilting point, especially as there is quite a variation from one soil to another.

Appendix 2

HYDROGRAPHICAL SURVEY

BASIC DATA OF WADIS

Table 1

SALLUM - SIDI BARRANI

No. of Wadis	Name of Wadi	Region	Catchment Area					Average slope
			Total area	Length	Geology			
					Quaternary	Tertiary Pliocene	Tertiary Miocene	
			km^2	km		km^2		
1		Sallum	2.69	3.30	0.40	-	2.29	
2		"	4.49	5.5	0.49	-	4.00	
3	Akrab	"	35.35	7.9	-	-	35.35	0.0056
4		"	0.70	1.4	-	-	0.70	
5	Hazeyat	"	39.29	12.0	-	-	39.29	0.0603
6		"	0.74	1.8	-	-	0.74	
7		"	0.54	1.5	-	-	0.54	
8		"	0.60	1.1	-	-	0.60	
9		"	37.05	13.0	-	-	37.05	0.0086
10		"	1.08	2.2	0.48	-	0.60	
11		"	2.36	4.0	0.36	-	2.00	
12		"	0.75	1.3	0.75	-	0.75	
13	Abbas	"	26.19	14.5	-	-	26.19	0.0523
14		"	1.77	2.8	0.50	-	1.27	
15	Haltaba	"	19.41	14.0	-	-	19.41	0.0011
16		"	0.86	1.8	-	-	0.86	
17		"	4.64	6.5	-	-	4.64	
18		"	3.50	7.0	-	-	3.50	
19	Shaaba	"	10.84	12.2	-	-	10.84	0.0480
20(1)		"	26.47	14.5	1.47	-	25.00	0.0227
21		"	1.72	3.7	0.52	-	1.20	
22		"	15.32	14.6	-	-	15.32	0.0011
23		"	6.67	3.5	1.67	-	5.00	
24		"	12.79	15.2	-		12.79	0.0016
25		"	13.55	14.9	-	-	13.55	0.0016

Table 1 (cont.)

No. of Wadis	Name of Wadi	Region	Catchment Area					Average slope
			Total area	Length	Geology			
					Quaternary	Tertiary Pliocene	Tertiary Miocene	
			km^2	km		km^2		
26		"	14.50	14.7	0.50	-	14.00	0.0015
27		"	11.79	14.5	1.00	-	10.79	0.0019
28		Sallum	29.99	14.4	1.99	-	28.00	0.0019
29		"	35.57	14.0	1.00	-	34.57	0.0017
30		Sidi-Barrani	2.19	2.5	0.69	-	1.50	
31		"	25.50	14.5	1.50	-	24.00	0.0003
32		"	1.67	3.1	1.10	-	0.57	
33		"	1.62	3.0	0.81	-	0.81	
34		"	10.92	11.5	0.92	-	10.00	0.0752
35		"	1.67	2.3	0.40	-	1.27	
36		"	1.77	1.9	0.70	-	1.07	
37 1/		"	19.89	13.1	1.70	-	18.19	0.0380
38		"	6.35	13.5	0.80	-	5.55	
39 1/		"	17.31	14.3	2.00	-	15.31	0.0005
40 1/		"	19.29	14.3	1.29	-	18.00	0.0540
41		"	17.01	15.6	1.01	-	16.00	0.0533
42		"	56.10	15.8	-	-	56.10	0.0186
43		"	20.97	13.0	0.97	-	20.00	0.0008
44		"	13.40	10.7	0.60	-	12.80	0.0134
45		"	10.74	9.6	0.74	-	10.00	0.0280
46		"	0.90	1.9	0.20	-	0.70	
47		"	1.87	4.0	0.67	-	1.20	
48		"	12.87	9.5	-	-	12.87	0.0592
49		"	3.81	6.5	0.51	-	3.30	
50		"	16.54	9.7	1.00	-	15.54	0.0145
51		"	14.50	10.1	1.00	-	13.50	0.0238

Table 1 (cont.)

No. of Wadis	Name of Wadi	Region	Catchment Area: Total area	Length	Geology: Quaternary	Tertiary Pliocene	Tertiary Miocene	Average slope
			km^2	km		km^2		
52		Sidi-Barrani	7.64	10.0	0.64	-	7.00	
53		"	6.75	10.0	-	-	6.75	
54	Kireiza	"	7.49	9.5	-	-	7.49	
55		"	1.20	2.5	0.30	-	0.90	
56 1/		"	1.65	2.0	0.30	-	1.35	
57	Rikeit	"	36.24	10.0	1.24	-	35.00	0.0183
58		"	1.05	2.0	-	-	1.05	
59		"	12.25	6.5	1.00	-	11.25	0.0122
60		"	2.35	6.0	0.35	-	2.00	
61		"	2.15	5.8	0.30	-	1.85	
62		"	3.09	6.0	0.60	-	2.49	
63		"	3.19	6.1	-	-	3.19	
64		"	43.79	13.0	1.95	-	41.84	0.0051
65 1/		"	8.87	7.0	0.47	-	8.40	
66		"	3.25	6.5	0.25	-	3.00	
67		"	3.37	5.5	-	-	3.37	
68 1/		"	1.37	2.0	0.37	-	1.00	
69		"	5.85	5.0	-	-	5.85	
70		"	6.00	5.4	-	-	6.00	
71	Arad	"	11.45	6.7	-	-	11.45	0.0574
72		"	7.50	6.0	1.75	-	5.75	
73	Hamad	"	17.87	8.0	2.45	-	15.42	0.0288
74 1/		"	3.25	3.6	1.25	-	2.00	
75		"	6.32	5.5	1.32	-	5.00	
76	Faturi	"	5.62	5.0	1.22	-	4.40	
77	Thimda	"	5.80	5.4	1.10	-	4.70	

Table 1 (cont.)

No. of Wadis	Name of Wadi	Region	Catchment Area		Geology			Average slope
			Total area	Length	Quaternary	Tertiary Pliocene	Tertiary Miocene	
			Km^2	km		km^2		
78	Sabaya	Sidi Barrani	11.50	9.1	3.80	-	7.70	0.0099
79	Hireiga	"	18.62	11.0	4.02	-	14.60	0.0101
80	Labda	"	39.52	16.0	7.70	-	31.82	0.0096
81	Khur 2/	"	239.25	33.0	89.25	-	150.00	0.0052
82	Kharuba	"	82.60	18.5	42.60	-	40.00	0.0051
83		"	164.46	26.1	-	-	164.46	0.0064

1/ Group of wadis

2/ Sanab
Basbus
Magran
Kabsh

Table 2

AREA BETWEEN SIDI BARRANI AND MERSA ASI

No. of Wadis	Name of Wadi	Region	Catchment Area					Average slope
			Total area	Length	Geology			
					Quaternary	Tertiary Pliocene	Tertiary Miocene	
			km^2	km		km^2		
84		East Sidi-Barrani	12.29	7.3	-	-	12.29	0.0038
85		"	3.54	4.5	-	-	3.54	
86		"	16.65	7.4	-	-	16.65	0.0048
87		"	8.11	8.0	-	-	8.11	
88 1/		"	4.10	7.8	-	-	4.10	
89 1/		"	0.95	1.3	0.45	-	0.50	
90		"	11.94	8.4	0.44	-	11.50	0.0067
91		"	13.21	8.5	1.21	-	12.00	0.0044
92		"	2.77	6.0	0.77	-	2.00	
93		"	10.13	8.1	0.53	-	9.60	0.0053
94		"	6.72	8.4	0.42	-	6.30	
95		"	5.61	8.3	0.61	-	5.00	
96		"	3.88	8.5	0.48	-	3.40	
97		"	11.59	8.5	2.25	-	9.34	0.0047
98		"	11.32	8.5	1.72	-	9.60	0.0043
99		"	1.40	1.7	0.30	-	1.10	
100	Mat-kila	"	15.21	8.5	1.01	-	14.20	0.0047
101 1/		"	20.25	9.0	0.80	-	19.45	0.0055
102		"	6.47	9.0	0.47	-	6.00	
103		"	2.01	4.0	-	-	2.01	
104	Nafla	"	9.37	9.0	0.81	-	8.50	
105		"	9.59	9.0	0.59	-	9.00	
106 1/		"	10.10	9.0	3.95	-	6.15	0.0058
107		"	3.90	8.8	2.75	-	1.15	

Table 2 (cont.)

No. of Wadis	Name of Wadi	Region	Catchment Area					Average slope
			Total area	Length	Geology			
					Quaternary	Tertiary Pliocene	Tertiary Miocene	
			km^2	km		km^2		
108		East Sidi-Barrani	3.95	8.7	1.50	-	2.45	
109		"	8.71	8.8	3.10	-	5.61	
110		"	6.92	8.9	1.20	-	5.72	
111 1/		"	11.01	8.7	5.80	-	5.21	0.0052
112		"	1.35	3.2	-	-	1.35	
113		"	3.04	5.3	0.30	-	2.74	
114		"	6.00	8.5	1.15	-	4.85	
115		"	6.05	8.4	-	-	6.05	
116		"	8.82	8.5	-	-	8.82	
117		"	11.04	8.0	-	-	11.04	0.0066
118		"	4.94	7.8	-	-	4.94	
119		"	1.25	2.5	-	-	1.25	
120		"	9.46	8.0	-	-	9.46	
121		"	1.06	2.0	-	-	1.06	
122	Tar-faya	"	6.25	8.0	-	-	6.25	
123		"	6.87	8.5	-	-	6.87	
124		"	8.32	8.6	-	-	8.32	
125		"	2.91	5.0	0.40	-	2.51	
126		"	1.17	2.0	-	-	1.17	
127	Ziba	"	28.54	16.4	-	-	28.54	0.0050
128	Sidra	"	5.82	6.0	-	-	5.82	
129		"	0.62	1.4	-	-	0.62	
130	Shamas	"	44.46	15.8	-	-	44.46	0.0048
131		Negeila	15.12	15.5	0.62	-	15.50	0.0077
132		"	15.80	16.5	-	-	15.80	0.0047
133		"	7.65	7.5	0.65	-	7.00	

Table 2 (cont.)

No. of Wadis	Name of Wadi	Region	Catchment Area: Total area	Length	Geology: Quaternary	Tertiary Pliocene	Tertiary Miocene	Average slope
			km^2	km		km^2		
134		Negeila	5.11	6.0	0.41	-	4.70	
135		"	10.90	13.4	-	-	10.90	0.0054
136	Marzuk	"	36.37	15.8	-	-	36.37	0.0049
137 1/		East Sidi-Barrani	11.31	3.0	-	-	11.31	0.0031
138		"	19.37	16.9	-	-	19.37	0.0045
139 1/		"	21.37	18.0	1.37	-	20.00	0.0057
140 1/		"	15.35	19.5	-	-	15.35	0.0035
141	Abu Ameira	"	10.00	21.0	-	-	10.00	0.0044
142	Shira	"	52.86	23.0	1.86	-	51.00	0.0034
143	Hida	"	22.06	23.5	-	-	22.06	0.0040
144 1/	Ihwira	Negeila	37.96	23.0	1.96	-	36.00	0.0047
145	Gharnuk	"	1.36	2.5	0.40	-	0.96	
146	Abu Hisha	"	34.17	23.6	1.67	-	32.50	0.0036
147	Halbida	"	53.36	24.1	1.56	-	51.80	0.0036
148	Tawila	"	34.62	24.5	1.62	-	33.00	0.0042
149	Shibeiti	"	21.04	24.2	1.74	-	19.30	0.0051
150	Enthely	"	51.42	25.0	2.12	-	49.30	0.0051
151	Zikeiri	"	3.19	4.5	1.64	-	1.55	
152	Abu Safiek	"	10.21	11.0	1.75	-	8.46	0.0087
153		"	15.04	13.5	1.54	-	13.50	0.0114
154	Wakal	"	17.71	23.0	1.71	-	16.00	0.0074
155		"	49.14	24.2	2.87	-	46.27	0.0045
156	Zeinab	"	29.52	23.7	-	-	29.52	0.0044

1/ Group of Wadis

Table 3

UM-EL-RAKHAM - MATRUH

No. of Wadis	Name of Wadi	Region	Catchment area					Average slope
			Total area	Length	Geology			
					Quaternary	Tertiary Pliocene	Tertiary Miocene	
			km^2	km		km^2		
157		Um-el-Rakham	2.27	3.0	1.00	-	1.27	
158	Sanab	"	52.69	23.3	3.00	-	46.69	0.0044
159	Thimayed El Asi	"	26.77	23.3	1.00	-	25.77	0.0039
160	Taniya	"	3.56	4.3	0.56	-	3.00	
161	Dab	"	81.01	21.3	1.75	-	79.26	0.0042
162 1/	Kenuda Abdiya	"	76.89	20.5	-	-	76.89	0.0042
163	Halazin	"	31.39	19.5	1.00	-	30.39	0.0008
164		"	2.87	3.5	1.67	-	1.20	
165	Mahlab	"	29.29	19.5	1.00	-	28.29	0.0038
166	Mahkin	"	19.75	19.0	1.75	-	18.00	0.0036
167 1/		"	42.46	20.5	4.46	-	38.00	0.0034
168 1/	Magwah	"	30.74	4.7	5.79	-	24.95	0.0104
169	Has	"	56.60	22.7	-	-	56.60	0.0063
170		"	8.37	5.7	-	-	8.37	
171		"	48.00	20.7	-	-	48.00	0.0032
172		"	1.40	3.4	-	-	1.40	
173	Um-el-Rakham	"	40.14	20.0	-	-	40.14	0.0028
174	Habis	"	5.47	6.7	-	-	5.47	
175 1/		"	4.52	3.6	-	-	4.52	
176A	Ashtan	El Qasr	88.93	19.8	-	-	88.93	0.0047
176B 1/		"	10.41	3.1	4.21	-	6.20	0.104
177	Senab	"	21.50	19.3	-	-	21.50	0.005
178	Washka	"	8.94	5.5	-	-	8.94	
179	Maguid	"	65.30	19.5	-	-	65.30	0.0036

Table 3 (cont.)

No. of Wadis	Name of Wadi	Region	Catchment Area					Average slope
			Total area	Length	Geology			
					Quaternary	Tertiary Pliocene	Tertiary Miocene	
			km^2	km		km^2		
180	Madwar	El Qasr	48.56	20.0	3.75	-	44.81	0.0053
181	Ramla	"	124.35	22.0	2.35	1.0	121.00	0.0047
182	Kharruba	"	60.15	16.0	-	-	60.15	0.0044
183 1/		Matruh	10.90	5.2	1.20	-	9.70	0.0129

1/ Group of Wadis

Table 4

AREA BETWEEN MATRUH AND RAS-EL-HEKMA

No. of Wadis	Name of Wadi	Region	Catchment Area					Average slope
			Total area	Length	Geology			
					Quaternary	Tertiary Pliocene	Tertiary Miocene	
			km^2	km		km^2		
184	Tawawiya	Matruh	25.30	9.5	-	-	25.30	0.0077
185	Kheir	"	35.36	14.5	-	4.36	31.00	0.0072
186 1/		"	24.36	7.5	-	-	24.36	0.0090
187	Naghamish	"	116.66	23.5	-	4.75	111.91	0.0048
188	Garawla Kalailib	"	77.80	22.0	-	9.63	68.17	0.0051
189	Zarga	"	125.82	20.7	-	9.12	116.70	0.0051
190	Huraiga	"	101.72	21.0	-	11.72	90.00	0.0098
191	Kassaba	"	87.16	20.3	-	3.16	84.00	0.0061
192 1/		"	10.36	5.3	-	5.76	4.60	0.0172
193		"	33.29	17.0	-	2.00	31.29	0.0048
194		"	22.97	15.0	0.70	1.70	20.57	0.0049
195 1/		"	2.08	2.8	1.08	1.00	-	
196		"	10.00	14.8	1.00	1.00	8.00	0.0005
197		"	1.25	1.9	0.83	0.42	-	
198		"	15.32	13.8	1.09	1.09	13.14	0.0218
199		Baqqush	27.74	12.2	1.14	1.14	25.46	0.0479
200		"	4.39	5.3	0.60	1.89	1.90	
201		"	11.25	9.9	0.25	1.00	10.00	0.0036
202 1/		"	7.37	3.8	-	3.87	3.50	
203		"	13.80	8.3	-	-	13.80	0.0047
204		"	12.42	9.0	1.60	-	10.82	0.0046
205		"	16.07	8.9	1.07	-	15.00	0.00114
206	Kharun	"	31.54	8.8	-	-	31.54	0.0018
207	Abu smeit	"	42.40	20.7	-	-	42.40	0.0049

1/ Group of Wadis

Table 5

AREA BETWEEN RAS-EL-HEKMA AND FUKA

No. of Wadis	Name of Wadi	Region	Catchment Area					Average slope
			Total area	Length	Geology			
					Quaternary	Tertiary Pliocene	Tertiary Miocene	
			km^2	km		km^2		
208	Madwar	Fuka	37.34	20.8	-	-	37.34	0.0039
209		"	0.97	1.9	-	-	0.97	
210	Khreiza	"	21.37	14.5	1.0	-	20.37	0.0073
211		"	19.50	11.6	-	-	19.50	0.0066
212		"	13.97	10.8	-	-	13.97	0.0082
213		"	0.97	1.5	-	-	0.97	
214	Midawla	"	25.67	9.6	-	-	25.67	0.0044
215		"	22.97	12.5	-	-	22.97	0.0061
216		"	21.94	13.5	0.94	-	21.00	0.0059
217		"	148.67	15.9	2.67	-	146.00	0.0053
218		"	135.56	21.1	3.56	-	132.00	0.0041

Appendix 3

HYDROLOGY

1. Calculation of rainfall/runoff correlation

The rainfall/runoff correlation in the wadis has been calculated by the formula:

$$R = b_1 + b_2 h + b_3 T \qquad (1)$$

where $R = x_1$ = amount of runoff

$h = x_2$ = amount of rainfall

$T = x_3$ = duration of rainfall

For the calculation of the parameters b_1, b_2, b_3, the following formulas could be used:

$$\left.\begin{aligned} & b_2 \; \Sigma (\Delta x_2)^2 + b_3 \; \Sigma (\Delta x_2 \Delta x_3) = \Sigma (\Delta x_1 \; \Delta x_2) \\ & b_2 \; \Sigma (\Delta x_2 \Delta x_3) + b_3 \; \Sigma (\Delta x_3)^2 = \Sigma (\Delta x_2 \; \Delta x_3) \\ & b_1 = \bar{x}_1 - b_2 \; \bar{x}_2 - b_3 \; \bar{x}_3 \end{aligned}\right\} \qquad (2)$$

where $\Sigma (\Delta x_2)^2 = \Sigma x_2^{\;2} - N \; \bar{x}_2^{\;2}$

$\Sigma (\Delta x_3)^2 = \Sigma x_3^{\;2} - N \; \bar{x}_3^{\;2}$

$\Sigma (\Delta x_1 \; \Delta x_2) = \Sigma x_1 x_2 - N \; \bar{x}_1 \bar{x}_2$

$\Sigma (\Delta x_1 \; \Delta x_3) = \Sigma x_1 x_3 - N \; \bar{x}_1 \bar{x}_2$

$\Sigma (\Delta x_2 \; \Delta x_3) = \Sigma x_2 x_3 - N \; \bar{x}_2 \bar{x}_3$

(N = number of observations)

2. Rainfall/runoff correlation in Wadi Kilo 9

a. Basic data

	x_1 = R	x_2 = h	x_3 = T (days)	x_2^2	x_3^2	x_1x_2	x_1x_3	x_2x_3
	314	14.0	2	196.0	4	4 396	628	28.0
	355	7.7	1	59.3	1	2 733	355	7.7
	600	6.0	1	36.0	1	3 600	600	6.0
	1 000	7.2	1	51.8	1	7 200	1 000	7.2
	2 041	10.7	1	114.5	1	21 839	2 041	10.7
	6 619	15.2	1	231.0	1	100 609	6 619	15.2
	15 657	35.5	5	1 260.3	25	555 823	78 285	177.5
Σ	26 587	96.3	12	1 948.9	34	696 200	89 528	252.3
$\bar{x}_i$	3 798	13.76	1.71					

N = 7

b. Calculation of parameters

$\Sigma\ (\Delta x_2) = 1\ 948.9 - 7 \times (13.76)^2 = 1\ 948.9 - 1\ 325.4 = \underline{623.5}$

$\Sigma\ (\Delta x_2 \Delta x_3) = 252.3 - 7 \times 13.76 \times 1.71 = 252.3 - 164.7 = \underline{87.6}$

$\Sigma\ (\Delta x_1 \Delta x_2) = 696\ 200 - 7 \times 3\ 798 \times 13.76 = 696\ 200 - 365\ 823 = \underline{330\ 377}$

$\Sigma\ (\Delta x_3)^2 = 34 - 7 \times (1.71)^2 = 34 - 20.47 = \underline{13.53}$

$\Sigma\ (\Delta x_1 \Delta x_3) = 89\ 528 - 7 \times 3\ 798 \times 1.71 = 89\ 528 - 45\ 462 = \underline{44\ 066}$

Replacing the above found values in the system (2)
we have the following equations:

$$\left.\begin{aligned} 623.5b_2 + 87.6b_3 &= 330\ 377 \\ 87.6b_2 + 13.53b_3 &= 44\ 066 \\ b_1 &= 3\ 798 - 13.76b_2 - 1.71b_3 \end{aligned}\right\} \quad (3)$$

from which we obtain: $b_1 = -3\ 922$
$b_2 = 800$
$b_3 + -1\ 923$

Thus the formula (1) can be written:

$R = 800h - 1\ 923T - 3\ 922$

3. Rainfall/runoff calculation in Wadi Ramla

a. Basic data

	$x_1 = R$	$x_2 = h$	$x_3 = T$ (hours)	x_2^2	x_3^2	x_1x_2	x_1x_3	x_2x_3
	43 900	8.4	5.2	70.56	27.04	368 760	228 280	43.68
	25 000	7.2	12.0	51.84	144.00	180 000	300 000	86.40
	2 000	1.5	0.5	2.25	0.25	3 000	1 000	0.75
Σ	70 900	17.1	17.7	124.65	171.29	551 760	529.280	130.83
$\bar{x}_i$	23 630	5.7	5.9	N = 3				

b. Calculation of parameters

$\Sigma\ (\Delta x_2)^2 = 124.65 - 3 \times (5.7)^2 = 124.65 - 97.47 = \underline{27.18}$

$\Sigma\ (\Delta x_2 \Delta x_3) = 130.83 - 3 \times 5.7 \times 5.9 = 130.83 - 100.89 = \underline{29.94}$

$\Sigma\ (\Delta x_1 \Delta x_2) = 551\ 760 - 3 \times 23\ 630 \times 5.7 = 551\ 760 - 404\ 070 = \underline{147\ 690}$

$\Sigma\ (\Delta x_3)^2 = 171.29 - 3 \times (5.9)^2 = 171.29 - 104.43 = \underline{66.86}$

$\Sigma\ (\Delta x_1 \Delta x_3) = 529\ 280 - 3 \times 23\ 630 \times 5.9 = 529\ 280 - 418\ 250 = \underline{111\ 030}$

Replacing the above found values in the system (2)
we have the following equations:

$$\left.\begin{aligned} 2\ 718 b_2 + 29.94 b_3 &= 147\ 690 \\ 2\ 994 b_2 + 66.86 b_3 &= 111\ 030 \\ b_1 &= 23\ 630 - 5.7 b_2 - 5.9 b_3 \end{aligned}\right\} \quad (3)$$

from which we obtain: $b_1 = -7\ 930$

$b_2 = 7\ 110$

$b_1 = 1\ 520$

Thus the formula (1) can be written

$R = 7\ 110h - 1\ 520T - 7\ 930$

4. Rainfall/runoff correlation in Wadi Tawila

a. Basic data

	$x_1 = R$	$x_2 = h$	$x_3 = T$ (hours)	x_2^2	x_3^2	x_1x_2	x_1x_3	x_2x_3
	2 000	7.7	4	59.29	16	15 400	8 000	30.8
	13 700	15.0	5	225.00	25	205 500	68 500	75.0
	500	3.4	1	11.56	1	1 700	500	3.4
Σ	16 200	26.1	10	295.85	42	222 600	77 000	109.2
$\bar{x}_i$	5 400	8.7	3.33	N = 3				

b. Calculation of parameters

$$\Sigma\ (\Delta x_2)^2 = 295.85 - 3 \times (8.7)^2 = 295.85 - 227.07 = \underline{68.78}$$

$$\Sigma\ (\Delta x_2 \Delta x_3) = 109.2 - 3 \times 8.7 \times 3.33 = 109.2 - 87.0 = \underline{22.2}$$

$$\Sigma\ (\Delta x_1 \Delta x_2) = 222\ 600 - 3 \times 5\ 400 \times 8.7 = 222\ 600 - 140\ 940 = \underline{81\ 660}$$

$$\Sigma\ (\Delta x_3)^2 = 42 - 3 \times (3.33)^2 = 42 - 33.33 = \underline{8.67}$$

$$\Sigma\ (\Delta x_1 \Delta x_3) = 77\ 000 - 3 \times 5\ 400 \times 3.33 = 77\ 000 - 54\ 000 = \underline{23\ 000}$$

Replacing the above found values in the system (2)
we have the following equations:

$$\left.\begin{aligned} 68.78b_2 + 22.2b_3 &= 81\ 660 \\ 22.2b_2 + 8.67b_3 &= 23\ 000 \\ b_1 &= 5\ 400 - 8.7b_2 - 3.33b_3 \end{aligned}\right\} \quad (3)$$

from which we obtain: $b_1 = -3\ 765$

$b_2 = 1\ 907$

$b_3 = -2\ 230$

Thus the formula (1) can be written:

$$R = 1\ 907h - 2\ 230T - 3\ 765$$

5. Monthly rainfall

a. Alexandria Meteorological Station

YEAR	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	TOTAL
1915-16	0.0	0.0	14.0	10.0	109.0	14.0	8.0	2.0	0.0	0.0	0.0	0.0	157.0
1916-17	0.0	0.0	21.0	45.0	66.0	39.4	13.3	1.0	0.0	0.0	0.0	0.0	185.7
1917-18	0.0	8.0	8.0	64.6	38.9	31.1	6.0	0.0	0.0	0.0	0.0	0.0	148.6
1918-19	0.0	0.0	52.8	49.7	35.8	3.7	0.9	0.0	0.0	0.0	0.0	0.0	142.9
1919-20	0.0	3.0	53.9	126.5	34.9	42.3	11.3	0.0	0.0	0.0	0.0	0.0	271.9
1920-21	0.0	0.0	6.4	38.6	22.9	20.2	56.9	0.0	8.8	0.0	0.0	0.0	153.8
1921-22	0.0	9.1	22.6	42.2	62.7	5.4	3.3	0.0	0.0	0.0	0.0	0.0	145.3
1922-23	0.0	0.0	10.5	105.8	16.8	19.3	1.5	0.0	0.0	0.0	0.0	0.0	153.9
1923-24	0.0	4.8	0.0	61.5	80.3	48.4	0.2	0.0	0.0	0.0	0.0	0.0	195.2
1924-25	0.0	8.6	54.8	78.4	106.2	10.3	13.5	4.4	0.0	0.0	0.0	0.0	276.2
1925-26	0.0	2.3	19.5	29.5	16.0	28.3	16.7	9.3	0.0	0.0	0.0	0.0	121.6
1926-27	0.0	0.0	7.1	88.1	30.2	71.8	5.3	0.0	0.0	0.0	0.0	0.0	208.2
1927-28	0.0	0.0	168.0	29.1	17.2	30.3	7.9	0.0	0.0	0.0	0.0	0.0	252.5
1928-29	0.0	0.0	28.3	16.4	79.0	28.0	2.0	13.0	0.0	0.0	0.0	0.0	166.7
1929-30	0.0	5.5	35.4	85.0	92.3	20.9	0.4	0.3	0.0	0.0	0.0	0.0	239.8
1930-31	0.0	19.5	25.0	36.9	3.8	4.0	1.4	4.0	0.0	0.0	0.0	0.0	94.6
1931-32	0.0	0.0	5.9	14.1	100.7	18.4	0.0	0.0	3.0	0.0	0.0	0.0	142.1
1932-33	0.0	9.4	68.8	51.4	9.6	11.5	4.4	1.4	2.2	0.0	0.0	0.0	158.7
1933-34	0.7	0.0	57.9	34.2	52.4	0.1	2.3	10.8	0.0	0.0	0.0	0.0	158.4
1934-35	0.0	0.0	3.9	100.5	40.9	37.9	9.3	0.8	0.0	0.0	0.0	0.0	193.1
1935-36	0.0	2.5	37.0	14.3	3.3	15.3	0.2	0.0	11.7	0.0	0.0	0.0	84.3
1936-37	0.0	0.0	26.9	67.8	61.9	3.6	0.0	5.6	0.0	0.0	0.0	0.0	165.8
1937-38	0.0	26.2	25.4	27.0	61.0	39.8	13.5	1.8	0.4	0.0	0.0	0.0	195.1
1938-39	0.8	0.0	82.0	28.5	24.5	16.6	12.0	0.0	1.0	0.0	0.0	0.0	175.4
1939-40	0.0	0.3	7.0	13.6	74.2	43.5	6.0	2.8	0.2	0.0	0.0	0.0	147.6
1940-41	0.0	5.0	21.3	45.7	5.5	20.8	21.8	0.2	0.0	0.0	0.0	0.0	119.3
1941-42	0.0	2.6	5.4	88.2	11.1	10.5	7.7	0.0	3.8	0.0	0.0	0.0	129.3
1942-43	0.0	9.9	14.6	35.2	84.5	24.6	9.0	12.0	1.0	0.0	0.0	0.0	190.8
1943-44	0.0	24.8	14.1	24.2	36.1	10.6	0.0	4.5	2.0	0.0	0.0	0.0	116.3
1944-45	15.8	0.0	0.7	59.4	28.1	54.4	18.0	0.6	5.4	0.0	0.0	0.0	182.4
1945-46	0.0	0.2	65.6	25.7	17.1	29.7	25.1	0.0	5.3	0.0	0.0	0.0	168.7
1946-47	2.7	2.7	41.2	19.8	67.1	5.6	0.5	0.0	0.3	0.1	0.0	0.0	140.0
1947-48	0.0	2.5	28.0	4.7	23.5	59.9	51.8	6.8	0.0	0.0	0.0	0.0	177.2
1948-49	0.0	1.6	51.8	86.8	67.8	43.3	12.5	10.6	0.0	0.0	0.0	0.0	274.4
1949-50	0.0	0.0	0.0	159.5	97.2	13.0	11.6	9.0	3.0	0.0	0.0	0.0	293.3
1950-51	0.0	5.1	8.3	2.8	32.5	15.2	10.2	0.0	0.3	0.0	0.0	0.0	74.4
1951-52	3.0	8.1	14.8	68.7	39.0	36.0	9.8	0.0	0.0	0.0	0.0	0.0	179.4
1952-53	0.0	14.5	16.1	23.8	29.5	13.6	21.8	4.0	0.0	0.0	0.0	0.0	123.3
1953-54	0.0	8.0	28.7	57.3	4.9	0.9	2.0	0.0	0.0	0.0	0.0	0.0	106.7
1954-55	0.0	8.7	121.7	97.1	1.0	14.7	8.7	5.7	0.0	0.0	0.0	0.0	257.6
1955-56	0.0	0.3	57.1	97.3	78.1	26.3	18.3	0.0	0.0	0.0	0.0	0.0	277.4
1956-57	7.1	6.7	6.8	107.1	78.9	27.0	49.3	4.9	1.0	0.0	0.0	0.0	264.5
1957-58	0.0	20.7	41.9	89.9	53.1	9.5	0.2	0.3	0.0	0.0	0.0	0.0	215.6
1958-59	0.0	4.7	22.6	25.4	63.9	70.6	2.2	0.0	0.0	0.0	0.0	0.0	189.4
1959-60	0.0	24.5	4.7	37.1	70.9	5.8	26.9	1.3	1.1	0.0	0.0	0.0	172.3
1960-61	0.0	0.2	64.1	4.7	38.7	88.5	1.5	0.0	9.8	0.0	0.0	0.0	207.5
1961-62	0.0	34.0	3.8	60.0	45.6	34.9	0.4	0.1	5.3	0.0	0.0	0.0	184.1
1962-63	2.4	13.9	0.0	58.1	33.6	16.4	18.8	18.0	1.0	0.0	0.0	0.0	162.2
1963-64	0.0	4.8	11.4	19.9	41.1	58.4	7.3	0.0	2.6	0.0	0.0	0.0	145.5
1964-65	1.3	0.4	60.4	120.5	100.9	14.2	4.1	4.0	0.0	0.0	0.0	0.0	305.8
1965-66	0.0	18.1	3.4	21.4	43.9	8.8	5.3	0.2	0.0	0.0	0.0	0.0	101.1
1966-67	23.2	6.0	117.5	63.5							0.0	0.0	
1967-68	0.0	2.1	39.6	24.3	10.5	5.0	3.9	3.0					

b. Burg El Arab Meteorological Station

YEAR	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	TOTAL
1951–52	7.0	3.0	4.0	76.0	38.5	18.0	2.5	0.0	0.0	0.0	0.0	0.0	149.0
1952–53	0.0	28.0	0.0	31.5	4.0	12.0	14.5	0.0	0.0	0.0	0.0	0.0	90.0
1953–54	0.0	0.0	30.5	43.5	10.4	3.9	0.0	0.0	0.0	0.0	0.0	0.0	88.3
1954–55	0.0	17.0	88.3	88.0	0.0	0.0	0.0	5.5	0.0	0.0	0.0	0.0	198.8
1955–56	0.0	6.0	97.5	69.0	57.5	14.5	12.5	0.0	0.0	0.0	0.0	0.0	257.0
1956–57	0.0			79.0	74.0	41.0	16.0	5.0	0.0	0.0	0.0	0.0	
1957–58	0.0	92.5	37.5	26.5	69.7	5.0	0.0	0.0	0.0	0.0	0.0	0.0	231.2
1958–59	0.0	0.0	0.0	20.0	39.0	84.5	0.0	0.0	0.0	0.0	0.0	0.0	143.5
1959–60	0.0	30.0	3.0	31.0	84.5	5.5	7.5	0.0	0.0	0.0	0.0	0.0	161.5
1960–61	1.0	0.5	71.5	8.0	34.5	70.0	1.5	0.0	6.3	0.0	0.0	0.0	193.3
1961–62	0.0	79.0	4.0	61.0	28.8	0.7	0.0	58.1	2.0	0.0	0.0	0.0	233.6
1962–63	3.0	22.0	0.0	13.5	2.0	10.5	11.0	0.0	0.0	0.0	0.0	0.0	62.0
1963–64	0.0	5.0	14.0	29.5	49.5	4.0	6.5	16.5	0.0	0.0	0.0	0.0	125.0
1964–65	0.0	0.0	56.5	98.0	66.0	1.5	3.0	13.0	0.0	0.0	0.0	0.0	238.0
1965–66	0.0	10.5	1.0	3.0	0.0	21.0	3.0	0.0	0.0	0.0	0.0	0.0	38.5
1966–67	0.0	0.0	142.5	0.0	32.9	9.0	8.0	0.0	0.0	0.0	0.0	0.0	192.4
1967–68	0.0	1.4	28.7	15.9	20.6	16.7	4.0	0.0	0.0				

c. El Dabaa Meteorological Station

YEAR	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	TOTAL
1910–11	0.0	2.5	11.5	8.5	22.0	29.0	22.0	13.5	3.0	0.0	0.0	0.0	112.0
1911–12	0.0	1.0	5.5	42.5	22.0	22.5	6.0	0.0	3.0	0.0	0.0	0.0	102.5
1912–13	0.0	0.0	3.0	15.0	7.0	20.0	14.0	0.0	0.0	0.0	0.0	0.0	59.0
1913–14	0.0	17.7	33.0	14.0	2.0	43.5	1.5	12.5	0.0	0.0	0.0	0.0	124.2
1914–15	0.0	0.0	1.7	27.5	17.5	6.3	5.5	1.0	0.0	0.0	0.0	0.0	59.5
1915–16	0.3	0.0	5.5	7.3	79.8	16.0	43.0	0.0	0.0	0.0	0.0	0.0	151.9
1916–17	0.0	0.0	3.0	36.1	32.5	38.0	2.0	1.5	0.0	0.0	0.0	0.0	113.1
1917–18	0.0	3.4	0.6	25.0	16.3	41.4	11.3	0.5	0.0	0.0	0.0	–	98.5
1918–19	–	–	–	–	–	0.0	0.2	0.0	3.3	0.0	0.0	0.0	
1919–20	0.0	0.0	44.0	42.0	37.0	91.0	0.0	0.0	0.0	0.0	0.0	0.0	214.0
1920–21	0.0	0.0	54.0	48.0	38.3	9.7	42.9	4.2	0.0	0.0	0.0	0.0	197.0
1921–22	0.0	4.6	8.3	41.5	19.2	5.6	26.9	0.0	0.0	0.0	0.0	0.0	106.1
1922–23	0.0	0.0	12.4	36.7	21.7	16.1	1.0	1.2	3.5	0.0	0.0	0.0	92.6
1923–24	0.0	1.7	0.0	23.9	55.7	39.5	2.0	0.0	0.0	2.5	0.0	0.0	125.3
1924–25	0.0	13.7	31.3	79.0	44.0	0.0	21.0	0.0	0.0	0.0	0.0	0.0	189.0
1925–26	0.0	0.0	29.0	2.0	14.5	6.5	41.0	26.0	0.0	0.0	0.0	10.0	129.0
1926–27	0.0	0.0	3.0	45.0	3.0	56.5	0.0	0.0	0.0	0.0	0.0	0.0	107.5
1927–28	0.0	0.0	91.0	4.0	0.0	21.5	0.0	0.0	0.0	0.0	0.0	0.0	116.5
1928–29	0.0	0.0	64.0	5.0	32.0	13.0	0.0	0.0	0.0	0.0	0.0	0.0	114.0
1929–30	0.0	2.0	8.5	62.0	126.5	16.0	0.0	0.0	0.0	0.0	0.0	0.0	215.0
1930–31	0.0	0.0	35.0	57.0	17.0	0.0	2.0	4.0	0.0	0.0	0.0	0.0	115.0
1931–32	0.0	0.0	19.0	9.0	66.5	48.0	1.0	0.0	0.0	0.0	0.0	0.0	143.5
1932–33	0.0	0.0	64.0	82.0	46.0	24.0	2.0	0.0	3.0	0.0	0.0	0.0	221.0
1933–34	0.0	0.0	9.0	67.5	30.5	28.5	0.0	9.0	21.0	0.0	0.0	0.0	165.5
1934–35	0.0	0.0	0.0	90.0	7.0	14.0	14.5	0.0	0.0	0.0	0.0	0.0	125.5
1935–36	0.0	0.0	13.0	0.0	17.0	4.0	0.0	0.0	4.5	0.0	0.0	0.0	38.5
1936–37	0.0	0.0	0.0	42.0	50.0	10.0	0.0	22.0	0.0	0.0	0.0	0.0	124.0
1937–38	0.0	14.5	36.0	19.0	47.0	48.0	30.0	0.0	0.0	0.0	0.0	0.0	194.5
1938–39	0.0	0.0	29.5	6.0	1.5	32.0	13.0	0.0	0.0	0.0	0.0	0.0	82.0
1939–40	0.0	0.0	33.0	21.0	11.0	30.0	19.0	0.0	0.0	0.0	0.0	0.0	114.0
1949–50	0.0	0.0	0.0	66.8	45.6	9.7	5.0	2.6	17.6	0.0	0.0	0.0	142.3
1950–51	0.0	0.8	37.0	1.6	0.0	16.6	4.5	0.0	0.0	0.0	0.0	0.0	60.5
1951–52	5.0	9.9	9.0	73.0	84.0	33.0	10.0	0.0	0.0	0.0	0.0	0.0	223.9
1952–53	0.0	31.0	19.7	19.0	4.0	6.7	14.9	0.0	0.0	0.0	0.0	0.0	95.3
1953–54	0.0	5.8	71.9	15.8	0.0	3.3	1.0	3.0	0.0	0.0	0.0	0.0	100.8
1954–55	0.0	2.5	52.0	71.4	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	128.9
1955–56	0.0	0.0	120.0	74.0	29.0	18.0	8.0	0.0	0.0	0.0	0.0	0.0	249.0
1956–57	0.0	8.4	18.3	87.0	48.0	15.0	50.0	0.0	5.0	0.0	0.0	0.0	231.7
1957–58	0.0	65.2	37.2	24.0	36.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	162.4
1958–59	0.0	0.0	0.1	–	39.0	64.0	0.0	0.0	2.0	0.0	0.0	–	
1959–60	–	–	–	–	–	0.8	0.9	2.4	1.5	0.0	0.0	0.0	
1960–61	1.4	0.0	58.5	14.7	41.6	38.6	0.7	0.0	0.0	0.0	0.0	0.0	155.5
1961–62	0.0	13.3	0.9	59.2	22.8	6.2	0.0	0.0	0.3	0.0	0.0	0.0	102.7
1962–63	26.2	13.6	0.0	4.0	8.0	6.3	7.4	0.0	30.4	0.0	0.0	0.0	95.9
1963–64	0.0	13.9	12.1	9.9	86.6	11.7	9.2	10.8	0.0	0.0	0.0	0.0	154.2
1964–65	0.0	0.0	42.9	79.5	63.1	6.6	17.6	1.1	0.0	0.0	0.0	0.0	210.8
1965–66	0.0	62.8	13.9	3.0	6.1	46.4	4.0	0.8	0.0	0.3	0.0	0.0	137.3
1966–67	4.4	1.1	40.1	32.8	41.9	9.6	3.8	0.3	0.0	0.0	0.0	0.0	134.0
1967–68	0.0	2.0	26.8	4.6	19.8	9.1	7.8	1.4					

d. Ras el Hekma Meteorological Station

YEAR	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	TOTAL
1956-57	0.0	7.5	13.0	53.4	54.0	39.6	14.8	0.0	1.7	0.0	0.0	0.0	184.0
1957-58	0.0	45.9	35.1	28.0	18.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	127.4
1958-59	0.0	1.4	5.0	7.7	19.5	46.2	0.0	0.0	0.0	0.0	0.0	0.0	79.8
1959-60	0.0	0.0	0.0	43.3	42.0	0.0	0.4	6.9	0.0	0.0	0.0	0.0	92.6
1960-61	0.0	0.0	9.5	5.5	65.8	53.0	0.0	0.0	0.0	0.0	0.0	0.0	133.8
1961-62	0.0	0.0	0.0	41.4	34.5	9.7	0.0	0.0	0.1	0.0	0.0	0.0	85.7
1962-63	17.4	15.3	0.0	6.3	9.8	2.0	13.9	0.3	5.3	0.1	0.0	0.0	70.4
1963-64	20.1	11.0	6.5	5.0	122.6	22.3	10.4	31.6	0.0	0.0	0.0	0.0	229.5
1964-65	0.0	0.0	43.9	108.3	42.6	6.0	16.3	12.2	0.0	0.2	0.0	0.0	229.5
1965-66	0.0	21.3	12.4	12.4	15.8	26.6	8.7	0.8	0.0	1.2	0.0	0.0	98.9
1966-67	4.7	1.0	39.4	27.5	34.6	2.7	7.3	1.3	0.0	0.0	0.0	0.0	118.5
1967-68	5.6	3.7	14.3	19.6	23.8	7.0	11.3	12.2					

e. Mersa Mathruh Airport Meteorological Station

YEAR	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	TOTAL
1921–22	0.0	2.0	0.7	0.0	13.8	0.0	22.5	0.0	16.0	0.0	0.0	0.0	55.0
1922–23	0.0	0.0	9.4	53.6	15.2	10.3	2.8	2.8	2.0	0.0	0.0	0.0	96.1
1923–24	0.0	76.5	0.0	21.3	36.9	27.2	0.4	0.0	0.0	6.2	0.0	0.0	168.5
1924–25	0.0	12.6	30.1	57.7	130.1	0.0	22.5	0.0	0.3	0.0	0.0	0.0	253.3
1925–26	4.5	13.2	11.5	2.7	20.2	16.4	19.2	29.8	0.0	0.0	0.0	14.0	131.5
1926–27	0.0	0.0	0.8	34.2	0.0	44.4	0.0	0.0	0.0	0.0	0.0	0.0	79.4
1927–28	0.0	4.2	92.9	11.5	1.2	40.1	17.7	3.5	0.0	0.0	0.0	0.0	171.1
1928–29	0.0	1.2	32.7	33.6	78.3	16.7	9.1	0.0	0.0	0.0	0.0	0.0	171.6
1929–30	0.0	4.8	29.8	52.7	211.5	7.5	1.5	3.2	0.0	0.0	0.0	0.0	311.0
1930–31	1.6	8.8	19.3	131.4	5.5	0.9	8.5	3.2	2.2	0.0	0.0	0.0	181.4
1931–32	0.0	9.8	12.6	6.5	105.3	25.6	0.0	0.0	0.0	0.0	0.0	0.0	159.8
1932–33	0.0	0.0	59.9	84.0	19.2	17.7	33.3	1.8	8.4	0.0	0.0	0.0	224.3
1933–34	0.0	4.2	6.8	78.7	29.9	60.3	0.0	0.0	10.8	0.0	0.0	0.0	190.7
1934–35	0.0	12.0	23.1	49.9	7.4	11.7	32.4	0.0	0.7	0.0	0.0	0.0	137.2
1935–36	0.0	0.0	23.2	1.5	3.8	0.0	1.8	0.0	17.8	0.0	0.0	0.0	48.1
1936–37	0.0	37.0	10.0	44.3	31.7	17.1	0.0	38.9	0.0	0.0	0.0	0.0	179.0
1937–38	0.0	2.1	4.2	1.8	36.4	58.7	19.8	1.5	0.0	0.0	0.0	0.0	124.5
1938–39	4.5	1.5	45.4	15.0	3.5	27.6	22.4	1.5	0.0	0.0	0.0	0.0	121.4
1939–40	0.0	0.0	36.6	33.0	12.0	17.4	4.2	0.0	0.0				
1943–44					23.4	0.0	2.0	0.0	0.0	3.0	0.0	0.0	
1944–45	4.6	0.5	37.5	18.0	16.7	21.3	4.8	2.0	3.5	0.0	0.0	0.0	108.9
1945–46	0.0	0.0	46.1	25.5	0.4	18.3	4.8	2.2	11.0	0.0	0.0	0.0	108.3
1946–47	2.2	12.9	14.5	1.1	14.6	1.1	4.4	0.0	0.0	0.0	0.0	0.0	50.8
1947–48	0.0	26.5	101.2	2.2	3.4	49.9	73.0	17.2	1.0	0.0	0.0	0.0	274.4
1948–49	0.0	0.5	61.5	68.5	54.1	10.0	14.0	1.9	3.4	0.0	0.0	0.0	213.9
1949–50	0.0	0.3	2.6	77.3	94.6	9.0	12.3	1.8	17.2	0.0	0.0	0.0	215.1
1950–51	0.0	12.6	5.4	0.6	7.2	3.6	4.2	0.5	0.0	0.0	0.0	0.0	34.1
1951–52	0.0	3.5	9.2	54.6	38.9	18.8	1.3	0.0	2.8	0.0	0.0	0.0	129.1
1952–53	0.0	16.5	2.4	6.1	2.5	3.4	12.0	0.2	4.1	0.0	0.0	0.0	47.2
1953–54	0.0	0.9	51.2	12.0	1.7	1.2	11.3	1.2	0.0	0.0	0.0	0.0	79.5
1954–55	0.0	3.0	33.6	40.2	0.9	1.2	1.6	0.6	0.0	0.0	0.0	0.0	81.1
1955–56	0.0	4.1	46.4	74.4	24.2	16.0	9.3	0.0	2.6	0.0	0.0	0.0	177.0
1956–57	0.0	41.7	16.1	76.2	38.1	59.3	34.6	5.7	5.1	0.0	0.0	0.0	276.8
1957–58	9.0	41.8	18.3	60.2	44.2	4.5	0.0	0.0	0.0	0.0	0.0	0.0	178.0
1958–59	0.0	55.5	1.5	31.2	18.2	33.2	0.2	0.1	0.0	0.0	0.0	0.0	143.9
1959–60	0.0	4.0	0.4	18.0	27.8	10.2	5.4	6.2	7.9	0.0	0.0	0.0	79.9
1960–61	0.0	0.0	29.1	16.5	51.0	45.6	9.2	0.0	0.2	0.0	0.0	0.0	151.6
1961–62	0.2	2.0	9.1	20.7	21.1	18.9	0.0	0.0	0.5	0.0	0.0	0.0	72.5
1962–63	6.4	19.4	0.4	5.8	5.7	9.6	14.9	2.3	1.9	0.3	0.0	0.0	66.7
1963–64	0.0	3.4	35.6	4.3	72.3	28.7	12.1	8.4	0.5	0.0	0.0	0.0	165.3
1964–65	2.5	0.0	28.8	63.4	53.5	4.7	5.7	5.9	0.0	59.5	0.0	0.0	224.0
1965–66	0.0	67.5	8.5	7.8	37.5	22.1	6.2	0.0	0.0	0.0	0.0	0.0	149.6
1966–67	10.0	6.0	43.8	18.6	32.0	5.0	7.7	1.9	1.0	0.0	0.0	0.0	126.0
1967–68	0.0	1.9	40.8	11.1	13.5	4.0	10.4	1.8					

f. <u>Mersa Matruh (El Qasr) Meteorological Station</u>

YEAR	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	TOTAL
1963-64					62.4	39.1	14.0	13.5	0.1	0.0	0.0	0.0	
1964-65	0.0	0.0	18.6	92.5	49.3	5.0	9.1	7.8		20.8	0.0	0.0	
1965-66	0.0	87.6	23.1	8.6	24.0	32.4	10.8	0.4	0.0	0.0	0.0	0.0	186.9
1966-67	8.8	3.2	38.9	20.3	23.1	8.6	10.7	2.7	2.8	0.0	0.0	0.0	119.1
1967-68	0.0	10.2	49.0	17.8	18.4	1.2	7.0	1.2					

g. Sidi Barrani Meteorological Station

YEAR	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	TOTAL
1921-22	0.0	2.0	4.0	2.0	17.0	2.0	22.0	0.0	0.0	0.0	0.0	0.0	49.0
1922-23	0.0	0.0	15.0	60.0	8.0	34.0	3.0	8.0	0.0	0.0	0.0	0.0	128.0
1923-24	0.0	1.5	17.0	0.0	17.0	55.0	35.0	0.0	0.0	0.0	0.0	0.0	125.5
1924-25	0.0	8.0	18.0	57.0	97.0	3.0	14.2	0.0	0.0	0.0	0.0	0.0	197.2
1925-26	0.0	55.0	47.0	9.0	17.0	5.5	35.0	0.0	0.0	0.0	0.0	0.0	168.5
1926-27	0.0	8.0	18.0	57.0	4.0	62.0	0.0	0.0	0.0	0.0	0.0	0.0	149.0
1927-28	0.0	23.0	8.0	6.0	3.0	51.0	3.0	4.0	0.0	0.0	0.0	0.0	98.0
1928-29	0.0	0.8	17.8	9.0	55.9	35.7	5.0	9.7	0.0	0.0	0.0	0.0	133.9
1929-30	1.5	37.0	14.2	33.1	31.3	6.7	13.5	0.0	0.0	0.0	0.0	0.0	137.3
1930-31	0.0	0.0	22.0	36.5	0.0	2.5	0.0	0.0	14.5	0.0	0.0	0.0	73.5
1931-32	0.0	0.0	25.1	0.0	77.8	11.0	0.0	0.0	0.0	0.0	0.0	0.0	113.9
1932-33	0.0	2.5	41.0	29.0	10.7	13.0	3.5	0.0	4.0	0.0	0.0	0.0	103.7
1933-34	0.0	0.0	11.0	60.3	24.0	88.0	0.0	1.0	0.0	0.0	0.0	0.0	184.3
1934-35	0.5	5.5	30.0	68.0	4.5	15.7	44.0	6.5	0.0	0.0	0.0	0.0	174.7
1935-36	0.5	1.0	12.0	4.3	16.0	12.0	5.0	0.0	17.0	0.0	0.0	0.0	67.8
1936-37	5.0	0.0	25.5	94.5	49.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	174.0
1937-38	0.0	0.0	15.0	0.0	18.8	61.2	19.0	0.0	0.0	0.0	0.0	0.0	114.0
1938-39	0.0	0.0	48.1	31.0	15.5	26.0	6.0	0.0	0.0	0.0	0.0	0.0	126.6
1939-40	0.0	0.0	70.0	9.0	25.5	48.0	22.0	0.0					
1947-48					6.3	68.6	99.6	16.1	2.3	0.0	0.0	-	
1948-49	1.0	23.7	58.9	74.9	65.7	26.6	37.6	5.0	2.0	0.0	0.0	0.0	295.4
1949-50	0.0	1.0	2.0	99.5	73.0	16.0	11.0	2.0	10.4	0.0	0.0	0.0	214.9
1950-51					18.7	1.7	9.8	5.7	0.8	0.0	0.0	0.0	
1951-52	0.0	4.3	10.5	45.7	40.8	5.0	3.8	0.0	0.5	0.0	0.0	0.0	115.1
1952-53	0.0	33.9	1.6	19.6	10.0	5.5	15.0	0.1	10.6	0.0	0.0	0.0	96.3
1953-54	0.0	0.0	68.9	24.7	5.3	6.2	16.6	0.7	0.1	0.0	0.0	0.0	122.5
1954-55	0.0	10.0	45.4	61.0	0.0	0.6	1.8	2.1	0.0	0.0	0.0	0.0	120.9
1955-56	0.0	0.1	34.8	57.6	19.9	5.5	10.2	0.0	2.8	0.0	0.0	0.0	134.4
1956-57	0.0	29.6	9.6	106.1	64.6	4.9	38.9	3.5	2.8	0.0	0.0	0.0	260.0
1957-58	0.0	11.1	6.7	40.3	78.8	4.3	1.2	0.0	0.0	0.0	0.0	0.0	142.4
1958-59	0.0	38.5	2.9	2.8	26.8	21.6	0.3	5.2	1.5	0.0	0.0	0.0	99.6
1959-60	0.0	48.1	2.0	25.8	28.5	13.3	14.0	0.0	28.5	0.2	0.0	0.0	160.4
1960-61	0.8	0.0	36.6	22.2	125.2	41.2	6.5	0.0	0.0	0.0	0.0	0.0	232.5
1961-62	0.0	10.4	0.7	45.6	40.0	32.1	0.0	0.3	0.1	0.0	0.0	0.0	129.5
1962-63	0.2	14.1	0.0	23.8	22.0	6.6	28.5	0.3	2.2	0.0	0.0	0.0	97.7
1963-64	1.8	20.5	7.1	3.7	73.9	21.7	5.3	0.7	1.2	0.4	0.0	0.0	236.3
1964-65	0.0	0.0	23.2	115.3	64.0	13.0	7.0	4.9	0.0	2.7	0.0	0.0	230.1
1965-66	0.0	79.0	2.7	8.2	31.5	18.1	16.4	0.0	0.5	0.0	0.0	0.0	156.4
1966-67	18.5	7.9	18.8	33.6	47.9	13.2	4.1	1.3	0.0	0.0	0.0	0.0	145.3
1967-68	0.0	39.6	41.0	19.3	20.4	0.4	1.5	0.0	0.0	0.0			

h. Sallum Meteorological Station

YEAR	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	TOTAL
1921-22	0.0	18.0	12.0	2.0	7.0	1.0	13.0	0.0	6.0	0.0	0.0	0.0	59.0
1922-23	0.0	0.0	45.0	6.0	11.0	18.0	0.0	8.8	0.0	0.0	0.0	0.0	88.8
1923-24	0.0	4.7	0.0	0.0	16.8	1.4	0.8	0.0	0.0	2.0	0.0	0.0	25.7
1924-25	3.4	5.0	23.2	47.1	96.0	4.5	3.5	5.2	0.0	0.0	0.0	0.0	187.9
1925-26	0.0	12.6	3.5	2.5	4.0	0.0	17.0	1.0	1.0	0.0	0.0	14.0	55.6
1926-27	0.0	0.0	4.6	49.5	0.0	45.0	0.0	6.0	4.0	0.0	0.0	0.0	109.1
1927-28	0.0	0.0	31.0	7.0	13.0	77.0	15.0	0.0	0.0	0.0	0.0	0.0	143.0
1928-29	0.0	3.0	0.0	31.0	35.0	30.0	9.0	2.0	0.0	0.0	0.0	0.0	110.0
1929-30	0.0	0.0	15.0	92.0	42.0	15.0	6.0	0.0	0.0	0.0	0.0	0.0	170.0
1930-31	0.0	0.0	1.0	43.5	2.0	0.0	0.0	2.0	4.0	0.0	0.0	0.0	52.5
1931-32	0.0	0.0	28.0	5.0	94.1	14.9	0.0	0.2	0.0	0.0	0.0	0.0	142.2
1932-33	0.0	1.1	17.1	48.6	13.2	19.5	16.0	0.0	4.9	0.0	0.0	0.0	120.4
1933-34	1.3	5.7	5.4	21.0	6.3	29.0	0.0	0.0	15.0	0.0	0.0	0.0	83.7
1034-35	0.9	8.8	63.1	36.2	0.3	1.9	15.9	0.4	0.7	0.0	1.8	0.0	130.0
1935-36	0.0	0.0	46.0	0.0	12.7	0.0	0.0	0.0	21.1	0.0	0.0	0.0	79.8
1936-37	0.0	1.0	15.2	39.9	25.0	23.4	0.0	0.0	0.0	0.0	0.0	0.0	104.5
1937-38	0.0	3.7	3.6	0.0	14.9	17.3	17.7	3.2	0.0	0.0	0.0	0.0	60.4
1938-39	0.0	0.0	25.1	7.2	12.6	27.3	6.0	0.0	1.7	0.0	0.0	0.0	79.9
1939-40	0.0	0.0	31.1	5.3	10.6	6.0	20.2	0.2	0.0				
1944-45									31.4	0.0	0.0	0.0	
1945-46		0.0			0.5	6.0	0.0	0.0	18.4	0.0	0.0	0.0	
1946-47	8.9	4.5	11.0	2.0	5.0	0.5	0.0	0.0	0.5	0.0	0.0	0.0	32.4
1947-48	0.0	73.1	227.5	0.0	4.2	11.0	58.5	2.0	2.0	0.0	0.0	0.0	378.3
1948-49	0.0	0.5	13.0	12.5	50.0	16.5	28.0	1.2	2.5	0.0	0.0	0.0	124.2
1949-50	3.0	0.0	0.0	22.9	47.3	4.2	5.1	0.0	9.7	0.0	0.0	0.0	92.2
1950-51	0.0	67.0	10.6	0.3	0.0	0.0	5.5	2.0	0.6	0.0	0.0	0.0	86.0
1951-52	0.0	0.8		34.0	22.1	1.2	3.5	0.0	0.0	0.0	0.0	0.0	
1952-53	0.0	4.0	0.0	3.3	0.0	6.0	15.4	0.0	2.9	0.0	0.0	0.0	31.6
1953-54	0.0	0.0	271.7	28.0	11.4	10.0	31.6	1.0	0.0	0.0	0.0	0.0	353.4
1954-55	0.0	2.6	9.9	16.1	0.3	0.0	0.9	0.0	0.0	0.0	0.0	0.0	29.8
1955-56	0.5	0.0	2.2	28.9	2.3	1.8	7.8	0.0	0.9	0.0	0.0	0.0	44.4
1956-57	0.0	25.8	0.1	133.9	55.2	0.9	31.6	1.9	1.7	0.0	0.0	0.0	251.1
1957-58	0.6	8.6	5.5	3.5	8.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.7
1958-59	0.0	32.4	0.3	0.9	2.3	32.7	0.8	0.8	2.2	0.0	0.0	0.0	72.4
1959-60	0.8	43.9	0.1	1.3	24.2	16.2	14.9	0.0	17.8	0.0	0.0	0.0	119.2
1960-61	0.0	0.0	3.6	18.3	40.0	32.1	5.5	0.0	0.0	0.2	0.0	0.0	99.7
1961-62	0.1	10.6	0.8	69.9	15.6	18.6	0.3	0.9	0.1	0.0	0.0	0.0	116.9
1962-63	0.0	10.6	0.5	6.1	3.7	8.3	9.8	0.8	5.2	0.0	0.0	0.0	45.0
1963-64	0.3	0.4	9.6	1.0	67.5	36.8	3.7	1.5	1.4	0.0	0.0	0.0	122.2
1964-65	0.0	0.0	3.8	22.7	16.2	1.2	8.9	10.5	0.0	1.0	0.0	0.0	64.3
1965-66	0.3	58.0	0.5	3.3	24.4	46.0	3.6	0.2	0.2	0.2	0.0	0.0	136.7
1966-67	21.2	24.9	1.7	6.2	27.2	1.3	1.5	5.1	0.0	0.0	0.0	0.0	89.1
1967-68	0.0	13.0	45.0	6.3	5.3	0.5	0.5	0.0					

Appendix 4

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