دراسات تنمية سيناء-المرحلة الاولى

Sinai Development Study
Phase I
Final Report

VOLUME V
WATER SUPPLIES AND COSTS

SUBMITTED TO:

THE ADVISORY COMMITTEE FOR RECONSTRUCTION
MINISTRY OF DEVELOPMENT
ARAB REPUBLIC OF EGYPT

USAID GRANT NO. 263-0113
MARCH, 1985

PREPARED BY:

Dames & Moore
In association with Industrial Development Programs SA

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LIST OF VOLUMES

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Volume II	Managing Sinai's Development
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VOLUME V

WATER SUPPLIES AND COSTS

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1.0 INTRODUCTION

This volume presents results of a water resources study done by Dames & Moore to assess the existing water-related data base for Sinai and to formulate a water development plan consistent with the Recommended Development Strategies for the peninsula. The following elements of the study are presented in detail in this volume:

- Evaluation of each major water resource (Section 2.0)
- Estimation of current water use and future water demand (Section 3.0)
- Cost analysis for each source of water (Section 4.0)
- Formulation of a preliminary, conceptual water plan for Sinai (Section 5.0).

The data used to prepare this report include meteorological data, stratigraphic data on geologic formations, and data pertaining to wells and springs. This information is delineated in tables in Appendix A to this volume; still more detailed information can be found in Working Paper 33 and other papers in the working files of the Sinai Development Study - Phase One.

1.1 WATER RESOURCES

The existing indigenous water resources--rainfall, surface water, and groundwater--are identified and quantified, and desalinization options are reviewed. The availability of Nile water for use in Sinai is discussed, as is weather modification (cloud-seeding).

1.2 WATER USE AND FUTURE DEMAND

Current water usage and anticipated future needs are discussed with explanations of the bases for these estimates. Projected water use for the year 2000 is presented for each subregion and for domestic, agricultural, industrial, and tourism requirements under three alternative strategies.

The agricultural sector, which is by far the greatest consumer of water within each of the strategies, is emphasized. Existing pipelines, as well as those under construction and proposed, are identified. Also identified are proposed areas of major land reclamation, based on the land capability analysis in Volume IV.

After completing an analysis of three alternative strategies, the Consultant developed a Recommended Strategy. That strategy includes elements of the water systems described in the other three. It is costed as a part of the "Investment Plan" in Volume III. The water systems designed for the Frontier and Dispersed Strategies are potentially extensions of the Recommended Strategy beyond 2000. Much of the data in this volume can be used in modifying or analyzing the water systems of the Recommended Strategy as described in Volume I.

1.3 COST ANALYSIS

Analyses of costs are given for groundwater development, surface water development, desalinization, and importation of Nile water by both pipeline and canal. Estimated capital investment and operating and maintenance costs are given for the Dispersed and Frontier Strategies; corresponding costs for the Recommended Strategy are reported in Chapter 6 of Volume III, An Economic Development and Investment Plan, 1983 to 2000.

Although lack of data makes it difficult to estimate the quantity and therefore the costs of all available surface water, costs are computed for three locations. Water spreading and runoff farms are discussed briefly. Comparisons of water-cost curves for the major water sources are presented for representative areas, and conclusions are given based on development costs and the quantity and quality of water resources.

1.4 PRELIMINARY SINAI WATER PLAN

Recommendations are made for the management of present and future water resources, including development, conservation, and monitoring. The establishment of a Sinai Water Authority and its proposed organizational structure are outlined.

Research projects are suggested and described. These include studies of groundwater potential, pipeline construction compared to canal construction, rainfall and runoff, cloud-seeding, and reservoir storage feasibility. Other specific projects concern upgrading the meteorological network, evaluating potential dam sites, well-drilling and testing, and performing hydrologic studies on small basins.

1.5 ISSUES

In evaluating Sinai water resources and planning the optimal development and allocation of water supplies to promote development, certain issues have emerged that should be addressed. These include the following:

- The need to provide management of all present and future water resources of the peninsula, so that the aims of development are promoted and, at the same time, water resources are conserved and used efficiently.

- Uncertainties regarding the quantities and quality of groundwater and the quantities of surface runoff available derive from a lack of data on local aquifers and on rainfall and runoff. These uncertainties make it difficult to plan with confidence for the optimum use of these resources.

- The deterioration of groundwater quality in certain areas, particularly near El Arish.

- The need to identify cost-effective systems of conveying Nile water in Sinai, including take-off points consistent with the location and areal extent of all those reclamation areas to be selected in the next few years. The optimum combination of canal- and pipeline-conveyed water should be selected. In certain locations, groundwater use should be considered to supplement Nile water irrigation during peak use.

- The financing of large Nile water conveyance projects. This issue includes obtaining the required loans for the capital investment of over two billion pounds (LE), and cost-recovery for water development projects, or recovery of the operation and maintenance costs.

1.6 RECOMMENDATIONS

- The management of water resources of the Sinai Peninsula by an agency that would be guided by a policy board. The functions of the agency would include the following:

  -- monitoring and information collection and processing

  -- establishment and management of water allocations

  -- planning and implementation of new water-development projects

  -- maintenance of water-supply civil works

  -- enforcement of or compliance with allocations

  -- education in good water management techniques.

- Immediate establishment of a temporary agency for the El Arish-Rafah area to monitor groundwater trends and use in the area, and to establish and enforce pumping quotas. After the formation of the Sinai-wide water agency, this temporary agency would be absorbed into the larger one.

- Immediate implementation of research and investigative projects to extend the present information base on Sinai water resources--an essential support for rational planning. The following recommended projects (discussed in Section 5.5) are listed in order of priority:

  -- Groundwater:

    - Exploratory well-drilling and testing program in areas with the greatest development potential

    - Geophysical surveys in the El Arish-Rafah area

  -- Nile water supplies:

    - Prefeasibility studies comparing the use of large pipelines and canals for land reclamation in Sinai

    - Prefeasibility study of alternate take-off points for Nile and drainage water

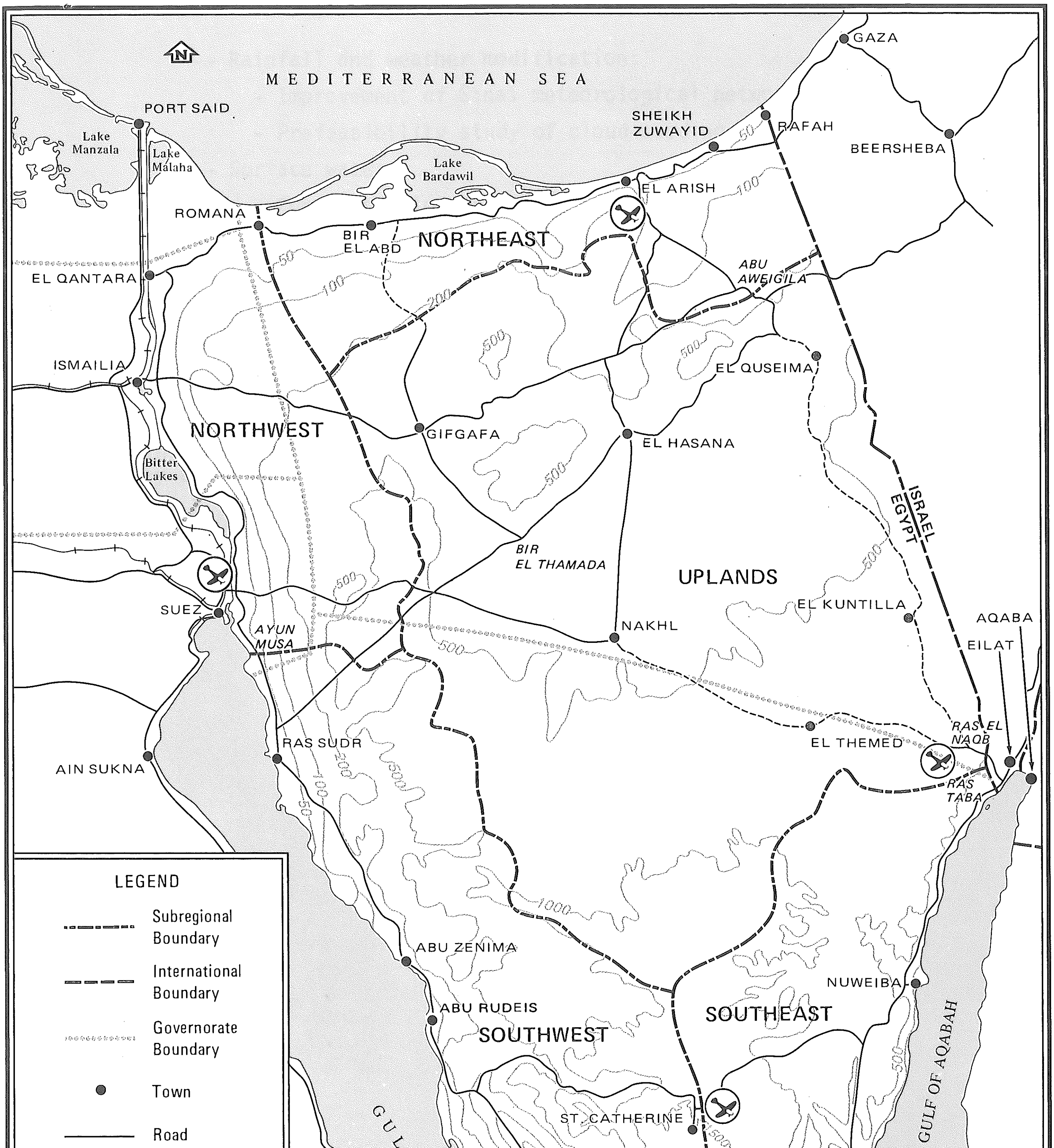

FIGURE 1.1
ORIENTATION MAP SHOWING CONTOURS, FIVE SUBREGIONS AND GOVERNORATES

-- Rainfall and weather modification:

  - Improvement of Sinai meteorological network
  - Prefeasibility study of cloud-seeding in Sinai

-- Surface water:

  - Runoff gauging stations
  - Hydrologic studies on small basins
  - Evaluation of potential large and small dam sites.

1.7 USE OF THIS VOLUME

Although this volume was prepared to be read as an integrated unit, chapters can be read separately. Readers interested in general issues and future plans, may wish to skim the detailed analysis in Chapter 2 and begin more careful reading with Chapter 3. Chapter 2 presents data currently available on the water resources of the peninsula, while Chapters 3 - 5 are oriented more towards projected future requirements and their probable costs, policy issues, plans and projects. Some readers of the draft have found it preferable to read Chapters 3 - 5 first, for an orientation on future prospects, before studying the resource picture (Chapter 2) in detail.

2.0 WATER RESOURCES ASSESSMENT

2.1 INTRODUCTION

This section reports the results of the Consultant's detailed assessment of existing and potential water resources in Sinai, including local surface water, groundwater, planned desalinization, current importation of water, proposed transfers of Nile water (including drainage water from Delta irrigation systems), and cloud-seeding possibilities. This assessment was the essential first step in preparing a water resources strategy, even in preliminary form, and in formulating recommendations for the management of water resources.

The assessment began in the final weeks of 1980, continued through 1981, was initially reported on early in 1982, and was reviewed and revised during the first quarter of 1983. Most of the results are reported in this volume. However, some additional data, figures and maps developed in the course of the analysis are in Working Papers and other project files at the Ministry of Development.

The evaluation of Sinai water resources relied primarily on data and information obtained from existing reports and from Government data files. Dames & Moore staff made four reconnaissance field trips to Sinai in 1981 to study geology, groundwater resources, and surface water potential. Information was obtained during these trips with respect to possible well-drilling sites and existing water pipelines. In addition, several dozen wells were inspected, and water level depths were measured and water samples analyzed for specific conductance and chloride content. Apart from such limited direct data collection, the majority of pertinent information on water resources consists of data and information collected by others, including that obtained by the Desert Institute during its field investigation from March to July 1981, as part of this contract.

Considerable effort was expended in the identification, collection, and study of over 300 references relevant to the water resources of Sinai. A list of references is included at the end of this volume. The references consist of government reports (both Egyptian and Israeli), journal articles, books, well logs, data sheets from several agencies, LANDSAT images of Sinai, 1:50,000-scale aerial photos purchased from the Ministry of Defense, 1:50,000- and 1:100,000-scale topographic maps, 1:250,000- and 1:500,000-scale maps of Sinai, and a 1:500,000-scale geologic map. These references were studied in detail, and any data relevant to the stratigraphy, aquifers, and water quality characteristics or surface water potential of Sinai were recorded on data forms. For example, stratigraphic information needed to characterize potential aquifers in Sinai was recorded by first noting the location of the well or exposed section measured. Information on the location and ground-surface elevation of each well or exposed section, as well as the reference providing the stratigraphic data, are given in Tables 2-1 and 2-2 in Working Paper No. 33, Water Resources. The stratigraphic data were recorded for each location in the same form as presented in Table 2-3 of Working Paper No. 33.

Detailed information on 716 water points is provided in Working Paper No. 34, described below, and can be found in SIS-I project files. Each card provides data on only one water point. Not all known wells or springs in Sinai are included in this data base, but an attempt has been made to include all water points about which some important facts are known, such as the depth or thickness of aquifers, well yields, or water quality. Some of the water points inventoried are not operational today (e.g., some consist of oil exploration wells that have been subsequently abandoned), but are included because they provide valuable data about the aquifers. The data base on Sinai water points brings together most of the significant information that has been collected by various investigators in this century. Because of the hydraulic continuity of several of the aquifers between Sinai and Israel, some Israeli water points located in the Negev are included in the data base.*

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*Hydrogeologic information cards (Working Paper No. 34) provide the information source or reference for each major parameter or characteristic. The number found under the "Info Source" column corresponds to the number given in parentheses in the left-hand margin of the reference list provided at the end of this volume. The "Year" column refers to the year of publication or issuance of the information source. In the column headed "Date" is given the date on which the particular measurement or sampling was performed, if known.

For each of the major water point parameters, an attempt was made to assess the reliability of the data. In most cases, this was difficult, and for most of the data, a reliability of "3" ("probably reliable") was assigned--with "4" representing highly reliable data. When inconsistencies or conflicting data were encountered, those data that appeared most reasonable and which were obtained from the most reliable data source were retained.

Water points are grouped into 30- by 30-minute grid squares. Each grid square is assigned a number according to the scheme given in Plate 5-1 (Data Map for Wells and Springs) of Working Paper No. 45, Preliminary Map Portfolio. The number of the grid square where each water point is located is entered on line 4 of the hydrogeologic information card. Within each grid square, water points are assigned numbers sequentially, as shown on Plate 5-1. This number is entered on line 1 of the hydro geologic information card. Elsewhere in this volume, water points are referred to by their I.D. number, which consists of the grid number and the water point number, separated by a hyphen. For more information on the method of coding data onto these forms, see Working Paper No. 34 in the SDS-I project files.

The other primary data category for this sector comprises meteorological data, particularly precipitation and evaporation data. Twenty-three meteorological stations have been identified in and adjacent to Sinai. A summary of relevant data from their records is given in Table 2-1.*

The stratigraphic data, hydrogeologic water point data, and meteorological data make up the basic data base for evaluation of the groundwater and surface water resources of the peninsula. Analyses relevant to the availability of water resources are based on these data and, to a lesser extent, on information provided on the geologic and topographic maps. The overall accuracy and reliability of the data base are good, but there are always a number of uncertainties with these types of data because of problems inherent in fieldwork (e.g., difficulties in locating data points accurately and the uncertain reliability of information obtained from local inhabitants).

In certain respects, the data base is inadequate for a reliable assessment of water resources. This is particularly true with respect to meteorological data, runoff measurements, and well data for the carbonate rocks. Given the several physiographic provinces of Sinai, the density of existing meteorological stations is inadequate, and for many of the stations data are available for only a few years. For example, rainfall data for the southern mountain region are available from the St. Catherine station for only a 3-year period. Moreover, data on daily rainfall, rainfall intensity, and certain other important rainfall parameters are not available for most of the stations.

Estimates of runoff flow for 4 years over the dam at Rawafaa on Wadi El Arish are the only available data on runoff quantities for any of the wadis of the peninsula. Therefore, in this report, estimates of runoff will rely on the results of studies made in similar terrain in other countries and on empirical formulae.

With respect to the groundwater assessment, data on aquifer permeabilities and well yields are essentially lacking for the Middle Cretaceous, Upper Cretaceous, and Eocene carbonates, which are potential aquifers on the peninsula. As a result, estimates of well yields likely from these units are only rough approximations. An exploratory drilling program is, therefore, essential and should be incorporated into the next phase of investigation, as discussed in detail in Section 5.5.

Available data confirm that most of the water currently used in Sinai is imported. There are pipelines and siphons under the Suez Canal at Port Said, Qantara, Deversoir, Hamdi Tunnel, and El Shatt. Pipelines enter from Israel at Rafah and Taba, and tanker trucks and ships regularly deliver water. The pattern of importation was changing during the time of the study and is outlined in Table 3-1 of this volume.

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*Details can be found in Tables 2-4 and 2-5 of Working Paper No. 33, Water Resources.

2.2 INDIGENOUS WATER RESOURCES

2.2.1 Rainfall

Of the 23 meteorological stations identified in and adjacent to Sinai, six are in Israel, four are in Egypt west of the Suez Canal, and the remaining 13 are in Sinai proper. Table 2-4 in Working Paper No. 33, Water Resources, gives the location, elevation, and years of record for each station, as well as the information source from which the meteorological data were obtained.

Of the 13 Sinai stations, the longest records are available for El Tor, Nakhl, and El Arish--with 48, 28, and 53 years of record, respectively. However, continuous uninterrupted records are not available for Nakhl and El Arish. The stations with the shortest records are Sharm El Sheikh and El Maghara, each with a record of only 1 year. The only data available for the southern mountain region are those for St. Catherine--from 1934 to 1937.

The average monthly rainfall data and Piche evaporation data were studied station-by-station.* These data include the average number of days each month when rainfall exceeds 0.1, 1, and 10 millimeters, as well as the maximum daily rainfall of record by month. A summary of the mean annual rainfall and evaporation data is given in Table 2-1. Analyses of detailed data indicate clearly that almost all of the rainfall in Sinai falls between October and May. Most of this is due to the low-pressure areas extending southward from the eastern Mediterranean at this time of year.

An isohyetal contour map was prepared based on the mean annual rainfall given in Table 2-1. Another analysis showed contours of the average number of days per year with rainfall greater than 1 millimeter.**

The central uplands and Southwest Subregion are the areas of lowest annual rainfall. In central Sinai, from the El Tih Plateau to Gebel El Maghara, mean annual rainfall ranges from 22 to 40 mm/year; along the southwestern coast, rainfall ranges from 10 to 22 mm/year. Rainfall is higher in the southern mountains (the 3-year average was 62 mm/year at St. Catherine), probably due to the orographic effect of the mountains. Northward and northeastward of Gebel El Maghara and Gebel El Halal, mean annual rainfall increases steadily, reaching 58 mm/year at Abu Aweigila and about 100 mm/year at El Arish. The increase in mean annual rainfall from El Arish to Rafah is particularly steep; Rafah has an average yearly rainfall of 304 mm/year.

The average number of rainy days per year (greater than or equal to 1 millimeter) ranges from 2 days at El Tor, 7 days at Abu Aweigila, and

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*See Table 2-5 of Working Paper No. 33, Water Resources.

**See Plates 3-2 and 3-3 of Working Paper No. 45, Preliminary Map Portfolio.

TABLE 2-1

Summary of Rainfall and Evaporation Data for Stations in and Adjacent to Sinai

No.	Station	Mean Annual Rainfall (mm)	Minimum Seasonal Rainfall (mm)	Maximum Seasonal Rainfall (mm)	Maximum Daily Rainfall (mm)	Average Daily Evaporation (mm)[a]
1	Port Said	79.0	44.0	165.0	58.0	5.3
2	Ismailia	37.7	--	--	50.8	7.6
3	Fayid	25.5	--	--	32.4	--
4	Suez (old)	24.7	Trace	82.0	31.0	9.2
4*	Suez (new)	19.6	--	--	49.6	11.5
5	Abu Rudeis	21.5	--	--	32.9	10.0
6	El Tor (low)	10.4	0.0	52.0	37.4	9.5
7	Sharm El Sheikh	23.8	--	--	20.4	--
8	St. Catherine	62.0	--	--	76.2	--
9	Ras El Naqb[b]	27.7	0.0	97.0	15.0	--
10	El Kuntilla	23.3	2.0	76.0	32.0	--
11	El Themed	29.0	0.0	313.0	142.0	--
12	Nakhl	22.1	0.0	68.0	22.7	11.4
13	El Hasana	27.9	10.0	77.0	32.0	--
14	El Maghara	43.7	--	--	9.0	11.4
15	El Arish	99.7	Trace	214.0	59.0	4.6
16	Abu Aweigila	57.8	--	--	49.0	--
17	El Quseima	63.4	25.0	123.0	24.2	9.0
18	Rafah (high)	304.1	--	--	37.0	--
19	Gaza[c]	336.5	237.0	497.0	84.2	4.9
20	Beersheba[c]	195.0	42.0	339.0	64.0	7.9
21	Shivta[c]	86.0	26.0	153.0	--	--
22	Avdat[c]	83.0	25.0	161.0	--	--
23	Eilat[c]	50.0	6.0	98.2	--	--

[a]Measured with a Piche evaporator.

[b]Airport near Ras Taba.

[c]Outside Sinai.

SOURCE: Derived from data in Tables 2-4 and 2-5 of Working Paper No. 33 in the SDS-I project files. Specific references are provided for each of the data entries. The references are keyed by number to the reference list at the end of this volume.

18 days at El Arish to 35 days at Rafah. Analysis of the data shows that there is a direct relationship between the mean annual rainfall and the average number of rainy days. On the average, the greater the number of rainy days, the greater the annual rainfall, as one would expect.

Annual averages are useful for certain long-term water balance evaluations, but the variability of rainfall from year to year and from storm to storm must be considered for the full assessment of an area's water resources potential. Desert areas such as Sinai are known to exhibit a greater variability of yearly rainfall than more humid regions. It is commonly held in Sinai that the large floods or torrents, particularly on Wadi El Arish, occur about once every 5 years. Tables 3-1 and 3-2 in Working Paper No. 33 provide year-by-year annual rainfall figures for El Arish and El Tor, respectively. While the magnitude of variation is greater at El Arish as a percent of the mean annual rainfall, it is apparent that the variability is greater at El Tor. Further analysis indicates that the standard deviation of the mean annual rainfall for those stations studied ranges from 11mm/year at El Tor to 40mm/year at El Themed. As a fraction of the mean annual rainfall, the standard deviation ranges from 0.38 at El Arish, 0.46 at El Quseima, 0.74 at Nakhl, and 1.06 at El Tor, to 1.37 at El Themed. In general, it is seen that the lower the mean annual rainfall, the greater the year-to-year variability as a fraction of the mean.

Diurnal mist and dew are sufficiently heavy in some high mountain valleys to be significant to the native flora and fauna and to support some economic grazing. The study found no data on this water source, and recommends that research be undertaken to learn more about its potential.

Annual rainfall probability curves for El Arish and El Tor are presented in Figure 2.1. The greater slope of the line for El Tor indicates the greater degree of variability of annual rainfall there compared to El Arish. On the plot of the log of annual rainfall versus probability, the data points for El Arish fall roughly on a straight line, indicating that annual rainfall at El Arish tends to have a log-normal distribution. On the other hand, the data points for El Tor fall on a curve rather than a straight line; this was also true for plots on normal probability paper. Hence, annual rainfall at El Tor appears to be neither normally distributed nor log-normally distributed.

2.2.2 Surface Water Resources

2.2.2.1 Hydrographic Basins and Basin Areas in Sinai. For the purpose of this study, Sinai has been divided into 25 basin areas to facilitate the analysis of runoff potential and water balance characteristics. Later, for planning purposes, these basins were grouped into subregions except for three "basins" (North Coast, Lower El Arish and El Hasana-El Hema) which are split between Northeast and Uplands subregions. For convenience in analysis, the largest basin, Wadi El Arish, is also subdivided into an Upper Basin and a Lower Basin, and the Upper Basin is subdivided in turn into smaller sub-basins or tributary basins.

In some cases, the basin areas represent basins drained by a single wadi or a single wadi system. This is the case for the El Arish Basin Area and the Gerafi, Feiran, Sidri, Baba, Gharandal, Sudr, El Hagg, El Giddi,

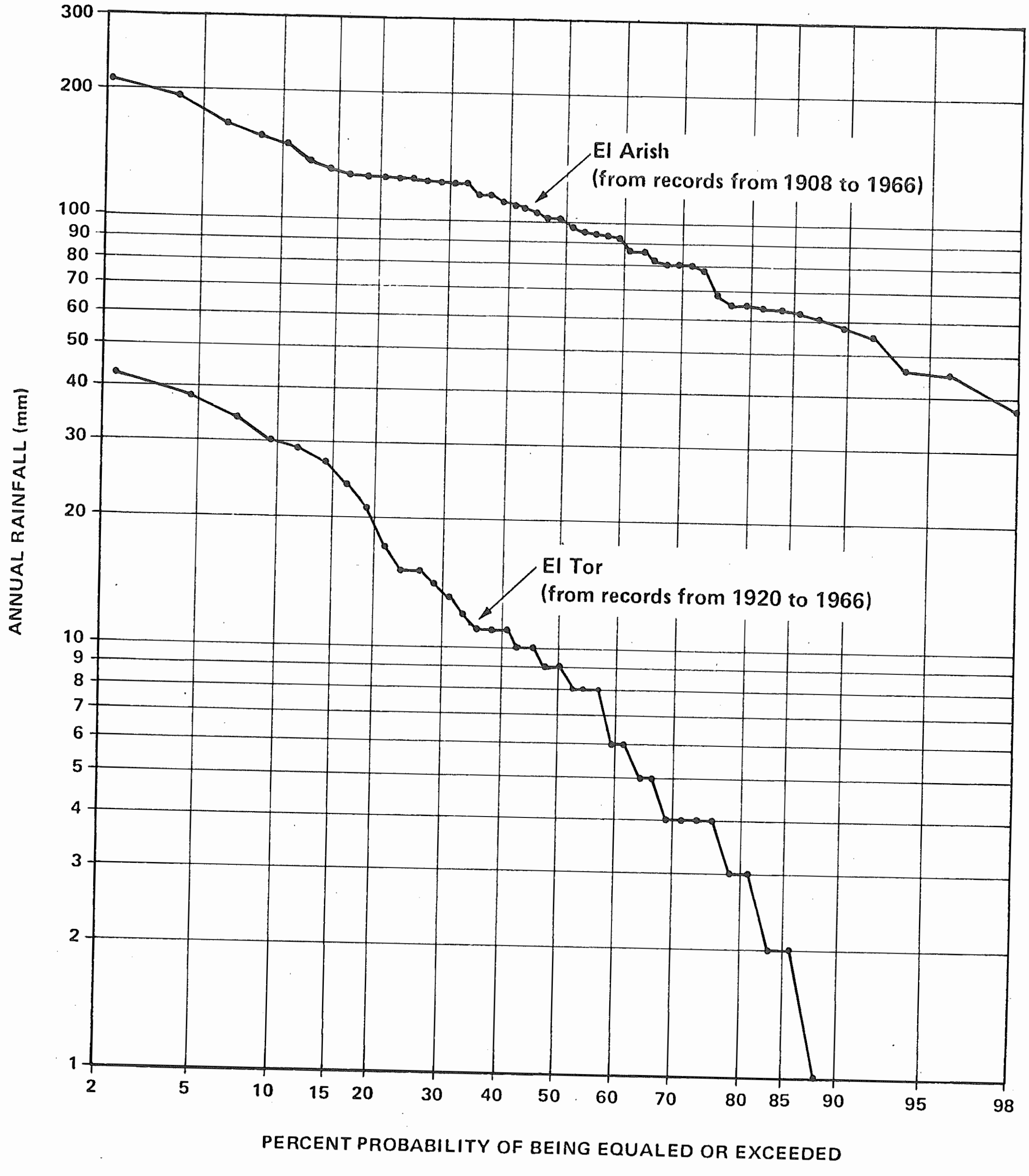

FIGURE 2.1

ANNUAL RAINFALL PROBABILITY CURVES
FOR EL ARISH AND EL TOR

Dames & Moore

and Hegayib Basin Areas. Most of the other basin areas are drained by more than one wadi. For example, the Umm Adawi Basin Area is drained by both Wadi Umm Adawi and Wadi Letih, and the Tayiba Basin Area is drained by Wadi Tayiba, Wadi Thal, and Wadi Waseiyit. The Wasit Basin Area is drained by the main wadi--Wadi Watir--and also by a number of comparatively short wadis located between Nuweiba and Eilat, which empty into the Gulf of Aqabah. In addition, the Wadi Zeleqa subbasin, which appears to have no outlet, is also included in the Wasit Basin Area.

Three of the basin areas have wadi systems that drain a portion of the basin area, but provide no outlet to the sea or to an adjacent basin. In such cases, rainfall, topographic, and soil conditions are such that no outlet has developed. Basin areas in this category are Umm Khisheib, Hegayib, and El Hasana-El Hema. The runoff accumulating at the lower end of these basin areas is disposed of solely by percolation and evaporation. Some investigators believe that the El Hasana-El Hema Basin Area drains into the lower basin of Wadi El Arish. While some underground seepage from the El Hasana-El Hema Basin Area may reach the lower Wadi El Arish Basin, there is no evidence from topographic maps and aerial photos to indicate that any wadi channels exist to carry surface runoff water across the basin boundary in that direction. In two of the basin areas--the north coast and northeast coast--no drainage system is presently in existence.* Hence, without any wadi-channeled runoff, rainfall on these two basin areas is disposed of by percolation and evaporation alone. The hydrographic basins of Sinai are shown on Figure 2.2 and listed in Table 2-2.

The total land area of Sinai is estimated at about 61,000 square kilometers. Of this, the Wadi El Arish Basin, consisting of those portions of the upper and lower basins in Sinai, covers an area of about 19,050 square kilometers, or approximately 31 percent of the area of the peninsula. Including the portion of the Wadi El Arish Basin outside Sinai, the total area of the basin is about 20,350 square kilometers.

Saad, El Shamy, and Sweidan (1086) studied the basins of Sinai and determined that the El Arish Basin as a whole has a drainage density of only 0.18 km^{-1}--significantly lower than that of most of the other basins of Sinai, with the exception of the Lahata, El Raha, El Giddi, and Hegayib Basins. The average for the basins draining to the Gulf of Suez or the Gulf of Aqabah is 0.29 km^{-1}. Considering that the southern part of the El Arish Basin is believed to have a higher drainage density and consequently higher runoff than the average for the basin, these authors concluded that the northern part has a correspondingly lower drainage density, indicating the likelihood of a high degree of groundwater recharge.

Topographic maps of central and north-central Sinai indicate the relatively low slope of the Wadi El Arish system in the area extending from Nakhl to El Arish. The average slope is estimated to be 4m/km. (1269) Moreover, three major natural controls in this wadi system are evident in the central part of the basin--at Gebel Kherim, Mitmetni,

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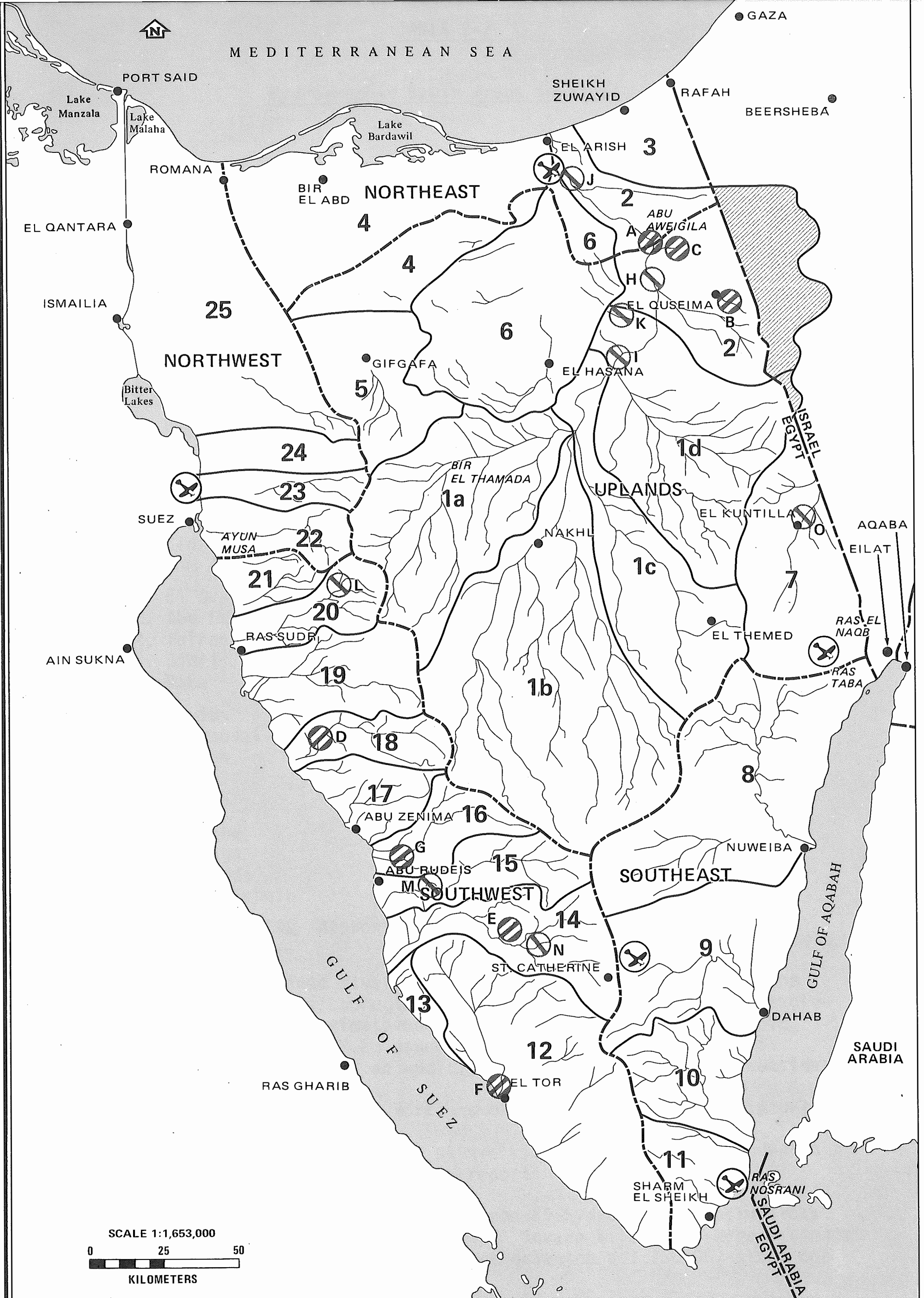
*With the exception of the relatively short Wadi Masagid in the North Coast Basin Area.



HYDROGRAPHIC BASINS, EXISTING DAMS AND POSSIBLE DAM SITES

LEGEND

25	HYDROGRAPHIC BASIN IDENTIFICATION NUMBER, REFER TO KEY FOR BASIN NAMES
(hatched box)	PORTION OF BASIN OUTSIDE SINAI PENINSULA
G	EXISTING DAM, REFER TO KEY FOR DAM NAME AND LOCATION
O	POSSIBLE DAM SITE, REFER TO KEY FOR SITE LOCATION

—KEY TO HYDROGRAPHIC BASINS—

IDENTIFICATION NUMBER	BASIN
1	Upper El Arish
1a	El Bruk
1b	El Ruaq
1c	El Aqabah
1d	Geraia
2	Lower El Arish
3	Northeast coast
4	North coast
5	Hegayib
6	El Hasana - El Hema
7	El Gerafi
8	Wasit
9	Dahab
10	Kid
11	Umm Adawi
12	El Qaa
13	Abu Durba
14	Feiran
15	Sidri
16	Baba
17	Tayiba
18	Gharandal
19	Wardan
20	Sudr
21	Lahata
22	El Raha
23	El Hagg
24	El Giddi
25	Umm Khisheib

—KEY TO EXISTING DAMS—

IDENTIFICATION LETTER	NAME AND LOCATION
A	Rawafaa Dam, Wadi El Arish
B	Gudeirat Dam, Wadi El Gudeirat
C	Perkins Dam, Wadi Sad
D	Two Small Dams on Wadi Gharandal
E	Dam on Wadi Nefuz
F	Dam at Wadi El Wadi, Wadi El Aawag (Destroyed)
G	Dam on Wadi Shellal

—KEY TO POSSIBLE DAM SITES—

IDENTIFICATION LETTER	LOCATION
H	El Daiqa Gorge, Wadi El Arish
I	Mitmetni Gorge, Wadi El Arish
J	El Lahfan Gorge, Wadi El Arish
K	Wadi El Hadira
L	Wadi Sudr
M	Wadi Sidri
N	Wadi Feiran
O	Wadi El Gerafi

—NOTES—

Additional Information Pertaining to Hydrographic Basins may be found in Tables 2-2, 2-4, 2-11, and 2-12.

FIGURE 2.2
HYDROGRAPHIC BASINS, EXISTING DAMS AND POSSIBLE DAM SITES

TABLE 2-2

Hydrographic Basin Areas in Sinai

Basin	Area (km2)	Subregion[a]
1. Upper El Arish	16,306[b]	UP
a. El Bruk	3,345	UP
b. El Ruaq	6,481	UP
c. El Aqabah	2,839	UP
d. Geraia	3,641	UP
2. Lower El Arish	2,749[c]	NE and UP
3. Northeast coast	963	NE
4. North coast	5,148	NE and UP
5. Hegayib	1,680	UP
6. El Hasana-El Hema	3,549	UP and NE
7. El Gerafi	2,446	UP
8. Wasit	4,204	SE
9. Dahab	2,684	SE
10. Kid	1,355	SE
11. Umm Adawi	964	SE
12. El Qaa	3,904	SW
13. Abu Durba	266	SW
14. Feiran	1,717	SW
15. Sidri	1,163	SW
16. Baba	841	SW
17. Tayiba	860	SW
18. Gharandal	829	SW
19. Wardan	1,569	SW
20. Sudr	895	SW
21. Lahata	603	SW
22. El Raha	847	NW
23. El Hagg	621	NW
24. El Giddi	703	NW
25. Umm Khisheib	4,641	NW
TOTAL	Approximately 61,000[d]	

[a] The Study Team defined five subregions for planning purposes. The boundaries of these subregions were based primarily, but not exclusively, on the approximate boundaries of groups of hydrographic basins. (See Figure 2.2, page 2-9.)

[b] Total basin area includes an additional 45 square kilometers outside Sinai.

[c] Total basin area, including portions outside Sinai, is approximately 4,000 square kilometers.

[d] Sinai basin areas add to 61,507 square kilometers but are rounded to 61,000 square kilometers in this report.

SOURCE: The Consultant divided Sinai into 25 hydrographic basin areas for the purposes of this Study. Square kilometers were estimated by planimeter after basins were drawn on a 1:750,000-scale map.

and the northeastern end of Gebel El Halal. At the two latter locations, the wadi passes through significant gorges. At Mitmetni, the gorge separates Gebels Tabaqet El Mitmetni and Taliat El Bedan. At Gebel El Halal, a sizable gorge--El Daiqa, through which the Wadi El Arish passes--separates Gebels El Halal and Dalfa.

These natural controls limit the flow downstream during floods by effecting a degree of storage and water spreading in the wide wadi beds and flood plains upstream of the controls. This no doubt induces a certain amount of percolation into the wadi alluvium at those locations. It also implies that some of the water stored temporarily in these spreading areas will be lost through evaporation. The evaporation occurring after the floods have passed, from the moist wadi bed and flood-plain soils, probably results in a concentration of salts in the upper soil layers. This is evident at least in the Wadi El Bruk part of the basin, from soil analyses made in 1981 by the Desert Institute.(0267) Another effect of such natural controls is to reduce the silt load of floodwaters downstream of the control. The broad spreading areas upstream of these natural gorges thus serve as natural siltation basins.

It can be concluded that the El Arish Basin differs significantly from most of the basins that empty into the Gulf of Suez or the Gulf of Aqabah. First, because of its generally low gradient, low drainage density, and the natural controls, the El Arish Basin can be expected to have a lower runoff yield per square kilometer of catchment area, at least as measured at the lower end of the basin. Secondly, because of the presence of the natural controls on Wadi El Arish, the average sediment load of floods on the wadi, as measured on the lower part of the basin, should be significantly less than would be expected from floodwaters in the wadis draining to the Gulf of Suez or the Gulf of Aqabah.

2.2.2.2 Runoff Information. There are no accurate data on large basin runoff in Sinai. Estimates have been made of total flood quantities occurring at Rawafaa Dam on the lower Wadi El Arish (north of Gebel El Halal) for 1948, 1950, 1951, and the 1965/1966 season. Qualitative descriptions of the size of the floods on the wadi, from 1925 to 1945, have been made by Government officials. This information is provided in Table 2-3. From this table, it would seem that if a "strong" flood can be equated with a quantity of about 20×10^6 cubic meters or greater, a "strong" flood on the lower Wadi El Arish could be expected every 2 to 4 years. There seems to be a relatively poor correlation between the annual rainfall at El Arish and the size of the flood, as shown in Table 2-3.

Because of the paucity of runoff data for the large basins of Sinai, it is necessary to estimate potential runoff yields and flood flows for the major wadis by means of empirical formulae. Estimated flood flows for the basins of Sinai have been computed using empirical formulae reported by Finkel (0403), which were derived from investigations of runoff in basins on the Israeli side of the Araba Valley.

TABLE 2-3

Reported Floodwater Quantities Flowing in the Lower Part of Wadi El Arish

Date	Magnitude of Flood (Torrent)	Annual Rainfall at El Arish (mm)	Reference
Oct. 1925	"Very strong"	114	1268
Dec. 1928	"Strong"	64	1268
Dec. 1930	"Strong"	110	1268
Oct. 1931	"Medium"	69	1268
Dec. 1933	"Strong"	82	1268
Oct. 1935	"Strong"	37	1268
Oct. 1937	"Very strong"	123	1268
Oct. 1938	"Medium"	126	1268
Oct. 1940	"Medium"	94	1268
Dec. 1942	"Strong"	98	1268
March 1943	"Weak"	121	1268
Jan. 1945	"Very strong"	--	1268
1945	7 days continuous flow at Mitmetni	--	(a)
1948	21×10^6 m^3(b)	87	1037, 1350
1950	18×10^6 m^3(b)	127	1037
1951	$\sim 3 \times 10^6$ m^3(b)	45	1037
1953	~800,000 m^3(c)	126	1350
1954-1964	Information missing	--	--
1965/1966	$>1 \times 10^6$ m^3(b)	193/63	1350
1967-1974	Information missing	--	--
1975	"Large flood" at El Arish	--	1265
1976-1979	Information missing	--	--
1980	"Large flood" at El Arish	--	1265

[a]Observed by Dr. A. Shata.

[b]At Rawafaa dam.

[c]The quantity reaching Wadi El Arish from Wadi Hareidin.

SOURCE: Derived from Government data. See references cited above.

Peak flood flows (Q_{max}), in cubic meters per second, are estimated by the equation:

$$Q_{max} = K_1 A^{0.67} \qquad \text{Eq (1)}$$

and, the volume of the annual flood (V), in 1,000 cubic meters, is given by:

$$V = K_2 A^{0.67} \qquad \text{Eq (2)}$$

where, A is the area of the basin in square kilometers, and K_1 and K_2 are constants depending on the probability of occurrence (0403):

Probability of Occurrence in a Given Year	K_1	K_2
(80%	0.01	0.168)
(10%	1.58	26.5)
(2%	4.3	72.2)

Finally, the duration (D) of each expected flood flow (in hours) can be estimated by:

$$D = V^{1.14} / Q_{max}. \qquad \text{Eq (3)}$$

Table 2-4 shows that peak flood flows range from 0.1 to 7.7 m^3/sec at a probability of 80 percent and from 55 to 3,310 m^3/sec at a probability of 2 percent. Average flood durations range from 19 to 33 hours at a probability 80 percent, and from 44 to 78 hours at a probability of 2 percent. As indicated in Table 2-4, flood flows are believed to be dissipated by infiltration into wadi beds, flood plain deposits or sand dunes before reaching the sea in seven of the basins, including Hegayib and Umm Khisheib. Some of the information in Table 2-4 compares favorably with that given in Table 2-3. For example, Table 2-3 indicates that flood volumes of approximately 21 x 10^6 cubic meters and 18 x 10^6 cubic meters were reported for the Lower Wadi El Arish in 1948 and 1950 respectively. These values correspond closely with the flood volume estimates at a probability of 10 percent, given in Table 2-4, for the Upper Wadi El Arish Basin (17.6 x 10^6 cubic meters) and for the entire Wadi El Arish Basin (20.4 x 10^6 cubic meters).

Potential runoff yields on an average annual basis have been computed for each Sinai basin area by means of three other empirical formulae. This estimation was carried out as a part of the water balance analysis, and the results are presented in Section 2.2.4.

TABLE 2-4

Estimated Flood Flows for Basins in Sinai

No.	Basin	Area (km^2)	Estimated Peak Flood Flow (m^3/sec)[a] P_{80}	P_{10}	P_2	Estimated Flood Volume ($m^3 \times 10^3$)[a] P_{80}	P_{10}	P_2	Average Flood Duration (hr)[a] P_{80}	P_{10}	P_2
	Entire Wadi El Arish, subtotal	19,055	7.7	1,220	3,310	130	20,400	55,600	33	67	78
1	Upper Wadi El Arish, subtotal	16,306	6.7	1,050	2,860	110	17,600	48,000	33	66	76
1a	El Bruk	3,345	2.3	360	990	39	6,090	16,690	28	57	65
1b	El Ruaq	6,481	3.6	570	1,540	60	9,490	25,800	30	60	70
1c	El Aqabah	2,839	2.1	330	890	35	5,460	14,900	28	56	64
1d	Geraia	3,641	2.4	380	1,050	41	6,450	17,600	28	57	66
2	Lower Wadi El Arish	2,749	2.6	410	1,110	44	6,870	18,700	28	58	67
3	Northeast Coast[b]	963	1.0	160	430	17	2,650	7,200	25	50	58
4	North Coast[b]	5,148	3.0	480	1,320	52	8,130	22,100	29	59	68
5	Hegayib[b]	1,680	1.4	230	620	24	3,840	10,500	26	53	61
6	El Hasana-El Hema[b]	3,549	2.4	380	1,030	40	6,340	17,300	28	57	66
7	El Gerafi	2,446	1.9	290	800	31	4,940	13,500	27	55	64
8	Wasit	4,204	2.7	420	1,150	45	7,100	19,300	29	58	67
9	Dahab	2,684	2.0	310	850	33	5,250	14,300	27	56	64
10	Kid	1,355	1.3	200	540	21	3,320	9,100	26	52	60
11	Umm Adawi	964	1.0	160	430	17	2,650	7,200	25	50	58
12	El Qaa	3,904	2.5	400	1,100	43	6,750	18,400	28	58	66
13	Abu Durba	266	0.4	67	180	7	1,120	3,000	22	45	52
14	Feiran	1,717	1.5	230	630	25	3,900	10,600	26	53	61
15	Sidri	1,163	1.1	180	490	19	3,000	8,200	25	51	59
16	Baba	841	0.9	140	390	15	2,400	6,600	25	50	57
17	Tayiba	860	0.9	150	400	15	2,500	6,700	25	50	58
18	Gharandal	829	0.9	140	390	15	2,400	6,500	25	50	57
19	Wardan	1,569	1.4	220	600	23	3,670	10,000	26	53	61
20	Sudr	895	0.9	150	410	16	2,500	6,900	25	50	58
21	Lahata	603	0.7	120	310	12	1,930	5,300	24	48	56
22	El Raha	847	0.9	140	390	15	2,430	6,600	25	50	58
23	El Hagg[b]	621	0.7	120	320	12	1,970	5,400	24	49	56
24	El Giddi[b]	703	0.8	130	350	14	2,140	5,800	24	49	57
25	Umm Khisheib[b]	4,641	2.9	450	1,230	48	7,580	20,700	29	59	67

[a] "P_{80}" refers to a probability of 80 percent, "P_{10}" refers to a probability of 10 percent, and "P_2" refers to a probability of 2 percent.

[b] Basins where flood flows are dissipated by infiltration into wadi beds, floodplain deposits, or sand dunes before reaching the sea. Indicated flood flows and flood volumes for these basins are more hypothetical than actual.

SOURCE: Based on empirical equations reported by Finkel (0403) for the Araba Valley.

Yair and Lavee (1485) reported on results of simulated rainfall on experimental plots along the Gulf of Aqabah, between Nuweiba and Eilat. The work was done on six talus slopes, with rock consisting of granite/ schist, magmatic dyke, sandstone, or limestone. The size of the controlled plot portion of each slope ranged from 70 to 140 square meters. Simulated rainfall--ranging from 4 to 12 millimeters and at intensities from 0.2 to 1.2 mm/min--was applied three times to each plot. The average runoff coefficient ranged from 7 percent on the coarse sandstone talus slope and 20 percent on the limestone slope to 25 percent on the granite/ schist or dyke rock talus slopes. The authors found that some of the runoff differences shown are due less to different lithology than to differences in the particle size distribution of the talus itself. They conclude that under talus slope conditions, and other things being equal, the greater the D_{50} (median particle size) of the upper gravelly layer, the greater the runoff yield.

Evanari, Shanan, and Tadmor (0384) report on results of runoff measurements on eight small watersheds on a research farm at Avdat in the Negev. Measurements were made from 1960 to 1967--during which time the annual rainfall ranged from 26 to 160 millimeters. Seven of the watersheds were small, ranging in size from 1 to 7 hectares. The average annual runoff coefficient for these seven watersheds ranged from 1.2 to 13 percent over the same 7-year period. The annual runoff coefficient for the largest watershed (345 hectares) ranged from 0.4 percent for the year of the lowest rainfall to 8.6 percent for the year of the next to highest rainfall. The authors' conclusion is that the larger the watershed, the smaller the runoff yield (in millimeters). Based on these measurements and on controlled runoff experiments, they further conclude that under those Negev conditions, lands of relatively low slope with little stone cover produce the greatest runoff yield. These results are important for comparable parts of Sinai, where runoff may be effectively conserved and used on a small scale for cultivation or livestock.

2.2.2.3 Existing Dams in Sinai. Seven dams in Sinai are mentioned in the literature. Details on these dams are provided in Appendix Table A-2. Three are masonry dams--Rawafaa Dam, Ein Gudeirat Dam, and Perkins Dam. (1268) Rawafaa and Wadi Nefuz (near Feiran Oasis) are currently silted up. The dam built at El Wadi, north of El Tor, has been washed away. Ein Gudeirat is masonry and badly damaged. The locations of seven historic dams are shown on Figure 2.2, along with sites proposed but not yet verified for future development.

Of the seven dams, Rawafaa is the most interesting from several points of view. An arched masonry dam located on Wadi El Arish, about 52 kilometers south of El Arish town, it was built in 1946 and reportedly had an initial capacity of about 3 million cubic meters.(1350) References (1268) and (1350) report that the dam is silted up; however, Taha (1350) also provides data indicationg that the dam was reduced in capacity from 3.03×10^6 cubic meters in 1949 to 2.94×10^6 cubic meters in 1958--equivalent to an average loss of capacity of only 10,000 m^3/yr. Assuming that the useful life of the reservoir would end if its capacity dropped to 1×10^6 cubic meters, and assuming an average siltation rate of 10,000 m^3/yr., it would appear that the reservoir should have a useful life up to the year 2150! The loss of capacity, estimated by Taha, may be considerably lower than actual, simply because the measurements appear to have been taken just behind the dam, where the sediment buildup is not likely to be as great as in the "delta" at the head of the reservoir. Clearly, more information is needed to reconcile these conflicting sources. Careful site inspections with surveyed measurements are recommended as soon as possible. Some of the reservoir capacity probably remains, in which case plans should be made for the most effective use of the reservoir water.

In addition to the problem of siltation, the Rawafaa reservoir experienced, or is experiencing, both evaporation and seepage losses. Several investigators have noted the presence of well-fractured Eocene limestone underlying the reservoir. This could lead to high seepage losses if the sediment has not been deposited thickly and uniformly enough over the entire reservoir area. The problem of seepage and evaporation losses from such reservoirs is discussed in Section 2.2.2.5.

2.2.2.4 Conservation and Use of Runoff Water. Several methods have traditionally been employed in Sinai to store or conserve runoff water for use as drinking water and for agriculture. In many areas, cisterns are being used to collect and store water for livestock and domestic use. Cisterns are presently used at El Feteh at Gebel El Maghara. Three kilometers west of El Hasana, "haraba" have been created in small caves in the mountains.(0233) These are of varying sizes, but average about 100 cubic meters in capacity. Inlets have been made in the roofs of the caves, and covers are provided for the inlets. The haraba fill up with runoff water during storms. The person or family who constructed the inlet and cover is the owner, and they generally padlock the cover shut when the haraba is not in use.(0233) With good rainfall periods, the water collected in a haraba can last a family for up to 1 year.

The Bedouin families in Sinai make use of floodwaters for agriculture. In many areas, the land in the wadi beds is plowed and cultivated after the first rains of a season. This is the practice, for example, in Wadi El Hasana (at a location about 7 kilometers southwest of El Hasana town), and in Wadi El Arish, 3 kilometers northeast of Nakhl. The crops grown include barley, corn (maize), tomatoes, watermelons, sesame, grapes, pomegranates, and olives.(0233)

In many cases, the Bedouins have constructed spreader dykes in the wadi beds, and cultivation is then carried out just upstream of the dyke. These are known locally as "El Oqum" and consist of low earthen or stone dykes.(1269) The effect of the dykes is to slow the passage of water downstream by spreading and storing some runoff water. At the same time, sediment is deposited behind the dykes and develops into relatively fertile agricultural soil. Frequently, before the dykes are stabilized by the substantial deposit of sediment, they are damaged or totally destroyed by floods and have to be rebuilt.(1269) In early 1982, there was a Government plan to construct three earthen dykes across Wadi El Hasana.(0233) A bar of blown sand reportedly serves as a natural spreader dyke in Wadi Abu Hagar, a tributary to Wadi Wardan, near Gebel Khoshira. The Bedouins reportedly cultivate beans, wheat, and other cereals behind this feature.(0890)

Sixty-two areas containing spreader dykes were inventoried by studying 1955-to-1956 aerial photographs obtained from the Egyptian Military Survey Department. Each of these areas generally includes several spreader dykes. Of the 62 areas, 40 are located on the Wadi El Arish Basin. A list showing spreader dykes areas in Sinai, is given in Data Entry WA-SU-4 in Volume VII.* In addition, there are other areas containing spreader dykes that could not be identified on the photo-mosaics. For example, earthen dykes have been constructed by the Bedouins north of El Rawafaa on the lower Wadi El Arish.(1037)

2.2.2.5 Future Regulation and Storage of Runoff. Traditionally, one thinks of public supply or irrigation, groundwater recharge, flood protection, electrical generation, or a combination of these as possible reasons for dam construction.

The supply of runoff water is too sporadic and irregular over the entire peninsula to think of constructing dams for hydroelectrical generation. At the present time, it would seem that the need for flood protection, by itself, is not sufficient to justify dam construction. The value of existing roads, bridges, and buildings likely to be damaged or destroyed by floods does not appear to justify a large expenditure for dam construction and maintenance in any area of Sinai. The flood wall at El Arish town, along the edge of Wadi El Arish, was designed to provide protection for the present level of development. There is certainly a need in many areas of Sinai for water for public supply and irrigation. But at what locations can sufficient quantities of water be stored, to be conveyed to the point of use at a reasonable cost? The answer, of course, requires an extensive analysis of each potential dam site, including:

- Expected yield from its catchment.
- Size of reservoir appropriate for the expected inflow sequence.
- Expected firm yield or release rate from the reservoir.
- Estimated cost of dam construction and of conveyance of water to the point of use.

Certain problems--typical of arid areas--are anticipated with any dam project in Sinai. They can be summarized as follows:

- Runoff-producing storms occur so infrequently that most or all potential reservoirs will be dry part of the time.
- Areas downstream of a dam will be deprived of normal wadi flow for cultivation and groundwater recharge.
- Seepage from the bed of the reservoir may indeed recharge an aquifer, but the aquifer may be one from which the groundwater cannot be conveniently or economically retrieved.
- Evaporation losses are likely to be high, particularly in the summertime, and will result in a major loss of water from the reservoir.

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*Locations are mapped as "1955-56 agricultural sites" in Plate 6-5 of Working Paper No. 45 in the SDS-I project files.

- Siltation of the reservoir is likely to occur at a rapid rate due to the relatively barren catchment areas found in arid regions.

With regard to areas downstream of a dam, it is important to assess the effects of dam construction on the use of wadi runoff. Local inhabitants, living a few to several kilometers downstream of a potential dam site, may depend on annual or biannual floods for cultivation of their crops and, indirectly, for groundwater recharge for their wells. If the plan is to supply reservoir water to communities farther downstream of these inhabitants, they could be completely bypassed and their livelihood threatened due to the absence of seasonal flooding.

Reservoir siltation is a serious problem in any arid environment. As a minimum, any potential reservoir site must be large enough to provide a substantial dead storage volume to accommodate the expected sediment load of inflowing runoff water. Under certain conditions, as mentioned in Section 2.2.2.1 with respect to the Wadi El Arish Basin, a significant portion of the sediment load of floodwaters may be dropped prior to reaching a given reservoir site. This will usually occur only if the basin is large, with a relatively low gradient, and contains one or more natural controls that create silting basins on their upstream side.

Development of the surface water resources of a basin involves choosing between large downstream reservoirs or small upstream reservoirs. The construction costs of downstream reservoirs are high, particularly in arid areas such as Sinai, where the high, but infrequent, peak flood flows necessitate a large spillway, the cost of which would probably be disproportionate to the value of water stored.(0403) Also, downstream reservoirs, generally located at relatively low elevations, tend to have high evaporative losses. On the other hand, small upstream reservoirs may involve relatively high unit construction costs because of problems of site accessibility.(0403) Of more importance, if small upstream reservoirs are a considerable distance from the potential points of use, this would necessitate a substantial investment in conveyances.

A case can be made for small upstream reservoirs, with dams of simple design, where the water is to be used for livestock and/or small-scale irrigation immediately downstream. A stronger case can be made for small dams to enhance the resource base of dispersed settlements such as El Kuntilla, El Quseima, Nakhl, El Themed, and Ras Taba.

Diversion works at downstream locations in arid areas tend to share some of the disadvantages of the large downstream dams. Because of infrequent floods, canals accommodating diverted flood flow may have to be relatively large to justify the cost of the diversion structure. A rough calculation was performed for a hypothetical diversion structure upstream of El Arish town to carry runoff water to groundwater recharge basins. It was estimated that diversion of only one-tenth of a flood flow (estimated to amount to 30 x 10^6 cubic meters of water), expected perhaps every 2 to 4 years, would require two canals--each 6 meters wide at the top and 2.4 meters deep. In addition, the diversion dam would have to be fairly long. All of this would involve relatively high cost, considering the infrequency of the event and that it would result in the recharge of, at most, only 3 million cubic meters of water each time. This is the amount currently estimated to be withdrawn from the Quaternary aquifer at El Arish over a 120-day period.

2.2.2.6 Eight Potential Dams. Several potential dam sites in Sinai have been suggested for consideration by different investigators. (Details on eight possible dam sites are given in Appendix Table A-3, see also Figure 2.2.) This by no means exhausts the potential, but includes the best and representative examples. The two most interesting locations, from the point of view of possible water supply to El Arish town and topography, are on Wadi El Arish--one in the El Daiqa Gorge at Gebel El Halal and the other at the Mitmetni Gorge separating Gebel Taliat El Bedan and Gebel Tabaqet El Mitmetni. As mentioned in Section 2.2.2.1, these two gorges, in their natural state, already serve as controls to the flood flows and effect a certain degree of water holdback and storage immediately upstream. The additional benefits that could accrue from either one of these dams must be weighed carefully against expected costs and drawbacks.

El Arish town is the community downstream of the two dam sites that is in most need of water. El Arish would be one logical point of use for water from either of the two possible reservoirs. Three major drawbacks of this proposal are that:

- It will result in depriving the area between Gebel El Halal and El Arish of seasonal wadi flows, resulting in the subsequent reduction of local groundwater recharge and groundwater quality.

- It will require a relatively long pipeline and possible pumping station to convey the water from the reservoir to El Arish, a distance of 63 kilometers for the closest of the two sites, El Daiqa.

- Because of high evaporative losses and the infrequency of floods, the dependable yield or release rate from each reservoir is expected to be modest.

Another option could be considered. To avoid the cost of conveyance of the water to El Arish and to provide water to users immediately downstream, the purpose of either the El Daiqa or the Mitmetni reservoir could be shifted, so that the water would be dedicated for irrigation (or industrial use) in the reach extending several kilometers downstream of the dam. This could provide some genuine benefits. But the drawback associated with this option is that the El Arish area would be largely deprived of seasonal wadi flow, which is one of the important sources of recharge for the Quaternary aquifer.

An analysis was made of the possible effects of evaporation and seepage on the constant release rate available from a reservoir at El

Daiqa. An average daily evaporation rate of 5.2 mm/day was assumed, based on results of the calculation of the reference evapotranspiration rate for El Arish by the modified Penman method (see Data Entry EN-CL-13 in Volume VII). For the purpose of the calculation, the steady-state seepage rate from the bottom of the reservoir was assumed to be one-fourth of the daily evaporation rate. The reservoir was assumed to have the shape of an inverted frustum of a cone, with a live capacity of 30 million cubic meters and a dead volume of 10 million cubic meters. The reservoir was assumed to be filled once every 3 years.

It should be noted that the assumed capacity of 30 million cubic meters for a reservoir at El Daiqa Gorge was based partly on an analysis performed by using the flood information given in Table 2-3. By making certain rough assumptions regarding the numerical equivalent of "very strong," "strong," "medium," and "weak" floods (reported in Table 2-3), a cumulative flood flow versus time graph was constructed for the lower Wadi El Arish, from which the reservoir capacity was estimated.

With the aid of a programmable calculator, daily accounting was made for 25 to 650 days of changes in storage resulting from evaporation and seepage and from a constant rate of release downstream. By performing several runs--each with a different constant release rate--a curve was developed relating the rate of constant release in cubic meters per day to the number of days to draw off all the live storage. This curve is shown in Figure 3-1 of Working Paper No. 33, Water Resources.

A derived curve, relating the constant rate of release to the percentage of the initial live volume that was released from the reservoir for downstream use, was also developed. It is clear that by increasing the release rate, the percentage of initial live volume that can be used downstream increases. At a release rate of 60,000 m^3/day, 55 percent of the initial live volume is recoverable, but the supply lasts only about 275 days. At a release rate of 20,000 m^3/day, 30 percent of the initial live volume is recoverable, and the supply lasts about 450 days.

Similar curves were developed for the Rawafaa Dam on the lower Wadi El Arish, for which it was assumed that seepage losses equaled evaporation losses. (See Figure 3-2 in Working Paper No. 33 in the SDS-I project files.) It was assumed that a live storage of 2.2 x 10^6 cubic meters still remains at Rawafaa (quite possibly an erroneous assumption), that there is a dead volume of 0.5 x 10^6 cubic meters, and that it fills once every 2 years. At a constant release rate of 3,000 m^3/day, it would be possible to recover about 30 percent of the initial live volume, with the supply lasting about 210 days. At a release rate of 1,000 m^3/day, only 13 percent of the initial volume is recoverable, but the supply lasts about 285 days.

The other site on Wadi El Arish, near Bir El Lahfan, would be an attractive location with respect to serving the El Arish area. It could, however, have certain problems--for instance, there may be no proper foundation for a dam structure and the underlying fractured and faulted Cretaceous rocks could mean high seepage rates. Detailed site investigations are required.

It is assumed that a dam at Bir El Lahfan would be founded at about elevation 40 meters, with a spillway crest elevation of 53 meters. The computed live capacity would be 11×10^6 cubic meters, with a dead storage of 2×10^6 cubic meters. Curves of release rate versus duration of expected supply were also developed for this site, assuming that the seepage loss rate equaled evaporation. The analyses showed, for example, that a release rate of 12,000 m^3/day could be sustained for 290 days, or 18,000 m^3/day for 250 days. It was assumed that the reservoir would fill on the average once in every 3 years.

Other potential dam sites might be considered in addition to the three mentioned on Wadi El Arish, as shown in Data Entry WA-SU-5 in Volume VII, though they do not have topographic characteristics as attractive as those at El Daiqa Gorge and at Mitmetni Gorge. The five locations selected are on the following wadis--Wadi El Hadira at Gebel El Halal (UP), Wadi Sudr near Ain Sudr (SW), Wadi Sidri near Gebel Maghara (SW), Wadi Feiran upstream of the oasis (SW), and Wadi El Gerafi near Kuntilla (UP).

The rate of siltation at these other locations is expected to be definitely higher than at the Wadi El Arish sites. With the exception of possible dams on Wadi El Hadira and Wadi El Gerafi, the distance to the points of use is considerable. This, taken with the high evaporation rate and the infrequency of storms, leads to a prediction that the benefit-cost ratio associated with dams at these five locations is unlikely to exceed 1:1. Some locations (e.g., Wadi El Gerafi) have lesser opportunities for alternative water sources.

To assess more closely the feasibility of developing water supplies on some of the large wadis of Sinai, preliminary site investigations and benefit-cost analyses might be performed for four of the most promising and representative dam sites--El Daiqa Gorge, Bir El Lahfan site, the Wadi Sudr site, and the site on Wadi Hadira (as an example of a small reservoir).

2.2.2.7 Potential for Small-Scale Runoff Water Conservation and Use. The conservation and use of runoff water, on a small scale, must be considered in any overall water and agricultural strategy for the peninsula, to include:

- Projects to conserve runoff water for range improvement and for the enhancement of intermittent cultivation.

- Projects to establish relatively intensive "runoff farms."

In both cases, project feasibility should be examined from two points of view. The physical characteristics of each site (e.g., position in the basin, topography, soils, and vegetation) must be suitable to ensure the project's success. The Bedouins or farmers who will use and maintain the proposed devices and systems must understand their operation and should be committed to work on a long-term basis.

For the improvement of rangeland and the enhancement of intermittent cultivation, several types of floodwater spreading systems have been used in different arid or semi-arid areas of the world. The presence of old spreader dykes at 62 locations in several wadis was already noted in Section 2.2.2.4.

In the right locations, properly designed and maintained spreader-dyke systems can be a real benefit for local range and cultivation improvement. These systems may consist of only a single long spreader dyke extending across the wadi and partially across the flood plain--often with outlet holes or outlet structures along its length. Alternatively, an upstream spreader dyke or diversion dyke may serve to divert a portion of the wadi flood flow to a series of other spreader dykes located downslope and well up on the flood plain on one side of the wadi. The dykes on the flood plain would be arranged in a series, so that overflow from one would be diverted to the next downgradient dyke, etc. A schematic representation of such a system is given in Figure 2.3.(1331)

To make such water-spreading systems economically attractive, the dykes should be constructed of locally available materials and be of simple design. In most cases, a low (0.5-meter settled height) stone or rock dyke is most appropriate because of the availability of the material and the relatively low cost of the initial construction and subsequent repair.

The purposes of new water-spreading systems in Sinai would be primarily to improve the rangeland at selected locations and to extend the areas that can be cultivated, at least intermittently. The use of properly designed and maintained water-spreading systems in several arid to semi-arid areas in the western United States has resulted in significant increases in the livestock carrying capacities of rangeland.(1331) The area just upstream of each spreader dam is where pasture improvement and crop cultivation take place. Two other important benefits from a water-spreading system are the increased percolation of runoff water to underlying shallow alluvial aquifers, and the reduction of soil erosion. If the underlying alluvial materials constitute a good aquifer, with induced local recharge, groundwater quality as well as quantity might be maintained at an acceptable level for irrigation, so that wells can be used in conjunction with surface water runoff to sustain local agriculture.

The locations for new water-spreading systems must be chosen carefully. In general, the upstream portions of basins are preferable because flood flows are not as large there, and the danger of flood damage to the dykes is thus reduced. Ideally, sites with a gently sloping plain without gullies are best.(1331) For Sinai conditions, slopes ranging from 2 to 5 percent should be acceptable. The soils should preferably be deep and of a sandy-to-loamy texture. Soils very high in soluble salts should be avoided.(1331)

Floodwaters can be diverted from the wadi to the water-spreading area by means of either a low earthen diversion dam or dyke or by means of partial diversions. A partial diversion consists of a diversion channel cut into the side of the wadi bed, which has its bottom at approximately

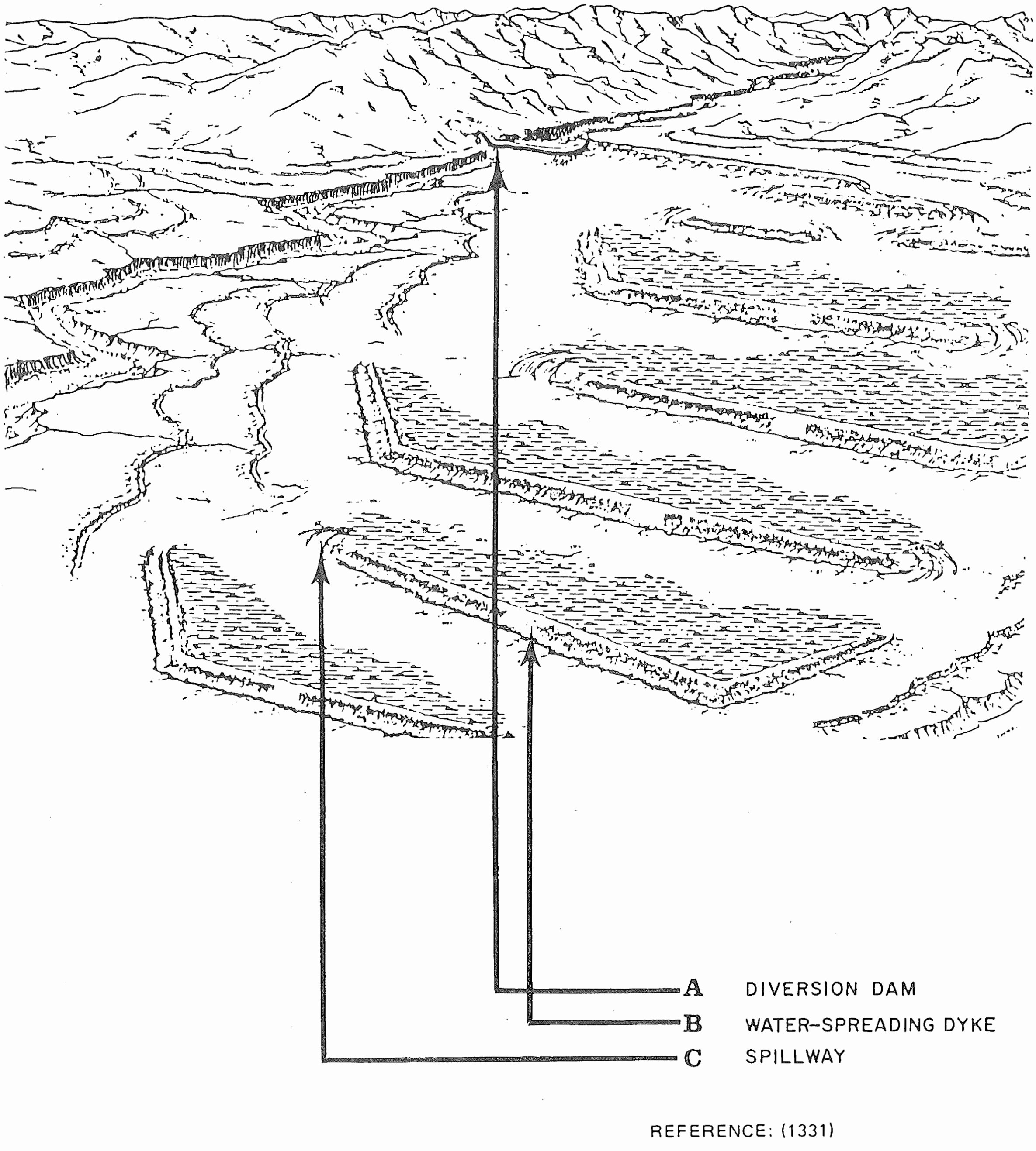


FIGURE 2.3
SCHEMATIC SKETCH OF A TYPICAL
WATER-SPREADING SYSTEM

Dames & Moore

the same elevation as the bottom of the wadi bed. The diversion channel is constructed with an acceptable uniform slope and extends from the wadi bed to the uppermost spreading dyke. Depending on the average sediment load of the upstream floodwaters, such diversion channels may need frequent cleaning.

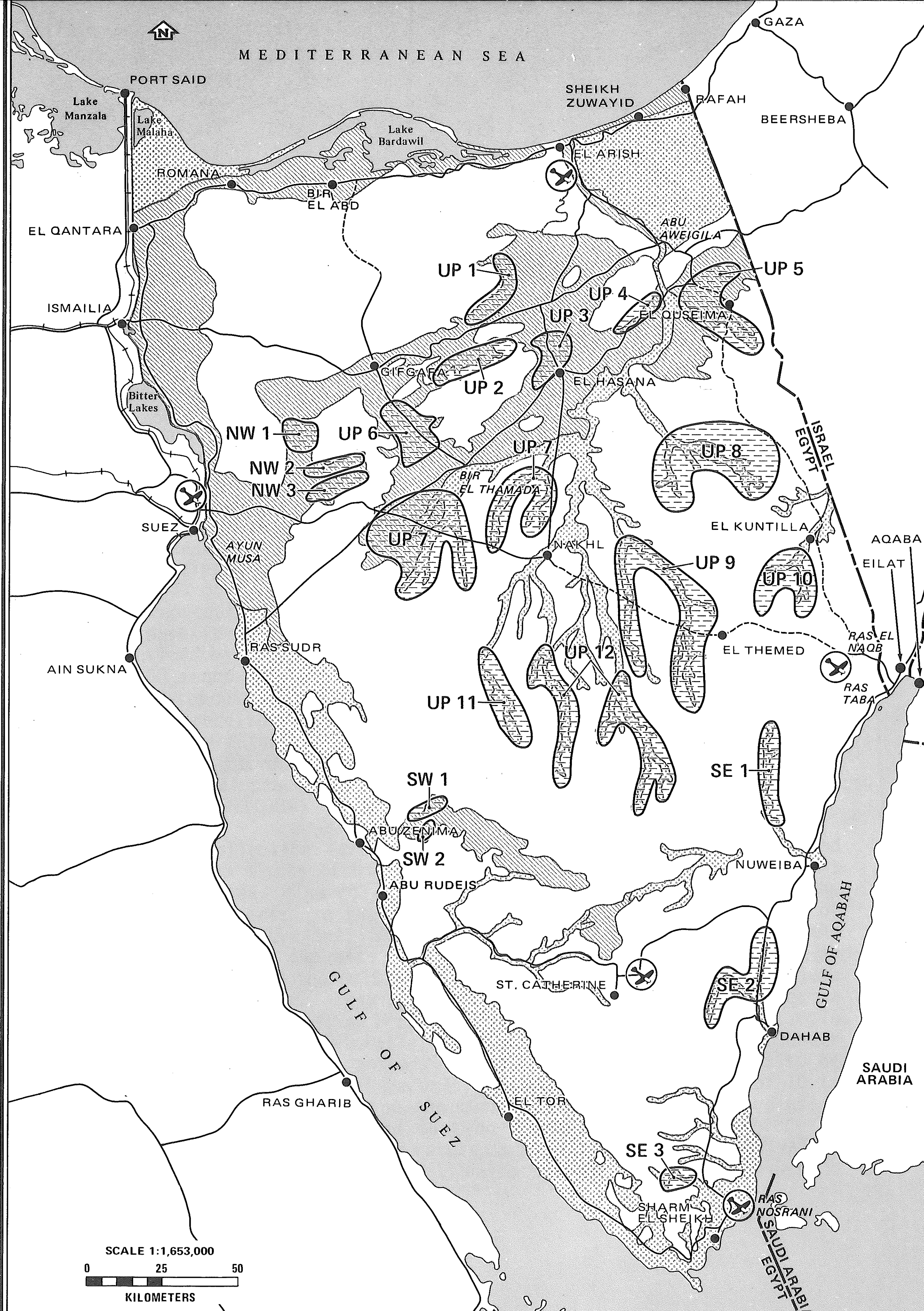
If the spreading area has an average slope of less than 2 percent, ponding-type spreading is recommended, using a series of spreader dykes, as shown on Figure 2.3. For slopes greater than 2 percent, wild flood spreading should be considered.(1331) Under this method, water is released at a number of points from one or two upper spreader dykes and is allowed to flow directly down the slope. In some cases, relatively short secondary dykes are placed in a staggered fashion downslope to diffuse the flow over as broad an area as possible.

Spreader dykes are generally located approximately along the land contour, with just enough slope to induce water movement from one end to the other. At the lower end of each dyke, a spillway must be constructed of sufficient width to convey the excess water downslope, either toward the next lower spreader dyke or as wild flooding.

If it can be justified economically, and if a suitable site exists, it is frequently advantageous to locate a small temporary storage reservoir upstream of the water-spreading system. Flood peaks which might otherwise be unmanageable could be handled by the water-spreading system; the time of water spreading would be increased for flows of short duration; and such storage reservoirs would serve in part as siltation basins and provide a measure of flood control.(1331)

Based on the results of the land capability analysis reported in Volume IV, it would appear that the most promising areas for small-scale cultivation or range improvement based on water-spreading systems include the upper reaches and tributary areas of the following wadis (Figure 2.4):

- Northwest Subregion
  1. Umm Khisheib
  2. El Giddi
  3. El Hagg
- Southwest Subregion
  1. Tayiba and El Hommur
  2. Baba (lower reaches)
- Southeast Subregion
  1. Watir
  2. Dahab
  3. Lithi
- Uplands Subregion
  1. Draining Gebel El Maghara
  2. Draining Gebel Yelleq
  3. El Hasana
  4. Draining Gebel El Halal
  5. El Gayifa
  6. Hegayib
  7. El Bruk
  8. Geraia
  9. El Aqabah
  10. El Gerafi
  11. Upper Wadi El Arish
  12. El Ruaq



CANDIDATE AREAS FOR AGRICULTURE BASED ON WATER-SPREADING SYSTEMS

LEGEND

—MAP UNITS—

SE 3 — CANDIDATE AREAS FOR AGRICULTURE BASED ON WATER-SPREADING SYSTEMS*

—SUITABILITY OF SOILS FOR CROP CULTIVATION—

1 LIMITATION

2, 3, OR 4 LIMITATIONS

MAJOR AGRICULTURAL PROJECTS UNLIKELY; LIMITATIONS TOO NUMEROUS, COSTLY OR SEVERE

*Groundwater may be used to supplement run-off in some areas.

—KEY TO NUMBERED MAP UNITS—

—NORTHWEST—

NUMBER	WADI OR TRIBUTARY AREA[a]
NW 1	Umm Khisheib
NW 2	El Giddi
NW 3	El Hagg

—UPLANDS—

NUMBER	WADI OR TRIBUTARY AREA[a]
UP 1	Draining Gebel El Maghara
UP 2	Draining Gebel Yelleq
UP 3	El Hasana
UP 4	Draining Gebel El Halal
UP 5	El Gayifa
UP 6	El Hegayib
UP 7	El Bruk
UP 8	Geraia
UP 9	El Aqabah
UP 10	Gerafi
UP 11	Upper Wadi El Arish
UP 12	El Ruaq

—KEY TO NUMBERED MAP UNITS—

—SOUTHWEST—

NUMBER	WADI OR TRIBUTARY AREA[a]
SW 1	Tayiba and El Hommur
SW 2	Baba

—SOUTHEAST—

NUMBER	WADI OR TRIBUTARY AREA[a]
SE 1	Watir
SE 2	Dahab
SE 3	Lithi

[a]Sites suitable for agriculture based on water-spreading systems are most likely to be found in the upper reaches and tributary areas of listed wadis; candidate areas most suited for early investigation and development are shown.

FIGURE 2.4
CANDIDATE AREAS FOR AGRICULTURE BASED ON WATER-SPREADING SYSTEMS

Site reconnaissance, combined with detailed analysis of aerial photos and topographic maps, will assist in identifying the best areas for promoting water-spreading agriculture. To establish a priority for developing these areas, it is necessary to consider the existing Bedouin population as well as any local plans to improve rangeland and cropland.

In addition to water-spreading systems, other water conservation practices, such as contour furrowing or soil pitting, can be considered for improving rangeland. With contour furrows, shallow ditches are dug along the contour for holding back rainwater.(1331) Cross dams are incorporated in the furrows at frequent intervals to keep the water well ponded. Soil pits consist of intermittent contour furrows, and can be dug by hand. Both of these methods generally cost less per feddan than water-spreading systems. They are recommended over water-spreading systems where the average slope exceeds 5 percent, and can be applied successfully on land having up to 10 percent slope. Areas for applying these two methods of runoff water conservation should be identified in the course of studying the above basin areas recommended for possible application of water-spreading systems.

The concept of "runoff farms" is relatively new in this century, though there is some evidence that some form of efficient runoff farming was practiced by the ancients, for example, by the Nabateans in the Negev about 2000 years ago.(0384) Two types of runoff farming are of interest for Sinai--conduit collection farms and microcatchments. Conduit collection farms receive runoff and overland flow water that is directly collected from adjacent small catchments by means of collection ditches or conduits. A microcatchment is a small artificially dyked area in which all of the runoff produced flows to one end where a single tree or bush is being cultivated.(0384)

Conduit collection farms involve a network of ditches that extend along the bottom slopes of hillsides and collect overland flow before it reaches a wadi bed. The collected runoff water is then conveyed to the farm area and diverted to the different terraced fields with the aid of diversion boxes. Evenari, Shanan, and Tadmor (0384) have studied the relationship between the size of the catchment area from which water is drawn and the size of the cultivated area for the ancient farms at Shivta and Avdat in the Negev. They found that the ratio of catchment area to cultivated area ranged from 17:1 to 30:1, with an average of 20:1. To compute the equivalent rainfall provided to the terraced fields under such conditions, the mean annual rainfall at Avdat is estimated to be 83 mm/yr, based on 7 years of records, and a runoff coefficient of 10 to 20 percent is assumed (based on the authors' rainfall-runoff studies at the site). It is also assumed that no rainwater will run off of the terraced fields. The calculated result is 249 to 415 mm/yr of equivalent rainfall, on the basis of a 20:1 ratio between catchment area and cultivated field.

A modern runoff farm was built at Avdat by the Israelis in 1959, patterned after the ancient runoff farms in the area.(0384) The terraced cultivated area receiving the runoff water amounted to 6.7 feddans. Of this, 2.8 feddans received runoff water from a catchment area of 73.1 feddans, which implies a catchment- to-field ratio of 25:1. The remaining cultivated area of 3.8 feddans drew its water from a 821-feddan catchment, for a ratio of 215:1. Over 7 years of measurement, the smaller catchment area produced nearly four times more runoff water per feddan than the large catchment. Typical yields on the Avdat runoff farm during 1966 and 1967 (0384), under essentially average rainfall conditions, were as follows:

- Wheat (grain), 1.1 to 1.8 tons/feddan
- Barley (grain), 2 tons/feddan
- Peas (seed), 2.4 tons/feddan
- Onions (seed), 0.27 tons/feddan
- Peaches, 35 to 75 kg/tree
- Apricots, 26 to 37 kg/tree
- Almonds, 2.4 to 3.5 kg/tree
- Loganberries, 1.7 to 3.9 kg/plant.

The same authors conducted experiments with microcatchments on the Avdat farm. The size of the catchments ranged from 15.6 to 1,000 square meters. The runoff coefficient for a 12-millimeter rainfall on these microcatchments was determined to range from 0.27 for the 62.5-square-meter plots to 0.41 for the 500-square-meter plots. Over a period of 6 years, a 20-square meter plot averaged 46 mm/yr runoff, for an average runoff coefficient of 0.44, while over the same period and on the same slope, an 80-square-meter plot exhibited an average runoff coefficient of only 0.21.

The trees and shrubs planted in the experimental microcatchments were pomegranates, apricots, almonds, carobs, olives, and saltbush.(0384) The pomegranate trees showed satisfactory growth from 1965 to 1969 on all plots ranging in size from 250 to 1,000 square meters. Saltbush yields, in kilograms per feddan, were the highest on catchments 31 to 62 square meters in size, and were somewhat lower on larger sized catchments. In general, it was concluded that microcatchments ranging in size from 31 square meters and upwards guarantee successful establishment of the trees and subsequent growth, even during drought years.

The modern science and technology of runoff farming is in its infancy, and further basic and applied research is needed. It is recommended that experimental runoff farms be established in Sinai to evaluate the conditions under which runoff farming can be a practical means of food production. It has been suggested that a minimum mean precipitation of 80 mm/yr is required to ensure the success of runoff farming.(0067) Research in Sinai might be able to show that--by increasing the ratio of catchment area to cultivated field area from 25:1 to perhaps 40:1, recognizing that this will involve additional expense--certain crops can be grown successfully in areas with mean annual rainfall between 60 and

80 millimeters. Experiments with microcatchments would also be carried out on these proposed farms.

Experimental or pilot runoff farms might be located in areas experiencing mean annual rainfall between 60 and 80 millimeters. Possible sites for such farms include the eastern side of Gebel El Halal in northern Sinai and the area near Wadi Feiran-Wadi El Sheikh in southern Sinai. If the results from the experimental runoff farms are positive, financial help could later be extended to local Bedouins or in-migrants from other parts of Egypt to establish private runoff farms in similar locations.

2.2.3 Groundwater Resources

2.2.3.1 Aquifers of Sinai. There are several important and potential aquifers in Sinai. They necessarily derive their characteristics from past geological events of sedimentation and structural movements on the peninsula, as well as from regional and local recharge conditions over the past centuries.* A list of groundwater availability areas related to these aquifers is given in Appendix Table A-4.

In broad terms, eight geologic units have been identified that serve as the primary aquifers in Sinai:

- Quaternary sands and gravels
- Miocene sandstone
- Eocene limestone
- Middle Cretaceous sedimentary rock
- Lower Cretaceous sandstone
- Jurassic sedimentary rock
- Cambrian to Triassic sedimentary rocks
- Precambrian crystalline rock.

The major Quaternary sand and gravel aquifers of Sinai are found in three locations--in the vicinity of El Arish town, in the Rafah-Sheikh Zuwayid area in the Northeast Subregion, and in the El Qaa Plain in the Southwest Subregion. In addition, wadi alluvia along many of the major wadis or in the deltas of wadis serve as aquifers. For example, the wadi alluvium in Wadi El Arish near Nakhl and near El Hasana yields good quantities of brackish-to-salty water in relatively shallow wells. Similarly, in the delta of Wadi Sudr and in the delta of Wadi Watir at Nuweiba, wells tapping the Quaternary sand and gravel yield good quantities of brackish water. (Figure 2.5)

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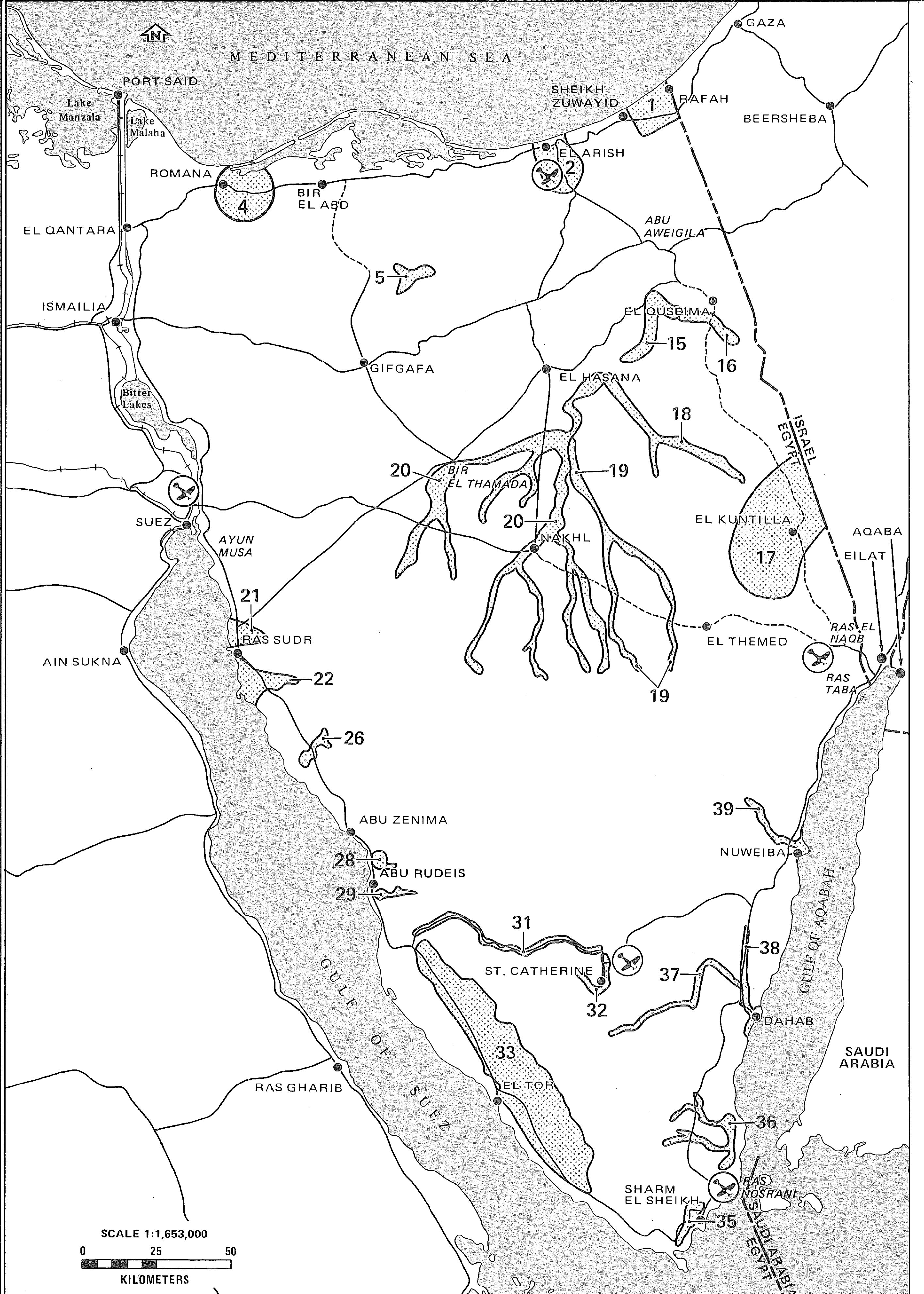
*A general discussion of the geology of Sinai is provided in Working Paper No. 41, Environment, dated April 1982, which can be found in the SDS-I project files. A 1:250,000-scale geology map of the peninsula is provided on Plate 2-5 of Working Paper No. 45, also in the project files.



AREAS OF POTENTIAL GROUNDWATER: QUARTENARY AQUIFERS

LEGEND

–MAP UNITS–

AQUIFERS

–KEY TO MAP UNITS–

NUMBER	AREA	AQUIFER
1	Rafah	Quaternary coastal aquifers
2	El Arish	Quaternary coastal aquifers
4	Rabaa	Pleistocene
5	Masagid Basin	Quaternary
15	Wadi El Arish upstream Gebel El Halal	Wadi alluvium
16	Wadi El Gayifa	Wadi alluvium
17*	Wadi El Gerafi	Wadi alluvium
18	Wadi Geraia	Wadi alluvium
19	Wadi El Aqabah	Wadi alluvium
20	Wadis El Bruk and El Arish	Wadi alluvium
21*	Wadi Sudr Delta	Wadi alluvium
22*	Wadi Wardan Delta	Wadi alluvium
26	Wadi Gharandal	Wadi alluvium
28	Wadi Baba, El Markha Plain	Wadi alluvium
29	Wadi Sidri and Delta	Wadi alluvium
31	Wadi Feiran and Wadi El Sheikh	Wadi alluvium and lake deposits
32	Gebel Katherina area	Wadi alluvium
33*	El Qaa Plain	Quaternary
35	Sharm El Sheikh	Wadi alluvium
36	Wadis Kid and Umm Adawi; Nebq area	Wadi alluvium
37	Wadi Nasb	Wadi alluvium
38	Wadi El Ghaib and Dahab area	Wadi alluvium
39	Wadi Watir and Nuweiba area	Wadi alluvium

*Estimated Total Available Groundwater Listed in Table 2-13.

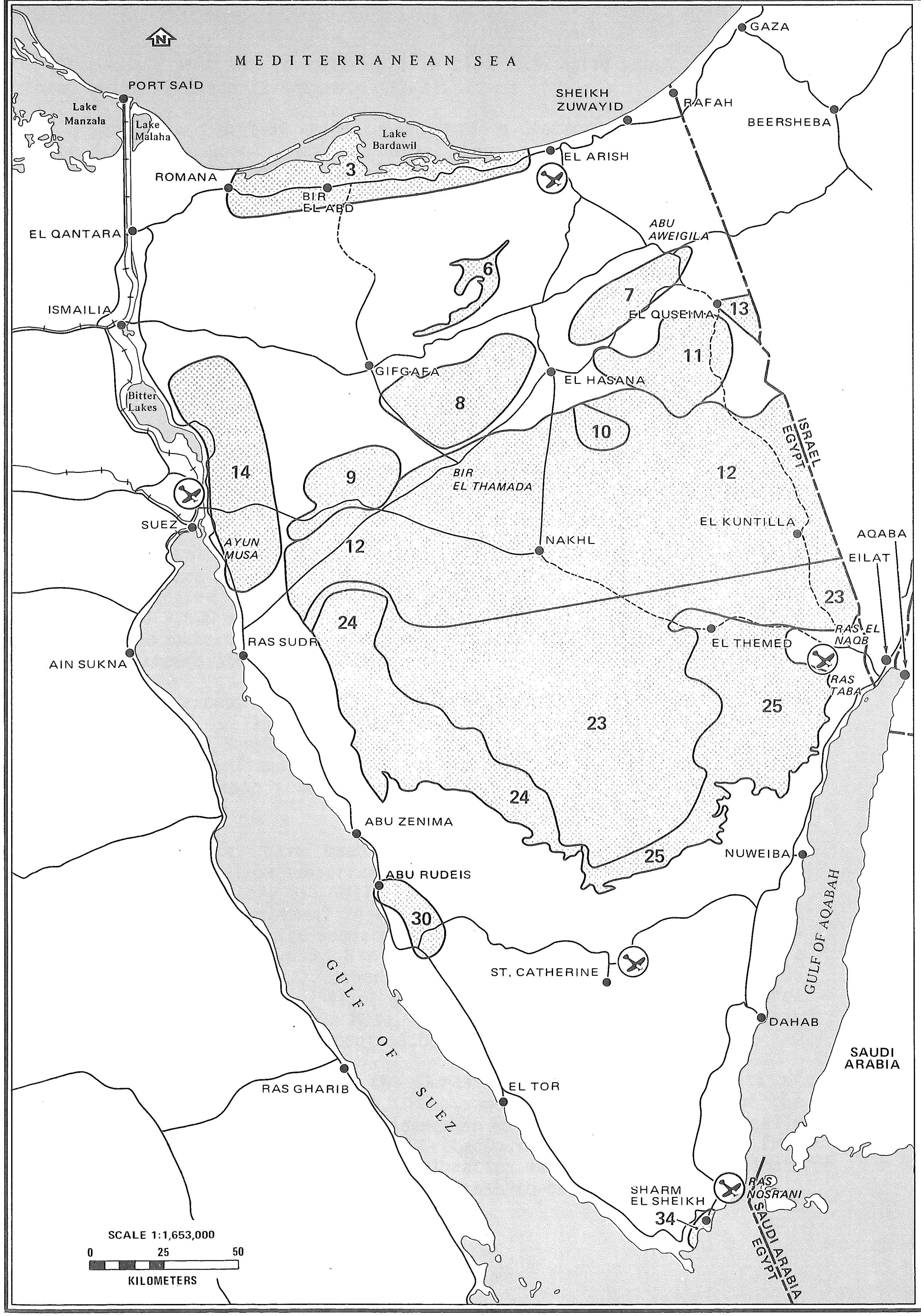
FIGURE 2.5
AREAS OF POTENTIAL GROUNDWATER: QUARTENARY AQUIFERS

Wells tapping the Quaternary aquifers exhibit the highest yields in Sinai, with a range of about 2 to 30 liters/sec. The best quality of water from Quaternary aquifers is found in wadis in the southern crystalline mountains and in the El Qaa Plain. In Wadi Feiran, within the crystalline-rock outcrop, groundwater from wadi alluvium commonly has a total dissolved solids (TDS) content of less than 500 mg/1. The El Qaa Plain aquifer appears to have a TDS content generally less than 2,500 mg/1, and usually less than 1,000 mg/1. The next best location in terms of quality is the Rafah-Sheikh Zuwayid area, where a Pleistocene aquifer at a 40- to 90-meter depth yields water with a TDS content of less than 4,000 mg/1, and where the surficial coastal sand aquifer along the shore yields water reported to have a TDS content of 250 to 2,100 mg/1.(1043c). The TDS of the water from the Quaternary aquifer at El Arish presently ranges from 1,200 to 5,000 mg/1. Significant increases in the TDS of the groundwater have been noted over the past 20 years, in an area north of the El Arish airport. This is discussed in more detail in Section 2.2.3.5.

The Miocene units serving as aquifers are sandstone, belonging to the Lower Miocene Gharandal Group, and sandstone and grits, forming a usually thin basal Miocene unit. These units occur on the west side, along the Gulf of Suez and in the Bitter Lakes area. At the Habashi oil exploration well (Well 23-1) east of Great Bitter Lake, a Miocene sandstone unit produced water with a TDS content of 1,000 mg/1, while further south at Ras Misalla, wells tapping basal Miocene (Wells 24-30 and 24-31) produced water with a TDS content of 2,600 to 5,000 mg/1. Further south, in Wadi Feiran and north of the El Qaa Plain, wells tapping Miocene sandstone units (Wells 36-30 through 36-32) yield water with a TDS content ranging from 3,900 to 5,300 mg/1. (Figure 2.6)

The Eocene limestone units in Sinai appear to yield water of usable quality at only a few locations. An oil exploration well located northeast of Ras Sudr--Abu Qiteifa - 1 (Well 24-33)--yielded water from Eocene rocks with a TDS content ranging from 1,200 to 1,990 mg/1. All other wells tapping Eocene limestone along the Gulf of Suez yielded water with a TDS content ranging from 8,500 to 200,000 mg/1. A well located south of Bir El Lahfan near Wadi El Arish, and presumed to tap Eocene limestone, was reported to have a TDS content of 2,540 mg/1. The most reliable Eocene source with acceptable quality water is in the Northeast Uplands Subregion, between El Quseima and El Kuntilla, close to the Israeli border. A spring in this area, Ain El Gudeirat (Water Point 52-23), is reported to yield water from Eocene limestone at a discharge rate of about 17 to 27 liters/sec, or 1,500 to 2,000 m^3/day, with a TDS content of about 1,500 mg/1.

In northern Sinai, the Middle Cretaceous (Cenomanian to Turonian) rocks consist of limestone, dolomite, and marl, and in the south, sandstone is also present. In many areas, from a hydrologic point of view, the overlying Lower Senonian rocks (lower part of the Upper Cretaceous) can be grouped with the Middle Cretaceous unit. The Lower Senonian rocks comprise limestone and marl, as well as sand and shale in the south. The Middle Cretaceous unit in Sinai is largely untested in terms of its possible yield to wells. In Israel, this unit supplies large quantities of water of a quality generally adequate for domestic nonpotable purposes



AREAS OF POTENTIAL GROUNDWATER: MIOCENE, EOCENE AND MIDDLE CRETACEOUS AQUIFERS

LEGEND

–MAP UNITS–

34	AQUIFERS

–KEY TO MAP UNITS–

NUMBER	AREA	AQUIFER
3.	North coastal strip.	Dune sand
6*	East side of Gebel El Maghara	Middle Cretaceous
7*	Gebel El Halal.	Middle Cretaceous
8*	Gebels Yelleq and Fallig	Middle Cretaceous
9.	Gebels Hamra and Giddi	Middle Cretaceous
10	Gebel Kherim.	Middle Cretaceous
11* . . .	Gebels Burga and Taliat El Bedan.	Middle Cretaceous
12* . . .	Central Sinai.	Middle Cretaceous
13	El Quseima.	Eocene
14	Great Bitter Lake to Ras Misalla.	Miocene sandstone
23* . . .	South Central Sinai	Middle Cretaceous
24* . . .	Gebel Somar to Gebel Igma.	Middle Cretaceous
25* . . .	El Themed to Ras El Gineina.	Middle Cretaceous
30	Abu Rudeis to El Qaa Plain	Miocene sandstone
34	Sharm El Sheikh	Miocene sandstone

*Estimated Total Available Groundwater Listed in Table 2-13.

FIGURE 2.6
AREAS OF POTENTIAL GROUNDWATER: MIOCENE, EOCENE AND MIDDLE CRETACEOUS AQUIFERS

(TDS content of 2,600 to 3,600 mg/l in five such wells south of the Dead Sea, Wells 71-8 and 72-4 through 72-7).

Springs and shallow wells tapping Middle Cretaceous rock in the belt extending from Gebel Somar to Gebel Igma produce good-to-very good quality water, ranging in TDS from 800 to 1,500 mg/l at a few tested locations. West of this belt along the Gulf of Suez, the water quality of the unit makes it unusable for most purposes. A well at Gebel Matulla (Well 35-24) produced water from Middle Cretaceous rocks, with a TDS content of 7,000 mg/l, and at an oil exploration well in the Wadi Baba Plain (Well 36-7), water from the unit registered a TDS content of 270,000 mg/l.

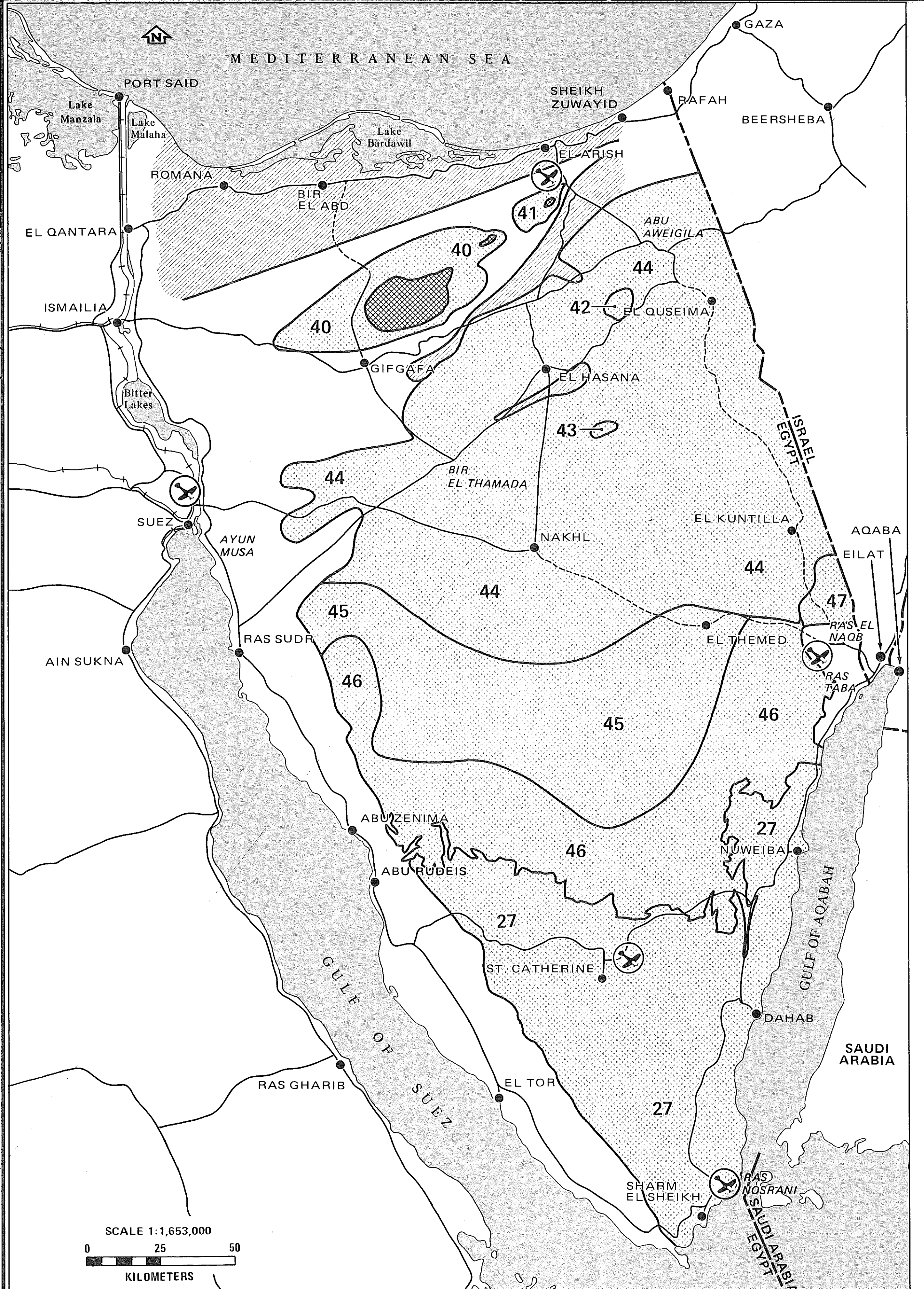
The Lower Cretaceous unit consists of sandstone in most areas of Sinai, with the exception of the area in the Uplands north of Gebel El Halal and Gebel El Maghara, where a facies change has occurred to the extent that the upper portion of the sequence consists of limestone and marl. In the literature, the Lower Cretaceous sandstone, together with any overlying Cenomanian sandstone, has been considered the upper unit of the "Nubian sandstone." The lowermost units of the "Nubian" range from Cambrian to Carboniferous in age, depending on the location and the correlation that was established. (Figure 2.7)

In the central and north-central Uplands (extending as far north as Lawyet El Lagama at Gebel El Maghara), the Lower Cretaceous sandstone has been demonstrated to have reasonably good quality water, with TDS ranging from 800 to 3,500 mg/l. However, in this area, with the exception of a few limited outcrop areas, the depth to the static piezometric level commonly exceeds 150 to 200 meters.

With the exception of wells at Ayun Musa (with a TDS content of 2,500 to 13,300 mg/l), wells tapping the Lower Cretaceous sandstone elsewhere along the Gulf of Suez have produced water with TDS ranging from 10,000 to 250,000 mg/l. Similarly, in the vicinity of the Mediterranean coast, water tapped at depth from Lower Cretaceous rocks ranges from 14,000 to 19,000 mg/l in TDS.

Jurassic rocks have been encountered in exposures at Gebel El Maghara, in the shallow subsurface at Ayun Musa (Wells 24-5 and 24-6), and at depth in exploratory oil wells in northern and central Sinai--at Nakhl (Well 44-2), El Hamra (Well 24-4), and El Khabra (Well 52-7). In the Gebel El Maghara area, the sequence consists of limestone and shale. With the exception of one well, Bir El Maghara (Well 32-10), which had a measured TDS of 2,800 mg/l, other Jurassic wells in this area range in TDS from 4,000 to 8,400 mg/l. Also, yields from Jurassic wells in the area are relatively low. At Ayun Musa, the TDS of water taken from Jurassic wells ranges from 3,100 to about 16,000 mg/l.

In the central Uplands, the Jurassic units commonly consist of sandstone with interbedded shale. The sandstone beds form part of the "Nubian sandstone" and can be considered in many cases to be hydraulically continuous with the overlying Lower Cretaceous sandstone. Evidence from drill stem tests performed in oil exploration wells in the area indicate that these Jurassic sandstones contain fresh-to-brackish water.



AREAS OF POTENTIAL GROUNDWATER: LOWER CRETACEOUS AND OLDER AQUIFERS

LEGEND

—MAP UNITS—

47	AQUIFERS
(cross-hatched)	AREA WHERE LOWER CRETACEOUS SANDSTONE IS MISSING
(diagonal hatched)	AREA WHERE DEPTH TO TOP OF LOWER CRETACEOUS SANDSTONE BELIEVED TO EXCEED 900m

—KEY TO NUMBERED MAP UNITS—

NUMBER	AREA	AQUIFER
27	Southern Mountains	Crystalline
40*	Gebel El Maghara area	Lower Cretaceous sandstone
41*	Risan Aneiza area	Lower Cretaceous sandstone
42	Gebel El Halal	Lower Cretaceous sandstone
43	Gebel Kherim	Lower Cretaceous sandstone
44*	Central Sinai	Lower Cretaceous sandstone
45*	South-central Sinai	Lower Cretaceous sandstone
46*	South Sinai	Nubian
47	East Sinai, Gebel El Hamra area	Lower Cretaceous sandstone

*Estimated Total Available Groundwater Listed in Table 2-13.

FIGURE 2.7
AREAS OF POTENTIAL GROUNDWATER: LOWER CRETACEOUS AND OLDER AQUIFERS

The Cambrian-to-Triassic sequence consists primarily of sandstone, with some shale and dolomite. It has been studied to a limited extent in its outcrop area south and southwest of Gebel El Tih, just north of the crystalline southern mountains. In this area, water quality from shallow wells ranges from good to brackish, with the few analyzed samples indicating a TDS content ranging from 950 to 3,900 mg/l.

The Precambrian crystalline rocks make up the bulk of the southern mountains. Groundwater occurs primarily in the joints and fault zones within these rocks. The yields of wells and springs depend on the size and extent of the fracture or fault systems that are tapped. As a whole, the groundwater contained in the crystalline rock aquifers constitutes the best quality groundwater in Sinai. The range in TDS from this unit is 200 to 2,500 mg/l, with the majority of water points exhibiting values less than 1,500 mg/l.

2.2.3.2 Stratigraphic and Spatial Characteristics of Phanerozoic Aquifer Units. Data on the depths, thicknesses, areal extent, and lithology of potential aquifer units of Cambrian age and younger, both in Sinai and in adjoining parts of Israel, were collected from a number of sources. Lists of the 69 well logs and 57 measured columnar sections used for stratigraphic evaluation are given in Tables 2-1 and 2-2, respectively, in Working Paper No. 33, Water Resources. Included in these tables are the location coordinates, the depth of the well or section, and the references from which the data were obtained. The detailed stratigraphic data, including some lithologic descriptions, are provided in Table 2-3, also in Working Paper No. 33. For each stratigraphic unit, the depth to the top of the unit and the thickness of the unit in meters are indicated, where known. A key to the symbols used for the stratigraphic units is given at the end of the table.*

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*Locations of the wells and column sections included in the stratigraphic analysis are shown on Plate 5-4 of Working Paper No. 45. Supplementary stratigraphic information obtained from surface resistivity soundings performed by Geofizika in 1962 (0466) is provided in Table 3-9 of Working Paper No. 33. This includes the estimated thicknesses of coarse-grained Quaternary deposits, as well as the estimated depths to the top of the Lower Cretaceous sandstone. Locations of the depth-sounding stations are given on Plate 5-4 of Working Paper No. 45.

Three contour maps were prepared, based on the stratigraphic information collected and on the geology map of Sinai (Plate 2-5 of Working Paper No. 45). These maps are considered "working maps" because there is not enough control to place great reliability in the location of most of the contour lines. However, the three maps were prepared to illustrate present best estimates of the spatial relationship and configuration of two important aquifer units.

The first map (Plate 5-5 in Working Paper No. 45) is an isopach map of the Middle Cretaceous unit (Cenomanian-Turonian). In the preparation of this map, it was found that many researchers (such as Said (1090)) have grouped Santonian and Turonian units. In such cases, the portion of that sequence belonging to the Turonian unit was estimated by the following method. According to reference (0190), the Santonian portion of the (cont'd)

In preparing this analysis, the Consultant endeavored to display the present-day thicknesses of each unit, taking into consideration those areas from which the unit has been partially or totally removed by erosion. This is not the analysis commonly prepared, which would indicate the original thickness of a unit prior to erosional degradation. The consideration of present-day aquifer thicknesses is more helpful in formulating plans for the possible groundwater development of an area.

The analysis indicates that the thickness of the Middle Cretaceous unit in central and northern Sinai ranges from 400 to nearly 700 meters, except close to those anticlinal areas where drastic erosion of the unit has taken place, such as at Gebel Hamra, Gebel El Minshera, Gebel Kherim, Gebel El Maghara, and Gebel El Halal. (See Plate 5-5 in Working Paper No. 45 in the SDS-I project files.) Toward the south, in the vicinity of the major outcrop areas, the thickness gradually decreases to 200 meters, and then declines to zero rather abruptly next to the contact with exposures of the Lower Cretaceous unit. The zero-thickness contour line in the vicinity of Gebel El Maghara indicates the approximate northern limit of the unit. Along the Gulf of Suez, west of the Eastern Boundary Fault,* the thickness of the unit is seen to range from 0 to 400 meters. The important role of past anticlinal folding and fault displacements in modifying the unit's thickness is clearly shown on the map.

The isopach map of the Lower Cretaceous sandstone and contiguous older sandstones, Plate 5-6 in Working Paper No. 45, shows that the thickness of this combined unit ranges from 400 to 560 meters over a broad area in northern and central Sinai. Toward the outcrop areas in the south, the unit's thickness gradually declines. North of Gebel El Maghara, the sandstone of the Lower Cretaceous unit disappears and is completely replaced by interbedded limestone and shale. In the Suez Rift Province, in the area extending southward from the Wadi Sidri Delta to Gebel Qabeliat, the thickness of this unit ranges from 800 to 900 meters.

Further analysis indicates that, apart from areas close to outcrops, the depth to the aquifer in northern and central Sinai ranges from 600 to 1,100 meters, with the greatest depths occurring in the two synclinal areas northwest and southeast of Gebels El Halal and Yelleq. The depth to the top of the unit declines gradually in the direction of the major outcrops in the south. (See Plate 5-7 in Working Paper No. 45 and Table 3-9 in Working Paper No. 33 in the SDS-I project files.)

(cont'd from p. 2-34) Turonian-Santonian sequence is equivalent to the Zihor Formation (Israeli formation term). An isopach map of the Zihor Formation is provided in reference (0190). The location of the relevant well or columnar section was plotted on that isopach map, and the approximate thickness of the Zihor Formation (±20 meters) for that location was noted. This value was then subtracted from the value for the thickness of the Turonian-Santonian sequence to obtain an estimate of the Turonian thickness.

*The area between the Gulf of Suez and the Eastern Boundary Fault is hereafter referred to as the "Suez Rift Province."

A regional hydrogeologic cross section from south to north was also prepared. (See Plate 5-14 in Working Paper No. 45.) The section extends from Wadi Khamila, south of Gebel El Tih, to the Mediterranean. The section is partly schematic, though it includes several measured sections and logged wells. It indicates possible fault orientations and displacements, and shows interpretations of basalt dyke intrusions and anticlinal/synclinal features. The assumed directions of flow within the Lower Cretaceous sandstone and contiguous older sandstones are also shown. The substantial effect of the fault and fold systems on groundwater flow is very apparent in the cross section.

The stratigraphic and spatial characteristics of the Quaternary aquifers in the vicinity of El Arish and in the El Qaa Plain are discussed in Sections 2.2.3.5 and 2.2.3.6, respectively.

2.2.3.3 Yield and Quality Characteristics of the Aquifers. Information and data on water points (wells and springs) in Sinai have been collected from a number of sources. A total of 716 water points are inventoried. Working Paper No. 34, Hydrogeologic Information Cards, provides details of this inventory. A summary of some of the most important information is given in Tables 3-10a through 3-10o of Working Paper No. 33 in the SDS-I project files. The water points are grouped by the geologic unit tapped, as follows:

- Dune sand
- Quaternary sediments
- Pliocene sediments
- Miocene sedimentary rocks
- Miocene dyke rocks
- Eocene rocks
- Paleocene rocks
- Upper Cretaceous rocks
- Middle Cretaceous rocks
- Lower Cretaceous rocks
- Jurassic rocks
- Cambrian to Cenomanian (undifferentiated)
- Cambrian to Triassic (undifferentiated)
- Precambrian crystalline rocks.

Water point coordinates, well depth, discharge rate, water level elevation, depth to static water level, and TDS content of the groundwater samples are provided in these tables. In many cases, the water level measurement or water analysis was performed at a water point more than once; these additional data, with the appropriate dates of data collection, are also provided in Working Paper No. 33.*

To aid in analyzing the yield and water quality data for the water points inventoried, the peninsula is divided into seven geomorphic groundwater provinces, as outlined on Figure 2.8:

- I--Mediterranean Foreshore Province
- II--Mobile Platform Province (including the major anticlinal mountains of Gebel El Maghara, Gebel Yelleq, and Gebel El Halal)
- III--Northern Stable Platform Province
- IV--Southern Stable Platform Province (separated from Province III by the Zarga El Naab fault)
- V--Southern Mountain Province, comprising Precambrian crystalline rocks
- VI--Suez Rift Province
- VII--Aqabah Rift Province.

The boundaries of these groundwater provinces are based primarily on geologic structural features--major axes of folds and major faults--under the working hypothesis that such features may tend to interrupt completely, or obstruct partially, the hydraulic continuity of aquifer units. Consequently, groundwater quality, as well as recharge relationships in the same aquifer unit, could differ considerably among the several provinces. Major discontinuities between geologic units in the fault blocks making up the Suez Rift Province and those in the adjoining provinces to the east are noted in the literature.

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*The locations of the water points are shown on Plate 5-1 of Working Paper No. 45. The locations of wells in the El Arish area are given on Plate 2-16. On each map, separate symbols are used to identify each different geologic unit tapped by the water points. The two water point maps, as well as Tables 3-10a through 3-10o in Working Paper No. 33, identify each water point by means of an I.D. number, for example, 35-7. The first number denotes the 30- by 30-minute grid square in which the water point is located, and the second number is the water point number assigned sequentially within each grid square. The location of the 30- by 30-minute grid squares is given on Plate 5-1, in the small-scale map of the peninsula and adjoining areas.

Plate 5-1 also provides the depth of each water point in meters, if a well, and the TDS content of the water sample. Where no water sample was analyzed, but a qualitative description is available, the water point has been placed in a water quality group, which is indicated on the data map. The definition of the water quality groups is provided in Table 2-5.

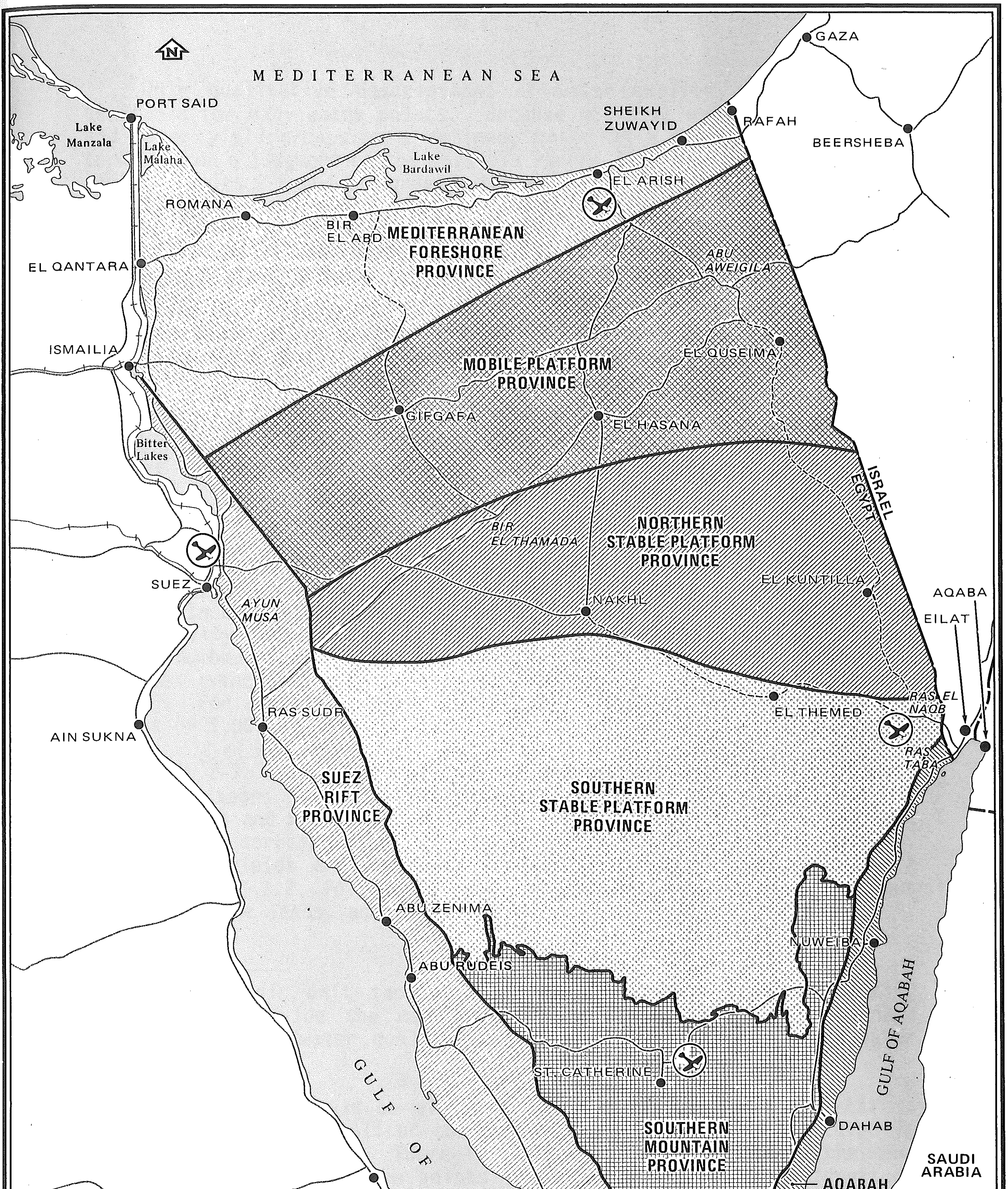

FIGURE 2.8
GEOMORPHIC GROUNDWATER AREAS

Only qualitative descriptions of water quality and yields were available for many water points. Because of this, water quality groups and water yield groups were defined, based on a number of qualitative terms and on a judgment of the possible ranges in TDS or yields that might apply. Tables 2-5 and 2-6 provide the arbitrary definitions for the water quality groups and yield groups, respectively. There are six quality groups, with "1" referring to highest quality water (TDS of 0 to 500 mg/l), and "6" to the poorest quality (TDS greater than 7,000 mg/l). Of the four yield groups, "1" refers to the highest yields (greater than 200 m^3/day (2.3 liters/sec)), and "4" to the lowest (less than 2 m^3/day). Based on these water quality and yield definitions, it was possible to place each water point into a particular water quality group and a yield group.

A statistical analysis of the water quality (TDS) data and the yield data for the inventoried water points was performed. In each case, the mean of the water quality groups was obtained to achieve what has been termed the "mean water quality index," and the mean of the yield groups was computed to give the "mean yield index."*

A summary of the results of the statistical analysis, by geologic unit and by groundwater province, is given in Tables 2-7 and 2-8, respectively. In evaluating the results of this analysis in terms of the mean water quality index and mean yield index, it is helpful to realize that integer numbers for an index are equivalent to the midpoint of the range of values associated with the corresponding group, as shown in Tables 2-5 and 2-6. For example, a water quality index of 2 is equivalent to a TDS content of 1,000 mg/l.**

Table 2-7 indicates that the mean quality index for the entire peninsula ranges from 2.4 for Precambrian Crystalline rock to 5 for Miocene rocks and 5.4 for Jurassic rocks. The mean value for all geologic units is 3.6, corresponding approximately to a TDS content of 2,800 mg/l. The highest yields are indicated for the Quaternary sediments, with a yield index of 1.2, followed closely by Miocene rock, Lower Cretaceous sandstone, dune sands, and Eocene rocks.

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*For each geologic unit tapped, Tables 3-13a through 3-13m in Working Paper No. 33 provide the mean values and estimates of the standard deviation for the water quality index and yield index, by groundwater province.

**Special attention should be given to Tables 3-13a, 3-13b, and 3-13i in Working Paper No. 33. All of the dune-sand water points are located in Province I (Table 3-13a). There is a significant difference in the mean quality index between those points located west and east of longitude 33°40' E. West of the line, the mean water quality index is 4.7, while to the east, the value is 2.3--indicating a much higher quality.

A similar trend is shown for the Quaternary sediments in Province I (Table 3-13b). A very high TDS level is seen west of longitude 33°40' E. (mean quality index of 5.6). In the El Arish area, the value (cont'd)

TABLE 2-5

Definition of Water Quality Groups

Descriptive Term	Quality Group	TDS Assumed Range (mg/l)[a]
"Very good"	1	0-500
"Good" "Fresh"	2	500-1,500
"Fairly good" "Fair" "Slightly brackish" "Slightly good"	3	1,500-2,500
"Brackish" "Slightly saline"	4	2,500-4,000
"Poor" "Not good" "Very brackish" "Fairly salty"	5	4,000-7,000
"Salty" "Foul" "High salinity" "Bad"	6	>7,000

[a]TDS = total dissolved solids.

SOURCE: Derived from References (1037), (1333), (1334), and (1365) to describe the quality of groundwater from a well or spring.

TABLE 2-6

Definition of Yield Groups

Descriptive Term	Yield Group	Assumed Yields (m^3/day)
"Very large quantity" "Large quantity" "Abundant" "Plentiful supply" "Unlimited supply"	1	>200
"Fairly large quantity" "Good quantity" "Good supply"	2	20-200
"Fair quantity" "Fair supply" "Medium supply" "Indifferent supply"	3	2-20
"Limited quantity" "Small quantity" "Very small quantity" "Poor supply"	4	<2

SOURCE: Derived from References (1037), (1333), and (1334) to indicate the quantity of water available from a well or spring.

TABLE 2-7

Summary of Water Quality and Yield Data for Water Points in Sinai, by Geologic Unit

Geologic Unit	Mean Quality Index (Q)	s_Q [a]	No. of Points With Quality Data	Mean Yield Index (Y)	s_Y [a]	No. of Points With Yield Data
Dune sands	4.1	1.5	51	1.8	1.2	16
Quaternary sand and gravel sediments	3.3	1.6	245	1.2	0.7	142
Pliocene	5.7	0.6	3	2.5	2.1	2
Miocene sedimentary rock	5.0	1.2	51	1.5	0.8	12
Miocene dyke rock	5.0	1.0	3	2.0	0	3
Eocene	4.9	1.6	28	1.9	1.1	10
Paleocene	4.0	0	1	--	--	0
Upper Cretaceous	3.7	1.6	30	2.6	1.2	21
Middle Cretaceous	3.0	1.7	37	2.8	1.1	20
Lower Cretaceous	4.1	1.5	39	1.7	0.9	10
Jurassic	5.4	0.8	12	2.5	0.7	7
Cambrian to Cenomanian (undifferentiated) and Cambrian to Triassic (undifferentiated)	3.3	1.3	19	2.8	1.3	4
Precambrian crystalline rocks	2.4	1.0	55	2.5	1.2	14
TOTAL	3.6	--	574	1.7	--	261

[a] "s" refers to the estimate of the standard deviation.

SOURCE: Derived from data presented in Tables 3-13a through 3-13m in Working Paper No. 33 in the SDS-I project files. The basic data on each of the 716 water points, including source reference, are given on the hydrogeologic information cards in Working Paper No. 34. Values are averaged over all groundwater provinces.

Table 2-8 indicates that the mean water quality indices for Provinces I, II, III, VI, and VII are comparatively close--ranging from 3.4 to 4.7, with an average of 4 (corresponding to a TDS value of 3,200 mg/l). The highest value of 4.7 relates to the Suez Rift Province, where groundwater quality is known to be generally poor. Provinces IV and V have mean quality indices of 2.8 and 2, respectively, which reflect the high groundwater quality found in the Middle Cretaceous aquifer on the western side of Province IV and in the crystalline and Quaternary units in Province V. The highest average yields are indicated for water points located in Provinces I, VI, and VII.*

The salinity in the Lower Cretaceous aquifer increases toward the west and toward the north. Westward of Gebel El Heitan and Gebel Dahak, the salinity in the unit increases rather sharply; the TDS exceeds 50,000 mg/l in a broad zone from Ras Misalla to Gebel Hammam Faraun in the Suez Rift Province. In the north, northward of Risan Aneiza and Gebel El Ubalyid, the salinity increases to 10,000 mg/l and above. In Israel in the vicinity of Gaza, TDS values exceeding 50,000 mg/l are recorded for the Lower Cretaceous unit. The higher salinity values in this unit indicate that a rather ineffective flushing process has occurred during Quaternary times due to:

- Lower permeability of the unit in Province I because of facies changes (replacement of sandstone by limestone and shale).
- Interruption of continuous flow paths in the aquifer in Province VI because of pronounced differential block faulting.

Because water quality has been found to vary considerably among the different Jurassic formations (0380), at least in Israel, the isosalinity

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(cont'd from p. 2-39) is 3.7, while in the Rafah-Sheikh Zuwayid area, east of longitude 34^{o} E., the quality index is only 1.6, corresponding approximately to the mean TDS of 958 mg/l shown. Table 3-13b also indicates the high quality of groundwater (a mean quality index of 1.4) from Quaternary sediments in Province V.

For the analysis of water points tapping the Middle Cretaceous unit (Table 3-13i), Province IV is divided into two sections. The area west of longitude 34^{o} E. displays a significantly higher water quality than the area to the east--with water quality indices of 2.1 and 3.9, respectively. In fact, the water quality of the western half of Province IV for the Middle Cretaceous unit is significantly higher than that for the rest of Sinai, which has a mean quality index of 4.2 for this aquifer unit. The latter figure, however, is based on only 16 widely scattered water points.

*Isosalinity contour maps for the Lower Cretaceous and Jurassic units are given in Plates 5-8 and 5-9, respectively, of Working Paper No. 45. A yield and water quality data map for the Middle Cretaceous unit is provided on Plate 5-10. Plate 5-8 indicates that the lowest salinity (less than 2,000 mg/l TDS) in the Lower Cretaceous aquifer occurs in central Sinai, and possibly also in South Sinai near the major outcrop areas.

TABLE 2-8

Summary of Water Quality and Yield Data for Water Points in Sinai, by Groundwater Province

Geomorphic Groundwater Province[a]	Mean Quality Index (Q)	No. of Points With Quality Data	Mean Yield Index (Y)	No. of Points With Yield Data
I	3.4	156	1.2	126
II	4.0	67	2.4	27
III	3.8	23	2.5	11
IV	2.8	66	2.7	40
V	2.0	75	2.4	13
VI	4.7	143	1.5	36
VII	3.9	44	1.6	8
TOTAL	3.6	574	1.7	261

[a] See Figure 2.8 for location of Groundwater Provinces, which are listed on page 2-37.

SOURCE: Derived from data presented in Tables 3-13a through 3-13m in Working Paper No. 33 in the SDS-I project files. The basic data on each of the 716 water points, including source reference, are given on the hydrogeologic information cards in Working Paper No. 34. Values are averaged over all groundwater provinces.

analysis must be considered very generalized and approximate. It appears that there is a steady increase in the salinity of water in the Jurassic rocks north and east of Gebel El Maghara and Gebel El Halal--exceeding a TDS level of 10,000 mg/l a few kilometers northward. In Israel, water from Jurassic rocks exceeds a TDS of 50,000 mg/l in wells located north of Nizzana and northeast of Rafah.*

2.2.3.4 Groundwater Flow Patterns. Groundwater movement in Sinai generally occurs in two patterns. A certain portion of the flow proceeds from the recharge areas to the sea, sometimes surfacing in wadis over a portion or all of the downgradient segment of the path. The remainder flows from recharge areas to depressions, where it is discharged by evapotranspiration. This latter pattern is most common in the dune areas of the Northeast Subregion and also possibly in portions of the Hegayib and the El Hasana-El Hema Basin Areas.

Groundwater flow between contiguous aquifers is a common part of both flow patterns and is controlled by the head differential across the adjacent aquifers. For example, the flow of groundwater from Miocene rocks and from crystalline rocks into wadi alluvium in southern Sinai has been reported in several instances. Interflow between the Lower and Middle Cretaceous units in Sinai and the Negev has been suggested by Arad and Kafri.(0116) Issar (0646) proposes rather significant groundwater movement among the Lower Cretaceous, Jurassic, and Cambrian-to-Triassic units in Sinai and Israel--the interflow induced to a large extent at the major regional faults.

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*Plate 5-9 in Working Paper No. 45 in the SDS-I project files shows TDS values and isosalinity contours for the entire Jurassic sequence. Yield and water quality characteristics of the Middle Cretaceous unit are shown on Plate 5-10. Well locations and I.D. numbers, as well as the yield group and water quality group, are plotted. The map points up the relatively high water quality (low TDS) of water points located on the west side of the major outcrop area from Gebel Somar to Gebel Raqaba, contrasted with that on the east side from Gebel Ghazlani to Gebel El Gineina (see also Tables 3-13a through 3-13m in Working Paper No. 33). One possible reason for the difference between the two areas is that, while the western side seems to have a well-developed surface drainage system, much of the eastern side appears to be inadequately drained. The eastern side is nominally drained by Wadi Zeleqa, but no clear outlet or any connecting channel by which runoff from the area can reach either the main wadi of the area, Wadi Watir, or the Gulf of Aqabah is evident on topographic maps. Hence, it is quite likely that in the entire Wadi Zeleqa Basin Area, because of the absence of seasonal flushing, salts are accumulating rather than being moved slowly out toward the sea. This has a direct effect on the quality of water in the underlying aquifer.

As shown on Plate 5-10, there are almost no data on the Middle Cretaceous unit in central and northern Sinai. This is one of the important tasks for the proposed exploratory well drilling program. In Israel, wells just south of the Dead Sea produce slightly saline-to-brackish water from the Middle Cretaceous unit, at generally high discharge rates.

Aquifer recharge areas for each of the major aquifer units, with the exception of the Precambrian crystalline rocks, are shown on Figure 2.9. (Further detail can be found on Plate 5-11 in Working Paper No. 45 in the SDS-I project files.) The crystalline rock recharge area is essentially the entire southern mountain region (Province V and most of Province VII), where recharge occurs by percolation of rain and runoff water into the fractures and fault zones.

It is assumed that the outcrop areas for the sedimentary aquifer units constitute their recharge areas. In some cases, however, these aquifers also receive water from contiguous aquifers, as discussed above. The estimated extent and boundaries of the recharge areas for the primary Quaternary aquifers of Sinai--those located in the El Arish area, the Rafah area, and the El Qaa Plain--are shown on Figure 2.9. The recharge areas for other Quaternary aquifers of Sinai, primarily wadi alluvium, are not shown since they consist basically of ribbon-like surface exposures of alluvium along the major wadis.

The sizes of the recharge areas for the consolidated rock aquifers and the major Quaternary aquifers have been estimated by planimetering the areas from 1:500,000- and 1:100,000-scale maps, respectively. The approximate sizes of the areas are provided in Table 2-9. The recharge areas for the Middle Cretaceous unit cover an area of approximately 6,400 square kilometers, while those for the Lower Cretaceous unit and the underlying older rocks together amount to only 2,060 square kilometers.

Table 2-9 also shows the average amount of recharge each recharge area is estimated to receive directly from rainfall or overland flow. These estimates are derived from the water balance analysis described in Section 2.2.4. It is seen from the table that direct recharge to the Lower Cretaceous and older rocks in Sinai is estimated at 90,000 m^3/day, while recharge to Middle Cretaceous rocks is approximately 192,000 m^3/day.

Groundwater flow paths in Quaternary aquifers commonly extend from the margins of the permeable deposits and continue downgradient, following closely the gradient of the associated wadi. In the case of the Rafah-Sheikh Zuwayid area, the gradient of the water table follows approximately the land surface slope to the sea. Recharge to the Quaternary aquifers is mainly from the percolation of rainfall and runoff waters, and from discharges from the consolidated rock units at the margins of the recent alluvium or Pleistocene deposits. Groundwater in these aquifers commonly discharges both to the sea and to the atmosphere by evapotranspiration. The latter occurs in oases below which the groundwater flows and at springs where water from the Quaternary aquifers seeps into the wadi bed.

The flow paths in the crystalline rock area are controlled by fracture patterns and fault zones, and it is believed that they generally extend no deeper than 100 to 200 meters. Discharge occurs in the form of springs, as well as by direct flow from the crystalline rock into adjacent Quaternary aquifers, which are found in the mountain wadis and in the low-lying deltas and plains bordering the Gulfs of Aqabah and Suez.

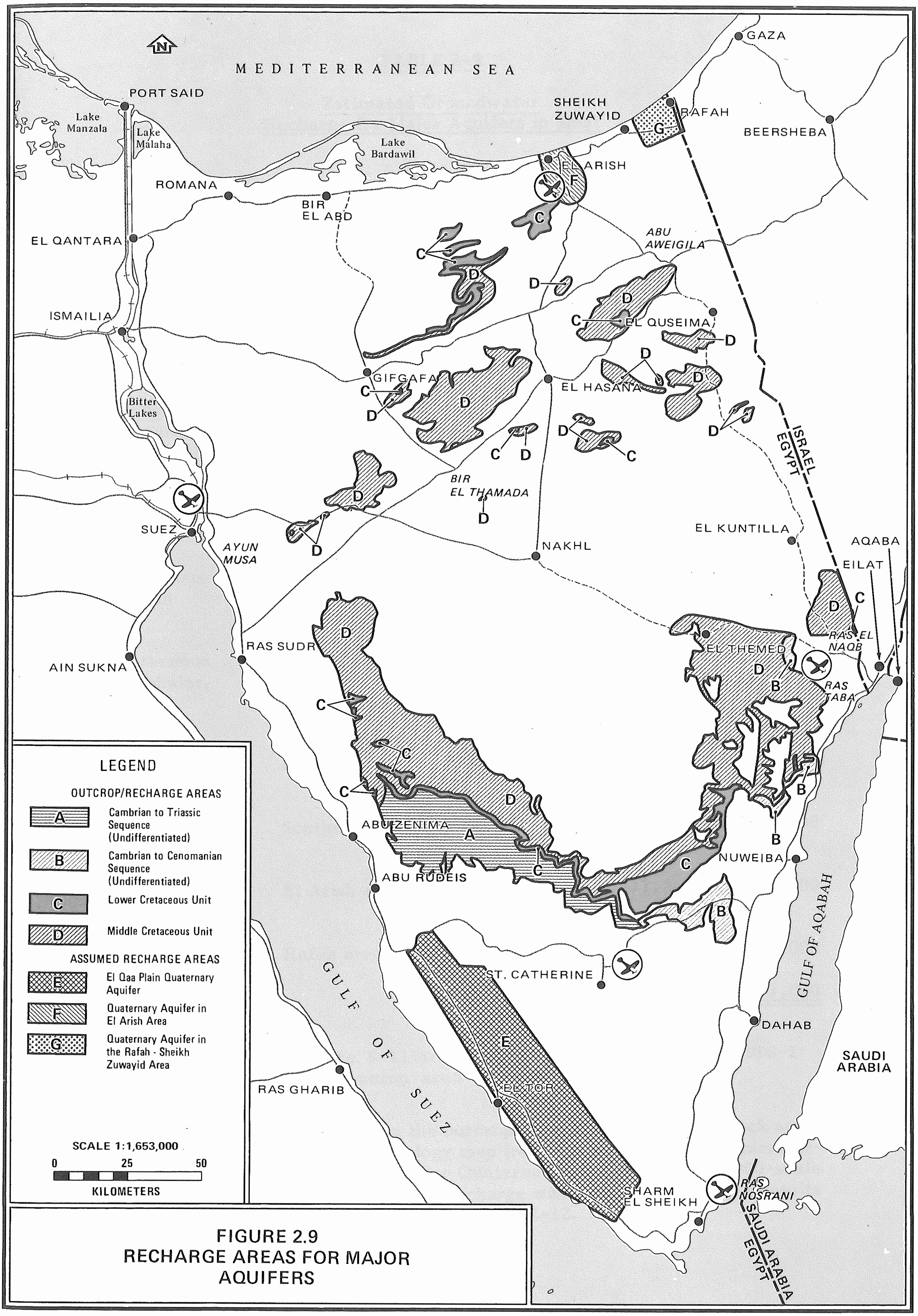

FIGURE 2.9
RECHARGE AREAS FOR MAJOR AQUIFERS

TABLE 2-9

Estimated Groundwater
Recharge for Major Aquifers in Sinai

Unit	Location[a]	Size of Outcrop or Recharge Areas (km^2)	Estimated Average Recharge ($m^3/yr \times 10^6$)	Estimated Average Recharge (m^3/day)
Cambrian to Triassic sequence (undifferentiated), primarily sandstones	Southern Sinai	920	13.0	36,000
Cambrian to Cenomanian sequence (undifferentiated), primarily sandstones	Southern Sinai	290	5.9	16,000
Lower Cretaceous sandstones	Southern Sinai	610	8.5	23,000
Lower Cretaceous sandstones and carbonates	Northern Sinai	240	5.4	15,000
Middle Cretaceous sandstones, shales, and carbonates	Southern Sinai	4,450	46.0	126,000
Middle Cretaceous carbonates	Northern Sinai	1,950	24.0	66,000
El Qaa Plain Quaternary aquifer	Southern Sinai	2,300	24.0	66,000
El Arish Quaternary aquifer	El Arish area	200	11.0	27,000
El Rafah Quaternary aquifers	Rafah area	180	14.0	38,000
TOTAL				413,000

[a]Refer to Figure 2.9 (and Plate 5-11 in Working Paper No. 45 in the SDS-I project files) for recharge/outcrop area locations.

SOURCE: Estimated by planimetering the outcrop areas for consolidated rock aquifers on a 1:500,000-scale geology map (reference (0385)) and planimetering the recharge areas for major Quaternary aquifers on 1:100,000-scale topographic maps. Mean annual recharge was estimated from the results of the water balance analysis. See Table 2-12.

Flow in the sedimentary rock aquifers commonly has a deep, regional component, extending over a large part of the peninsula and beyond. Flow in the Lower Cretaceous sandstone in some ways serves as an example of groundwater flow in all of the sedimentary rock units of Sinai.

Plate 5-12 in Working Paper No. 45 in the SDS-I project files presents a model of groundwater flow in the Lower Cretaceous unit.* As shown, the number of data points in Sinai is far fewer than would be needed to justify the number of piezometric contour lines shown. The contour lines represent an interpretation of likely groundwater flow conditions. According to the scheme presented on the plate, flow within Province IV takes place from the recharge (outcrop) areas in the south toward the north. Eastward and westward components of flow are strongly developed in the vicinity of the Zarga El Naab fault, which extends westward from slightly north of Eilat toward El Themed, to the Nakhl area, and finally to Gebel Raha in the west. It is believed that a portion of the flow is diverted into this fault zone, flowing toward the west (on the west side) and toward the east (on the east side). The remainder of the flow crosses the fault zone into Province III, which consists of the area between the two major east-west faults on the peninsula.

In Province III, flow in the Lower Cretaceous aquifer is mainly to the west on the western side, and to the east on the eastern side, the ultimate discharge areas being the Gulf of Suez and the Araba Valley in Israel, respectively. In the center (e.g., at Abu Hamth and Nakhl), a groundwater high is maintained--probably by flow from the south. The piezometric contours also indicate that a component of the groundwater flow in Province III tends to enter the two bordering faults.

In Province II--the area of pronounced anticlinal/synclinal folding--three patterns of groundwater flow in the Lower Cretaceous unit are discernible. (See Plate 5-12 in Working Paper No. 45 in the SDS-I project files.) First, concentric or partially concentric flow occurs away from the outcrop areas at Gebels El Maghara and El Halal. Secondly, there is a deeper, more regional flow toward the east or east-northeast, which tends to discharge in Israel along the Araba Valley and in the Dead Sea. Lastly, on the west side, flow occurs in the southwest direction, part of which moves to and through the province's southern bounding fault.

There is no evidence of any flow in the Lower Cretaceous unit in Province I, north of Gebel El Maghara. It is quite possible that the predominant carbonate/shale facies present is of low permeability, so that the preponderance of flow is diverted, in the northern part of Province II, toward the east.

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*A regional hydrogeologic cross section A-A', from south of Gebel El Tih to the Mediterranean, is shown in Plate 5-14 in Working Paper No. 45. It provides further details of the Consultant's interpretation of flow in the Lower Cretaceous unit. It should be noted that it is unlikely that there is any major groundwater flow north of El Khabra. Rather, as indicated above, the flow is essentially diverted eastward toward Israel, and ultimately to the Dead Sea.

2.2.3.5 Groundwater Conditions of the Quaternary Aquifer in the El Arish Area. The Quaternary aquifer at El Arish consists primarily of Upper Pleistocene sands and gravels and underlying kunkar ("fagra")--also referred to in some literature as "kurkar"--of Lower Pleistocene age. These units are underlain by a Pliocene Beach conglomerate, followed by Neogene Saqia Beds, which are saliferous marl beds (1190) and serve as the effective lower boundary of the aquifer.

Taha (1350) has described the kunkar as "complex marine and continental deposits, composed of calcareous sandstone." Paver and Jordan (1036) define fagra as a loosely cemented shell rock containing a high percentage of cavities (up to 0.5 to 1 centimeter in diameter), or as calcareous sandstone, which is similarly porous. Logs of reclamation wells drilled in the El Arish area in the early 1960's and during 1979 to 1980 indicate that the fagra unit consists of partially indurated calcareous sandstone, which was encountered in some wells. Shata (1210) has pointed out that the kunkar series is present in the form of buried ridges, in a strip between El Arish and Rafah, which is probably no more than 7 kilometers wide. In the El Arish area, the fagra unit is reported to range in thickness from 5 to 40 meters (1350). The thickness of the overlying younger sand and gravel unit ranges from 6 to 30 meters. Evidence from well completion reports and well logs from the area indicates that the Upper Pleistocene sand and gravel unit probably supplies as much or more water than the underlying calcareous zone.*

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*Plates 5-17, 5-18, and 5-19 in Working Paper No. 45 in the SDS-I project files show hydrogeologic cross sections in the El Arish area--Sections B-B', B'-B", C-C', D-D', and E-E'. The locations of these sections are given on Plate 5-16.

Cross Sections B'-B", C-C', D-D', and E-E' show the presence of an uppermost sand or sand and gravel layer that is calcareous in places and ranges in thickness from 5 to 30 meters. This layer appears to be reasonably permeable and could receive and hold percolating rainwater or wadi floodwaters to recharge the underlying aquifers. Over a fraction of the area, this layer is replaced by a clayey horizon, ranging in thickness from 4 to 20 meters. Immediately underlying the upper layer is a sandy or gravelly clay layer, from 5 to 30 meters in thickness, that serves to partially confine the underlying aquifer zone. However, this layer is not continuous across the entire area. For example, Well 41-87 (B7) on Cross Section B'-B" indicates that no clayey zone was encountered over the full depth of 60 meters. With one exception, the wells used to construct these four sections, located north of the El Arish airport, ranged from 35 to 62 meters in depth and, hence, did not penetrate the underlying calcareous sandstone. In the El Maazar well (Well 41-56 on Cross Section E-E'), which is 94 meters deep, the total thickness of calcareous sandstone was found to be about 40 meters.

Cross Section B-B' (on Plate 5-17) extends northward from the vicinity of Bir El Lahfan to the El Arish airport. In this section, not only was the Lower Pleistocene calcareous sandstone penetrated (its thickness ranges from 6 to 27 meters), but also the underlying Pliocene conglomerate, sand, and clay layers, and, on the south end, a Miocene (?) clay layer. Moreover, faults are inferred, as shown on the section, because at two separate locations, Cretaceous sediments were encountered--clay, shale, and limestone--and the presence of two small horst blocks is (cont'd)

Table 3-13b in Working Paper No. 33, Water Resources, provides information on well yields and water quality pertaining to the Quaternary aquifer in the El Arish area. The recorded well yields range from 0.6 to 28 liters/sec, and the mean well yield is 17.8 liters/sec, with a standard deviation of 5.7. Clearly, the aquifer's transmissity is adequate for the supply of moderate-to-fairly large quantities of water.

The groundwater problem at El Arish is unsatisfactory water quality.* Table 3-13b shows that the mean TDS value for El Arish

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(cont'd from p. 2-50) assumed. It is important to note that Well 41-116 (GDDO 31) was dry and that Well 41-114 (PW 29) was nearly dry, with water seeping into the well very slowly. In both cases, this may have been due to the nature of the well construction. For example, at Well 41-114, the screen was placed opposite a lower gravel layer with clay interbeds and an upper gravel layer, which may be isolated as far as receiving recharge waters. If the well screen had been placed in the lower calcareous sand and sandstone layer, it may have encountered adequate water.

Cross Section B-B' indicates that downward vertical movement of recharge waters, rainfall, or the wadi floodwaters to the calcareous sand and sandstone layer could be quite slow because of the apparent low permeability of the entire overlying sequence. Geofizika (0466) suggested the possibility of recharge of this Pleistocene aquifer from the Cretaceous rocks in the Bir El Lahfan area. Indeed, considering its position relative to the calcareous sand and sandstone layer, and the fact that it appears to be well fractured, the Cretaceous limestone horst shown in the section at Well 41-117 could be a source of water to the Pleistocene unit, if there is an appropriate head differential across the two units. More investigation is required to confirm this possibility.

*Isosalinity maps for the Quaternary aquifer in the El Arish area are provided on Plates 5-20 and 5-21, in Working Paper No. 45, for the early 1960's and for 1981, respectively. Water with the lowest TDS values appears to occur south of town, mostly on the west side of the wadi, but also to an extent on the east side, in the vicinity of the bend in the wadi. The poorest quality water is found east of the El Arish-El Lahfan road. Over the intervening years, it is apparent that in the area north of the airport, water quality deteriorated noticeably, so that the zone on the east side of the wadi where the TDS was less than 2,000 mg/l shrunk considerably. The zone where TDS exceeded 4,000 mg/l appears to have shifted from a location due east of town to about 1,000 meters north of the airport.

Plate 5-22 indicates the area where water quality has declined over the past two decades. An increase in the TDS level of the groundwater appears to have taken place only in the area bounded on the south by the airport and by a zero-change contour on the north, which extends eastward of the south part of El Arish town. Within this area, there are three locations where peak increases occurred, representing a 1,500 to 1,700 mg/l increase over the period. The source of this more brackish water is not entirely clear. It is possible that the source water is moving in from the east, possibly along and south of Wadi El Maazar. Plate 5-23, showing water level contours for the El Arish area, provides some support for this, as discussed later in this section.

groundwater in the 1980 and 1981 period was 2,923 mg/l, with an estimated standard deviation of 774. Reference to Table 3-10b in Working Paper No. 33 shows that the range in TDS across the area during this period was 1,500 to 4,917 mg/l. A summary of the TDS data for El Arish wells from 1954 to 1981 is provided in Table 3-17 of Working Paper No. 33 in the SDS-I project file.

Seawater intrusion does not appear to be the cause of the deterioration of water quality in the aquifer. It is possible that there has been a relatively low level of pumping from the wells on the north side of the area; otherwise seawater intrusion might have been clearly observed. To aid in identifying the source of the saline water, as well as in evaluating the degree of ongoing seawater intrusion in the aquifer, an intensive groundwater sampling and monitoring program is highly recommended. Moreover, a surface resistivity survey should be considered. These recommendations are discussed in detail in Section 5.5.

Before discussing recharge of the Quaternary aquifer at El Arish, the information available on groundwater flow in the aquifer must be summarized. The 1979 to 1980 data on the static groundwater levels in wells in the area are provided in Tables 3-10a through 3-10o of Working Paper No. 33 in the SDS-I project files. Based on these data, a water level contour map for the area was prepared (Plate 5-23 in Working Paper No. 45). Because of uncertainties with respect to the reference points used in the measurements, the location of contour lines is approximate; nevertheless, the map is judged to be sufficiently accurate to provide a reliable indication of the direction of flow and, in most places, of the magnitude of the water level gradient. The groundwater flow appears to be moving generally from east to west, or from southeast to northwest. With the exception of one unexplained high of 2.2 meters above mean sea level--at Well 41-70 (PW 18), in the area north of the airport--the range in water level elevation is from -0.5 to 1.5 meters. If the below-sea-level values are correct, special concern about seawater intrusion is justified. The low value of -1.5 meters, found at the airport in Well 41-114 (PW 29), is indicative of the isolated and slowly permeable nature of the unit it taps. As mentioned previously, if that well had tapped the underlying calcareous sand, a better water supply would probably have been available, and it may have evidenced a static water level greater than +1.5 meters. This would have demonstrated its hydraulic continuity with the aquifer underlying the area to the north.

It is believed that recharge of the Quaternary aquifer at El Arish occurs by three means--direct rainfall on the recharge area, percolation beneath the wadi bed during small wadi flows and large floods, and upward movement along fault systems from lower (possibly Cretaceous) units. The possibility of leakage from underlying Cretaceous units to the Quaternary aquifer, via faults, is suggested by Geofizika (0466) and later analyzed by Saad (1085). Saad assumed that the flow proceeded basically from the south, at a hydraulic gradient of 0.0032, and over a front width of 5 kilometers. He applied the highest of two measured values for aquifer transmissivity, 1.05 m^2/min, for the area near Well 41-42 (GDDO 22). His computed result was 24,000 m^3/day as the average contribution to the aquifer from lower units.

It is assumed that vertical flow may very well be occurring along this fault system into the Quaternary aquifer, and that it is probably occurring all along the fault zone to the southeast of the area. It is further assumed that the faults extend from north of Bir El Lahfan northeastward to Wadi El Maazar and beyond, as shown on Plate 5-23 in Working Paper No. 45. This is inferred from the faults shown on Cross Section B-B' and from several sharp bends in Wadi El Maazar, which are possibly structurally controlled. Because of the existence of two dry, or nearly dry, wells in the southern part of the area, along Wadi El Arish, and due to the absence of any current water level data for that area, flow is assumed to occur only from the east or southeast. The assumption is that water discharges vertically upward via the faults into the Quaternary aquifer, and then moves laterally in a northwest direction, becoming more westerly as it approaches the El Arish-El Lahfan road.

Two calculations were performed to estimate the average flow that may recharge the Quaternary aquifer via the fault system. One was drawn from Saad's May 1962 water table map for the area (1085), and the other was derived from the contour map for 1979 to 1980 (Plate 5-23 in Working Paper No. 45 in the SDS-I project files). Both maps show that the major groundwater movement is from east to west or southeast to northwest. The average gradient across this front of approximately 8 kilometers, on Saad's map, is 0.0013, while that across a 7-kilometer front of contours, shown on Plate 5-23, is about 0.0005. Using an average (0.86 m^3/min) of the two transmissivity values computed by Saad for the area at Wells 41-113 and 41-42, an average flow of 12,800 m^3/day was calculated on the basis of the 1962 map, and an average flow of 4,300 m^3/day was determined from the 1979 to 1980 data. Assuming that the flow from this source has not changed significantly in the last 20 years, the two values were averaged to yield 8,500 m^3/day--the estimated long-term average supply rate to the Quaternary aquifer from lower geologic units.

To this component of recharge were added the computed values for the contribution from rainfall and from percolation of storm runoff in the wadi. For the rainfall contribution, a water balance analysis was performed over the entire area of the assumed recharge area, shown on Plate 5-11 in Working Paper No. 45. The result was an estimated average recharge due to rainfall percolation of 8,700 m^3/day. The recharge contribution from the percolation of floodwater runoff was based on the average number of days per year (1.3), over the entire Wadi El Arish Basin, in which rainfall exceeds 10 millimeters, under the assumption that such storms will produce runoff. This estimated recharge component was computed to be 9,800 m^3/day.

Thus, the estimated average recharge rate to the Quaternary aquifer at El Arish is the sum of the three components--8,500, 8,700, and 9,800 m^3/day--or, 27,000 m^3/day, as given on Table 2-9. Of the 27,000-m^3/day average recharge quantity, it is estimated that perhaps 25,000 m^3/day is extractable from wells, as shown in Table 2-10. The primary components of groundwater use are pumpage for agriculture

TABLE 2-10

Estimation of Pumpage From Wells in the El Arish Area, Fall 1981

Agricultural Use

Crop	No. of Feddans Irrigated	Estimated Irrigation Duration (days/yr)	Estimated Consumptive Use Rate (mm/yr)	Total Estimated Consumptive Use (m^3/yr)	Total Estimated Consumptive Use (m^3/day)
Citrus	30	320	1,830	0.23×10^6	630
Pomegranate, almonds, figs, guavas, cashurina	40	320	1,830	0.30×10^6	840
Vegetables, grapes, melons, etc.	450	130	1,020	1.90×10^6	5,240
Olives	700[a]	320	580	1.70×10^6	4,630
TOTAL	1,220	--	--	4.10×10^6	11,340

Assuming an overall irrigation and conveyance efficiency of approximately 80 percent, gross pumpage for agricultural purposes	~14,300
Public Supply, from town supply wells	8,100
Public Supply, from military wells[b]	2,600
TOTAL	25,000

[a] Approximately 70,000 olive trees.

[b] Water was pumped from the military wells as El Arish by pipeline to Abu Aweigila and Quseima, and to El Hema, Gifgafa, and Umm Khisheib, until early 1982.

SOURCE: Derived from data supplied by the agricultural officer at El Arish.

(irrigation) and pumpage for public supply. Agricultural use was determined by obtaining estimates from the local agricultural department regarding the number of irrigated feddans presently under each crop, and then by estimating the average consumptive use for each of the crops. It is estimated that 14,300 m^3/day is pumped for irrigation, and that 10,700 m^3/day is pumped for public supply.

If current groundwater pumpage is approximately equal to the average recharge rate, why is there such deterioration in groundwater quality in the aquifer over a large part of the area? The answer may relate to the quality of the groundwater assumed to be flowing into the aquifer from lower units by means of faults. If the source is indeed a Cretaceous unit, data shown on the isosalinity contour map of the Lower Cretaceous aquifer (Plate 5-3 in Working Paper No. 45) indicate that the TDS content of groundwater could exceed 10,000 mg/l. With water of that quality making up about one-third of the computed recharge, it is not unreasonable to find (after mixing) the degree of salinity present in the aquifer today, at least along the eastern side.

2.2.3.6 Groundwater Conditions in the El Qaa Plain. The aquifer underlying the El Qaa Plain consists of a thick sequence of sand and clayey-sand layers of Quaternary age, which fill the synclinal between Gebel Qabeliat to the southwest and the mostly crystalline mountains to the northeast. A north-south hydrogeologic cross section is provided on Plate 5-15 in Working Paper No. 45 in the SDS-I project files; the data are based on logs of five land reclamation wells drilled by the General Company for Research and Groundwater (REGWA) in 1981. The wells ranged in depth from 120 to 250 meters. At no location was consolidated bedrock (sedimentary rock) encountered. Existing data indicate that the public supply wells at El Tor also tap the Quaternary aquifer; thus, the aquifer is probably continuous from the northern part of the El Qaa Plain at least as far south as El Tor.

As shown in Table 3-10b in Working Paper No. 33, Water Resources, relatively high well yields--from 26 to 32 liters/sec--have been obtained from these new REGWA wells (Wells 36-38, 47-1, and 47-11 (El Qaa No. 3, No. 2, and No. 1, respectively)). The three public supply wells (47-15, 47-16, and 47-17) are reported to yield about 25 liters/sec, and their depth ranges from 80 to 150 meters.

Only limited data are available on water quality for the recently drilled REGWA wells. Data obtained informally from REGWA in March 1983 indicate a range in TDS of 950 to 4,992 mg/l. Values of 950 mg/l and 1,300 mg/l were reported for waters from Well 47-11 (No. 1) and Well 36-40 (No. 6), respectively. An unexpectedly high value of 4,992 mg/l was obtained for Well 47-1 (No. 2), which is located about 30 kilometers north of El Tor and 3 kilometers east of the El Tor-Feiran highway.

In June 1981, the Desert Institute analyzed water samples obtained from the El Tor public supply wells. TDS ranged from 600 to 650 mg/l. There is some evidence that south of El Tor and westward, within 1 kilometer of the Gulf of Suez, water in Quaternary deposits tends to be of poorer quality. (See Plate 5-1 in Working Paper No. 45 in the SDS-I project files.) Nine kilometers southeast of El Tor, Well 47-32 in 1972 produced water with a TDS of 2,429 mg/l, from a depth of 150 meters. Wells located in the El Tor area and tapping Quaternary deposits show a range in TDS of 800 to 3,800 mg/l. Possible seawater intrusion is one likely explanation for the higher salt content.

The static water level depths, shown on the cross section on Plate 5-15 in Working Paper No. 45, range from 28 to 67 meters below ground. Because the ground surface elevation at each well is only approximate, the water level elevations are likewise approximate. They do indicate, however, a general water level gradient in the aquifer from the northern part of the El Qaa Plain toward El Tor. It is possible that a substantial fraction of the total subsurface flow in the aquifer discharges to the sea in the vicinity of El Tor.

The boundaries of the recharge area for the El Qaa Plain Quaternary aquifer are outlined on Plate 5-11 in Working Paper No. 45. A portion of the adjoining crystalline mountain area is included because it is believed that much of the water recharging the crystalline rocks that border the plain ultimately discharges, possibly at depth, into the Quaternary aquifer. As shown on Table 2-9, the assumed recharge area is approximately 2,300 square kilometers, and the average recharge rate is estimated at 66,000 m^3/day. The recharge rate was computed from results of the water balance analysis, discussed in Section 2.2.4. Of the 66,000 m^3/day, it is estimated that only 30,000 m^3/day is readily extractable from wells. In addition, if groundwater is removed from storage over a long period of time by pumping from a regular network of wells, it is estimated that an additional amount of 80,000 m^3/day could be withdrawn on a continuous basis--making a maximum total of 110,000 m^3/day available from this aquifer. (The method used for this estimate is discussed in Section 2.2.4, and the results are provided in Table 2-13.) Pumpage from the Quaternary aquifer in 1981 probably did not exceed 2,800 m^3/day.

To confirm that up to 110,000 m^3/day can be withdrawn from the aquifer without any adverse effects, it is highly important to implement a detailed groundwater monitoring program for the El Qaa Plain as soon as possible. It should include regular groundwater sampling and analysis, as well as recording of groundwater levels, well pumping rates, and pumping schedules. This is discussed in more detail in Section 5.5.

2.2.3.7 <u>Existing Use of Groundwater</u>. Estimates of the present water usage in Sinai are given in Table A-1 in the appendix of this volume. Most of the groundwater presently exploited in Sinai is being withdrawn from six areas:

- El Arish area--about 25,000 m^3/day from the Quaternary aquifer.
- Rafah-Sheikh Zuwayid area--about 15,000 m^3/day from the two Quaternary aquifers.
- Abu Rudeis--about 800 m^3/day from nearby Quaternary wells.

- Feiran Oasis--an estimated 1,400 m^3/day from wadi alluvium.
- Wadi Feiran (at junction with El Tor road)--about 1,300 m^3/day from Miocene sandstone, for the oilfields.
- El Tor area--about 2,800 m^3/day from the Quaternary aquifer.

Small amounts of groundwater are withdrawn elsewhere--the total amounting to approximately 2,800 m^3/day. At Ayun Musa,* free discharge from springs and wells tapping Miocene and Lower Cretaceous units is estimated to amount to 500 to 1,000 m^3/day. At Ein Guderat, the spring from Eocene limestone is discharging between 1,500 to 2,000 m^3/day (Water Point 52-23).

Thus, the current estimated total groundwater use in Sinai is about 49,000 m^3/day. Of this, 47,000 m^3/day is drawn from Quaternary sediments or dune sand. The remaining 2,000 m^3/day is drawn from Miocene, Eocene, and Cretaceous units. The springs at Ein Guderat provide an additional 1,500 to 2,000 m^3/day for potable water at El Quseima, the village near the spring, livestock, and irrigation from Eocene limestone. The unused flow at Ayun Musa accounts for perhaps an additional 1,000 m^3/day from Miocene and Lower Cretaceous units.

2.2.4 <u>Quantification of Existing Water Resources</u>

2.2.4.1 <u>Water Balance Analysis</u>. The purpose of the water balance analysis is to estimate average groundwater recharge as well as the potential runoff yield of the basins. Data required to provide reliable water balance results were largely missing. The available rainfall data were incomplete, and there were essentially no runoff or evapotranspiration data for Sinai, apart from some Piche evaporometer data. Nevertheless, it was felt that it would be worthwhile for planning purposes to provide order-of-magnitude estimates for the components in the water balance equation. In performing the water balance analysis, the simplified equation:

$$G_r = P - E_t - R_o \qquad \text{Eq (4)}$$

was assumed, where G_r is the recharge to the groundwater, P is precipitation, E_t is evapotranspiration, and R_o is the net surface runoff leaving a basin. The units used were millimeters per year averaged over each basin area studied. Because the interest was in long-term averages, no change from year-to-year in the amount of water stored either as groundwater or in the soil mantle was assumed.

Precipitation data were available for most stations on mean annual rainfall (P) and the average number of rainy days with rainfall greater than 10 millimeters (N_s) (Table 2-11). Based on the isohyetal map presented on Plate 3-3 in Working Paper No. 45 in the SDS-I project files, average values for P and N_s were estimated for each of the basin areas listed in Table 2-11. In the absence of available data, it was necessary

*Includes springs and wells at Ras Misalla which supply Ras Sudr.

TABLE 2-11

Estimated Rainfall Parameters for Each Basin Area in Sinai

No.	Basin[a]	A Area (km^2)	P Total Mean Annual Rainfall (mm)[b]	N_s Average No. of Days/Yr With Rainfall (≥10 mm)	P_s Estimated Rainfall (mm) Per Storm (≥10 mm)
1	Upper El Arish	16,306[c/]	-	-	-
1a	El Bruk	3,345	27.7	1.08	13.5
1b	El Ruaq	6,481	28.0	1.02	18.3
1c	El Aqabah	2,839	26.4	0.90	19.3
1d	Geraia	3,641[c/]	28.0	1.25	13.2
2	Lower El Arish	2,749[d/]	64.0	2.49	18.2
3	Northeast coast	963	154.0	4.60	23.0
4	North coast	5,148	63.0	2.05	18.0
5	Hegayib	1,680	35.8	1.25	15.5
6	El Hasana-El Hema	3,549	45.0	1.56	17.9
7	El Gerafi	2,446	26.7	1.00	17.3
8	Wasit	4,204	36.5	1.34	19.3
9	Dahab	2,684	53.5	2.04	17.8
10	Kid	1,355	49.0	1.87	17.8
11	Umm Adawi	964	39.0	1.45	18.5
12	El Qaa	3,904	31.6	1.14	20.2
13	Abu Durba	266	13.0	0.32	25.0
14	Feiran	1,717	47.0	1.59	23.4
15	Sidri	1,163	36.0	1.19	23.5
16	Baba	841	33.6	1.11	23.5
17	Tayiba	860	26.5	0.62	29.1
18	Gharandal	829	26.5	0.67	27.8
19	Wardan	1,569	24.0	0.60	27.8
20	Sudr	895	22.1	0.40	33.8
21	Lahata	603	22.1	0.40	33.8
22	El Raha	847	24.0	0.43	33.8
23	El Hagg	621	25.5	0.46	32.1
24	El Giddi	703	27.5	0.50	31.2
25	Umm Khisheib	4,641	41.0	0.96	25.0
	SINAI	61,000[e]	39.4	1.33	20.1

[a/]See Figure 2.2 and Tables 2-2, 2-4, and 2-12 for more information on hydrographic basins.

[b/]Estimated from the isohyetal contour map (Plate 3-3 in Working Paper No. 45).

[c/]Total basin area includes an additional 45 km^2 outside Sinai.

[d/]Total basin area, including portion outside Sinai, is approximately 4,000 km^2.

[e/]Sinai basin areas add to 61,507 km^2, but are rounded to 61,000 km^2 in this report.

SOURCE: Derived from meteorological station data and Plate 3-3 in Working Paper No. 45.

to estimate the quantity P_s shown in the table, which is the average amount of rainfall per storm of 10 millimeters or greater.

Apart from local overland flow, the assumption was that no measurable surface runoff would result from basin areas unless a given storm provided 10 millimeters of water or more. Thus, it was assumed that all runoff from storms of less than 10 millimeters was lost as evapotranspiration.

In estimating evapotranspiration losses, it was decided that estimates based on the Modified Penman method (0269) of computing reference evapotranspiration rates (ET_0) would be more reliable than the available Piche evaporometer data. Therefore, monthly values of ET_0 were computed for five meteorological stations in Sinai--El Arish, Nakhl, Abu Rudeis, El Tor, and St. Catherine. Data on wind speed and cloudiness for St. Catherine were extrapolated from the Nakhl, El Tor, and El Arish stations. The data used and the computed results are given in Data Entries EN-CL-13, -14, -15, -16 and -17 in Volume VII. The computed ET_0 values, averaged on an annual basis, range from 4.9 mm/day for El Arish to 8 mm/day for Abu Rudeis.

The next step in estimating evapotranspiration losses on each basin consisted of an inventory of what are defined as the "primary evapotranspiration areas" (PEA). The location and areal extent of such areas were estimated from 1:100,000-scale topographic maps over all of Sinai. Aerial photomosaics were not available at the time of the analysis. Subsequent study of the photomosaics indicated that the topographic maps were probably reliable with respect to the general location of large vegetated areas. The areas identified on the topographic maps were placed in four categories:

- Areas containing palm trees in sand dunes.
- Areas containing grass and shrubs.
- Wadi beds with cultivation or shrubs and palms apparent.
- Wide wadi beds showing no apparent vegetation.

The area in square kilometers under each category was totaled for each basin area. The size of the PEA's in all categories ranged from zero for the Dahab Basin Area to 1,460 square kilometers for the Geraia subbasin of Wadi El Arish. The total area covered by all such areas on the peninsula was about 8,700 square kilometers.

For each region in Sinai, monthly ET_0 values were established based on the values for the five stations given in Data Entries EN-CL-13 through EN-CL-17 in Volume VII. Appropriate coefficients to apply to the ET_0 values were then selected for each category of PEA identified. For areas with palm trees in sand dunes and areas with grass and shrubs, the coefficient was based on an assumed density of vegetation ranging from 3 to 6 percent. For cultivated wadi beds, for the months of November through February, coefficients provided in Figure 6 of reference (0269) were used; for the remaining months, a density of ground cover ranging from 0.5 to 2 percent was used as the coefficient. For wide wadi beds with no apparent vegetation, coefficients applicable for initial crop development (0269) were used for the 4 winter months; for the remaining months, the coefficient was assumed to be zero. Based on consumptive use estimates, the average annual evapotranspiration from crops irrigated from wells in the El Arish and the Rafah-Sheikh Zuwayid areas was also estimated. (The reference figure is reproduced as Figure A.1 at the end of the Appendix to this Volume.)

In addition to evapotranspiration from the PEA's, evaporation was also assumed to occur over the entire area for 4 days following each rainfall of 10 millimeters or more. In this case, a coefficient was selected from Figure 6 of reference (0269) to apply to the ET_0 value over the entire area. Finally, all rainfall in storms of less than 10 millimeters was assumed to be lost through evapotranspiration.

By summing these components, the estimated average annual evapotranspiration (ET) for each basin was obtained, as shown in column I of Table 2-12. The computed evapotranspiration loss, averaged over each basin area, ranged from 10 mm/yr for the Abu Durba Basin Area to 83 mm/yr for the Northeast Coast Basin Area. The net annual ET for Sinai as a whole is estimated to be 24 mm/yr, after subtracting the estimated ET for those crops irrigated from wells.

In the absence of any runoff data, empirical equations were used to estimate the average quantities leaving each basin as surface runoff. First, the runoff that could be produced by the average-sized storm exceeding 10 millimeters was estimated. This estimate was multiplied by the average number of days per year with rainfall greater than or equal to 10 millimeters. For comparison, three runoff equations were used. The results of the computations, as well as the values used for the computations for each basin area, are shown in Tables 3-22, 3-23, and 3-24 of Working Paper No. 33 in the SDS-I project files. Each table shows the computations for a different method, involving the use of one of the three runoff equations obtained from the literature. The equations are modified slightly to include the normalized drainage density in the coefficient, defined as $D_i/\bar{D}$, where D_i is the drainage density of a particular basin in km^{-1}, and $\bar{D}$ is the mean drainage density for all of Sinai. The values of D_i in each case were obtained from an analysis of Sinai basins performed by Saad, El Shamy, and Sweidan.(1086) It was reasoned that the greater the drainage density of a basin, the more surface runoff that could be expected on the average, other factors remaining the same.*

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*Method 1, shown in Table 3-22 of Working Paper No. 33, involves the use of an equation attributed to Ball that was used by Saad, El Shamy, and Sweidan. (1086) This equation, modified to include the normalized stream density, is:

$$V = 750 \, (D_i/\bar{D}) \, A \, (P_s - 8) \qquad \text{Eq (5)}$$

(cont'd)

TABLE 2-12

Sinai Water Balance Summary (mm/yr)

A	B	C	D	E	F	G	H	I	J	K	L
No.	Basin[a]	Size (km^2)	Estimated Mean Annual Rainfall	Inflow Runoff (R_i) from Upstream Basins	Estimated Outflow (R_a) Runoff[b]	Portion of Runoff Lost in Spreading Areas[c]	Net Annual Runoff Leaving Basin (R_n)[d]	Estimated Total Annual ET on Basin[e]	Estimated Annual ET on Lands Irrigated by Groundwater	Net Annual ET on Basin[f]	Estimated Mean Annual Groundwater Recharge[g]
1	Upper El Arish										
1a	El Bruk[h]	3,345	28	0.0	0.9	0.5	0.4	23	0.0	23.0	4.6
1b	El Ruaq[h]	6,481	28	0.0	1.3	0.2	1.1	19	0.0	19.0	7.9
1c	El Aqabah[h]	2,839	26	3.0	1.3	1.5	2.8	19	0.0	19.0	7.2
1d	Geraia[h]	3,641	28	2.2	1.0	2.5	0.7	27	0.0	27.0	2.5
2	Lower El Arish	2,749	64	2.6	8.3	9.4	1.5	47	1.6	45.4	19.7

[a]For locations of basins see Figure 2.2.

[b]Due only to rainfall on basin.

[c]Due to percolation in "spreading areas."

[d]Net annual runoff = column E + column F - column G.

[e]ET = evapotranspiration. Values for evapotranspiration have been averaged over each entire basin area. No significant change in soil or groundwater storage is assumed, year to year.

[f]Net annual evapotranspiration = column I - column J.

[g]Mean annual groundwater recharge = column D + column E - column H - column K.

[h]According to the basin division formulated, subbasins 1a and 1b contribute water to 1c; 1c in turn contributes to 1d.

TABLE 2-12 (cont'd)

A No.	B Basin	C Size (km^2)	D Estimated Mean Annual Rainfall	E Inflow Runoff (R_i) from Upstream Basins	F Estimated Outflow (R_a) Runoff[b]	G Portion of Runoff Lost in Spreading Areas[c]	H Net Annual Runoff Leaving Basin (R_n)[d]	I Estimated Total Annual ET on Basin[e]	J Estimated Annual ET on Lands Irrigated by Groundwater	K Net Annual ET on Basin[f]	L Estimated Mean Annual Groundwater Recharge[g]
3	Northeast coast	963	154	0.0	0.0	0.0	0.0	83	6.0	77.0	77.0
4	North coast	5,148[i]	63	0.0	0.0	0.0	0.0	37	0.0	37.0	26.0
5	Hegayib	1,680	36	0.0	0.0	0.0	0.0	28	0.0	28.0	8.0
6	El Hasana-El Hema	3,549	45	0.0	0.0	0.0	0.0	25	0.0	25.0	20.0
7	El Gerafi	2,446	27	0.0	1.3	0.0	1.3	19	0.0	19.0	6.7
8	Wasit	4,204	37	0.0	4.8	0.0	4.8	17	0.0	17.0	15.2
9	Dahab	2,684	54	0.0	6.6	0.0	6.6	26	0.0	26.0	21.4
10	Kid	1,355	49	0.0	5.8	0.0	5.8	24	0.0	24.0	19.2
11	Umm Adawi	964	39	0.0	5.4	0.0	5.4	23	0.0	23.0	10.6
12	El Qaa	3,904	32	0.0	2.8	0.0	2.8	19	0.0	19.0	10.2
13	Abu Durba	266	13	0.0	1.2	0.0	1.2	10	0.0	10.0	1.8
14	Feiran	1,717	47	0.0	7.1	0.0	7.1	19	0.0	19.0	20.9
15	Sidri	1,163	36	0.0	6.4	0.0	6.4	15	0.0	15.0	14.6
16	Baba	841	34	0.0	4.7	0.0	4.7	13	0.0	13.0	16.3
17	Tayiba	860	27	0.0	4.5	0.0	4.5	15	0.0	15.0	7.5
18	Gharandal	829	27	0.0	2.8	0.0	2.8	12	0.0	12.0	12.2

[i] 4,575 km^2 exclusive of Lake Bardawil.

TABLE 2-12 (cont'd)

A	B	C	D	E	F	G	H	I	J	K	L
No.	Basin	Size (km^2)	Estimated Mean Annual Rainfall	Inflow Runoff (R_i) from Upstream Basins	Estimated Outflow (R_a) Runoff[b]	Portion of Runoff Lost in Spreading Areas[c]	Net Annual Runoff Leaving Basin (R_n)[d]	Estimated Total Annual ET on Basin[e]	Estimated Annual ET on Lands Irrigated by Groundwater	Net Annual ET on Basin[f]	Estimated Mean Annual Groundwater Recharge[g]
19	Wardan	1,569	24	0.0	2.5	0.0	2.5	14	0.0	14.0	7.5
20	Sudr	895	22	0.0	2.8	0.0	2.8	14	0.0	14.0	5.2
21	Lahata	603	22	0.0	1.1	0.0	1.1	16	0.0	16.0	4.9
22	El Raha	847	24	0.0	0.9	0.0	0.9	19	0.0	19.0	4.1
23	El Hagg	621	26	0.0	0.4	0.0	0.4	14	0.0	14.0	11.6
24	El Giddi	703	28	0.0	0.2	0.0	0.2	15	0.0	15.0	12.8
25	Umm Khisheib	4,641	41	0.0	0.0	0.0	0.0	21	0.0	21.0	20.0
	SINAI	61,507[j]	39.4	--	--	--	2.1[k]	--	--	23.7	14.2

[j] Sinai basin areas add to 61,507 km^2, but are rounded to 61,000 km^2 in this report.

[k] Includes only those basin areas from which the net annual runoff flows to the sea. Thus, R_n values for Upper El Arish subbasins have been omitted. The value is averaged over a 62,805-km^2 area, which includes the portion of the Wadi El Arish catchment outside Sinai.

SOURCE: Derived from the water balance analysis described and documented in Section 2.4.4.1 of this volume.

In all three methods, once the quantity of runoff, V (in cubic meters), is computed, R_a, the estimated average annual runoff (in millimeters per year), is computed by the equation:

$$R_a = \frac{V}{A \times 10^3} N_s \qquad \text{Eq (8)}$$

where N_s is the number of days per year with rainfall equaling or exceeding 10 millimeters.

Comparison of the results from Tables 3-22, 3-23, and 3-24 in Working Paper No. 33, Water Resources, shows that Method 1 predicts a much higher average annual runoff quantity than do Methods 2 and 3. Method 3 predicts a slightly higher annual runoff than Method 2, except in a few basins, such as the Northeast Coast or Hegayib Basin Areas where surface drainage is either not fully developed or not developed at all. As an example of the results using the three methods, the Wadi El Bruk subbasin showed an annual runoff of 3.2 mm/yr by Method 1, 0.6 mm/year by Method 2, and 1.1 mm/yr by Method 3. The annual runoff for the Feiran Basin was computed to be 21.8 mm/yr by Method 1, 5.3 mm/yr by Method 2, and 8.8 mm/yr by Method 3. The runoff computed for the El Gerafi Basin was 6.1 mm/yr by Method 1, 1.3 mm/yr by Method 2, and 1.4 mm/yr by Method 3.

(cont'd from p.2-60) where V is the average runoff per storm greater than or equal to 10 millimeters (in cubic meters), A is the basin area in square kilometers, and P_s is the estimated average rainfall, in millimeters, of storms equaling or exceeding 10 millimeters.

Table 3-23 shows the results of computation with the second runoff equation, derived from the portion of Strange's table (0299c) applicable to a "good" average catchment in a "damp" condition. (Assuming a "dry" condition for the catchment resulted in extremely low computed runoff.) The resulting equation is:

$$V = 1{,}000\ (D_i/\bar{D})\ A\ P_s\ R_p \qquad \text{Eq (6)}$$

where R_p is the fraction of precipitation that becomes runoff, from Strange's table, and all other parameters are as defined for Equation (5).

The third method, shown in Table 3-24, involves use of the U.S. Soil Conservation Service method.(1152) The equation in this case is:

$$V = 25{,}400\ (D_i/\bar{D})\ A\ \frac{(P_s - 0.2\ S)^2}{(P_s + 0.8\ S)} \qquad \text{Eq (7)}$$

where S = (1,000/N) - 10; N is the runoff curve number appropriate to a particular hydrologic soil group, crop, and land cultivation practice; and the other parameters are as defined for Equation (5). Runoff curve numbers (N) appropriate for fallow conditions and for antecedent conditions, ranging between dry and average (conditions I and II), were selected.

For three-fifths of the basins an average of the results from Methods 2 and 3 was used. This decision was guided by the results of runoff measurements made in the Negev on small watersheds.(0384) For Basin Areas 3, 4, 5, 6, 21, 22, 23, 24, and 25 (one-third of all basins), where stream density was low or undeveloped and where there was no outlet to the sea, the results from Method 3 were used. An average of the results from all three methods was applied to the Lower El Arish Basin since it was felt that the equation for Method 1 would have more validity in this higher rainfall zone.

The final selected values for the estimated outflow runoff for each basin area are given in column F of Table 2-12. The values range from zero for a basin area such as the North Coast or the Hegayib Basin to 8.3mm/yr for the Sinai portion of the Lower El Arish Basin. The values are relatively low for the subbasins of the Upper El Arish Basin (ranging from 0.9 to 2 mm/yr) and for the El Gerafi Basin Area (1.3 mm/yr). Basin Areas 8 through 11, in the Southeast Subregion, average 5.6 mm/yr, and those in the Southwest Subregion, including Feiran, Sidri, Baba, and Tayiba, average 5.7 mm/yr.

In the water balance summary table (Table 2-12), inflow data from upstream subbasins of the El Arish Basin are shown in column E. According to the division of subbasins adopted for the El Arish Basin, the El Bruk and El Ruaq subbasins drain into the El Aqabah subbasin, which in turn drains into the Geraia subbasin. The Geraia subbasin and the two subbasins in Israel drain into the Lower El Arish Basin Area in Sinai. For those subbasins contributing water to downstream subbasins, the value under column H for the contributing basin was added to the value under column E for the receiving basin, after adjusting the number for basin size.

The presence of natural controls and natural spreading areas in Wadi El Arish is discussed in Section 2.2.2. Since such spreading areas are not taken into account in the runoff equations used, the amount of runoff water that might percolate below these areas was estimated--based on the approximate size of the spreading areas (from 1:100,000-scale topographic maps), an assumed average percolation rate, and the average number of days per year with rainfall equal to or exceeding 10 millimeters. These estimates are given in column G of Table 2-12.

The net surface outflow (R_n), the estimated surface runoff yield expected from a given basin area, is found in column H of the table. This value is obtained by subtracting the amount lost due to percolation in spreading areas from the sum of R_a (surface runoff due only to rainfall on the basin area) and R_i (inflow surface runoff from upstream subbasins). The R_n values range from zero, for Basin Areas 3 through 6, to 7.1 mm/yr for the Feiran Basin Area. The average for Sinai as a whole is 2.1 mm/yr.

The last column (column L) of Table 2-12 provides the estimated groundwater recharge in millimeters per year, averaged over each basin area. This was calculated, on the basis of Equation (4), by subtracting the sum of the net surface runoff (R_n) and the net annual ET from the sum of the mean annual rainfall and inflow runoff from any upstream subbasins. The estimated average annual groundwater recharge values range from 1.8 mm/yr for the Abu Durba Area to 77 mm/yr for the Northeast Coast Basin Area. The overall average for Sinai is computed to be about 14 mm/yr.

2.2.4.2 Estimates of Groundwater Recharge for the Major Aquifers in Sinai. Average groundwater recharge rates were calculated for each recharge area shown on Plate 5-11 in Working Paper No. 45 in the SDS-I project files. This was accomplished by determining the fraction of the recharge area found in different adjacent basin areas. Then, for each recharge area, the weighted average of the recharge values found in column L of Table 2-12 was computed. These weighted average recharge rates were then applied to each recharge area. A summary of the results is provided in Table 2-9. The 413,000 m^3/day recharged into these major aquifers is about half of the total recharge, but the proportion cannot be reliably projected. Much of it cannot be recaptured.

- Average recharge to the Cambrian-to-Triassic and Cambrian-to-Cenomanian undifferentiated rocks is 52,000 m^3/day. Lower Cretaceous rocks receive about 38,000 m^3/day.
- The Middle Cretaceous unit, as a whole, receives an estimated 192,000 m^3/day.
- Quaternary aquifers in the Rafah area are estimated to receive recharge at an average rate of 38,000 m^3/day.
- The Quaternary aquifer at El Arish receives about 27,000 m^3/day.
- The Quaternary aquifer at El Qaa Plain receives 66,000 m^3/day.

2.2.4.3 Groundwater Availability in Sinai. The determination of groundwater availability in the different areas of Sinai requires an integration of five essential types of information--hydrogeologic data on water points, stratigraphic information on the major aquifers, estimates of recharge to each aquifer, aquifer hydraulic data, and unit costs for well construction and pumping from wells. The method for obtaining the groundwater cost information is described in Section 5.0.

Plate 5-1 in Working Paper No. 45 in the SDS-I project files and the water point data in Tables 3-10a through 3-10o (Working Paper No. 33) were reviewed to determine the most likely areas in which to exploit groundwater of reasonably acceptable quality. Well depth, static water level, and groundwater quality (as indicated by TDS) were noted for each aquifer and each area. Then, the stratigraphic data given in Table 2-3 of Working Paper No. 33 were reviewed, and the isopach maps (Plates 5-5 and 5-6) and the contour map of the depth to the top of the Lower Cretaceous aquifer (Plate 5-7) were studied. On the basis of this information, 47 "groundwater availability areas" (GAA) were identified. A given groundwater availability area is limited to what a single aquifer can deliver. Hence, if more than one potential aquifer underlies a particular location, at least two GAA's will overlap at that location.

Plates 6-1 and 6-2 in Working Paper No. 45 show the boundaries and extent of each GAA. Plate 6-1 includes the GAA's for all the Quaternary, Miocene, Eocene, Middle Cretaceous, and Crystalline aquifers, while Plate 6-2 shows the GAA's for the Lower Cretaceous aquifer and lower contiguous sandstones. This information is illustrated in Figures 2.5-2.7.

Details on the estimated ranges of the important parameters for each GAA were recorded on a special form. Tables 3-25a through 3-25uu (Working Paper No. 33) show these completed forms, one for each GAA. The hydrogeologic information entered on the forms includes ranges for estimated depth to the top of the aquifer, estimated well depth, static water level, possible well discharge rate, drawdown, TDS content of the groundwater, natural recharge to the aquifer in the area, and estimated quantity of groundwater extractable from the aquifer by wells in the GAA. A parameter termed the "degree of confidence" reflects the amount of hard information upon which the particular estimated range of values is based. Under the scheme used, "1" indicates the highest degree of confidence, while "4" is the lowest. Of the 47 areas identified, the El Arish area (Area No. 2) has the highest degree of confidence for hydrogeologic information--a level of 1.2, while the lowest degree of confidence is for four different GAA's involving the Middle Cretaceous aquifer (Areas 9, 10, 12, and 23)--with an average value of 3.6.

The cost estimates provided on the lower half of the GAA forms (Tables 3-25a through 3-25uu in Working Paper No. 33) were obtained with the aid of cost curves, making use of the ranges for well depth, pumping water level, and well discharge provided on the hydrogeologic portion of the form. In calculating the total volume of water pumped per year, it was assumed that pumping would take place an average of 8 hr/day. The cost of water per cubic meter is computed at the wellhead. In this analysis, the diesel price assumed was LE 0.025 per liter.

Under the comments section of the form, ideas are presented regarding water quality or recharge, and certain recommendations are made regarding the need for test wells in each area and the siting of new wells. For example, for GAA No. 36, involving wadi alluvium in the Wadi Kid, Umm Adawi, and Nebq areas, it is recommended that test wells be drilled to at least 40 meters, with the upper 30 meters cased and grouted to seal off the upper part of the aquifer, which is known to contain highly saline water. Based on one deeper well in the area, it is possible that water of reasonably satisfactory quality could be obtained at deeper levels in the alluvium, which could probably be recharged from the crystalline rocks to the west.

A summary of the information given on the groundwater availability forms (Tables 3-25a through 3-25uu in Working Paper No. 33) is provided in Appendix Table A-4. This table deviates from the information given in Tables 3-25a through 3-25uu, in that the estimated long-term withdrawable groundwater in each case is based on the "water balance" approach. Data given in Tables 3-25a through 3-25uu also include the results of a new analysis, to be discussed below. In reviewing these estimates of groundwater availability, it is important to keep in mind not only the degree of confidence of the information base, but also three other considerations that could affect any planned groundwater development:

- In identifying the groundwater availability areas, the potential aquifers have been limited to those capable of supplying water with a TDS content of less than 8,000 mg/l. Obviously, this includes not only freshwater, but also brackish-to-saline water. Therefore, in considering any area for possible groundwater development, special attention must be paid to the estimated range in TDS. Knowledge of the possible water quality should affect decisions regarding potential groundwater development and the initiation of a test drilling program.

- The amount of groundwater estimated to be withdrawable (item 10 in Tables 3-25a through 3-25uu in Working Paper No. 33) is the total groundwater available in the area, including that presently being exploited and that which may be withdrawn from any future wells.

- In Appendix Table A-4 the groundwater shown as available is calculated on a "water balance" approach, wherein one assumes that a large fraction of the natural recharge can be captured, and that only a negligible amount of groundwater can or should be removed from storage.*

2.2.4.4 Groundwater Availability in Selected GAA's Analyzed as to Maximum Allowable Drawdown. In early 1983 the Consultant reviewed and revised the analysis of groundwater availability for selected GAA's. The areas selected for reanalysis included those aquifers that are known to have a reasonably broad areal extent with no major problems of water quality -- the Middle Cretaceous and the Lower Cretaceous aquifers, and a few Quaternary aquifers including the El Qaa Quaternary aquifer. This new approach emphasized the physical constraints on the maximum allowable drawdown in a well, rather than assuming, as was done previously, that the available groundwater was limited to a portion of the estimated recharge.

For each GAA analyzed, the drawdowns from a hypothetical network of equally spaced wells, each pumping at equal rates, were estimated over a 30-year period by means of the Theis equation, which was applied to the simultaneous pumping of all the wells using the principle of superposition. Approximate values for aquifer parameters were estimated. This method was repeated for several well spacings, until the minimum well spacing was found for which the drawdown in each well would not be excessive. Excessive drawdowns over the assumed 30-year period were defined as those resulting in the dewatering of more than two-thirds of the saturated

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*There are some theoretical and practical drawbacks to the water balance method of estimating available groundwater withdrawal, as pointed out by Bredehoeft, Papadopoulos, and Cooper.(0248)

thickness of a water-table aquifer, or more than 20 percent of the thickness of a confined aquifer.

Cost considerations were also addressed in the analysis. However, it appeared that physical constraints, as described above, were limiting in all cases. Total water costs at the well head under the maximum permitted drawdowns ranged from LE 0.04 to LE 0.40 per cubic meter, with the costs for most of the cases falling below LE 0.02.

As the final step in the analysis, the sum of the discharges of the hypothetical wells in each GAA was added to that portion of the estimated recharge for the area that was judged to be capturable. The resulting figure is the updated groundwater availability estimate under the assumption of an optimum drawdown over a 30-year period.

A summary of the results of this analysis is provided in Table 2-13. The analysis was performed for those areas considered to be the most significant from the point of view of groundwater supply in Sinai. The El Arish and Rafah areas were excluded from this hypothetical analysis because considerable data for these areas indicate that the available groundwater is constrained by potential or actual water quality deterioration. Because of this, the Consultant concluded that no additional groundwater withdrawal is practical over and above that indicated in Appendix Table A-4 -- namely, 25,000 m^3/day for the El Arish area and 30,000 m^3/day for the Sheikh Zuwayid-Rafah area.

Table 2-13 presents a significant increase in the estimated available groundwater in certain areas as a result of the new analysis. Particularly notable are the increases computed for the various Uplands locations and the El Qaa Plain. The potential yield from the Middle Cretaceous aquifer in Central Sinai, for example, is computed now to be approximately 55,000 m^3/day, rather than 10,000 m^3/day; and the Lower Cretaceous aquifer, in roughly the same area, is computed to yield up to 180,000 m^3/day, rather than the 10,000 m^3/day estimate based on the water balance approach. The maximum yield from the Quaternary aquifer in the El Qaa Plain is estimated at 110,000 cubic meters per day, compared with the earlier estimate of 30,000 m^3/day. In sum, for these two areas, the optimizing rather than the balancing approach indicates seven times as much water (345,000 m^3/day compared with 50,000).

It should be borne in mind that the figures for potential groundwater withdrawal resulting from the new analysis assume a uniform distribution of wells over the entire area. Less groundwater would be available if the wells are clustered together in only a few locations (assuming uniform aquifer conditions). Also, when considering the quantities of groundwater that might be available in each area, it is important to recognize the likely range in water quality, which is given in terms of total dissolved solids in the last column of Table 2-13.

We cannot emphasize too strongly the fact that most of the estimates of groundwater availability provided in Table 2-13 and in Tables 3-25a through 3-25uu and 3-26 (in Working Paper No. 33) are extremely crude

TABLE 2-13

Estimated Total Available Groundwater for Selected Areas*

Area	Aquifer	Case I 1982 Estimate of Available Groundwater[a] (m^3/day)	Case II 1983 Estimate of Available Groundwater[b] (m^3/day)	Estimated Average Cost of Groundwater Under Case II (LE/m^3)	Estimated TDS of Water[c] (mg/l)
6. East side of Gebel El Maghara	Middle Cretaceous	5,000	10,000	0.10	2,000-5,000
7. Gebel El Halal	Middle Cretaceous	5,000	15,000	0.10	1,500-4,000
8. Gebels Yelleq and Fallig	Middle Cretaceous	9,000	20,000	0.10	1,500-4,000
11. Gebels Burga and Taliat El Bedan	Middle Cretaceous	2,000	12,000	0.10	2,000-4,000
12. Central Sinai	Middle Cretaceous	10,000	55,000	0.23	1,500-4,000
17. Wadi El Gerafi	Wadi alluvium	7,000	15,000	0.06	1,500-3,000
21 Wadi Sudr Delta	Wadi alluvium	1,200	4,000	0.05	2,500-5,000
22. Wadi Wardan Delta	Wadi alluvium	1,200	6,000	0.05	2,000-7,000
23. South central Sinai	Middle Cretaceous	12,000	43,000	0.17	1,500-4,000
24. Gebel Somar to Gebel Igma	Middle Cretaceous	12,000	37,000	0.09	1,000-3,000
25. El Themed to Ras El Gineina	Middle Cretaceous	12,000	32,000	0.13	2,000-6,000
33. El Qaa Plain	Quaternary fluvial deposits	30,000	110,000	0.04	600-5,000
40. Gebel El Maghara	Lower Cretaceous sandstone	6,000	46,000	0.13	1,200-6,000
41. Risan Aneiza	Lower Cretaceous sandstone	2,400	30,000	0.15	2,000-7,000
44. Central Sinai	Lower Cretaceous sandstone	10,000	180,000	0.41	1,500-2,500
45. South central Sinai	Lower Cretaceous sandstone	10,000	35,000	0.23	1,500-2,500
46. South Sinai	Nubian aquifer (Lower Cretaceous and older)	7,000	57,000	0.18	1,500-3,500

*Figures 2.5-2.7 give locations. The only other major areas considered to have substantial groundwater potentials are the Quaternary aquifers near El Arish and Rafah (see Table 2-9), which are already actively exploited (and in the opinion of some observers probably over exploited).

[a]Based on the "water balance" approach (see Appendix Table A-4).

[b]Based on an optimum drawdown caused by a network of wells over a 30-year period.

[c]TDS = total dissolved solids.

SOURCE: Derived from the reanalysis of groundwater availability undertaken early in 1983 and described and documented in Section 2.2.4.3 above.

approximations, and were computed for the purposes of the very preliminary peninsula-wide planning required for this study. This points up again the urgency of performing a carefully formulated exploratory well drilling and aquifer testing program, such as recommended and described in Section 5.5.2.

2.2.5 Desalinization Options

2.2.5.1 Introduction. As of May 1981, there were 22 operational desalinization plants in Egypt, with an aggregate capacity of 9,800 m^3/day. (0302) They range in daily capacities from 100 to 2,000 cubic meters and employ three basically different desalinization technologies--electrodialysis, distillation, and reverse osmosis. In Suez, a 2,400-m^3/day reverse osmosis plant was under construction to convert brackish water to potable quality water for the Suez Cement Company.

There are plans to install at least seven new desalinization units in Sinai. These are shown as Unit Nos. 1 through 7 on Figure 2.10 and in Table 2-14. Four electrodialysis units were being used at El Arish in 1983, each with a capacity of 400 m^3/day. The water source is the existing town wells, and the units are being placed in different sections of the town. It is expected that the charge for this water will be LE 0.25 per cubic meter. A reverse osmosis unit (Unit No. 5), with a capacity of 200 m^3/day, is planned for nearby El Masaid. A similar unit of the same capacity is to be installed at Bir El Abd, and local groundwater will be used as the feedwater.

In South Sinai, a reverse osmosis unit, with an approximate capacity of 625 m^3/day, has been delivered to Ras Sudr. Arrangements are now being made to complete the installation of this unit. The feedwater is assumed to be either local groundwater from the Wadi Sudr delta alluvium or piped water from flowing wells at Ras Misalla.

A number of processes or energy sources should be considered in evaluating the possibility of any additional desalinization units for Sinai. Generally, the selection of a particular process or energy source will be governed by the probable cost, as affected by:

- Salt content of the possible feedwaters
- Cost of pumping the feedwater to the plant site
- Desired purity of the output water
- Required capacity of the unit, in m^3/day
- Energy efficiency of the processes considered
- Availability of different energy sources at the site.

The major desalinization processes comprise reverse osmosis, electrodialysis, and distillation. Reverse osmosis (RO) and electro-

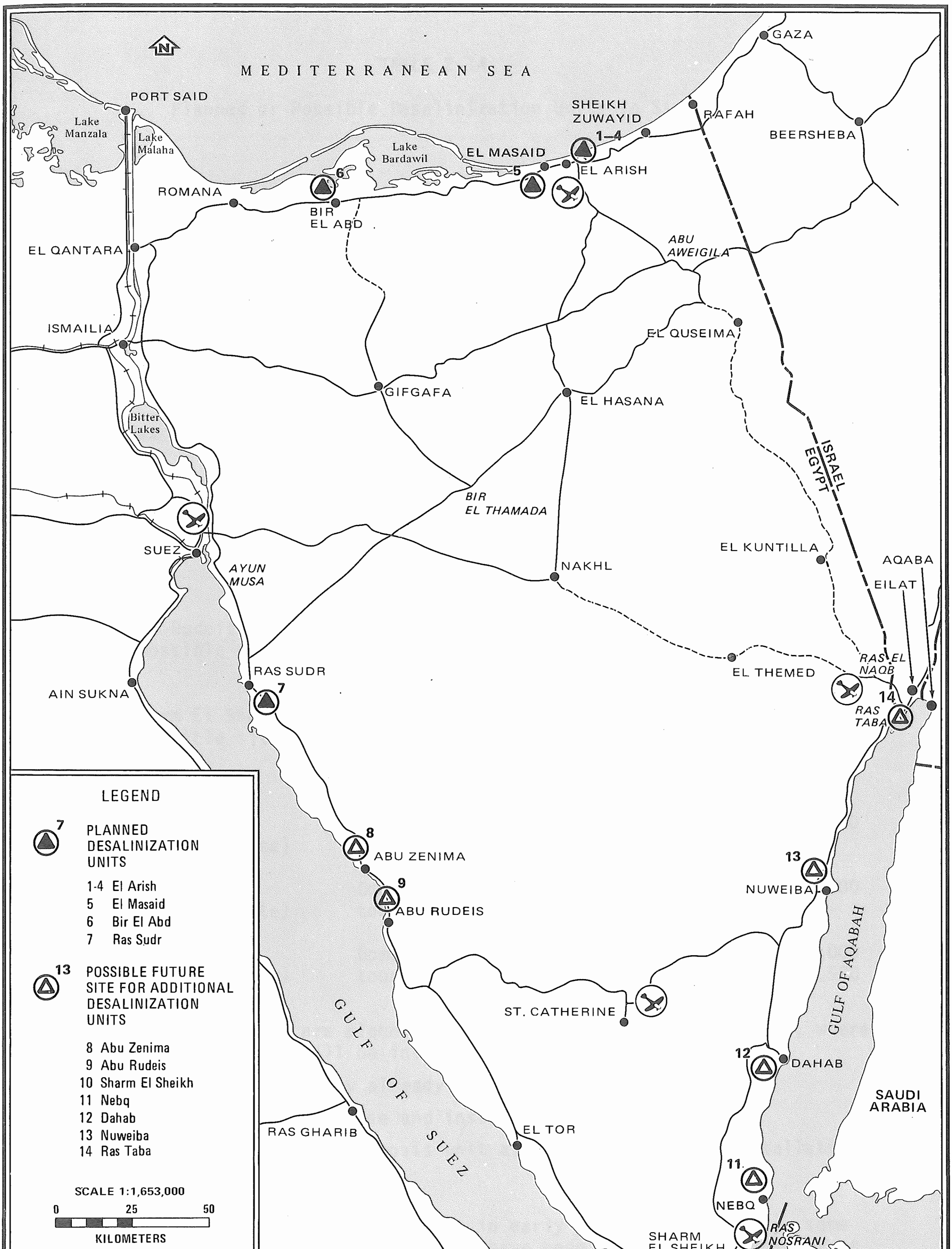

FIGURE 2.10
LOCATION OF
DESALINIZATION UNITS

TABLE 2-14

Planned or Possible Desalinization Units in Sinai

Unit No.	Location	Purpose	Feedwater (TDS in mg/1)	Capacity (m^3/day)
1-4	El Arish[a/], [b/]	Potable supply	Local groundwater (2,000-4,000)	1,600 (4 units)
5	El Masaid[c/]	Potable supply	Local groundwater (3,000-6,000)	200
6	Bir El Abd[c/]	Potable supply	Local groundwater (5,000-8,000)	200
7	Ras Sudr[d/]	Domestic Supply	Local groundwater (3,000-5,000)	625
8	Abu Zenima (possible site)	Domestic and industrial supply	Seawater	1,200
			Groundwater, piped from 15 km east (3,000-5,000)	1,200
9	Abu Rudeis (possible site)	Domestic and industrial supply	Local groundwater (3,000-5,000)	2,000 5,000
10	Sharm El Sheikh (possible site)	Domestic and tourism supply	Seawater	1,200
			Local groundwater (4,000-7,000)	1,200
11	Nebq (possible site)	Domestic and tourism supply	Local groundwater (4,000)	1,000
12	Dahab (possible site)	Domestic and tourism supply	Local groundwater (2,000-4,500)	1,000
13	Nuweiba (possible site)	Domestic and tourism supply	Local groundwater (2,000-3,500)	1,000 1,500

a/ Reverse-osmosis units are planned for all locations except El Arish, where electrodialysis units will be installed.

b/ These units are essentially already installed.

c/ Plans are underway to purchase and install these units.

d/ There is already a reverse osmosis unit at Ras Sudr, but its installation is not yet complete.

SOURCE: Derived from SDS-I field trips in early 1983. Subsequently, some additional desalinization units have been planned, most notably at Ras Taba (Number 14 on Figure 2.10).

dialysis (ED) involve the use of membranes. Distillation may be of the multistage flash evaporation type (MSF) or the vapor-compression type (VC). Electrical energy is generally required for both the RO and ED processes; the ED process requires direct current. In addition to electrical energy, heat is required for distillation--it can be provided by fossil fuels, such as diesel oil or gas. Alternatively, in vapor compression distillation, mechanical energy is applied to produce high-temperature vapor for use as a heat source instead of steam.

Pilot studies are underway in several countries on the use of solar energy to power different types of desalinization units. These units are basically still in the experimental stage, but solar energy must be seriously considered as a possible energy source in an area such as Sinai.

2.2.5.2 Description of Desalinization Processes

- Reverse osmosis--The reverse osmosis (RO) process uses hydraulic pressure to force pure water from saline feedwater through a semipermeable membrane. The process is now used for desalting brackish water and, in certain circumstances, seawater.

  The two important characteristics of an RO membrane are flux (rate of flow per unit area of membrane) and salt rejection. The percentage of salt rejection is a function of the feedwater salt composition, the operating pressure, and the membrane. Membranes can be tailor-made to produce the highest salt rejection for a water of a particular chemical content and composition. A salt rejection of 90 percent is usually adequate for brackish feedwaters, while better than 98 percent is required to produce potable water from seawater. The operating pressure in an RO unit for most brackish waters is 400 $lb/in.^2$ (psi) or more. With seawater, operating pressures of 800 psi are common.

  Pretreatment is essential for the proper operation of the equipment and to prolong the life of the membrane. (Refer to the flow diagram for a reverse osmosis system, Figure 3-12, in Working Paper No. 33 in the SDS-I project files.) The pretreatment process and regular membrane maintenance serve to minimize membrane fouling due to scaling by calcium and magnesium sulfate and carbonates; by metal oxides; or due to plugging by suspended solids or biological growth.

  Chlorination is usually recommended, with a residual of 0.3 to 1 ppm chlorine, to control biological growth. If the membrane is of the polyamide type, all residual chlorine must be removed prior to fluid entry into the membrane assembly. Membrane life is normally assumed to be 3 years with brackish feedwaters, and 2 years for seawater.

- Electrodialysis--Electrodialysis (ED) uses a direct current to transfer ions across a membrane, and the electrical energy is consumed in proportion to the quantity of salts removed. For economic reasons, the ED process is generally limited to feedwaters with a TDS level of 5,000 mg/l or less. Present research on this process is aimed at making seawater desalinization by ED practical through high-temperature operation using thin membranes. A schematic flow diagram for an electrodialysis unit is given on Figure 3-13 in Working Paper No. 33, Water Resources.

The heart of the system is the electrodialysis membrane stack, which consists of several compartments, each containing a pair of membranes separated by a spacer. One of the membranes is cation-permeable when a direct current is imposed on the solution, allowing cations but not anions to pass through, while the other of the pair is anion-permeable, which permits anion passage, but blocks cations. In addition to the membrane compartments, each ED stack includes an inlet feedwater channel, an outlet output water channel, and two electrodes. The extent to which the feedwater is desalted in the ED process depends on its residence time in the stack and the current density, which is kept as high as possible to increase production.

Electrical power is used for pumping water through the system, in addition to providing for transfer of ions in the stack. Rectifiers are used to convert alternating current to direct current for application to the membrane stack. For pumping, the power required is about 1 kWh/m^3 of product water. Current applied to the membrane stack is commonly consumed at a rate of about 1.32 kWh/m^3 for each 1,000-ppm reduction in salinity. In general, the power requirements decrease as the temperature rises. One can assume a 1 percent decrease in power consumption with each 0.5^oC rise above 21^oC, and a 1 percent increase with each 0.5^oC below 21^oC.

- <u>Multistage flash evaporation</u>--Multistage flash evaporation (MSF) is a type of distillation process based on the principle that water will boil at progressively lower temperatures as it is subjected to progressively lower pressures. If a series of vessels (stages) are arranged as shown schematically in Figure 3-15 of Working Paper No. 33 in the SDS-I project files, and the pressure relationship $P_3<P_2<P_1$ is maintained, as preheated water is introduced (with the brine stream) into each stage in succession, part of it will suddenly vaporize (flash) until the water temperature is again in equilibrium with the vapor pressure. The spiral tubes shown in the figure carry cool feedwater and act to condense the water vapor, which is then collected in a chamber from which it enters the product water stream.

In any distillation plant, the feedwater (generally seawater) must be treated to prevent formation of scale due to precipitation of the salts as it is being heated to its highest temperature. The deposition of such scale on the surfaces of the heat transfer tubing in the brine heater seriously affects the operation of the plant since the scale reduces the transfer of heat from the steam to the brine.

The MSF process involves four streams:

- Feedwater (seawater) stream--Consists of the cold raw water that flows through the condenser tubes in the heat rejection section. As the seawater leaves this section, a portion is returned to the sea. The remainder is treated and flows to the decarbonator and the deaerator, where bicarbonate, carbon dioxide, and oxygen are removed.

- Brine recycle stream--Consists of recycled brine and makeup water. The makeup water is comprised of the feedwater that has flowed through the heat rejection section. The mixture of brine and makeup water is pumped through the tubes of the entire heat recovery section; at the end of this process, the mixture enters the brine heater, where it is heated to its highest temperature. The hot mixture then flows to the flashing chambers. The resultant vapor is condensed by transferring its latent heat to the brine mixture flowing in the tubes of the heat recovery stage. The condensate (product water) is collected in trays. The flashing process continues at progressively lower pressures. After the last stage, a portion of the brine is removed as blowdown,* and the balance is returned to the suction side of the recycle pump.

- Product-water stream--Begins as the distillate produced from the condensing vapor flows along in trays--gradually increasing in volume until it leaves the last stage. The stream is then directed to the product water pump. As the water flows from stage to stage, its temperature is reduced by flashing to a lower pressure. The temperature of the final product, however, is generally greater than $30^{\circ}C$ and may require cooling.

- Vapor stream--Consists of two major streams--the steam admitted to the brine heater and the vapor resulting from the liquid flashing in each stage. Condensate from the brine heater usually is returned to the boiler, while condensate originating from flashing becomes the product water.

- Vapor compression distillation--The principle of vapor compression (VC), by which temperature and pressure increase, can be

*In "once-through" plants, all of the last-stage brine is blown down, and none of it is recycled.

used in combination with any of the distillation processes. In this way, the enthalpy of low-temperature vapor can be increased, so that the vapor can be used as the heat source rather than fresh steam. This permits the use of mechanical energy rather than the normal thermal energy.

2.2.5.3 Solar Desalinization. Research and development efforts in several countries have been directed toward the design and testing of solar-powered desalinization units. As an indication of the interest in solar desalinization systems, over 25 papers on this subject were presented at a solar desalinization workshop held in March 1981.(1308) Some of the current research efforts are being directed at improving the efficiency of solar collectors. However, despite the level of research, it seems that few units or modules are commercially available at present.

One solar-powered reverse osmosis unit has recently been delivered to Jeddah, Saudi Arabia, by Water Services of America.(1378) The unit uses two high-pressure, hollow, fine-fiber permeators and two low-pressure permeators to reduce the salt content of the incoming seawater from 42,800 mg/l to below 100 mg/l TDS. The solar system uses an 8-kilowatt array of 210 ribbon photovoltaic cells to convert the sun's rays into electricity. The unit is designed to deliver only about 4 m^3/day of potable water. No cost data were available.

A pilot plant that uses a solar-powered electrodialysis process (SPED) has been designed under the auspices of the Office of Water Research and Technology (OWRT) of the U.S. Department of the Interior. (0822) The SPED plant is designed to produce 150 m^3/day of potable water and uses photovoltaic solar collectors to produce the direct current needed for electrodialysis and to charge batteries to be used during periods of low sunlight and at night, if necessary. A process flowsheet for the SPED plant is shown on Figure 3-18 in Working Paper No. 33 in the SDS-I project files. By using the product recirculation pump as the feed pump, with the main feed pump off, the power requirement of the plant is reduced from one-fourth to one-half of full-flow requirements. The cost of desalinization of brackish water (about 2,200 mg/l TDS) is estimated to be LE 2.2 per cubic meter.

A detailed conceptual system design has been formulated for a solar-powered, multiple-effect diffusion (MED) distillation unit.(1039) Parabolic trough solar collectors are coupled to a primary heat transfer loop and heat storage subsystem to provide thermal energy to the steam generator. The steam engine/generator subsystem generates power for the plant auxiliaries or for export, and the engine feeds exhaust steam at atmospheric pressure to the MED desalinization subsystem. Based on systems simulation and analysis, the MED unit appears to be one of the most efficient thermal distillation approaches known to date. The net energy consumed by the MED unit for desalinizing seawater (44,000 mg/l TDS) is only about 75 kJ/kg of product water. The plant has a rating of 6,000 m^3/day of potable water of high quality (<10 mg/l TDS).

In the conceptual MED plant, a special heat-transport oil (MCS-2046 from the Monsanto Chemical Corporation) is heated by the glass-mirrored parabolic short-focus solar collectors.(1039) The hot oil flows to a large insulated storage tank, which supplies thermal energy to the desalinization system at a constant rate, and is further pumped to a steam boiler and produces steam at 193°C. The MCS-2046 oil was selected for its compatibility with the system and its expected long life. Similarly, the heat receiver in the solar collector is expected to require very infrequent replacement.

The MED plant is designed so that the solar collector arrays and the desalinization subsystem are highly modular.(1039) The 172 solar collector rows are individually controlled; each row can be isolated without affecting adjoining rows. Similarly, the 20 modules making up the desalinization subsystem are independent, and failure of one will not impair the performance of the other 19 modules. The results of an economic analysis of this MED system have not yet been published.

Another conceptual solar-powered plant has been formulated at the University of California's Sea Water Conversion Laboratory.(1355) The designed plant is a solar-powered, multi-effect distillation plant driven by a solar boiler, with an average daily output of 45,400 kilograms of saturated steam at 60°C. Using a very high performance evaporator, it was found that optimized water costs ranged from LE 1 to 2.64 per cubic meter of product water for brackish water feed, to LE 1.54 to 3.36 per cubic meter for seawater feed. Under these conditions, the daily productivity per unit area of solar collector ranged from 65 to 130 liters/m^2--20 to 40 times the average productivity of simple solar stills.

Recently, simple solar stills have been successfully constructed using TEDLAR film (registered trademark of the E.I. duPont de Nemours & Co.) because of its high resistance to deterioration from exposure to ultraviolet light. Figure 3-19 in Working Paper No. 33 in the SDS-I project files illustrates a number of still designs for single-effect solar distillation. All of these use stationary solar collectors to supply the heat. The following are basic requirements of a good solar still unit for small field applications:

- Easy assembly in the field
- Construction from local materials to minimize transportation costs
- Light weight for ease of handling and shipping
- Effective life of 10 to 20 years with normal maintenance
- No requirement for external power sources
- Dual service as a rainfall catchment surface
- Ability to withstand prevailing winds
- Construction from materials that will not contaminate the collected rainwater or the distillate
- Conformance with standard civil and structural engineering standards.

Cascaded greenhouse-type solar stills, similar to the one illustrated in Figure 3-19 in Working Paper No. 33, are being tested at the International Research Center in Cairo by Dr. Namal Helwa and her coworkers. Stills of this type can be employed at locations with very low freshwater demand (i.e., for limited household needs). Until more sophisticated systems become commercially available, simple solar stills may be well-suited to supply the domestic requirements of small settlements in Sinai that are close to seawater or brackish wells.

2.2.5.4 Process Selection. In selecting among the three traditional desalinization processes, a number of factors must be considered. The chemical content and composition of the feedwater must receive primary attention, along with the desired plant capacity, the quality of the product water required, the energy efficiency of the process considered, and the cost of available energy.

In general, for treating seawater, only the distillation and reverse osmosis processes should be considered, though the latter is applied more commonly to the desalinization of brackish water. Electrodialysis is effectively limited to feedwaters of less than 5,000 mg/l TDS. Power consumption by the different processes is dependent on a number of plant-design parameters, as well as feedwater characteristics. Typical power consumption rates, in kilowatt-hours per cubic meter of product water, have been calculated as follows (0404):

• MSF process	13.8	($70^{o}C$)*
	15.5	($90^{o}C$)
	15.5	($115^{o}C$)
• VC process	11.0	($100^{o}C$)
• RO process (without energy recovery)	9.5	($35^{o}C$)
• RO process (with energy recovery)	6.6	($35^{o}C$)
• ED process		
- for pumping	1.0	($35^{o}C$)
- for direct current (for each 1,000-mg/l reduction in salinity)	1.32	($35^{o}C$)

In ED plants, power requirements are inversely affected by temperature. Warmer feedwaters reduce resistance and, therefore, power consumption. However, the membranes available today are limited to a maximum temperature of $38^{o}C$.

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*Excluding power required to transport feedwater to the plant and waste brine from the plant. Maximum temperatures are given.

The energy requirements of an MSF plant vary substantially depending on whether it is operated as a single- (desalinization only) or dual-purpose (desalinization and power) station. At a performance ratio of 10, a single-purpose MSF plant was computed to have a heat input requirement of about 265 kJ/kg of product, compared to 140 kJ/kg for a dual-purpose plant.

Where there is a need for large quantities of both water and electric power, consideration should be given to dual-purpose plants where steam exhausted through a back-pressure turbine might be used in the desalinization plant. Alternately, in a conventional steam-electric power plant, steam may be extracted from various locations in the turbine cycle (e.g., at the crossover of the high- and low-pressure sections of the turbine). For more remote locations, the use of exhaust heat (from a gas turbine that generates electricity) to generate steam for a vapor compression plant may present a more favorable option.

The size of a unit and the time required for installation should also be considered in selecting from among the several processes. Construction/installation periods range from 2 to 3 months for small vapor compression plants to 20 months for the larger MSF plants, after receipt of equipment onsite. Electrodialysis and small reverse osmosis plants are compact and are usually shipped largely preassembled; installation requires only a few weeks at most for piping interconnections and power tie in. Reverse osmosis plants in large sizes are partly preassembled as modules. Large pumps must be carefully aligned and cemented in place. Installation times can range from 6 to 10 months after equipment has arrived onsite. Shakedown and performance tests should be completed in 60 days or less, unless some unusual problems arise.

2.2.5.5 Future Desalinization Units for Sinai. Table 2-14 provides details on the desalinization units that may be installed in Sinai sometime in the future. Figure 2.10 (derived from Plate 6-3 in SDS-I Working Paper No. 45) shows the locations of Unit Nos. 8 through 14, in addition to the new or planned units discussed in Section 2.2.5.1.

The sites for potential new units are located on the coasts of the Gulfs of Aqabah and Suez, where the local aquifers generally do not provide water of a potable quality--at Abu Zenima, Abu Rudeis, Sharm El Sheikh, Nebq, Dahab, Nuweiba, and Ras Taba. The process selected in each case is based on probable feedwater quality as well as required capacity.

The estimated costs of desalinizing brackish water and seawater are discussed in Section 4.0. In general, it appears that the cost of solar-powered desalinization presently tends to fall in the upper part of the cost range for conventional desalinization or slightly higher. However, by the time many such solar units are commercially available, the unit costs may have decreased. In any case, at present, small solar stills should be seriously considered for supplying the potable water requirements of small communities in Sinai.

2.3 EXTERNAL WATER RESOURCES

2.3.1 Introduction

This subsection discusses the current use of Nile water, the potential use of imported Nile water, and the potential for cloud-seeding. Other potential external water resources, such as the Jordan River and Galilee reservoirs, are not considered. The term "Nile water" includes water from drainage canals.

At present, over half the water consumed in Sinai originates in the Nile. Siphons pass under the Suez Canal at Port Said, Qantara, and Deversoir. The Hamdi Tunnel carries water through a 500-millimeter pipe and has space for a second pipeline. The first will go to Abu Rudeis. The second has been proposed to go to Bir El Thamada and the Uplands.

Present works in process and plans for importing Nile water into Sinai for domestic and industrial purposes involve an estimated total supply of 50,000 m^3/day, which is equivalent to approximately 0.018 milliard m^3/yr.* The pipeline from El Qantara to Bir El Abd, now nearing completion, will bring to Sinai about 4,000 m^3/day, and the planned pipeline from El Qantara to El Arish will import another 25,000 to 30,000 m^3/day. The pipeline in design from the Hamdi Tunnel to Abu Rudeis will bring 10,000 to 15,000 m^3/day of Nile water into Sinai. A small pipeline serves Port Fouad. The capacity of the Deversoir siphons is 3 million m^3/day. A siphon from Port Tewfiq to El Shatt has been designed. Details on these pipelines are given in Table A-2 in Appendix A to this volume (see also Plate 6-3 in Working Paper No. 45).

Nile water is distributed by tanker truck to about half of Sinai and by tanker ship to the cities on the Gulf of Suez coast. The Ras El Nabq airport is receiving freshwater by pipelines from Eilat, and a pipeline from Gaza to the Rafah area is reported to be in operating condition.**

In sum, in 1982, about 65,000 cubic meters of Sinai's daily water consumption of 115,000 cubic meters was from external sources. The estimated cost of such imported water is relatively high--ranging from LE 0.37 to 0.95 per cubic meter--depending on the size of pipeline and tanker assumed and the distance or height the water has to be transported.

2.3.2 Potential External Water Sources

2.3.2.1 The Nile and Drainage Canals. In evaluating the feasibility of supplying additional Nile water to Sinai, it is helpful to distinguish two categories of demand for imported Nile water:

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*One milliard = 1.0 x 1,000,000,000--one billion or 1,000 million.
**Personal communication, Dr. Ali Abu Zeid.

- Piped water intended primarily for domestic purposes and moderate industrial uses.

- Piped canal water intended for the irrigation of crops in land reclamation areas.

When considering the importation of large quantities of Nile water for land reclamation, the issue of Nile water availability is added to the constraint of cost. The cost of Nile water imported in volume to irrigate proposed large reclamation areas in Sinai ranges from LE 0.02 per cubic meter for canal water transported to areas close to the Suez Canal, to LE 0.06 to 0.50 per cubic meter and even higher for piped water to irrigate more distant areas. (Refer to the full discussion on Nile water conveyance costs in Section 4.0.)

Work is currently underway by the Government of Egypt to formulate a Land Master Plan. Under this project, relatively detailed field studies of land potential and soil characteristics of all potential land reclamation areas are being performed. When completed in 1984, the Land Master Plan will provide better information on soils as one basis for a ranking of potential reclamation areas.

In addition to this project, a semi-detailed soil survey is currently being performed by REGWA on 300,000 to 350,000 feddans selected from the original Reclamation Areas 1, 2, and 3 in Sinai.* The selection was based on a reconnaissance soil survey of the three areas performed by REGWA in 1980 and 1981. On the basis of the updated information, when it is available, from the Land Master Plan studies and the current REGWA survey, it is possible that the results indicated in Table 2-15 (and in Table 2-16) could be significantly revised.

- <u>SDS-I Land Capability</u>--In addition to the reclamation areas indicated in Table 2-15, the SDS-I land capability analysis has identified other candidate areas to be studied for irrigated agriculture. Figure 2.12 and Table 2-16 indicate a number of areas in Sinai that, because of their land characteristics, location, and topography, appear to the SDS-I Study Team to offer the best chance for success with irrigation. The table also indicates the number of feddans that--subject to the results of detailed soil surveys-- is likely to be identified as productive, irrigable land. It should be noted that Area NW-1 of Table 2-16 is in the same location as Area 3 of Table 2-15. Also, Areas NW-2 and NE-1 given in Table 2-16, taken together, correspond approximately to Reclamation Areas 1 and 2, given in Table 2-15. Areas NW-3 and NW-4 of Table 2-16 correspond approximately with Areas 4 and 5, respectively, of Table 2-15. Because of the criteria applied in the most recent land capability analysis, the net feddanage expected to be irrigated in each of the areas listed in Table 2-16 is considerably smaller than that indicated for the corresponding areas in Table 2-15.

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*Five reclamation areas proposed in the Government's Water Master Plan are shown in Figure 2.11 and described briefly in Table 2-15.

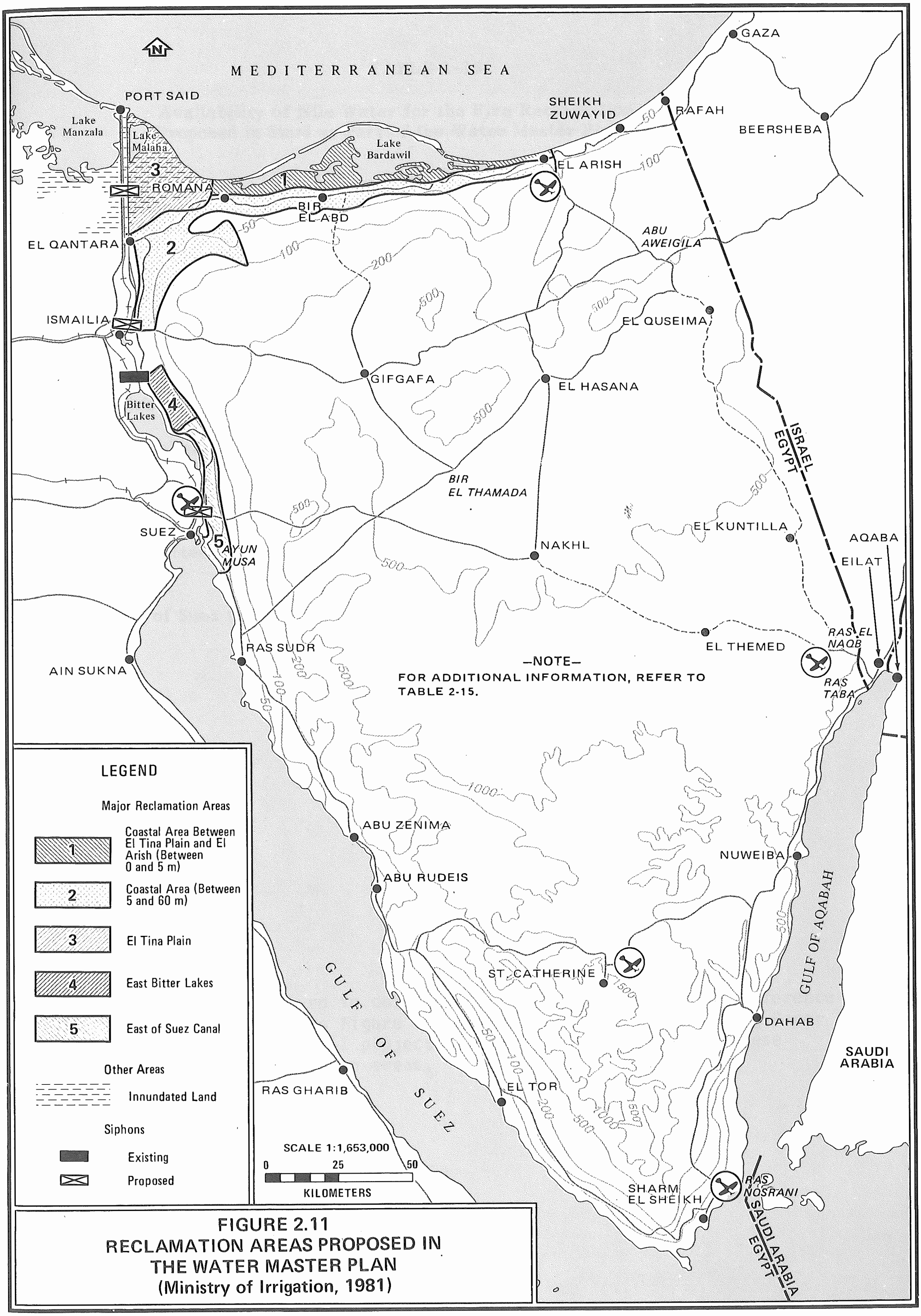

FIGURE 2.11
RECLAMATION AREAS PROPOSED IN THE WATER MASTER PLAN
(Ministry of Irrigation, 1981)

TABLE 2-15

Availability of Nile Water for the Five Reclamation Areas Proposed in Sinai as Part of the Water Master Plan of 1981

A	B	C	D	E	F
No.	Name	Gross Area (feddans)	Proposed Method of Irrigation	Source of Water	Total Annual Water Duty ($m^3 \times 10^6$)
1	Coastal area between El Tina Plain and El Arish	265,000	Surface	El Salaam Canal	1,855
2	Coastal area between contours 5 and 60	250,000	Sprinkler	Salhia Canal (from Ismailia Canal)	1,250
3	El Tina Plain	135,000	Surface	El Salaam Canal	945
4	East Bitter Lakes	30,000	Sprinkler	Suez Irrigation Canal	150
5	East of Suez Canal	55,000	Sprinkler	Suez Irrigation Canal or Maadi-Suez pipeline	275

SOURCE: Information given in columns A through F was taken from Reference (0862). Refer to Figure 2.11 (and to Plate 5-3 in Working Paper No. 45 in the SDS-I project files) for the location of these proposed reclamation areas.

More specifically, the SDS-I Study Team estimates that the total area likely to be identified as suitable for irrigated agriculture in Sinai will be about 328,700 feddans. It is assumed that the potential land productivity and soil characteristics of these areas, taken as a whole, correspond to those of the original Reclamation Areas 2, 4, and 5--a conservative assumption, since it is likely that, on balance, soils are somewhat better than those identified in the earlier reconnaissance. Based on this assumption, proposals incorporated in the Water Master Plan, and other available information, it is understood that there should be sufficient Nile water available to irrigate all of the areas identified in Figure 2.12 and in Table 2-16 by the year 2000.

The conveyance of Nile water to these areas is an important consideration. If large irrigable tracts are identified in northwest Sinai and along the Mediterranean coast as a result of ongoing soil surveys, there will be little doubt that conveyance by large canals will be the method of choice. However, if only small-to-moderate size tracts are identified, and if they are separated by relatively large distances (which is implied by the figures provided in Table 2-16), the alternative of large pipelines should be considered. The potential water loss from canals, and also possibly their capital costs, would dictate this. The costs and other considerations concerning large pipeline systems are discussed below in Section 4.4. A recommendation for detailed pipeline versus canal feasibility studies for Sinai is presented in Section 5.5.4. The pipeline corridors recommended for conveying Nile water to some of the more accessible reclamation areas are on Figure 5.1.

On the basis of allocations already incorporated in or implied by the Water Master Plan and other information it analysed, the Study Team concluded that the supply of Nile water is sufficient to fulfill domestic demands, most industrial demands, and requirements to reclaim more than 300,000 feddans for agriculture in Sinai.

2.3.3 Cloud-Seeding Possibilities

Cloud-seeding experiments recently performed in several places in the world have demonstrated the possibility of increasing storm rainfall or even average monthly rainfall in target areas. The science and technology of cloud seeding is still quite new, and the optimum combinations of land topography, air temperature, upper and lower air movements, cloud temperature, size, and structure are not fully understood, for most areas. The results of recent cloud-seeding experiments have many times been conflicting. In view of this, recommendations for Sinai are necessarily limited due to the need for additional pertinent meteorological data and the design of appropriate cloud-seeding experiments.

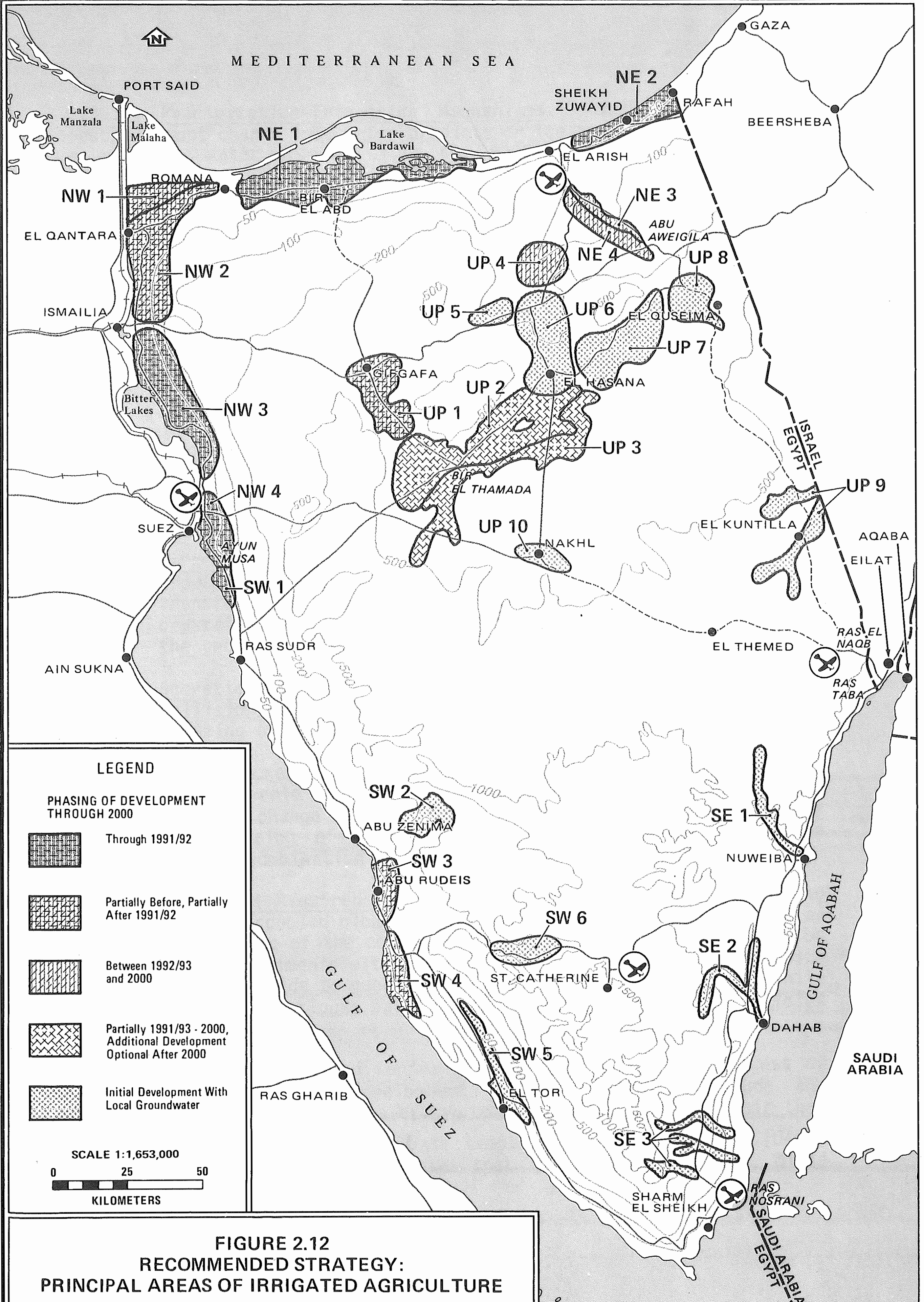

FIGURE 2.12
RECOMMENDED STRATEGY:
PRINCIPAL AREAS OF IRRIGATED AGRICULTURE

—PRINCIPAL WATER SOURCE FORSEEN FOR INDIVIDUAL AREAS OF IRRIGATED AGRICULTURE—

(Areas are keyed to map by identification numbers, and the water source is listed for each area as forseen in the recommended strategy and three alternatives.[a])

NUMBER	AREA	PRINCIPAL WATER SOURCE, BY STRATEGY (Refer to Key to Principal Water Sources for descriptions.)			
		RECOMMENDED	FRONTIER	DISPERSED	ALL COASTS
	—NORTHWEST SUBREGION—				
NW 1	El Tina Plain	NP-11	—	NI	—
NW 2	El Qantara-Baloza	NP-2	NI	NI	NI
NW 3	East Bitterlakes	NP-E	NI	NI	NI
NW 4	East of Suez (joins SW 1)	NP-1	NI	NI	NI
	—NORTHEAST SUBREGION—				
NE 1	Romana - El Mazar	NP-3	NI	NI	NI
NE 2	Sheikh Zuwayid - Rafah	NP-4	NI	NI	NI
NE 3	Lower Wadi El Arish: LRU* G	NP-5	NI	NI	NI
NE 4	Lower Wadi El Arish: LRU* D	NP-5	NI	NI	NI
	—UPLANDS SUBREGION—				
UP 1	Gifgafa	NP-9	NI	NI	GW
UP 2	Wadi El Bruk: LRU* C	NP-10	NI	NI	GW
UP 3	Wadi El Bruk: LRU* A	NP-10	NI	NI	GW
UP 4	El Sirr Plain	NP-6	—	NI	NI
UP 5	Wadi El Hema	OE-9	—	—	—
UP 6	El Hasana	OE-10	NI	NI	GW
UP 7	Middle Wadi El Arish	OE-10	NI	NI	GW
UP 8	Wadi El Gayifa/El Quseima	OE-10	NI	GW	GW
UP 9	Wadi El Gerafi/El Kuntilla	GW	—	GW	—
UP 10	Nakhl (Research Station)	GW	—	—	—
— —	Gebels El Maghara, Yelleq and El Hallal	MR/GW	—	—	—
	—SOUTHWEST SUBREGION—				
SW 1	East of Suez (joins NW 4)	NP-1	NI	NI	NI
SW 2	Hosh El Bagar/Ramlet Himeiyir Plain	OE-8	—	NI	—
SW 3	Abu Rudeis	NP-7	GW	NI	NI
SW 4	Wadi Feiran Delta	NP-8	—	NI	NI
SW 5	El Qaa Plain	OE-8	GW	NI	NI
SW 6	Wadi Feiran Upstream	GW	GW	GW	GW
— —	Industrial Area North of Ras Sudr	NP-12	—	—	NI
	—SOUTHEAST SUBREGION—				
SE 1	Wadi Watir (northwest from Nuweiba)	GW	GW	GW	GW
SE 2	Wadis El Ghaib and Nasb (north and west of Dahab)	GW	GW	GW	GW
SE 3	Three Wadis West of Nebq	GW	GW	GW	GW

[a]The Recommended Strategy is summarized in Volume I of this report. It represents a synthesis and refinement of concepts and proposals considered earlier in the planning process. The Frontier, Dispersed and All Coasts alternative strategies were prepared in less detail earlier in the planning cycle as one basis for further analysis of Sinai's development potential and for discussion with the Steering Committee. The strategies differ not only with respect to the principal sources of water recommended for each area of irrigated agriculture (for instance, as this table shows, the "Frontier" alternative proposed much less Nile water for the Southwest and substantially more for the Uplands than the Recommended Strategy) but also in the number of feddans proposed for irrigation. Strategies are fairly similar with respect to their recommendations for Northwest, Northeast and Southeast subregions and differ mainly in their treatment of agricultural potentials in the Uplands and the Southwest.

*Land Resource Unit, as defined Volume IV.

—KEY TO PRINCIPAL WATER SOURCES—

NP-11 — Nile water conveyance systems, probably mainly by pipeline. In some of these areas groundwater will also be used for agriculture to the extent sustainable supplies of appropriate quality are available, but transfers through Nile systems are expected to be the principal source of irrigation water once the Recommended Strategy is implemented. (For additional information on water conveyance systems, refer to Figure 5.1).

NP-E — Existing Nile water siphons serving the East Bitter Lakes area.

NI — Nile water conveyance systems. Specific proposals (for example, capacities and routings) have been superseded by the Recommended Strategy.

OE-9 — Optional extensions of Nile water conveyance systems. Initial development with local groundwater is strongly recommended as soon as aquifers are tested.

GW — Development mainly with local groundwater to the extent sustainable supplies are available.

MR/GW — Managed runoff, supplemented by any available groundwater.

TABLE 2-16

Candidate Areas for Irrigated Agriculture

Subregion (Subtotal)	Description	Estimated Net Area That Can Be Reclaimed[a] (000 feddans)
Northwest (71.0)	1. El Tina	20.0
	2. Qantara-Baloza	16.0
	3. East Bitter Lakes	30.0[b]
	4. East of Suez (joins SW-1)	5.0
Northeast (52.0)	1. Romana-El Mazar	20.0
	2. Sheikh Zuwayid-Rafah	15.0
	3. Lower Wadi El Arish: LRU G	7.0
	4. Lower Wadi El Arish: LRU D	10.0
Uplands (156.0)	1. Gifgafa	16.0
	2. Wadi El Bruk: LRU C	47.0
	3. Wadi El Bruk: LRU A	21.0
	4. El Sirr Plain	10.0
	5. Wadi El Hema	5.0
	6. El Hasana	20.0
	7. Middle Wadi El Arish	25.0
	8. Wadi El Gayifa/El Quseima	5.0
	9. Wadi El Gerafi	7.0
Southwest (48.0)	1. East of Suez (joins NW-4)	1.0
	2. Hosh El Bagar/Ramlet Himeiyer Plain	8.0
	3. Abu Rudeis	6.0
	4. Wadi Feiran Delta	8.0
	5. El Qaa Plain	25.0
Southeast (1.7)	1. Wadi Watir, northwest from Nuweiba	0.6
	2. Wadis El Ghaib and Nasb, north and west of Dahab	0.4
	3. Three Wadis west of Nebq	0.7
	TOTAL	328.7[c]

LRU = Land Resource Unit as defined in Volume IV.

[a] The precise number and location of feddans most suitable for major reclamation and irrigation projects will be more clearly defined when REGWA and other soil surveys, now in process, and detailed feasibility studies have been completed.

[b] Including 14,000 feddans already being developed.

[c] In the Recommended Strategy about 10,900 feddans of this total are proposed for irrigation with local groundwater, provided availability is verified. These areas include 4,000 feddans in the Northeast subregion, 2,900 feddans in the Uplands, 4,300 feddans in the Southwest and 1,700 feddans in the three wadi systems of the Southeast subregion shown in this table and Figure 2.12.

SOURCE: Derived from SDS-I land capability analysis, summarized in IV, The Land and the Environment of Sinai, especially Chapter 3.

2.3.3.1 Precipitation-Triggering Mechanisms. Water vapor in the atmosphere must change into water droplets or ice crystals before a cloud can appear. Water droplets form on condensation nuclei, while ice crystals develop on ice nuclei (freezing nuclei). These cloud particles grow to the stage where precipitation can occur (water droplets or ice crystals), as explained in the following paragraphs.

- Coalescence--The process by which cloud vapor becomes raindrops is triggered by the direct collision and coalescence of water droplets. (1301) Droplets carried upward by ascending currents fall relative to their size and the rising air columns. Very small droplets (less than 18 micrometers) are unable to collide with one another. When the radius of a droplet is greater than about 18 micrometers, collision can occur.

  Collision and coalescence are necessary for the development of precipitation from warm clouds. The temperature of the clouds must be above $0^{o}C$, and they must be comprised entirely of water droplets.

- Bergeron process--This process is concerned with the initial growth of ice crystals. Growth by the direct deposition or transfer from water vapor to ice may be rapid while the ice crystal is small. However, because of expended latent heat, the growth rate decreases as the ice crystal becomes larger.

- Accretion process--Ice crystals also grow appreciably by collision with supercooled droplets. This leads to the freezing of water on the surface of the ice crystal.

The Bergeron and Accretion processes are necessary for the development of precipitation from cold clouds.(1301) Ice crystals in these clouds may grow by the direct change of water vapor to ice (the deposition Bergeron process), by freezing of the supercooled water droplets (Accretion process), or by a combination of these processes.

2.3.3.2 Conditions Required for Cloud Seeding. Experiments involving the seeding of supercooled clouds as well as warm clouds have provided an understanding of some of the conditions required for cloud seeding to be effective. The experiments with supercooled clouds involved seeding with dry ice or silver iodide to generate the formation of ice crystals, while in the subtropics warm clouds have been seeded with hygroscopic particles or water droplets.

The conditions required for rainfall initiation by the process of coalescence, without the development of ice crystals, include the presence of an appropriate mass of hygroscopic particles in the air that enters the clouds, and a cloud base temperature exceeding $10^{o}C$.(0435) Existing information (0435) indicates that in the area of Sinai, cloud base temperatures tend to exceed 10°C only in the summer and early fall, when cloud development is generally sparse.

There seems to be more likelihood of success in rain enhancement in Sinai by making use of the Bergeron and Accretion processes. Cumulus clouds, formed from convection currents, appear to be the most suitable cloud form for seeding, when they reach levels where ice crystals form.

2.3.3.3 Results of Israeli Cloud-Seeding Experiments. The results of cloud-seeding experiments in Israel are generally relevant to Sinai conditions. In northern Sinai, the cloud systems are similar to those over Israel on some days during the winter season. The Israeli experiments involved the seeding of winter clouds from an aircraft.(0262) A solution of silver iodide in acetone was burned at a rate of 13 liters/hr and was released just below the cloud bases in a region displaced upwind from the target area by a distance equal to the wind speed multiplied by 30 minutes. Only those clouds whose tops reached or exceeded the -5°C level (i.e., colder than -5°C) were seeded.

The clouds seeded were of the continental cumulus form with a strong vertical structure.(1301) The bases ranged from 8° to 9°C, and the tops ranged from -13° (at 4,000 meters) to -25°C (at 7,000 meters). Thus, the clouds seeded were partly warm and partly supercooled. Conversion of ice crystals to solid precipitation particles, rather than collision coalescence, was the dominant mechanism on the majority of the rainy days during these experiments.

On each day during the experiments in Israel, one of two experimental areas, "north" or "center," was randomly designated as the target area; if suitable clouds were located, seeding was carried out.(0262) Daily rainfall data were collected by a network of about 45 rain gauges operated by the Israeli Meteorological Service. The experiment was evaluated by a crossover comparison of amounts of precipitation in the two areas on two types of days, designated as "north-seeded" or "center-seeded."

The results of these experiments indicate that over five and one-half seasons, the rainfall was about 18 percent greater over the entire area as a result of cloud seeding.(0262) By excluding the coastal and eastern part of the target areas from the analysis, because they were not generally accessible to the aircraft, the average additional rainfall during seeding was found to be 27 percent.

2.3.3.4 Essential Meteorological Data Required for Cloud Seeding. The basic meteorological data required to evaluate the feasibility of cloud seeding in Sinai include:

- Precipitation data
- Air temperature data at the ground surface and for upper air masses
- Wind velocity data, near the ground and for upper air masses
- Data on cloudiness, cloud height, and cloud structure.

Available data on precipitation are presented in Volume VII and in Tables 2-5a through 2-5x in Working Paper No. 33 in the SDS-I project files. Isohyets and contours of the number of rainy days (greater than or equal to 1 millimeter) are given on Plates 3-3 and 3-2 respectively, in Working Paper No. 45. However, the density of stations and the extent of the rainfall data are not sufficient for an adequate evaluation of the cloud-seeding potential on the peninsula. Air temperature data are available at ground level, but temperatures at higher levels are essentially lacking. Although surface wind velocity data are available for several stations in Sinai, no data are available on wind velocity and other characteristics of the upper air masses, which are essential for any evaluation of cloud-seeding potential.

Data on the clouds of Sinai are almost completely restricted to data on cloudiness, in oktas, for selected stations. As an example of these data, Volume VII displays curves for January, April, July, and October 1966 on the number of days during which a given sky cover was equaled or exceeded at El Arish. Data on sky cover and the associated number of rainy days at El Arish for the 1960's and 1970's are given in Table 3-27 in Working Paper No. 33 in the SDS-I project files. Data are lacking for Sinai on cloud type, cloud structure, and temperature profiles and nuclei content of clouds--without which it is impossible to estimate the frequency and conditions in Sinai when seedable cloud formations may occur.

2.3.3.5 Tentative Assessment. Based on very limited data and results of the experimental studies in Israel, there is a fair possibility of increasing rainfall by perhaps 10 to 25 percent through cloud seeding during the wintertime in certain parts of North Sinai. Future studies should concentrate particularly on the region north of latitude $30^{o}30'$ N.

If, on the basis of this preliminary assessment, it is decided to proceed with studies to evaluate the feasibility of cloud seeding in Sinai, a rather substantial commitment of resources and manpower will be required, including:

- Data collection and literature review
- Expansion of the existing meteorological network in Sinai
- Analysis of data
- Design of and preparation for cloud-seeding experiments
- Performance of experiments and evaluation of results.

Data collection will involve the collection and organization of all available observational data on rain and cloudiness in North Sinai. Maps as well as profiles should be prepared to depict detailed topographic and plant-cover characteristics.

The existing meteorological network in Sinai will have to be improved and extended as soon as possible. This implies that first-order stations be established at several selected locations and that the density of stations be increased. The Institute of Water Resources, under the Water Research Center of the Ministry of Irrigation, has initiated a study on the water resources of Sinai. As a part of this study, the Institute has already established new first-order meteorological stations at El Qantara, El Arish, Nakhl, Ras Sudr, and Abu Rudeis. Additional first-order stations and up to 18 second-order stations are planned for the near future. Assuming that the first-order stations have been set up to provide regular data on upper-air parameters, as well as the other data specified in Section 2.3.2.4, the planned network may suffice for this purpose.

Following establishment of the upgraded network of meteorological stations, a minimum of 3 years will be required before there will be sufficient data to justify extensive analysis. The data analysis will lead to the design of possible cloud-seeding experiments.

The first step in the design of the experiments is to select the most favorable catchment areas, target areas, and control areas for cloud seeding in the northern region. A dense rain-gauge network suitable for the target and control areas would then be designed, and established after marking the boundaries of the target and control areas. In addition, all the arrangements required by current international agreements on cloud seeding would have to be made. These agreements require the designation of a national body responsible for undertaking cloud-seeding experiments. They also specify that formal assistance in the design and performance of the experiments be sought from the World Meteorological Organization (WMO) and from one developed country involved in cloud-seeding experiments. Documentation on the proposed cloud-seeding experiments should be provided to the WMO.

The performance of the experiments and the evaluation of results will be the last and most important stage in the evaluation of the feasibility of cloud seeding in Sinai. Based on initial results, the form of subsequent experiments could be modified so as to provide a more complete understanding of the several conditions required for effective cloud seeding.

3.0 WATER USE AND FUTURE DEMAND

3.1 CURRENT USE OF WATER

3.1.1 Water Use

In late 1981, water use in Sinai was approximately 115,000 cubic meters per day (m^3/day). Of this total, about 43,000 m^3/day consisted of groundwater used near the supplying wells or springs; 6,300 m^3/day was Sinai groundwater conveyed to other parts of Sinai; and 65,700 m^3/day was water imported from west of the Suez Canal or from Israel. About three-fifths of all water used was imported. Of the groundwater withdrawn and used locally, about 10,900 m^3/day was used for public supply and 32,200 m^3/day for irrigation. This is shown on Table 3-1.*

Five water pipelines were in operation in 1981 for public supply purposes in Sinai. The military pipelines from El Arish supply well water from El Arish to El Hema, Gifgafa, and Umm Khisheib. Water was conveyed from Israel via a National Water Carrier pipeline to the Rafah-Sheikh Zuwayid area to supplement groundwater obtained from the two Quaternary aquifers there. Water from three flowing wells at Ras Misalla is presently supplied via pipeline to Ras Sudr. A military pipeline conveys about 2,000 m^3/day of water from El Tor wells to Sharm El Sheikh. Water is pumped from Eilat to Ras El Naqb airport. (Figure 3.1)

Two new pipelines to supply potable water are currently under construction in Sinai, and construction is expected to begin soon on a third. The first pipeline, which will carry Nile water from El Qantara to Bir El Abd, is nearing completion; only one or two pumping stations remained to be finished in early 1983. This pipeline will carry approximately 4,000 m^3/day of potable water for the communities of Bir El Abd, Negila, Rabaa, Romana, Baloza, and Gilbana. The second pipeline, when complete, will convey about 500 m^3/day of El Arish groundwater from the El Hema pumping station to El Hasana. Construction of a 700-millimeter pipeline to carry about 28,000 m^3/day of Nile water from El Qantara to El Arish started in 1983.

Feasibility studies and design activities initiated work in 1983 to extend another pipeline (500 mm maximum) from the Hamdi Tunnel, located north of Suez, to Abu Rudeis. Its purpose is to provide potable or domestic water to the communities located along the Gulf of Suez.

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* To avoid double accounting, the water trucked to Bir El Thamada and El Hasana from the El Hema pumping station (34 m^3/day has been dropped as a separate item, and, thus, is not included on Table 3-1. It is assumed that the 34 m^3/day is taken from the 100 m^3/day diverted from the pipeline flow at El Hema.

TABLE 3-1

Summary of Estimated Late 1981 Water Use in Sinai

		Estimated Average Use (m^3/day)
Water withdrawn from wells or springs in Sinai and used locally, subtotal		43,049
- Used for public supply	10,879	
- Used for irrigation	32,170	
Water withdrawn from wells or springs and conveyed to other parts of Sinai, subtotal		6,250
- El Arish groundwater	2,600	
- El Tor groundwater	2,000	
- Ras Misalla groundwater	150	
- Wadi Feiran groundwater	1,300	
- Crystalline-rock groundwater in Southeast Subregion	200	
Water imported from outside Sinai, subtotal		65,690
- Nile water		
by pipeline	55,500	
by truck	190	
by tanker	(a)	
- From Israel		
from Eilat to Ras El Naqb	N/A	
from National Water Carrier at Rafah	10,000	
TOTAL		114,989

SOURCE: Derived from the detailed estimates of use shown on Table A-1 in Appendix A.

(a) Abu Rudeis and the Feiran and Belayim oilfieds receive fresh-water from Suez by tanker.

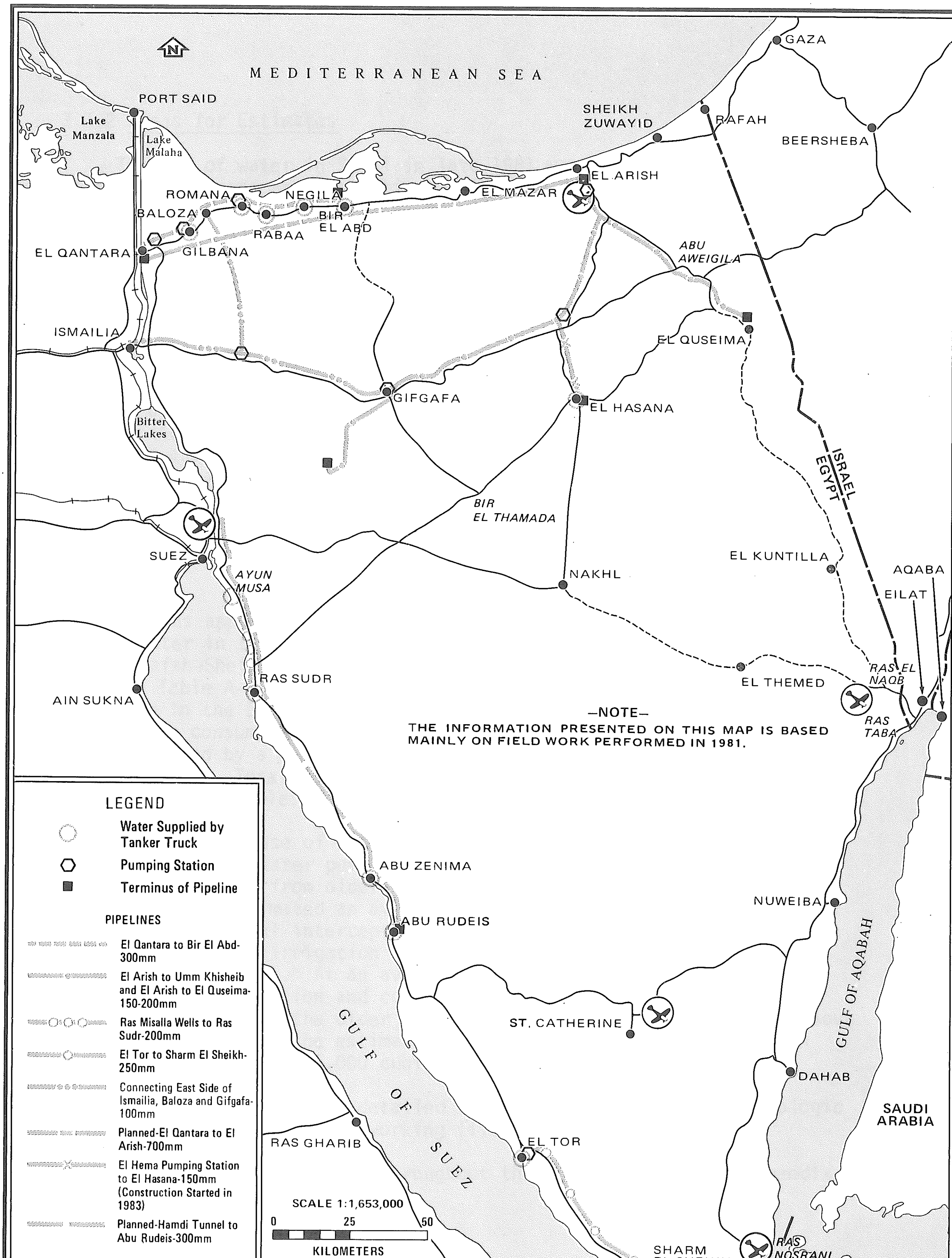

FIGURE 3.1
EXISTING AND PLANNED DOMESTIC WATER SUPPLY SOURCES, AS OF DECEMBER, 1981

3.1.2 Basis for Estimates

The use of water in Sinai in late 1981 was estimated on the basis of several sources and assumptions which are documented in project files. The estimated quantities for late 1981 are provided by community and by type of water source in Table A-1 in Appendix A. A summary of information on the existing and proposed domestic water pipelines in Sinai is given in Table A-5.

For El Arish and for most communities receiving water by pipeline (El Tor, Gifgafa, and Sharm El Sheikh), the average public supply quantities in cubic meters per day were obtained from town council officers or the military officers in charge of the pumping stations. For the other communities, public supply use was estimated on the basis of the existing population. A high use rate of 100 liters/capita/day (lcd) was assumed for El Qantara, Nuweiba, Dahab, and Nebq. For other communities, a use rate of 30 lcd was assumed. Where potable water is supplied to a community by truck, the remaining domestic use was assumed to be 20 lcd. The quantities presently delivered by truck, as shown in Table A-1 in Appendix A, were derived from the results of an infrastructure survey of each community conducted by Dames & Moore in 1981.

Various approaches were used to estimate the current agricultural use of water in the four primary agricultural centers of Sinai: El Arish, Rafah-Sheikh Zuwayid, East Bitter Lakes, and Feiran Oasis, as shown in Table A-1 in Appendix A. The number of feddans cultivated to each crop in the El Arish area was obtained from the agricultural officer there. The consumptive use rate was provided by the project's irrigation consultant and by a Dames & Moore survey of irrigation water use in the El Arish area. Total consumptive use was computed for each crop type, as shown in the table.

Agricultural use of water in the Rafah-Sheikh Zuwayid area in 1981 consisted of water pumped from wells making up the "coastal interceptor drain"* and from older irrigation wells located in the interior. Asmon (0146)** estimated an average pumpage of 8,200 m^3/day for the 28 wells in the coastal interceptor drain, all of which is used for irrigation. The older irrigation wells were estimated to irrigate an area of about 400 feddans. At an average consumptive use of 5,000 m^3/yr/feddan and an irrigation and conveyance efficiency of 80 percent, the total water use from the older irrigation wells was computed to be about 6,800 m^3/day. Thus, the estimated daily water use for irrigation in this area in 1981 was 15,000 cubic meters.

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* Wells 51-31 to 51-58 are detailed in Working Paper No. 34, Hydrologic Information Cards, in the working files of SDS-I.

** The four-digit references throughout the text are found in Appendix B to this volume.

As shown in Table A-1, the estimated use of water for the East Bitter Lakes agricultural area is 55,000 m^3/day. The estimated average flow for irrigating the New Mit Abul Kom and Heroes' Village areas is 43,200 m^3/day, based on pumping information obtained from an Arab Contractors' engineer at New Mit Abul Kom. An area of only about 300 feddans was being cultivated in the Youth Farms area in 1981; at a water duty of 8,000 m^3/yr/feddan, an average flow of 6,600 m^3/day was being consumed in this area. In addition, canal seepage losses from the siphon at the Suez Canal to the farm areas were estimated to be 5,000 m^3/day.

About 100 feddans are cultivated and irrigated in Feiran Oasis. At an average water duty of 5,000 m^3/yr/feddan, the average water use for irrigation is computed to be about 1,350 m^3/day.

The information on pipelines provided in Table A-5 was obtained from several sources. Engineers from The Arab Contractors provided data on the El Qantara-Bir El Abd pipeline, as well as the design concepts for the planned El Qantara-El Arish pipeline. The remaining pipeline information was obtained from Dr. Ali Abu Zeid of the Sinai Development Authority, the Governors of North and South Sinai, and other governorate officials. The locations of certain pipelines were confirmed by on-site inspections.

3.2 WATER DEMAND UNDER ALTERNATIVE STRATEGIES

3.2.1 Water-Use Projections

To estimate the water demands that may exist by the year 2000 as a result of different strategies for development that were considered by the SDS-I team, unit water-use rates were assigned for each type of use.

Unit irrigation water duties for the Northeast subregion were estimated on the basis of the computed potential evapotranspiration combined with appropriate crop coefficients. (0269). The generalized results of this analysis are given in Table 3-2, which shows the estimated water duties per year per feddan in the Northeast for surface, sprinkler, and drip irrigation methods, and for field crops or vegetable crops, as well as for orchards. The unit irrigation water duties shown are based on an assumed conveyance efficiency of 90 percent and on irrigation efficiencies of 50, 70, and 90 percent for surface, sprinkler, and drip irrigation methods, respectively.

The values shown in Table 3-2 were applied to all the reclamation areas lying north of Gebel Yelleq and Gebel El Halal. South of this, correction factors were applied to these values on the basis of the estimated relative potential evapotranspiration (ET_0) of each area. The ET_0 values for three representative places--El Arish, Nakhl, and El Tor--as computed by the Modified Penman method (0269), are presented in Table 3-3. A correction factor of 1.1 was applied to all reclamation areas in the northeast uplands (Wadis El Bruk and Middle El Arish). Based on the relative ET_0 value for El Tor, shown in

Table 3-2

Unit Irrigation Water Duties for the Northeast Subregion
(m^3/feddan/yr)

	Field or Vegetable Crops		Orchards	
Irrigation Method*	Single Crop per Year	Double Crop per Year	Citrus	Olives
Surface	6,000	9,000	11,000	8,000
Sprinkler	4,000	6,500	--	--
Drip	3,000	5,000	6,000	4,000

* Irrigation efficiencies assumed: surface methods, 50 percent; sprinkler irrigation, 70 percent; drip irrigation, 90 percent.

SOURCE: Working Paper No. 33 of the Sinai Development Study, Phase One, April 1982; and FAO Irrigation and Drainage Paper No. 24, 1977.

Table 3-3

Potential Evapotranspiration Rates for
Representative Areas in Sinai
(m^3/feddan/yr)

Station	ET_o	Relative ET_o
El Arish	7,500	1.0
Nakhl	8,400	1.1
El Tor	11,500	1.5

SOURCE: Working Paper No. 33 of the Sinai Development Study, Phase One, April 1982; and FAO Irrigation and Drainage Paper No. 24, 1977.

Table 3-3, the factor 1.5 was applied to all proposed reclamation areas located on the southeast and southwest coasts, including the El Qaa Plain.

A factor between 1.2 and 1.3 was applied to those potential reclamation areas located along wadis in the Southeast and Southwest Subregions at elevations of 150 meters or higher. For example, for computing the unit water duty for drip-irrigated vegetables cultivated in the general area of Feiran Oasis, the value of 5,000 m^3/yr per feddan was multiplied by 1.2 to obtain 6,000 m^3/yr per feddan, assuming two crops a year.

A relatively simple scheme was adopted for initial estimates of domestic water demand. The use rate in lcd was assumed to increase with the size of the community. Thus for communities smaller than 1,000 population, a use rate of only 10 lcd was assumed, while at the other extreme, communities of 50,000 population or greater were assumed to consume water at a rate of 100 lcd. The domestic use rates include water demands for commercial enterprises and institutions as well as for purely household needs.

The assumptions made to estimate the water demands of tourism are detailed in Table 3-4 below, based on a requirement of 150 liters per visitor-day in a hotel, and 15 liters for each visitor at restaurants, rest stops, beach resorts, and national parks. Water use by industrial or mining enterprises was estimated on the basis of unit water use in m^3/day per employee, for each type of enterprise.* A summary of the use rates is provided overleaf in Table 3-5. The fresh water consumption rate per employee ranges from 0.05 m^3/day for handicraft manufacture or mining of glass sand or salt, to 36.0 m^3/day for a fertilizer plant. For the latter, 36.0 m^3/day/employee represents only half of the total water demand; the remainder is to be made up by sea water, highly brackish groundwater, or recycled water.

Table 3-4

Assumptions of Water Requirements for Tourism

Type of Location	Requirement per Visitor (liters/day)	Average Number of Visitor Days
Hotel	150	No. of rooms x 1.7 x 0.8
Restaurant and rest stop	15	No. of employees x 10
Beach resort and national park	15	No. of employees x 5

3.2.2 Water Requirements by the Year 2000

Variations in water requirements under the alternative development strategies depend primarily on the areal extent of the irrigated agriculture, which varies significantly from strategy to strategy, and on the projected sizes of the major settlements.

* Based on information in Working Paper 36 from the files of the Sinai Development Study, Phase I.

Table 3-5

Assumptions Regarding Freshwater Requirements for Industrial and Mining Enterprises

Type of Enterprise	Assumed Water-Use Rate (m^3/day/employee)
Fertilizer plant	36.0*
Petrochemical plant	16.0*
Cement plant	7.0
Agricultural processing, sulfur extraction	2.0
Mineral processing	1.5
Industrial park industries, petroleum production	0.5
High-technology factories, quarrying	0.4
Manufacture of agricultural implements, fish processing	0.3
Light industries	0.2
Manufacture of clothes; storage of agricultural products; kaolin, turquoise, potash, and gypsum extraction	0.1
Handicrafts manufacture; mining of glass sand and salt	0.05

* Constitutes approximately half of the total water demand. The remainder is assumed to be provided by seawater or highly brackish water.

SOURCE: Working Papers Nos. 36 and 37 of the Sinai Development Study, Phase One, April 1982.

Volume IV identifies candidate areas for irrigated agriculture. The Consultant selected about twenty areas for possible incorporation in various strategies, considering soil, location, and topography as analyzed on maps and in the field. These are shown on Figure 2.12.

The reclamation sites included in each alternative strategy were selected from within these areas. The area of irrigated land considered for the year 2000 varies from around 100,000 feddans for All Coasts, to around 200,000 feddans for Frontier, and over 300,000 feddans for the Dispersed Strategy. The Dispersed Strategy demands four times as much fresh water as the All Coasts. The strategy recommended in this Final Report provides for approximately 200,000 feddans in irrigation-reclamation projects (including about 11,000 feddans using groundwater) and keeps open various options for extending feddanage either when the strategy is finalized on the basis of feasibility studies and/or in the period after the turn of the century.

A summary of the estimated water requirements by the year 2000 is provided in Table 3-6 for each subregion, based on the three alternative strategies considered early in 1983 and the synthesis recommended after further discussion and analysis.

It is clear that the water demand for agriculture under the different strategies is many times* that for all the other uses--public or domestic water supply, industrial and mining use, and tourism demands. Land reclamation (irrigation) water demands by the year 2000 range from 598 x 10^6 m^3/yr under the All Coasts Strategy to 2,368 x 10^6 m^3/yr under the Dispersed Strategy. The next biggest water demand, domestic use, ranges from 29.8 x 10^6 m^3/yr under All Coasts Strategy to 33.3 x 10^6 m^3/yr under the Dispersed Strategy.

The Northeast and Uplands Subregions exhibit the greatest projected water demands by a large margin. They are followed in order by the Northwest, the Southwest, and the Southeast Subregions. With respect to the irrigation water demand, it was assumed in all cases that two crops would be irrigated annually on each reclamation area. The purpose of this was to reduce the capital cost of conveyances per unit of water delivered annually.

Details of the estimated water demands by the year 2000 by subregion are provided in Tables A-6 through A-8 in Appendix A.

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*The ratio between irrigation and all other uses varies from about 14 to about 55 times, depending on the strategy.

Table 3-6

Summary of Projected Water Requirements in the Year 2000, by Subregion, for Four Strategies (million cubic meters per year)

Subregion	Irrigated Agriculture	Domestic Water	Industry and Mining	Tourism	Total
	(a) Recommended Strategy				
Total	1,590.0	31.0	86.7	0.4	1,708.1
Northwest	544.8	4.3	1.6	*	550.7
Northeast	392.8	18.1	6.1	0.2	417.2
Uplands	426.5	2.1	0.4	*	429.0
Southwest	214.8	5.3	78.3	*	298.4
Southeast	11.1	1.2	0.3	0.2	12.8
	(b) Frontier Strategy				
Total	1,491.3	30.6	7.2	0.3	1,529.4
Northwest	255.4	7.1	0.6	0.1	263.2
Northeast[a]	1,186.6	19.8	1.3	*	1,207.7
of which Uplands	(828.1)	n.a.	n.a.	n.a.	n.a.
Southwest	45.4	2.1	4.7	0.1	52.3
Southeast	3.9	1.6	0.6	0.1	6.2
	(b) Dispersed Strategy				
Total	2,368.3	33.3	9.1	1.0	2,411.7
Northwest	282.3	6.3	2.5	0.2	291.3
Northeast[a]	1,492.8	21.3	.6	0.3	1,515.0
of which Uplands	(1,100.0)	n.a.	n.a.	n.a.	n.a.
Southwest	588.6	4.1	5.9	0.1	598.7
Southeast	4.6	1.6	0.1	0.4	6.7
	(c) All Coasts Strategy				
Total	597.9	29.8	8.0	0.3	636.0
Northwest	188.0	4.5	0.5	0.1	193.1
Northeast[a]	299.4	17.9	1.3	*	318.6
of which Uplands	(57.5)	n.a.	n.a.	n.a.	n.a.
Southwest	105.2	5.8	4.7	0.1	115.8
Southeast	5.3	1.6	1.5	0.1	8.5

n.a. Not available.
* Less than 0.05
a/ Includes Uplands.

Source: Calculations by the Consultant.

4.0 WATER-COST ANALYSIS

4.1 INTRODUCTION

The following water-cost analysis involved computation of the capital costs and operation and maintenance costs to supply water from different sources, and culminated in the calculation of water costs in pounds per cubic meter (LE/m^3) for each source and location. The purposes of this cost analysis were as follows:

- To identify the required capital outlay for primary Nile water pipelines* for each of three development strategies to the year 2000 and for the Recommended Strategy.
- To provide water costs in LE/m^3 for each source and location as an aid in selecting the most appropriate water source for each location, given its estimated water requirements by the year 2000.

A capital cost analysis for the primary Nile water pipelines proposed under alternative development strategies was performed because the required capital investment in pipelines exceeds that for any other water-supply development by a factor of more than 15. Thus, it was felt that a relatively detailed and careful analysis of the pipeline capital costs was justified. These costs have been based on assumed take-offs at Qantara and Ismailia only. Prefeasibility analysis of alternative take-off points (Minia, Beni Suef, Maadi, Cairo, and Suez) could result in lower costs.

In most cases the economic costs or world-market prices were used; for example, the world-market exchange rate for the Egyptian pound, an estimate for the social cost of capital, and the economic cost of electric power and diesel fuel. In the case of diesel fuel, most analyses were done using both the internal price of diesel fuel in Egypt in 1981 (LE 0.025/l), and the external or border price (LE 0.18/l). In the analysis, all pumping of water, whether in pipelines or out of wells, was assumed to be done by means of pumps powered by diesel engines. Use of Sinai natural gas, coal, solar, or wind energy will reduce costs. Costs and assumptions common to all the types of water-resource development considered include the following:

- Energy Costs:
  - -- Electric power: LE 0.042/kilowatt-hour
  - -- Diesel fuel: LE 0.025/liter (Egyptian market price)
LE 0.18/liter (border price)
- Exchange Rate: LE 1.15/US Dollar
- Discount Rate:** 10 percent

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* These will also carry some drainage water from the El Salaam Canal.

** Used for annualizing capital expenditures.

- Average Life Expectancies:

-- Water-well pumps	10 years
-- Pipelines and pumping stations	25 years
-- Water wells	25 years
-- Desalinization plants	30 years
-- Major civil works, including dams, barrages and regulators	50 years

In all cases, prices and costs refer to those existing in late 1981.

In the following subsections we discuss the methodology and results of cost analysis for groundwater development, desalinization, Nile water conveyance, and local surface-water development. (See Table 4-1 for water availability and estimated cost by subregion). Finally, a comparative analysis of different water sources, by area, is presented.

4.2 GROUNDWATER DEVELOPMENT COSTS

The lowest estimated cost of groundwater is for relatively shallow wells tapping Quaternary aquifers, which are known to deliver moderate-to-high yields. The range here is generally from LE 0.01 to 0.11 per cubic meter. Because of uncertainties regarding well discharge, and the pumping water level, wide ranges are seen in the estimated cost of water for areas involving the Middle Cretaceous aquifer and the Lower Cretaceous sandstone. The greatest range for the Middle Cretaceous aquifer is LE 0.03 to 0.63 per cubic meter for the El Themed to Ras El Gineina area; and the greatest range for the Lower Cretaceous sandstone is LE 0.02 to 1.99 per cubic meter for Gebel El Halal. Until test drilling and test pumping are performed in several locations on these two aquifers, it will not be possible to provide narrower ranges.

Groundwater development costs include the cost of well construction, pumps and their installation, and pump operation. The cost of well construction is based on estimates provided by The Arab Contractors and The General Organization for Research & Groundwater (REGWA) for drilling in three types of geologic formations--unconsolidated alluvium, consolidated sedimentary rock, and crystalline rock. Well construction is defined to include not only the actual drilling and setting of any required casing, but also provision of well screens and gravel pack when required, complete well development, and pump installation--including construction of a pump platform, performance of a 16-hour pumping test, and drill-rig mobilization and demobilization. A generalized equation was developed on the basis of the estimates received, relating the total capital expenditure to the well depth for each type and diameter of well:

$$c_w = ad^2 + bd + c \qquad \text{Eq (9)}$$

where c_w is the total cost of well construction, d is the depth of the well in meters, and a, b, and c are parameters of the equation, their value dependent on the type of geologic strata as well as the intended well diameter.

TABLE 4-1

Sinai Water Resources Availability and Estimated Cost by Subregion

	Groundwater			Desalinized Water			Nile Water	Local Surface Water		
Subregion and Aquifer Type	Estimated Quantity Available[a] (m^3/day)	Approximate TDS[b] (mg/l)	Cost Range (LE/m^3)	Feedwater	Quantity per Desalinization Unit (m^3/day)	Cost (LE/m^3)	Cost of Piped Water (LE/m^3)	Type	Quantity (m^3/day)	Cost (LE/m^3)
Northwest										
Miocene sandstone	10,000	1,000-8,000	0.02-0.30	Groundwater	1,000	0.40	0.03-.24	Nil	Nil	--
Northeast and Uplands										
Quaternary coastal aquifers (Romana to Rafah)	70,000	400-7,000	0.01-0.12	Groundwater	400	0.45	0.08-.36	Storage reservoirs	3,000-30,000 (released 1 year out of 3 or 4)	0.40-1.20[c]
Wadi alluvium (Wadi El Arish and tributaries, and Wadi El Gerafi)	30,000	1,500-6,000	0.02-0.21	Seawater	1,200	1.70	0.23-.56			--
Eocene limestone (near El Quseima)	3,000	500-3,000	0.01-0.14	--	--	--	0.47-.56	Spreader dyke storage and conservation	20,000[d] (on 1,500 feddans)	0.02-0.03
Middle Cretaceous aquifer	225,000	1,000-6,000	0.01-0.65	--	--	--	--		--	--
Lower Createaceous and Nubian aquifer	350,000	1,000-7,000	0.01-2.00	--	--	--	--	--	--	--
Southwest										
Wadi alluvium (Wadi Sudr to Wadi Feiran)	20,000	200-7,000	0.02-0.70	Groundwater	1,000 5,000	0.40 0.33	0.12-.45	Spreader dyke storage and conservation	4,000[d] (on 300 feddans)	0.01-0.03
El Qaa Quaternary aquifer	110,000	600-5,000	0.01-0.10	Seawater	1,200	1.70	0.48-.52			
Miocene sandstone	2,000	2,500-8,000	0.01-0.20	--	--	--	--	--	--	--
Crystalline rock	15,000	200-2,500	0.03-0.45	--	--	--	--	--	--	--
Southeast										
Wadi alluvium (Wadi Watir to Wadi Umm Adawi)	8,000	300-4,000	0.02-0.60	Groundwater	1,000	0.40	--	Spreader dyke storage and conservation	4,000[d] (on 300 feddans)	0.01-0.03
Miocene sandstone (Sharm El Sheikh)	600	2,000-7,000	0.07-0.40	Seawater	1,200	1.70	--		--	--
Crystalline rock	15,000	200-2,500	0.03-0.45	--	--	--	--	--	--	--

a/ Includes any amount presently pumped from wells in addition to the amount presently used

b/ TDS = total dissolved solids

c/ Delivered to El Arish

d/ Estimated long-term annual average

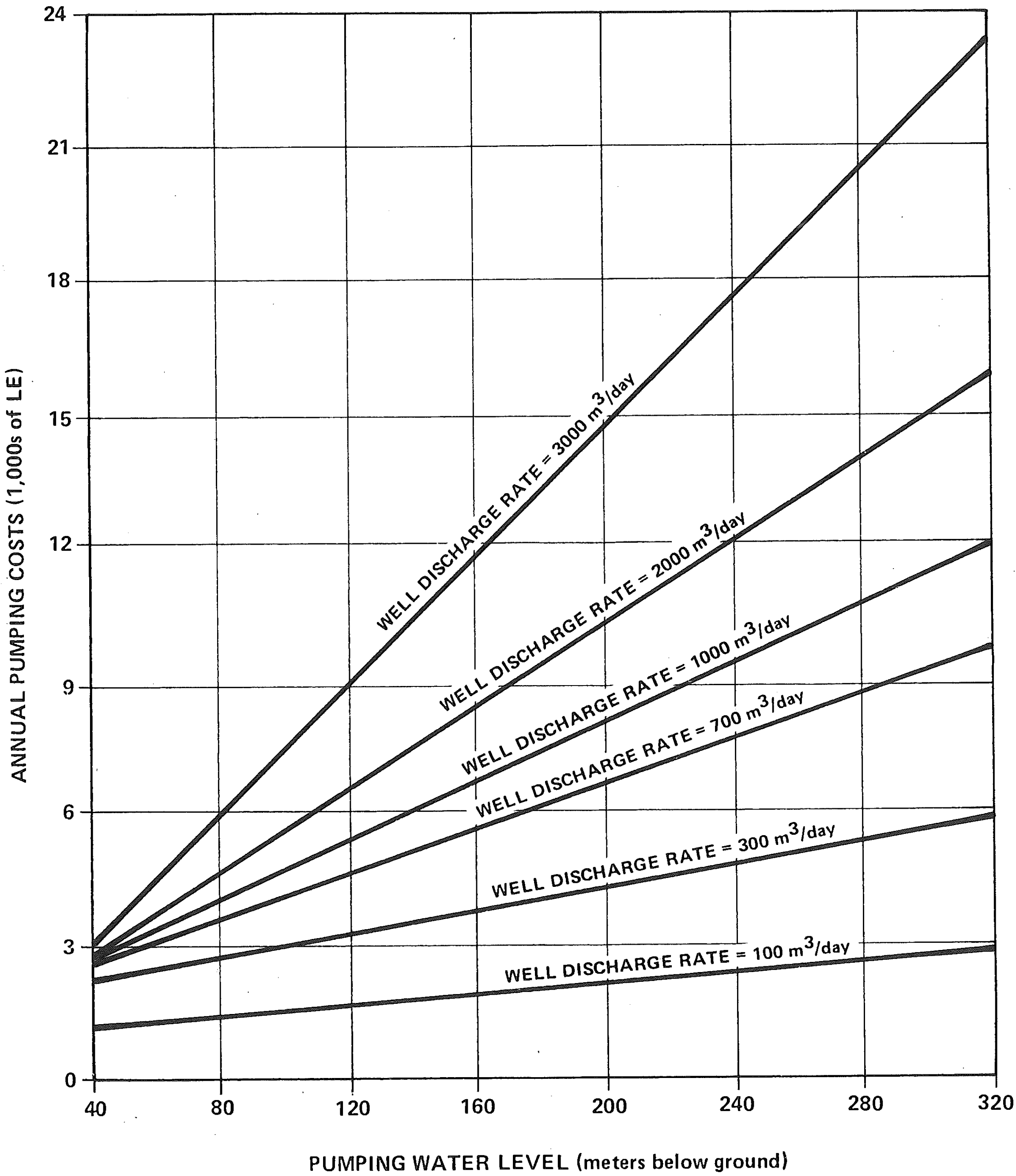
SOURCE: Calculations by the Consultant in memoranda in Project files. Also see Appendix Table A-13.

Equation (9) was modified to provide an annualized cost of well construction, assuming an average well life of 25 years and a discount rate of 10 percent. The resulting estimated costs (1981 prices) for well depths ranging from 50 to 1,000 meters are shown on Table 4-2 and the corresponding curves are provided in Figure 4.1. Well diameters of both 200 and 300 millimeters are considered for the wells drilled in unconsolidated alluvium and in consolidated sedimentary formations. For crystalline rock, only one well diameter (200 millimeters) is considered. The highest cost is for alluvial wells, while the lowest is for crystalline wells. For example, a 200-millimeter-diameter alluvial well, 300 meters deep, is estimated to have an annualized cost of LE 7,900, compared to LE 6,300 for a crystalline well. The cost of water based on well construction costs alone is computed from the annualized costs given in Table 4-2. In the computation, it is assumed that pumping is performed on the average for 8 hours per day.

The other component of the capital requirement for groundwater is the cost of the pumping unit. Pump prices are based on quotations received from the Johnston pump dealer in Cairo. This information was extrapolated over a range of pumping rate capacities and heads. The estimated total capital costs were then obtained in each case by summing the capital costs for the well construction and those for the pump unit and applying a factor of 1.1 to provide for engineering design and supervision costs.

Annual pumping costs are based on an assumed pump efficiency of 70 percent and an assumed 3.9 horsepower-hour (HP-hr) energy yield from 1 liter of diesel fuel. (0644). It was assumed that the pumps operate for only 8 hours per day. Maintenance, repairs, and attendance costs are assumed to be a function of the product of the discharge rate and the average pumping lift, and to range from LE 200 to 1,200 per year for each well. The total estimated operation and maintenance costs are obtained by summing the annual costs due to pump operation and maintenance, repair, and attendance. For the groundwater availability areas (discussed in Section 2.2.4) the cost of groundwater was estimated using Figure 4.1, based on the local price of diesel fuel (LE 0.025/l). Combined annual operation and maintenance costs, together with the computed cost of water, are given in Table A-9 in Appendix A.

In other words, the overall annual cost of groundwater is obtained by summing the annualized cost due to well construction and pump installation, and the annual operational and maintenance costs, which include the costs of pumping. The total cost of water in LE/m^3 is found by dividing the total annual costs by the number of cubic meters pumped annually. For a particular type of well construction, specified well depth, and pumping level, the relationship between the total cost of water and the well discharge rate (pumping an average of 8 hours per day) can be determined.



ASSUMPTIONS:

1. 10-year life for pumping unit.
2. Pumping only occurs 8 hours per day.

NOTE:
An example reading from this table would be as follows: To bring 2,000 m^3/day of water up from a depth of 240 meters, the annual pumping cost would be LE 12,000.

FIGURE 4.1

ANNUAL GROUNDWATER PUMPING COSTS

Dames & Moore

TABLE 4-2

Annualized Capital Costs of Well Construction (LE)[a/]

Well Depth	Well in Consolidated Sedimentary Formation		Well in Unconsolidated Alluvium		Well in Crystalline Rock
(in meters)	(200 mm)	(300 mm)	(200 mm)	(300 mm)	(200 mm)
50	1,680	1,790	2,280	2,610	1,650
100	2,530	2,750	3,300	3,740	2,470
200	4,370	4,810	5,470	6,130	4,260
300	6,420	7,090	7,860	8,740	6,260
500	11,130	12,240	13,230	14,550	10,860
700	16,660	18,210	19,420	21,180	16,270
1,000	26,470	28,680	30,220	32,640	25,920

[a/] Annualized costs are computed on the basis of a 25-year well life and a 10 percent discount rate. Inside well diameters are 200 or 300 millimeters, as shown.

This is illustrated in Figure 4.2. Example 1 of this figure shows the cost-discharge relationship for a 300-millimeter-diameter well in unconsolidated alluvium, 150 meters deep, with a pumping lift of 70 meters. Compared to the influence of well yield on water cost, an increase in the price of diesel fuel has a relatively small effect. In Example 1, water costs exceed LE 0.10/m^3 only if the discharge rate is less than about 800 m^3 day (9.2 liters/second).

The computed values for annualized well construction costs, annual cost of pumping (O&M), and the estimated water cost per cubic meter for each area are given in Working Paper 33, Water Resources (see pages 5-11 to 5-17). Because of considerable uncertainty in many of the areas with respect to the possible depth of the pumping water level and the possible discharge rate, a wide range in the costs of water is foreseen.

4.3 DESALINIZATION COSTS

The desalinization costs presented here are based upon a recent publication on this subject by the Oak Ridge National Laboratory in the United States. (1041a) Several assumptions were made in estimating the costs for desalinization in addition to those given in Section 4.1.

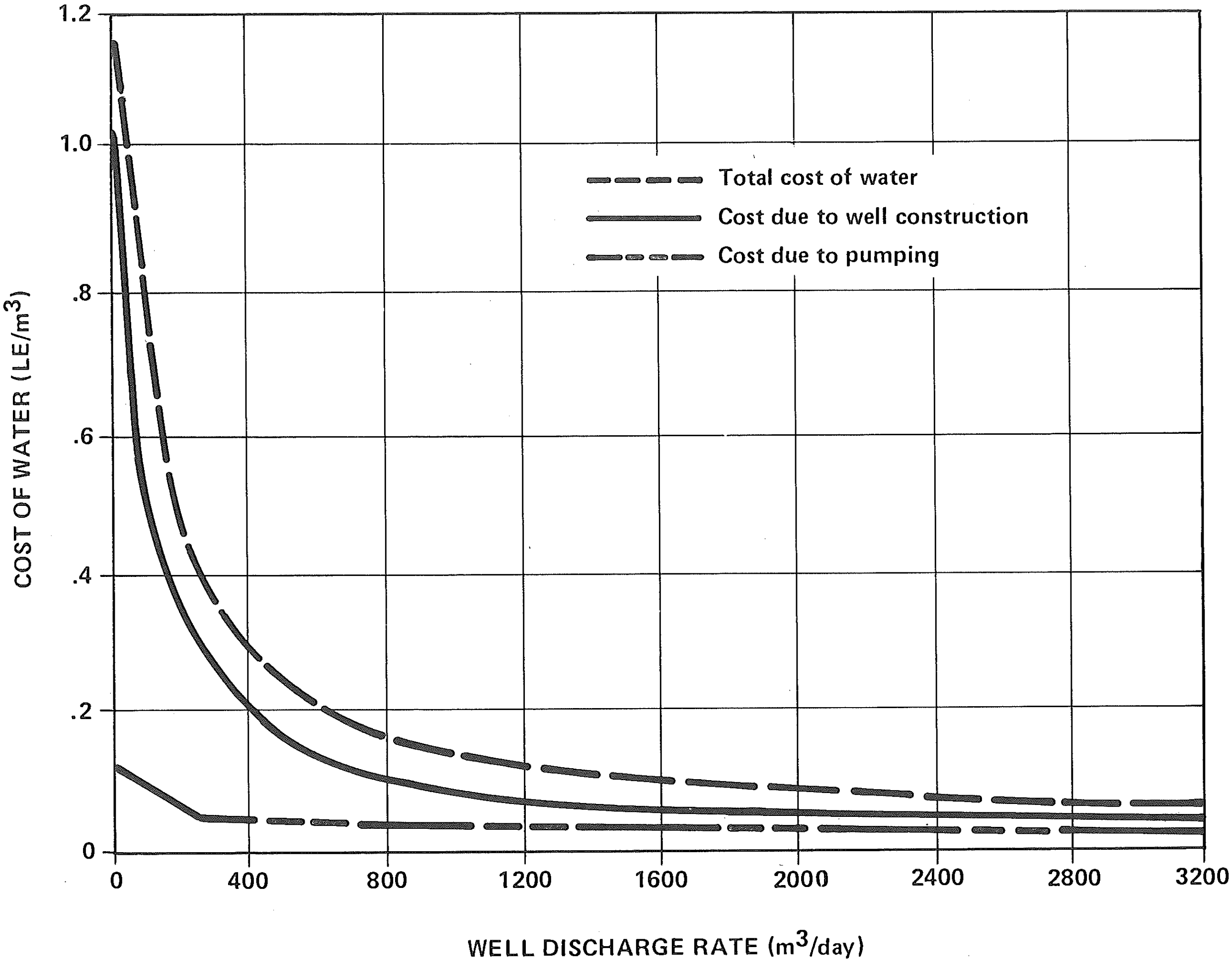
Plant investment costs include the costs for site development; the civil works required for brine disposal; installation of intake and outfalls, where required; and provision of electrical switchgear. Capital costs do not include certain site-specific costs, such as those required for land purchase, or storage and distribution of product water. Working capital is assumed to be 5 percent of the total direct capital cost. A contingency and engineering fee equal to 16 percent of the direct and indirect capital costs is included.

Operating and Maintenance costs are based on a plant load factor of 85 percent for seawater desalinization (distillation or reverse osmosis) and 95 percent for membrane plants desalinizing brackish groundwater. Included in the O&M costs are electrical energy, membrane replacement, spare parts, and regular attendance and servicing. Membrane replacement costs are based on a 3-year life for reverse osmosis membranes and a 7½-year life for electrodialysis membranes.

Operation and maintenance costs are based on the assumption that skilled operators and maintenance technicians have been trained by the vendor's engineers prior to the routine operation of the equipment. This is an essential requirement and will strongly affect the plant on-stream factor, and therefore the cost of the water.

Based on our modification of the cost figures to coincide with Egyptian conditions (1041a), desalinization cost curves were prepared and appear in Working Paper 33, Water Resources, as well as in other project files. These include the estimated capital-cost requirements versus plant capacity for five types of plants--multistage flash distillation, reverse-osmosis seawater desalinization, and brackish water desalinization by reverse osmosis (both 3,500 and 6,000 ppm feedwaters) and electrodialysis (3,500 ppm sodium chloride-type feedwater). The capital costs for brackish-water plants are significantly less than for those desalinizing sea water.

In general the cost of desalinizing brackish waters is in the range of LE 0.20 to 0.40 per cubic meter of product water (assumed to have a TDS of about 500 ppm), compared to LE 1.00 to LE 1.80 per cubic meter for desalinizing seawater.



ASSUMPTIONS:

1. 300mm-diameter well in sedimentary rock.
2. Well depth is 500 meters.
3. Pumping water level is 130 meters below ground.

FIGURE 4.2

PROTOTYPICAL COST OF WATER FROM WELLS

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The estimated cost components are shown on Table A-10 in Appendix A. The plant investment costs for 13 planned or potential desalinization units in Sinai range from LE 165,000 for the 200-m^3/day capacity reverse osmosis (RO) plants for Bir El Abd and El Masaid, to LE 3,000,000 for a possible 1,200 m^3/day RO plant desalinizing seawater at Abu Zenima. Operating expenses are seen to range from LE 22,000 per year for the Bir El Abd or El Masaid units to LE 344,000 per year for a possible 5,000 m^3/day RO plant at Abu Rudeis. The estimated cost of desalinization (per cubic meter) at the 13 plants ranges from LE 0.33 to LE 1.70 per cubic meter. The estimated cost of supplying brackish groundwater, for all but the seawater desalinization units, is added to the desalinization cost to give the total cost of desalinized water. The lowest cost water (LE 0.39 per cubic meter) is that from the possible 5,000 m^3/day RO plant at Aub Rudeis. The highest cost water (LE 1.70 per cubic meter) is predicted for the seawater desalinization units that could be considered for Abu Zenima and Sharm El Sheikh.

4.4 COST OF IMPORTING NILE WATER

The Recommended Development Strategy requires Nile (and drainage) water. The question is how to choose the least expensive and most efficient method of conveyance; that is, a choice between the use of canals and large pipelines. The Consultant's preliminary assessment is that in most cases large pipelines would be more appropriate for the following reasons:*

- A substantial portion of the conveyance corridors being considered involves a gradual increase in land-surface elevation.
- Most of the tracts finally identified for reclamation, after performance of suitable soil surveys, are expected to be of relatively modest size, perhaps 5,000 to 15,000 feddans, and separated from each other by considerable distances.
- Most soils in Sinai are highly permeable.

Because of these considerations, pipelines may be the most appropriate means of conveyance over most portions of each conveyance corridor.

4.4.1 Nile Water by Pipeline

Costs of pipelines (installed) and pumping stations were obtained from estimates included in the Ministry of Irrigation proposal for the Maadi-Suez pipeline, and a recent estimate for the World Bank-funded Gulf of Suez project. (1040). The cost to construct a siphon under the Suez Canal was assumed to be 10 times the cost, per unit distance, of installing pipelines on land. In most cases, it was assumed that a pumping station would be required every 25 kilometers on level ground, and every 25 meters of rise in ground elevation. Storage facilities were not included. Ten percent was added to all capital costs for engineering design and supervision. Figure 4.3 provides generalized cost curves, illustrating the effects of pipeline length, elevation, volume and other factors on the average cost per cubic meter of Nile water delivered to irrigation sites in Sinai.

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* Section 4.4.2 presents costs for canals that may be most appropriate in some reaches--for example, to serve the El Tina Plain.

Figure 4.3(a) Relationship of Capital Costs to Pipeline Capacity

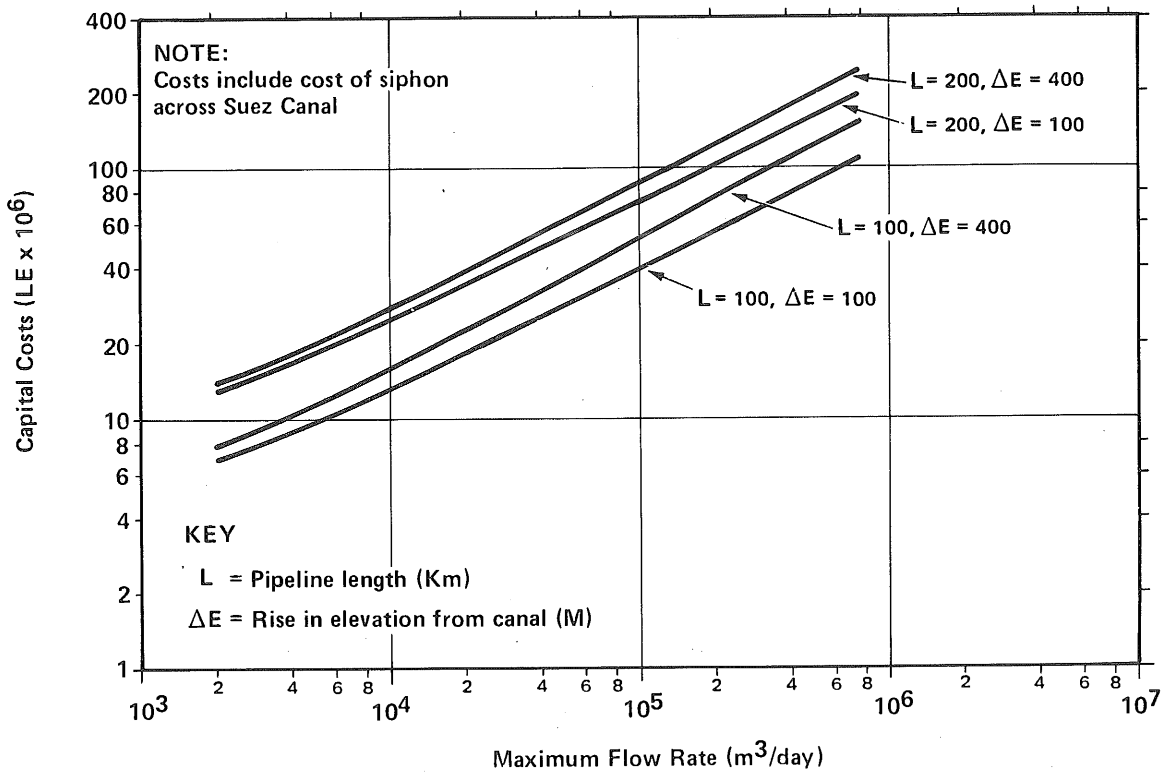

Figure 4.3(b) Water Costs (LE per cubic meter) Related to Pipeline Capacity

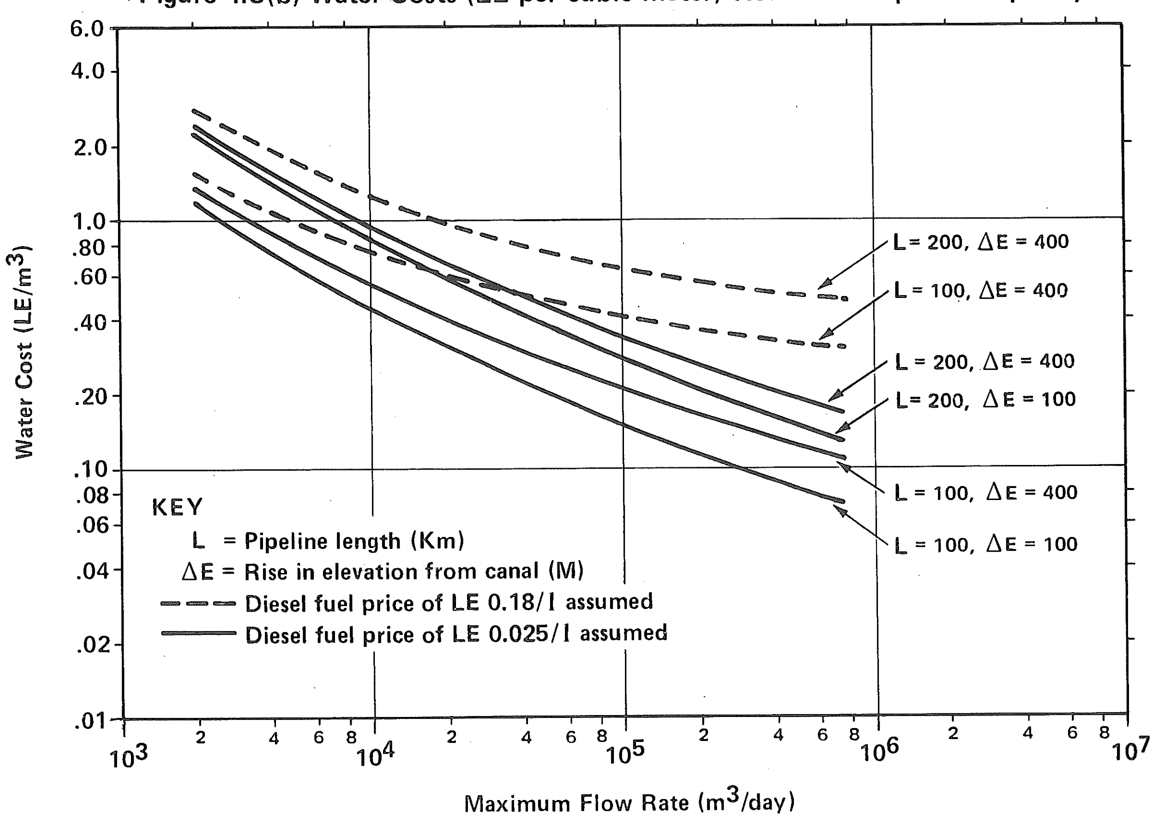

FIGURE 4.3
ESTIMATED COSTS OF NILE WATER PIPELINES

Dames & Moore

Inspection and general annual maintenance costs were assumed to be a function of pipeline length, the ground elevation at destination, and the flow rate. In computing annual pumping costs use was made of both the 1981 local price of diesel fuel and the border price (LE 0.025 and LE 0.18 per liter, respectively). Pump efficiency in each case was assumed to be 70 percent, and diesel fuel was assumed to result in an energy yield of 3.9 HP-hr per liter. (0644)

In the analysis, the average number of hours pumping per day on a year-round basis varied depending on the use. For public-supply, tourism, and industrial purposes, an average pumping period of 18 hours per day was assumed; for irrigation purposes, the figure used was only 7.6 hours, based on the following considerations:

- Irrigation will take place for two crops a year, over a period of 260 days out of 365 (70 percent)
- During the hottest peak-use days, farmers may be assumed to irrigate for no more than 16 hours per day
- The ration of peak use to average daily use on a medium- to large-size project can be taken as 1.5 (which may be about three times the lowest demand)
- No storage facilities would be built either in the primary or secondary systems.

From the above, the average daily hours of pumping are calculated to be:

$$\left(\frac{16}{1.5}\right)\left(\frac{260}{365}\right) = 7.6 \text{ hrs/day}$$

If these assumptions hold true, one result is that for any given quantity of water annually a much larger pipeline is needed for irrigation purposes than for other uses.*

In the selection of a particular pipeline size to accommodate a particular required flow, an arbitrary decision was made to select uniformly that pipe size which would result in friction loss of approximately 0.003 meters/meter (for new wrought iron or schedule 40 steel pipe (U.S. standards)).

The curves shown in Figures 4.3a and 4.3b are general illustrations of the applications of all the information and assumptions discussed above. Figure 4.3a provides some general curves for the unit capital costs involved in 100-km and 200-km long pipelines, for two cases--100 meters and 400 meters rise in elevation. Figure 4.3b shows the corresponding curves for the total water cost involved for selected distances and lifts, including different

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*The assumptions that led to the average pumping day and the pressure assumed inside the pipe are conservative. This is appropriate to a reconnaissance level of study. Similar studies in Egypt and elsewhere have, for instance, assumed 20 and more hours a day pumping during peak demand and the use of storage reservoirs. In Sinai storage could in may cases be filled during low-cost, off-peak energy periods. Cropping may be arranged to use the fields for more than 70 percent of the year. Prefeasibility studies which are aimed at cost-saving and managing peak demand might reduce substantially the conservative estimates presented here.

curves on the basis of local and border prices of diesel fuel. Unlike the case of groundwater supply costs discussed in Section 4.2, an increase in the price of diesel fuel does appear to have a significant effect on the cost of pipeline water, especially for the 400-meter elevation case. It is important to recognize that the curves on Figure 4.3 relate cost to the maximum flow rate, or the assumed pipeline capacity, not to the average annual pumpage divided by 365.

A cost analysis was performed for the major pipelines that are presently planned or under construction in Sinai for the purpose of conveying Nile water for public supply or limited land reclamation. These include the pipeline to Bir El Abd from El Qantara, and the proposed pipelines from El Qantara to El Arish, from Hamdi tunnel to Abu Rudeis, and from Maadi to Suez and thence to the East of Suez relamation area. In the analysis of the proposed Hamdi Tunnel-Abu Rudeis pipeline, it was assumed the pipeline would have a diameter of 300 mm, although currently pipe sizes of 350 to 500 mm are being considered.* Expected water costs for these projects range from LE 0.14/m^3 for the Maadi-Suez pipeline, to LE 0.95/m^3 for the Hamdi Tunnel-Abu Rudeis pipeline (300 mm). The diesel-fuel price assumed for these calculations was LE 0.025/liter. (See Appendix Table A-12.)

Detailed cost analyses were performed for the pipelines required under various alternative strategies. These analyses are based on the water requirements for each subregion provided in Tables A-6, A-7, and A-8 of Appendix A. In all cases the maximum size considered was two-meter diameter pipeline, having an estimated maximum flow rate (or capacity) of 750,000 m^3/day (8680 l/sec). Thus, for areas having large water requirements, several pipelines of this diameter were required.

Pipeline systems were located to serve proposed reclamation areas because agricultural demand dominates the water requirements. However, the water requirements for public supply, industries, and tourism within or adjacent to each reclamation area are included as a part of the total water requirement for the area. The number of pipelines and their size were selected accordingly. Figure 4.4 illustrates four major water conveyance systems, which were analysed by sections in order to estimate the costs of various alternative patterns of development (especially alternative plans for land reclamation).

Secondary pipelines refer to the secondary pipeline system required in each reclamation area to distribute the water to the fields. It was assumed secondary pipelines would generally consist of a system of parallel pipes spaced 400 meters apart through each reclamation area.

The estimated total capital cost for pipeline systems under the Frontier Strategy is about LE 2.8 billion without the secondary pipelines, and LE 3.2 billion with the secondary pipelines. The Dispersed Strategy would require an investment of LE 5.5 billion without the secondary pipelines, and LE 6.1 billion with them. Calculations performed for the case of the All Coasts Strategy gave an estimated LE 1.5 billion capital investment cost for the required primary pipeline system. The Recommended Strategy calls for a capital expenditure of LE 2.2 billion for major water conveyances and about LE 300 million for secondary pipelines, mostly as part of the agricultural development budget. (See Appendix Table A-13)

Water costs vary rather significantly from area to area. Considering a diesel fuel price of LE 0.025/l and primary pipelines only, the cost to supply Nile water to selected areas is approximately as shown below:

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*Personal communication Eng. Ashraf Aluba, President ECG Consultants

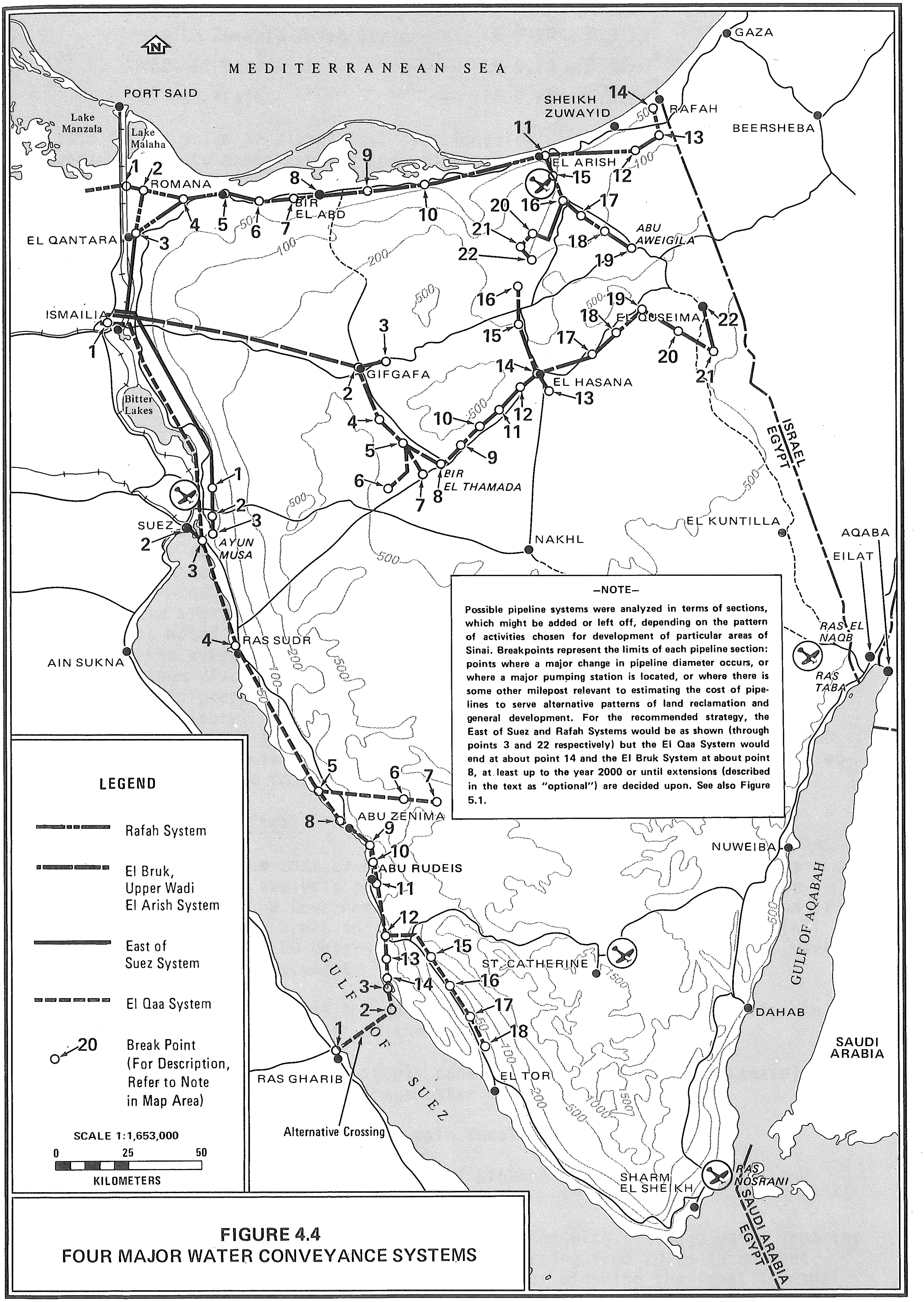

FIGURE 4.4
FOUR MAJOR WATER CONVEYANCE SYSTEMS

Qantara-Baloza	-	LE 0.03 - 0.08/m^3
Sheikh Zuwayid-Rafah Strip	-	LE 0.28 - 0.35/m^3
Wadi El Brud Area	-	LE 0.33 - 0.46/m^3
El Qaa Plain	-	LE 0.48 - 0.52/m^3

A rise in the price of diesel fuel can significantly affect the price of delivering water to areas located some distance away from the Suez Canal or to areas of high elevation. (See Appendix Table A-13.)

It should be noted that there is an alternative source of Nile water for reclamation area NW-4 (East of Suez). In preparing Appendix A-8, the Consultant assumed that water for this reclamation area would come by pipeline from Ismailia at a cost of LE 0.16 to 0.22/m^3 (diesel price of LE 0.025/1). An alternative possibility is for water to be brought to Suez (before being siphoned under the Suez Canal) by means of a Maadi-Suez pipeline, which was being considered by the Ministry of Irrigation in the early 1980s. Under this proposal a pipeline would provide for some of the water needs of Suez city and might also serve irrigation requirements in the East of Suez reclamation area. The Consultant estimated the cost of water to Sinai under this alternative to range from LE 0.14 to LE 0.18/m^3, which would make it more economical than the pipeline from Ismailia suggested earlier. Both sources should be considered when detailed feasibility studies are prepared for irrigated agriculture in this reclamation area.

Some comparative curves showing water costs vs average daily discharge for Nile water conveyed by pipeline are provided in Figure 4.5. In these figures, the water-cost relationship for five selected areas are shown for illustration--the El Qaa Plain, the El Arish-Bir Lahfan area, the Baloza-Romana-Negila area, the Wadi El Bruk area and the Sheikh Zuwayid-Rafah area. It should be noted that the discharge rate plotted on the abscissa of these figures is the average daily discharge (yearly requirement divided by 365), not the maximum discharge rate shown on the general cost curves provided on Figure 4.3. In preparing these curves, it was assumed water would be used for two-crop agriculture. It will be observed that on Figure 4.5 the curves all flatten to horizontal lines beyond an average discharge rate of about 230,000 m^3/day. This is because this average rate represents a pipe size of about two-meters under irrigated conditions, as described earlier in this subsection.

4.4.2 Nile Water by Canal

An estimate of the cost of Nile water conveyed by canals in Sinai was prepared, based on an analysis of information provided in the Water Master Plan (0859, 0863) of the Government of Egypt, which called for reclamation of 735,000 feddans in five areas in the Northwest and Northeast Subregions (all at elevations less than 60 meters above sea level). The following items were included in the cost assessment:

- The Sinai share of the general works replacement and operation in the Nile system west of the Suez Canal
- Widening of the main supply canals (Ismailia, El Salaam Canals) bringing Nile and drainage water to Sinai
- Pumping of water into the main canals in Sinai
- Construction and maintenance of siphons under the Suez Canal and major delivery canals in Sinai.

For the first item, the cost of blending Nile water with drainage water from the Bahr Hadous drain is included--the proportion varying from 20 to 40 percent drainage water. For the second item, the costs of widening the Ismailia Canal

Figure 4.5(a) Nile Water Delivered to the El Qaa Plain, the El Arish - Bir El Lahfan Area, and the Baloza - Romana - Negila Area

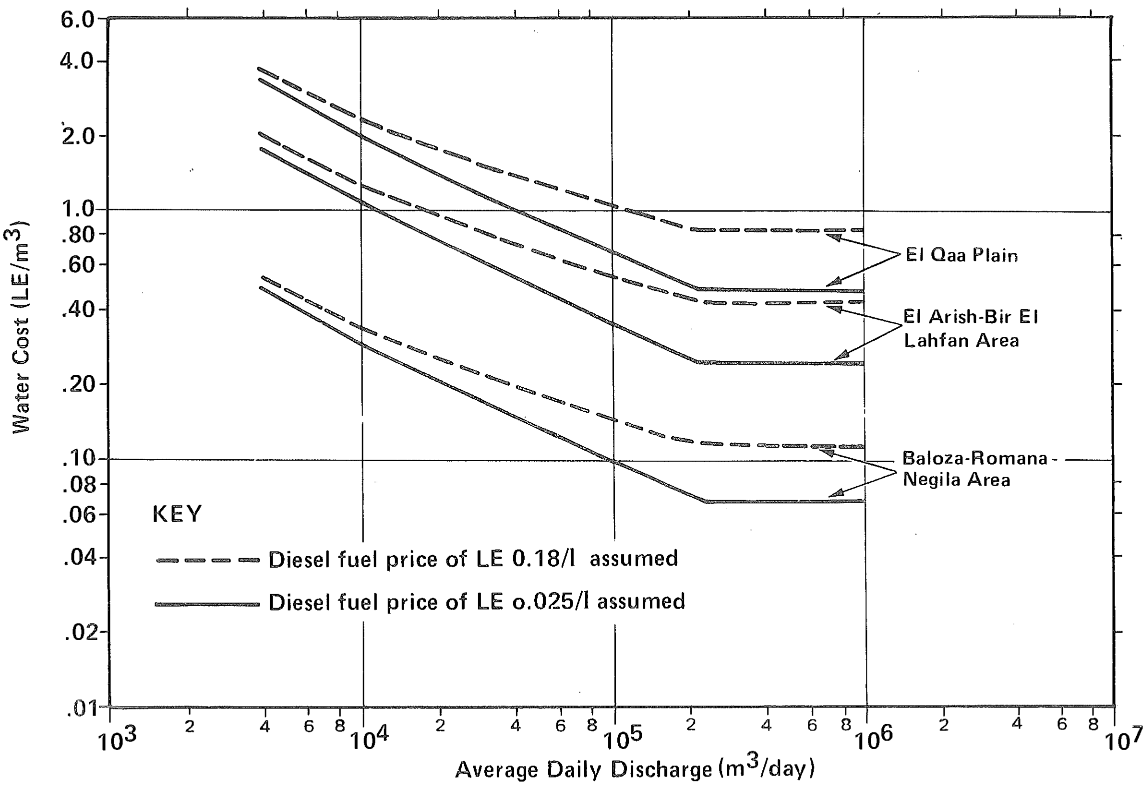

Figure 4.5(b) Nile Water Delivered to the Wadi El Bruk and the Sheikh Zuwayid - Rafah Areas

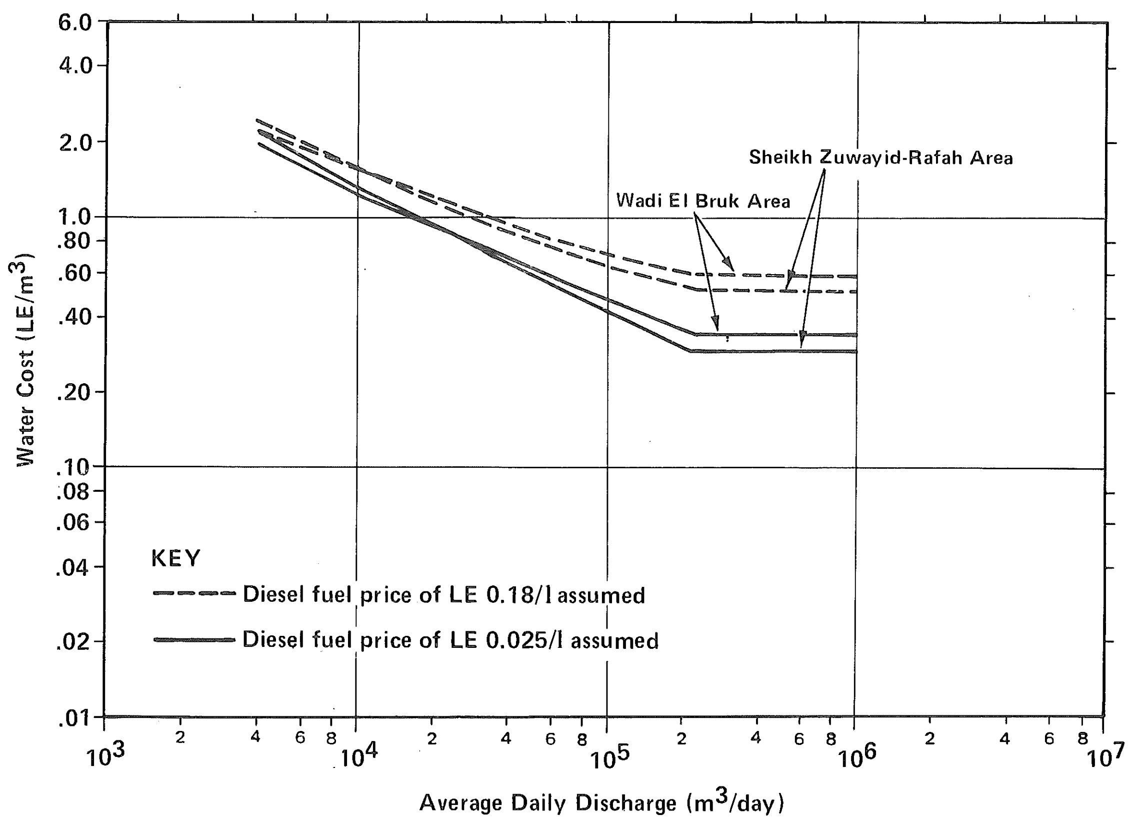

FIGURE 4.5

RELATIONSHIP OF ESTIMATED NILE WATER COSTS TO PIPELINE CAPACITY, LE PER CUBIC METER DELIVERED TO VARIOUS LOCATIONS

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are taken from reference document (0715). For the fourth item, canal construction costs in Sinai are based on the cost of the Jonglei I Canal, also described in the Water Master Plan. (0859). Of the four components making up these estimates, the second, pertaining to the widening of the main supply canals west of the Suez Canal, is the most costly. Its share of the total water cost ranged from 61 to 74 percent. The cost of water that would be brought by canals to Sinai ranges from LE 0.019 to 0.023 per cubic meter. (Table A-11 in the Appendix.)

On the basis of land capability analysis (Volume IV) it seems reasonable to carry water by canal through the El Tina Plain as the soil is impervious and the demand may be quite continuous rather than interrupted. As those costs were calculated differently, no general conclusions can be drawn from the El Tina case concerning the relative advantages of pipelines and canals elsewhere in Sinai.

A low cost per unit of water for canal conveyance would recommend including canal conveyance in the proposed Nile water conveyance system wherever feasible. In Section 5.5, the Consultant proposes a feasibility study, to compare pipeline and canal conveyance systems, for each proposed reclamation area.

4.5 SURFACE-WATER DEVELOPMENT COSTS

As described in Section 2.2.2, the development of surface-water resources in Sinai is generally more uncertain that the development of groundwater resources. Possible surface-water development includes:

- Construction of dams
- Water spreading techniques
- Cloud seeding
- Dry farming
- Cisterns
- Draw down farms
- Runoff farms.

Because of the paucity of runoff data, it is difficult to estimate the quantity of water likely to be available for release from reservoirs in Sinai. As a result, any estimates of the costs of such water are likely to be subject to may uncertainties. Nevertheless, rough estimates of flow in the lower Wadi El Arish have been used to compute order-of-magnitude costs of water for three potential dam locations on this part of the wadi--the existing Rawafaa Dam and potential dams proposed by some experts for the El Daiqa Gorge and Bir Lahfan--at LE 1.20, 0.40, and 0.65 per cubic meter respectively. In all three cases, it was assumed that water would be conveyed from the reservoir by pipelines to the El Arish area, where it would be diverted to basins for recharging the Quaternary aquifer. Costs have not been estimated for the many small dams that seem feasible. The lowest dam water costs appear to be similar, at the dam, to the cost of delivering Nile water by pipeline to the dam site.

4.5.1 Rawafaa Reservoir

As discussed in Section 2.2.2, the present extent of siltation in the Rawafaa Reservoir is not clear. For the purposes of this analysis, it was assumed that there is a present live capacity of 2.2 million cubic meters, and that the reservoir fills on an average once in every two years. An average release rate of 3,500 m^3/day over a 210-day period was also assumed.

The costs involved in providing the water from the Rawafaa Reservoir to the El Arish area include those related to the construction and maintenance of a 300-millimeter pipeline and to the preparation and maintenance of silting and recharge basins in the El Arish area. Based on a preliminary analysis, it is assumed that the natural gradient is sufficient to carry the water in the pipeline; thus, no pumping station is required. The recharge basins are assumed to have an average intake rate of 0.1 m^3/day. The area set aside for silting basins is assumed to be equal to that required for the recharge basins. The costs of preparation of these basins are assumed to amount to LE 1,000 per feddan, while annual maintenance costs are assumed to be LE 300 per feddan. The final computed cost of the water, recharged into the aquifer, is LE 1.20 per cubic meter.

4.5.2 El Daiqa Site

With regard to a possible dam in the El Daiqa Gorge, there is great uncertainty about how often the reservoir might be filled. For the purpose of this analysis, it is assumed that a live capacity of 30×10^6 cubic meters will be filled once in every three years. An average release rate of 30,000 m^3/day over a 390-day period is assumed.

The costs involved in providing water from the El Daiqa Reservoir to the El Arish area include those related to dam construction, construction and maintenance of a 700-millimeter pipeline, and preparation and maintenance of silting and recharge basins in the El Arish area.

The dam at El Daiqa was assumed to be a rubble masonry arch dam--170 meters long, 14 meters wide at the foundation base, and 2 meters wide at the top. The base of the dam was assumed to be at elevation 157 meters and the spillway crest at elevation 173 meters. The total dam volume was computed to be about 18,000 cubic meters. An average round-trip haul distance of 10 kilometers and a hauling cost for the rock material of LE 3 per cubic meter were assumed. Surface soils at the dam site were assumed to be removed down to 3 meters. Unit construction costs were obtained via Engineer Ahmad Ali Kamal from Mr. M.M. Seddick, Chairman of REGWA. These costs ranged from LE 2.50 per cubic meter to excavate soil to LE 35 per cubic meter to supply limestone and construct rubble masonry with mortar, assuming a haul distance of only 50 meters. The previously estimated cost of hauling (LE 3 per cubic meter) was added to these unit costs. On the basis of these various assumptions the cost to face the dam surfaces with limestone and mortar was estimated at LE 20 per square meter. The total cost of the dam--including all construction, design and engineering, test borings, grouting, aprons, and sluice works--was estimated to be LE 1,700,000.

The assumptions made for the El Daiqa Reservoir with respect to the pipeline and the required silting and recharge basins at El Arish are similar to those discussed earlier for the Rawafaa Reservoir. The annualized cost for the pipeline was computed to be about LE 1.3 million compared to only LE 173,000 per year for dam construction. The total annual costs, including about LE 100,000 for operating costs, were estimated to be LE 1.6 million. This resulted in an estimated cost of water recharged at El Arish of LE 0.40 per cubic meter.

4.5.3 Bir Lahfan Site

A dam at the Lahfan Gorge on Wadi El Arish was assumed to have a live capacity of 11 million cubic meters and would be filled on an average of once every 3 years. Based on an analysis of the effects of evaporation and seepage on the duration of a constant release rate, an average release rate of 18,000 m^3/day, sustained on the average for 250 days, was selected.

The costs involved in providing water from a reservoir at Bir Lahfan to the El Arish area include those related to dam construction, construction and maintenance of a 600-millimeter pipeline, and preparation and maintenance of silting and recharge basins in the El Arish area.

The dam at Bir Lahfan was assumed to be a rock-fill dam with a masonry upstream membrane. The upstream face of the dam was assumed to have a slope of 1 vertical on 0.5 horizontal, and the downstream face was assumed to have a slope of 1 on 1.3. Based on a 1:50,000-scale topographic map, the length of the dam was estimated to be 1,000 meters at the top elevation of 55 meters. The base of the dam was estimated to be at elevation of 41 meters, while the spillway crest was at elevation 53 meters. Thus, the total estimated dam volume would be 150,000 cubic meters, more than eight times that estimated for the El Daiqa Dam. An average round-trip haul distance of 80 kilometers was assumed, resulting in an estimated haul cost of LE 10 per cubic meter of limestone rock. Surface soils at the site were assumed to be removed down to a depth of 2 meters. Unit construction costs were similar to those assumed for the El Daiqa Dam, except that the main rock fill section was computed at LE 25 per cubic meter plus haul charges of LE 10 per cubic meter. The cost of membrane construction was estimated at a rate of LE 30 per square meter. On the basis of all these assumptions the total cost of the dam, including design and engineering, test borings and grouting, all construction, aprons, and sluice works, was estimated to be LE 7,700,000.

The assumptions made for the Bir Lahfan reservoir with respect to the pipeline and the required silting and recharge basins at El Arish were similar to those discussed earlier for the Rawafaa Reservoir. The annualized cost for the pipeline was computed to be only LE 265,000--compared to LE 775,000 per year for dam construction. The total annual costs, including about LE 40,000 for operation and maintenance, were estimated to be about LE 1.1 million. This resulted in an estimated cost of water recharged at El Arish of LE 0.72 per cubic meter. If the average round-trip haul distance for construction materials could be reduced from the estimated 80 kilometers to 8, the average water cost would be reduced to LE 0.64 per cubic meter.

4.5.4 Costs for Water Spreading and Runoff Farms

At the time of the writing of this report, only a few costs were available related to runoff conservation structures. In Western Australia the cost to prepare graded and rolled catchments to harvest rainfall amounted to \$30 to \$40 per acre in 1968. (0944) This might translate into LE 80 to 120 per feddan in terms of 1981 prices, which includes the cost of cambered strips running downhill, a collecting ditch, and a 1,000-cubic-meter-capacity collection tank (one for every 2 to 4 feddans). Costs on this order might be expected for the water-spreading dyke construction described in Section 2.2.2. Unit costs can be assumed to apply to the number of feddans immediately upslope of each spreader dyke, where soil moisture will definitely be enhanced because of the presence of the spreader dyke system.

Evenari, Shanan, and Tadmore (0384) have estimated the cost of microcatchment construction to range from \$5 to \$20 per hectare in the late 1960's. This might equate to LE 7-25 per feddan in 1981 prices, the actual amount depending on the size of the microcatchments.

The cost of runoff farms can vary considerably depending on local conditions and the type and sophistication of collection channels, diversion boxes, and flow meters employed. The reconstruction of an ancient runoff farm at Shivta in the Negev took approximately 2,000 man-days (0384). The actual area cultivated was about 1.7 feddans, and adhered to the original simple design, which included no mortar in the construction of channels and diversion boxes. The authors estimated that a family with three to four children could do this work over a period of one or two years.

A good deal of such construction is being carried out in Eastern Sinai and costs could be acquired by commissioning a prefeasibility study.

4.6 COMPARISON OF WATER COSTS FROM DIFFERENT SOURCES

Generalized water-cost curves for differing water sources have been prepared for eight representative areas listed below (Figures 4.6-4.9):

Area	Subregion	Figure
Baloza-Romana-Negila	NW & NE	4.6(a)
Sheikh Zuwayid-Rafah	NE	4.6(b)
El Arish-Bir Lahfan	NE	4.7(a)
Gifgafa	UP	4.7(b)
Wadi El Bruk	UP	4.8(a)
Middle Wadi El Arish/ Wadi El Gayifa	UP	4.8(b)
Abu Rudeis-El Markha-Wadi Sidri Delta	SW	4.9(a)
El Qaa Plain	SW	4.9(b)

In each case, the average daily discharge is plotted versus the cost of water in LE/m^3 for each major water source -- groundwater, desalinized water and Nile water. All the cost curves are based on a diesel fuel price of LE 0.025/l. Moreover, the Nile-water pipeline cost curve in each case assumes irrigation of two crops each year.

The bands representing groundwater costs in Figures 4.6-4.9 indicate there is a degree of uncertainty regarding the elements that make up groundwater costs. The biggest uncertainty concerns well yields. The higher the average yield from an aquifer, the lower the unit water cost. In this regard, our present knowledge of possible well yields from the Lower Cretaceous and Middle Cretaceous aquifers is poor indeed; hence, the groundwater costs for these aquifers are represented by wide bands, reflecting the uncertainty in the estimates.

An important feature of these curves is the fact that the point on the abscissa, where the groundwater curves end on the right side, indicates the estimated limit of groundwater quantity from the particular aquifer

Figure 4.6(a) Baloza - Romana - Negila Area

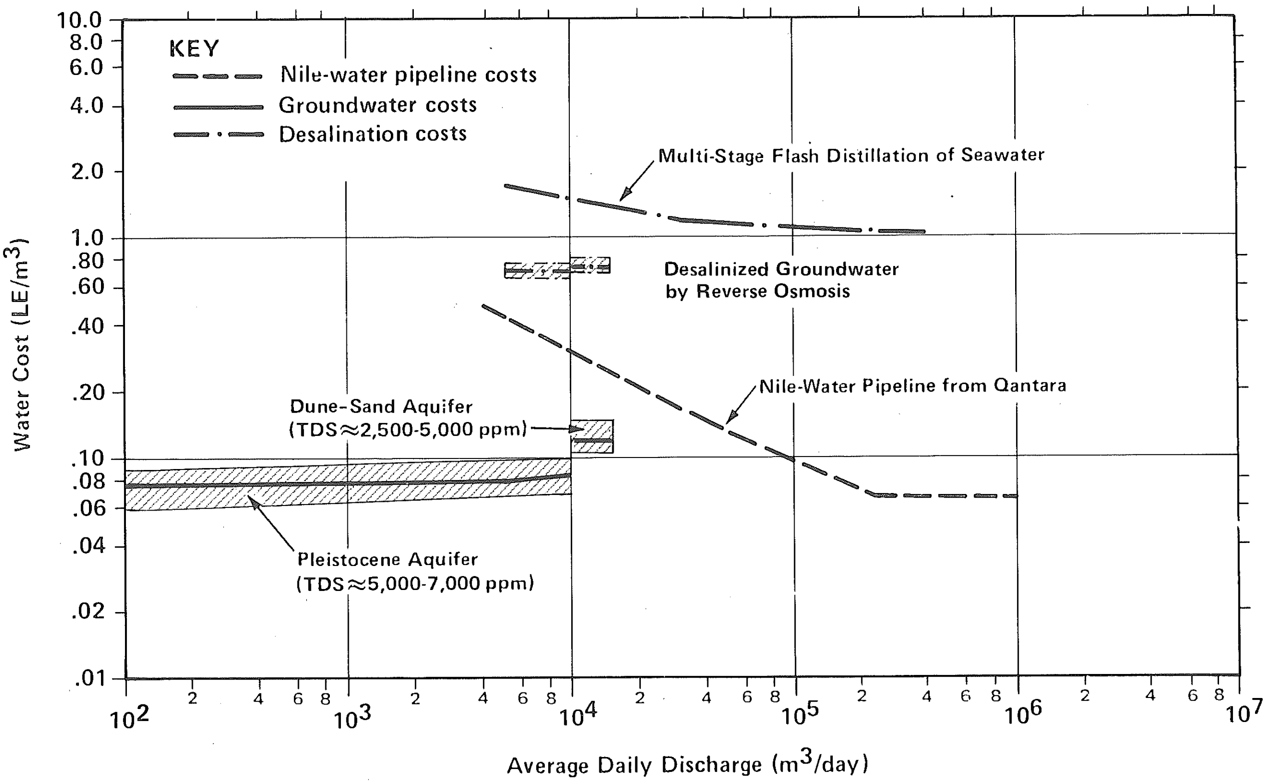

Figure 4.6(b) Sheikh Zuwayid - Rafah Area

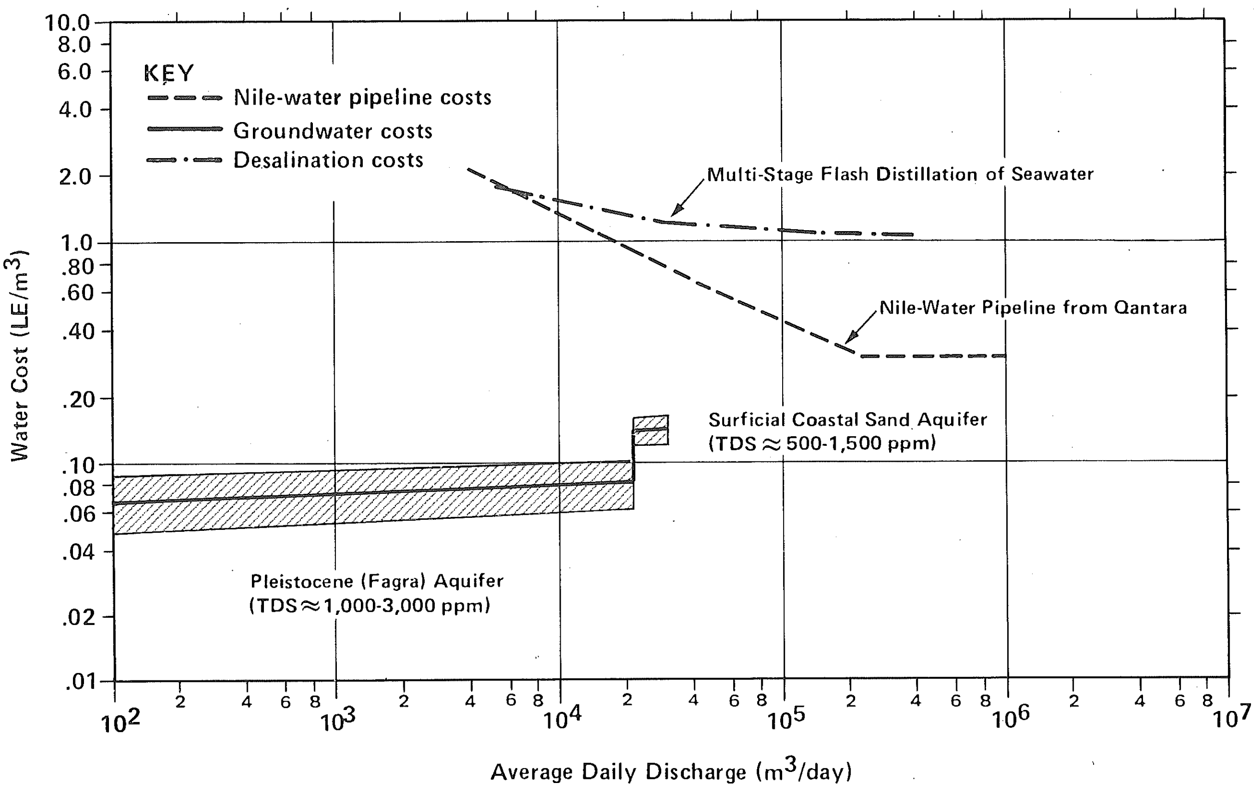

FIGURE 4.6
GENERALIZED WATER-COST CURVES:
NORTH COAST AREAS

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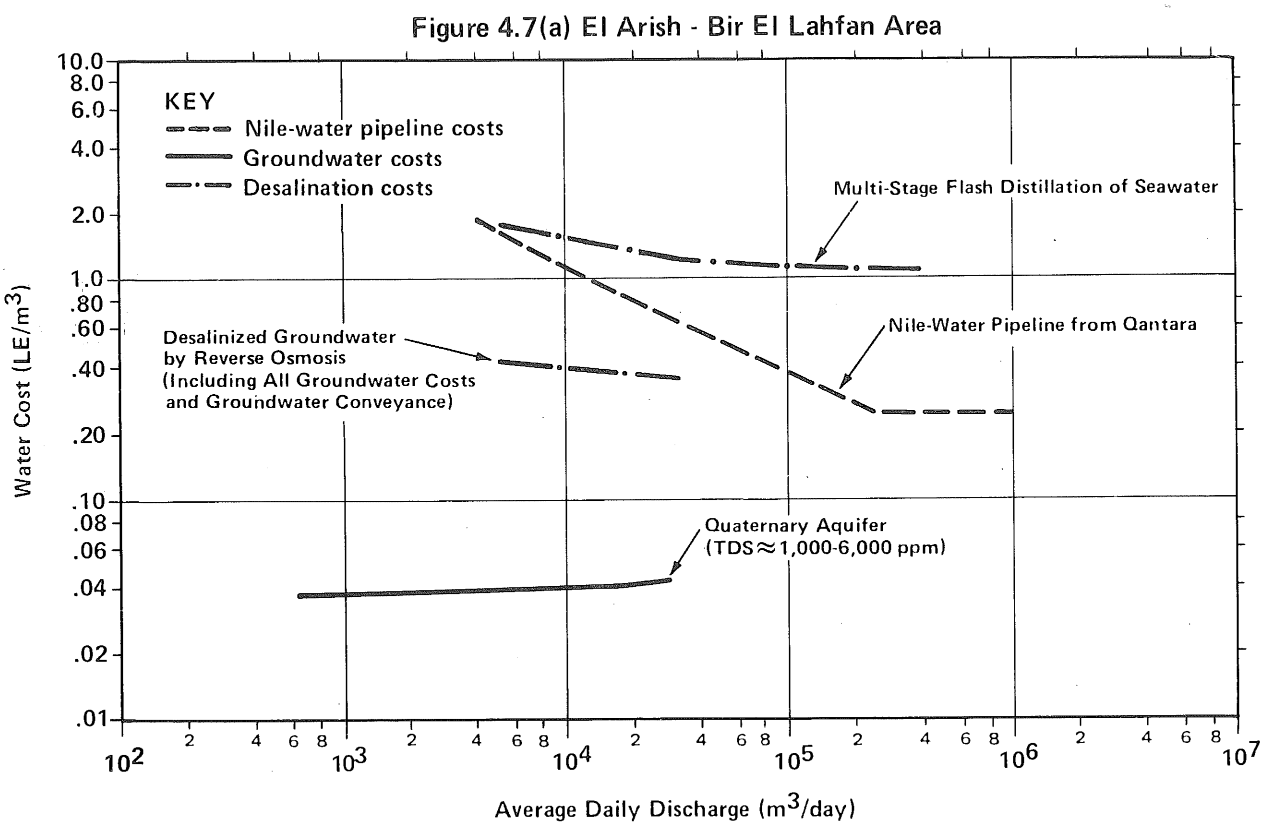

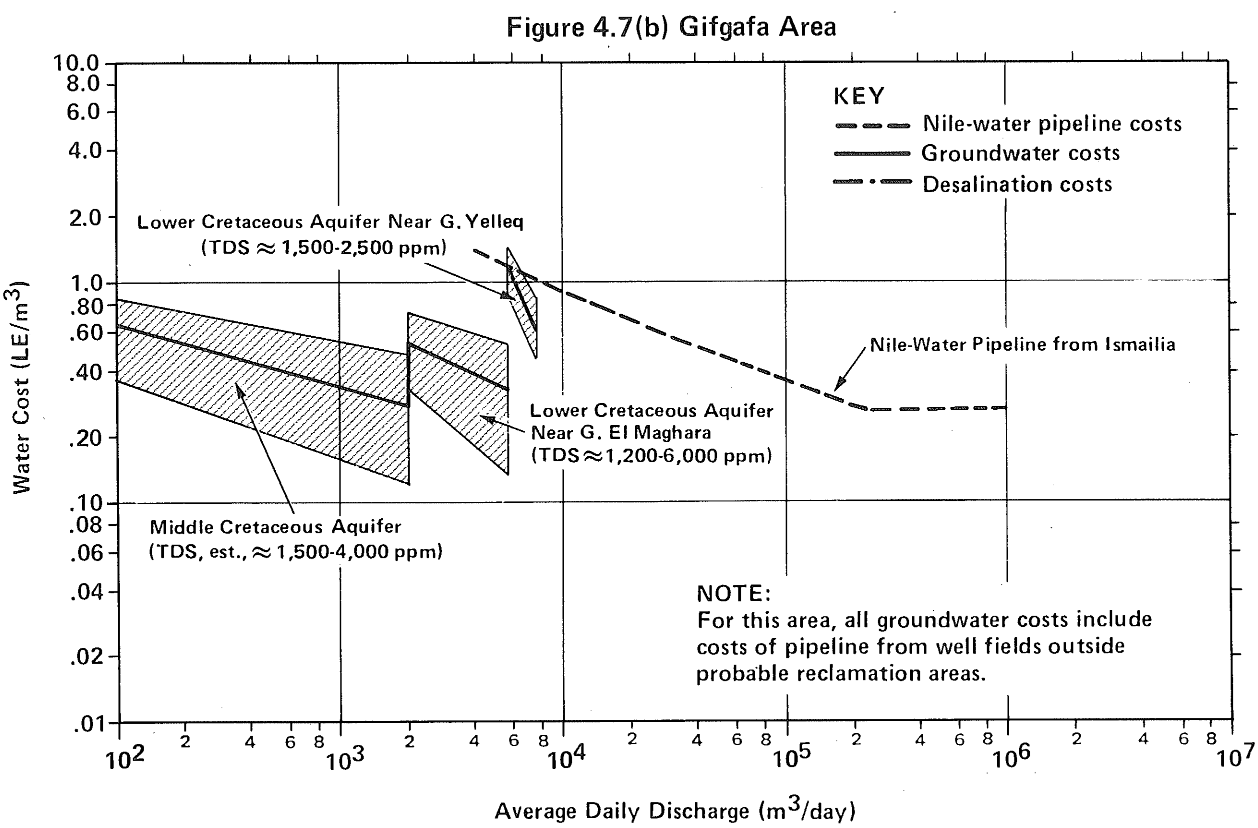

FIGURE 4.7
GENERALIZED WATER-COST CURVES:
LOWER WADI EL ARISH AND GIFGAFA AREAS

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Figure 4.8(a) Wadi El Bruk Area

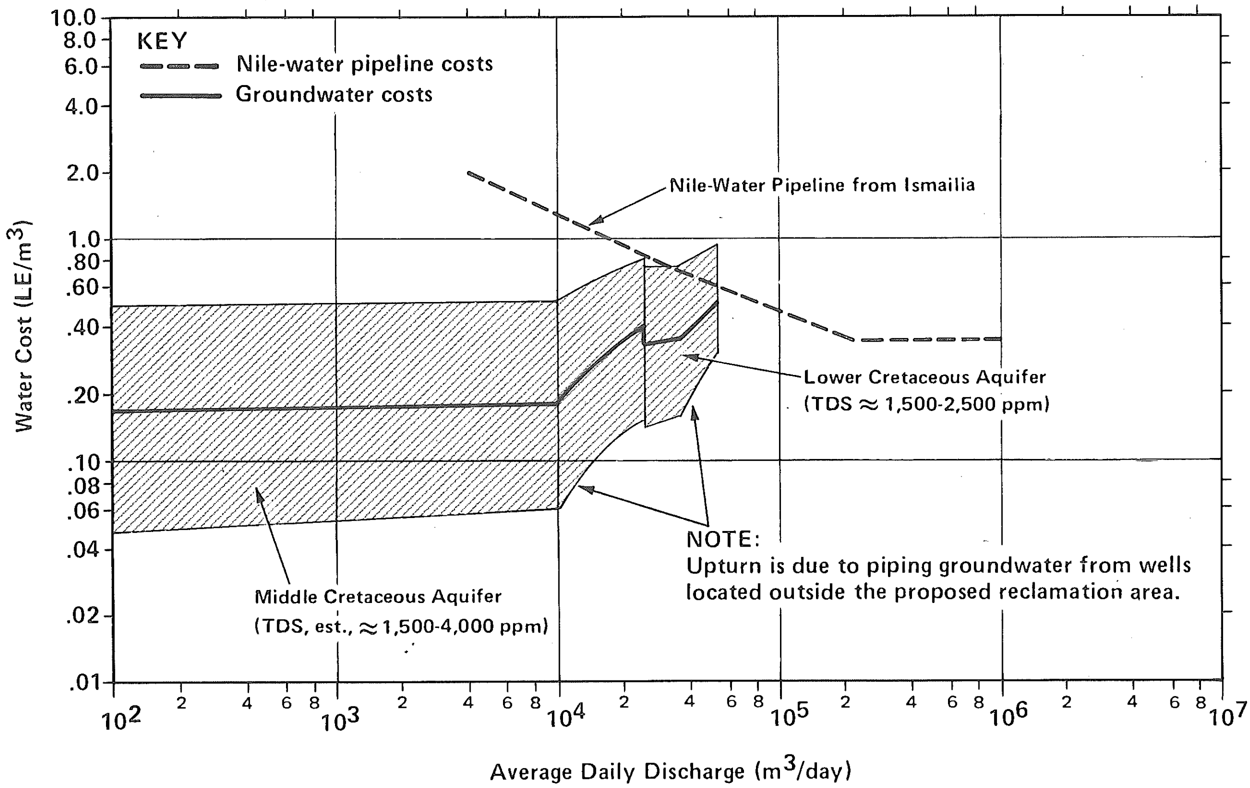

Figure 4.8(b) Middle Wadi El Arish - Wadi El Gayifa Area

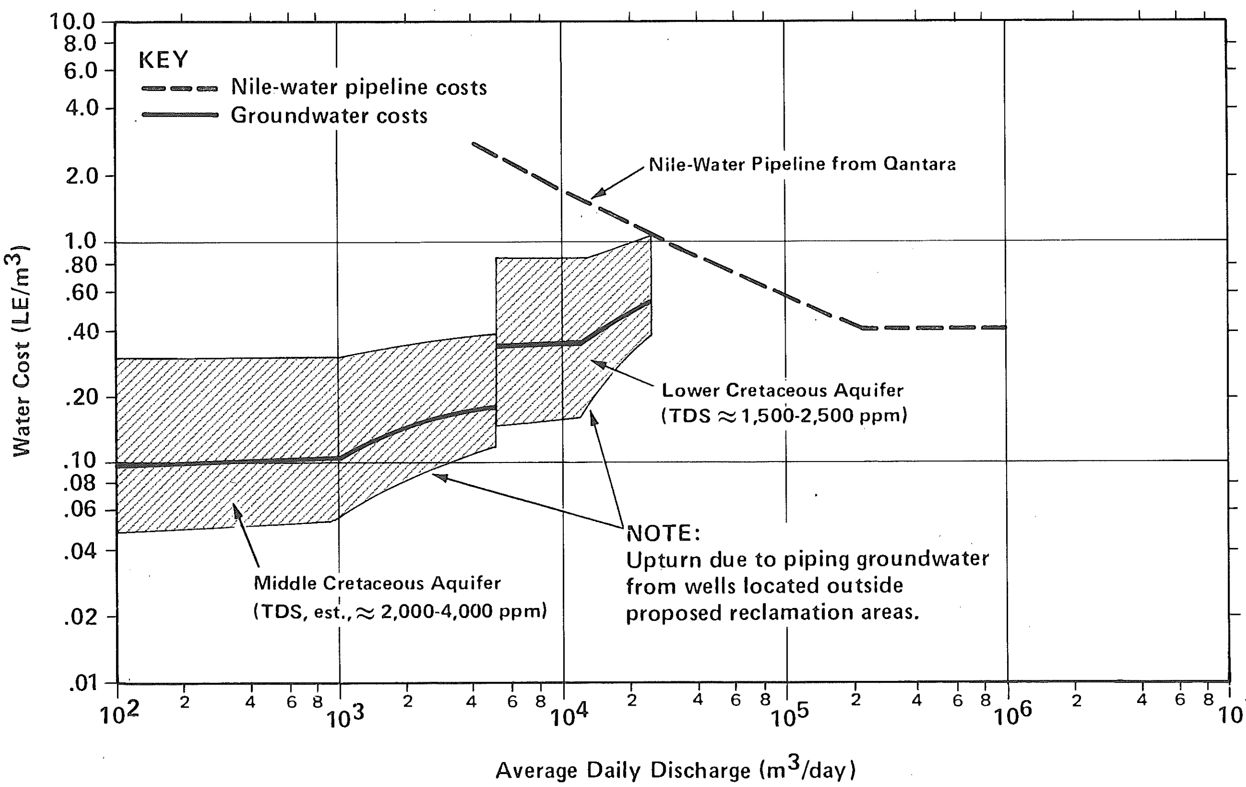

FIGURE 4.8

GENERALIZED WATER-COST CURVES:
WADI EL BRUK AND MIDDLE WADI EL ARISH

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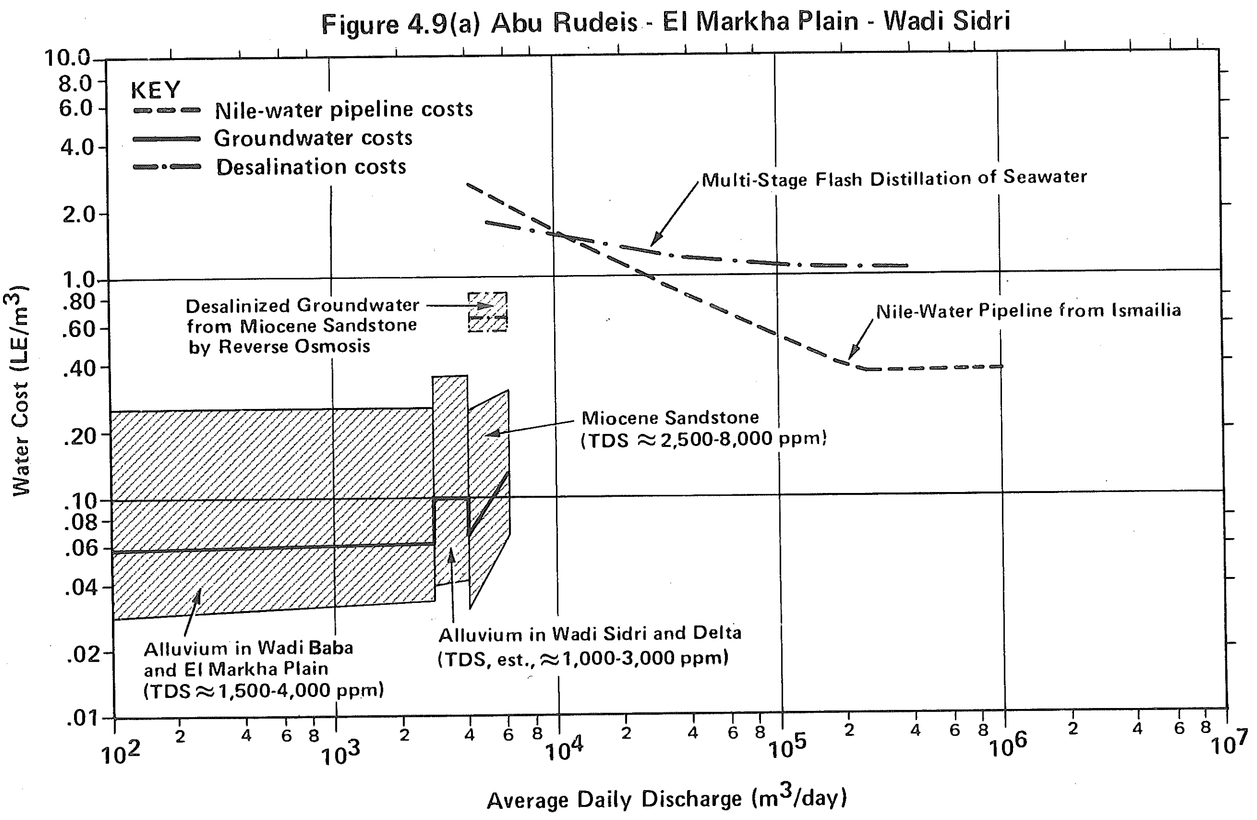

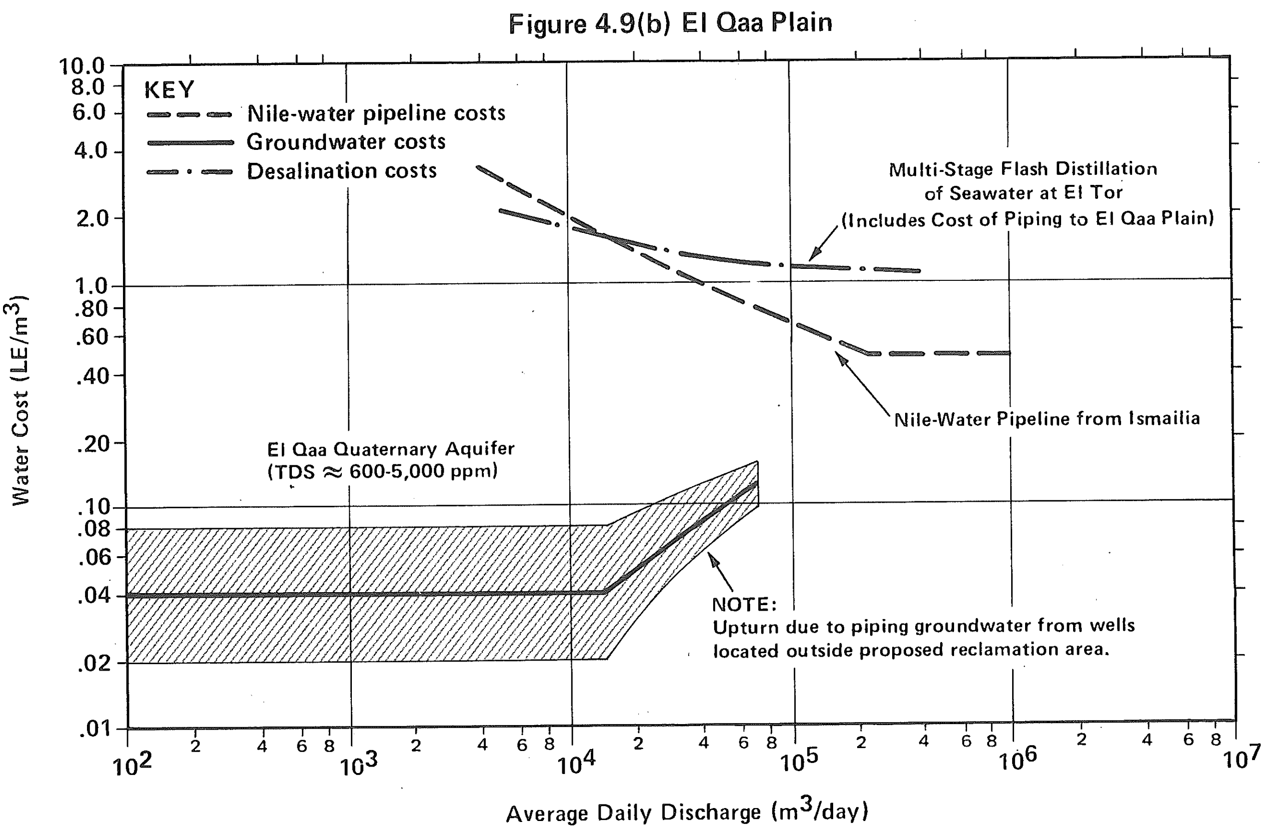

FIGURE 4.9

GENERALIZED WATER-COST CURVES: ABU RUDEIS AND EL QAA AREAS

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unit. In certain areas were another aquifer is available at a higher price, the cost band for this aquifer is indicated just to the right of that for the first aquifer. The quantity of water available from the second aquifer is indicated by the length of the band (the abscissa value at the right-hand end minus the abscissa value at the left-hand end). Where desalinization of groundwater could be considered, the costs shown on the desalinization curves include the cost to produce the groundwater and any pipeline conveyance costs. In all cases the estimated quality of water in terms of total dissolved solids (TDS) in ppm is indicated for each aquifer unit.

Water-cost curves are useful in selecting a particular water source for an area, or a particular combination of water sources to serve an area. For example, in the Sheikh Zuwayid-Rafah area (See Figure 4.6(b)) groundwater would be available only up to an estimated 30,000 m^3/day at a cost of LE 0.05 to 0.10/m^3 for the Pliestocene Aquifer and LE 0.12 to 0.17/m^3 for the Surficial Coastal-Sand Aquifer. Beyond 30,000 m^3/day it would be necessary to import water, the next least expensive source. The figure shows that if an additional increment of 30,000 m^3/day were obtained by pipeline from the Nile, the cost of water would rise to LE 0.75/m^3, while if an additional increment of 150,000 m^3/day is obtained, the water cost would decline somewhat to LE 0.36/m^3.

In another example cost curves for the Wadi El Bruk area (Figure 4.8(a)) clearly indicate the uncertainty with respect to the cost of groundwater from the Middle Cretaceous and Lower Cretaceous Aquifers. Taking the low end of the range, it might make sense to develop both aquifers up to their combined maximum quantities appropriate for the proposed reclamation area, estimated to be 53,000 m^3/day, and then utilize Nile water for an equal increment or more. But at the high end of the cost range for groundwater, it would pay to exploit only the Middle Cretaceous Aquifer for an estimated 25,000 m^3/day, and then to utilize Nile-water pipelines, assuming that the additional increment from such a pipeline would at least equal 25,000 m^3/day.

4.7 CONCLUSIONS

The water sources for Sinai--groundwater, desalinized seawater or brackish groundwater, Nile water and surface water--all have their unique cost characteristics. In general, the cost to develop groundwater is less than the others; however, the estimated quantity of groundwater is quite limited, and there is considerable uncertainty regarding both the quantity and the quality of many of the aquifers in different places. Generally, Nile and drainage water supply is the least expensive source after groundwater. For large diversions of Nile water by pipeline for irrigation purposes (average daily discharge of 200,000 m^3/day or more), water costs range from about LE 0.07/m^3 for the northwest Baloza-Negila area, to over LE 0.50/m^3 for the southwest El Qaa Plain. It is interesting to note that the costs for Rafah, Bir El Thamada and Abu Rudeis are about the same order of magnitude, assuming Ismailia and El Qantara take-offs.

The capital costs required for the proposed Nile-water pipelines are more than 20 times the cost of developing the other types of water supplies. For the primary pipeline systems, the capital cost for the Frontier and All Coasts Strategies was estimated to be LE 2.8 billion and LE 1.5 billion, respectively. The Dispersed alternative would have cost LE 5.5 billion.

After discussion with the Steering Committee and further analysis the Consultant prepared a Recommended Strategy, summarized in Volume I of his Report, which calls for investment of over LE 2.2 billion in the primary conveyance system bringing Nile water to four of the five sub-regions of Sinai.

The alternative strategy calculations were all based on a population of about one million in the year 2000; therefore, the primary water conveyance cost was seen to vary from LE 1,500 to LE 5,500 per person. Costs for the Recommended Strategy were estimated at nearly LE 2,300 per person.

5.0 WATER PLAN

5.1 INTRODUCTION

This water plan has two purposes: to set the direction for water planning in the Sinai Peninsula and to recommend key elements of a long-range Sinai master plan for water. It is preliminary in nature.

Three elements of the water plan are presented here: a water strategy fitted to the overall development strategy, a framework for management of water in Sinai, and early research and development projects.

Volume I of this report, after considering various alternatives, describes a Recommended Strategy for the settlement of Sinai. In the following section the water strategy implications of three alternative strategies are discussed. That is, we address what the nature and extent of the supply of water from the several sources would be for each development strategy up to the year 2000. (See Table 5-1). The overall strategy recommended in Volume I represents a synthesis of the alternatives considered earlier; consequently, the water plan presented in Volumes I and III has been fashioned out of the analysis presented here and components considered in the context of the three possible alternatives at an earlier stage in the study.

Section 5.3 presents a framework for the management of all existing and future water resources on the peninsula. Management proposals include arrangements for the consistent monitoring and prudent development and conservation of all water supplies whatever development strategy is adopted for Sinai. The organizational structure and staffing needed to accomplish the objectives of efficient water management in Sinai are explored. Section 5.4 describes an organizational structure that is required immediately for the management and monitoring of groundwater in the El Arish-Rafah area (eastern zone of the Northeast Subregion).

The last component of the water plan, presented in Section 5.5, recommends water-related research projects for implementation in the very near future. These projects are largely investigative studies that would broaden the essential information base presented in this volume for rational water planning in the next several years. The information to be provided by these projects will confirm, or modify in an important way, the conclusions presented in Section 5.2. The recommended studies projects would cover the following topics:

- Groundwater potential (including an exploratory drilling program)
- Feasibility of constructing large pipelines versus canals in different parts of Sinai
- Rainfall and runoff patterns
- Cloud-seeding in Sinai
- Feasibility of storage reservoirs.

TABLE 5-1

Sinai Water Demands and Proposed Allocations of Nile Water, in the Year 2000, by Subregion, for the Recommended Strategy and Three Alternatives
(million cubic meters per year)

Subregion and Use	RS	FR	DI	AC
	Nile Water			
Northwest, subtotal	550.7	263.2	291.3	193.1
Irrigation	544.8	255.4	282.3	188.0
Public Supply	4.3	7.1	6.3	4.5
Industry and Tourism	1.6	0.7	2.7	0.6
Northeast/Uplands[a/], subtotal	808.1	1,184.5	1,477.0	294.9
Irrigation	784.1	1,165.9	1,457.6	278.7
of which Uplands	(411.3)	(827.4)	(1,084.8)	(57.5)
Public Supply	17.4	17.4	18.5	14.9
Industry and Tourism	6.6	1.2	0.9	1.3
Southwest, subtotal	250.5	6.2	548.0	108.5
Irrigation	170.6	b/	542.6	103.4
Public Supply	3.5	1.5	1.3	3.3
Industry and Tourism	76.4	4.7	4.1	1.8
Southeast, subtotal	b/	b/	b/	b/
Nile Water, subtotal	1,609.3[c/]	1,453.9	2,316.3	596.5
	Groundwater[d/]			
Northwest, subtotal	e/	e/	e/	e/
Northeast/Uplands[a/], subtotal	38.1	23.2	38.0	23.7
Irrigation	35.2	20.7	35.2	20.7
of which Uplands	(15.2)	(0.7)	(15.2)	--
Public supply	2.8	2.4	2.8	3.0
Industry and Tourism	0.1	0.1	--	--
Southwest, subtotal	47.9	46.1	50.7	7.3
Irrigation	44.2	45.4	46.0	1.8
Public Supply	1.8	0.6	2.8	2.5
Industry and Tourism	1.9	0.1	1.9	3.0
Southeast, subtotal	12.8	6.2	6.7	8.5
Irrigation	11.1	3.9	4.6	5.3
Public Supply	1.2	1.6[f/]	1.6[f/]	1.6[f/]
Industry and Tourism	0.5	0.7	0.5	1.6[f/]
Groundwater, subtotal	98.8	75.5	95.4	39.5
Total Water Demand	1,708.1	1,529.4	2,411.7	636.0

FR, DI, and AC represent Frontier, Dispersed and All Coasts alternative strategies considered at an early stage in the 1983 analysis. RS is the Recommended Strategy proposed by the Consultant after discussions with the Steering Committee and further analysis. The Recommended Strategy is summarized in Volume I of this Report.

a/ Uplands not originally considered a separate subregion. Prior to formulation of the Recommended Strategy, Uplands requirements were included with those of the Northeast subregion.

b/ Groundwater only.

c/ Total Nile water requirement for irrigation is 1,499.5 million cubic meters per year; the estimated requirement for all other uses is 109.8 million cubic meters.

d/ Including desalinized groundwater.

e/ No significant quantity of groundwater yet proven in this subregion.

f/ Between 800,000 and 1.4 million cubic meters per year desalinized groundwater included. No other figure includes more than 600,000 cubic meters per year of desalinized groundwater.

Source: Calculations by the Consultant. See also Tables A-6 to A-8 in the Appendix.

In summary, the study's water plan consists of three parts:

- Water strategies consistent with the overall strategies for development and settlement of Sinai

- A framework for the efficient management of water in Sinai

- Steps recommended to complete essential research and investigations

5.2 WATER-SUPPLY DEVELOPMENT UNDER ALTERNATIVE DEVELOPMENT STRATEGIES

In selecting the specific water supply and source for each need and community, reference was made to the water-cost versus quantity curves prepared for eight representative areas of Sinai. These curves were particularly helpful in the selection process as they indicate not only the comparative costs of different sources and quantities of water, but also the estimated limit of availability of local groundwater. In addition, during this planning process, pertinent information on groundwater availability and quality in other areas was used to estimate the probability of each local groundwater source providing for the expected water demands of the local community.

The Recommended Strategy and three alternatives considered earlier would impose demands for fresh water varying from about 636 to over 2,400 million cubic meters a year as detailed in Tables 3-6 and 5-1 earlier in this volume. There is considerable uncertainty concerning groundwater availability and quality in many areas. As discussed in Chapter 2, the quantities of available groundwater in Sinai are estimated to be relatively low. Consequently, the alternative water strategies include as a major component the transfer of Nile and drainage water into Sinai. This involves high capital costs, as discussed in Chapter 4, but offers no apparent engineering difficulties.

The construction of large-diameter pipelines to convey Nile water to the major reclamation areas is postulated. Over certain sections of each conveyance corridor it may be economically advantageous to transport the water by canal, and thus some cost savings could be effected. This could be the case in the Wadi El Bruk area, for example, between Bir El Thamada and El Hasana, over which distance there is a more or less steady downward slope in the land surface. The feasibility of utilizing canals rather than large pipelines in such areas would depend on the size of each reclamation tract finally selected, and on the distance between tracts. Based on the land capability analysis (Volume IV), the reclamation tracts selected following reconnaissance and detailed soil surveys are likely to be of modest size--each perhaps 5,000 to 15,000 feddans in extent--and separated by relatively large stretches of land not capable of being reclaimed, using normal methods.

Consequently, the use of canals for the primary transport of Nile water to each such reclamation tract would probably involve such large losses due to seepage and evaporation that their use could not be justified. The final decision in this regard, however, must await the performance of the necessary soil surveys for the potential reclamation areas recommended in this study and prefeasibility studies. Meanwhile, one possible system of conveyances, consistent with the Recommended Strategy, has been sketched in Figure 5.1.

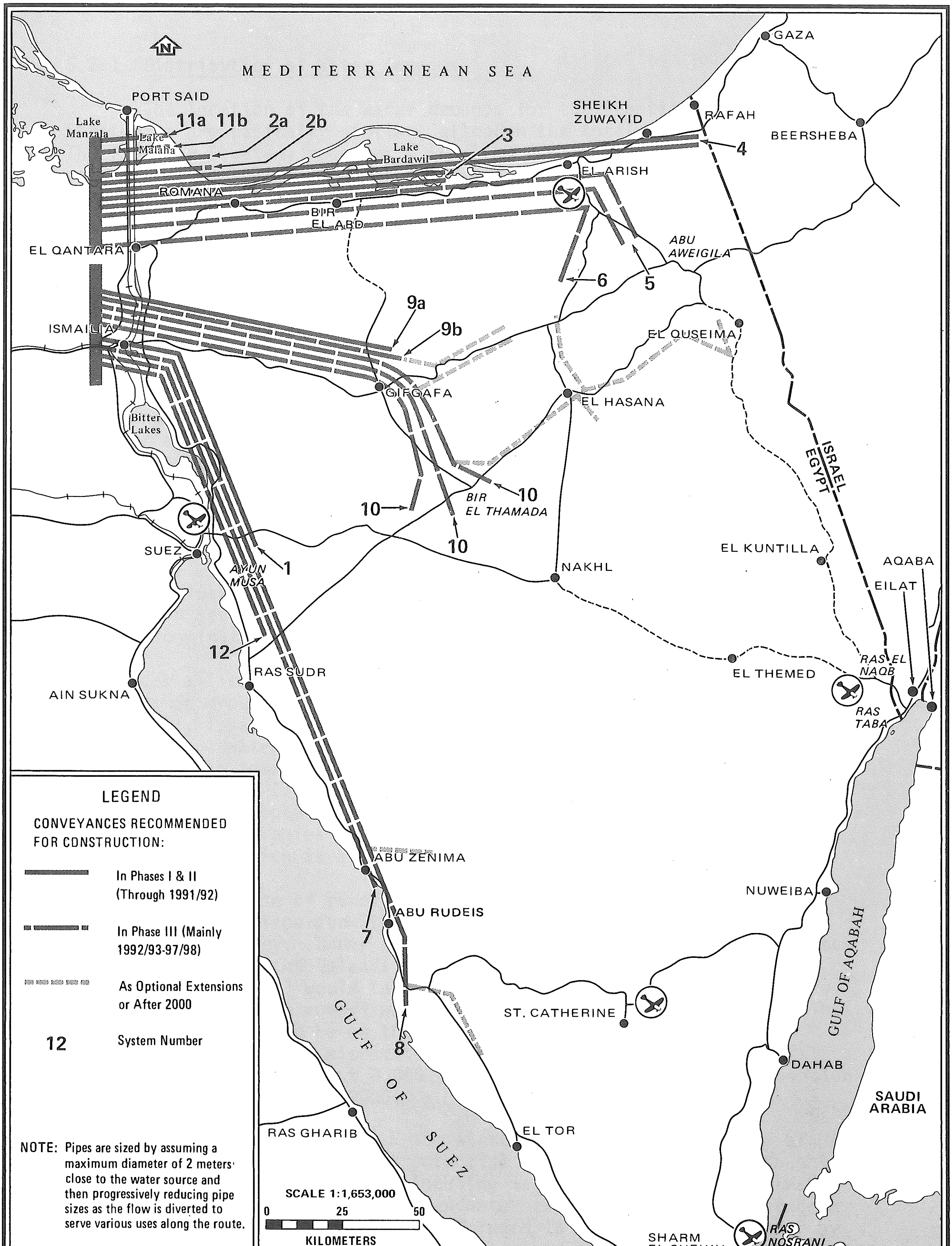

FIGURE 5.1
RECOMMENDED STRATEGY: SCHEMATIC DIAGRAM OF MAJOR WATER CONVEYANCES

5.2.1 Distribution of Water Demands

The location of the water demands for the Frontier and Dispersed Strategies are basically similar, although the total quantities differ. The Frontier Strategy requires a total of 1,525 million cubic meters per year for agriculture, of which 1,453 million would be Nile water, compared to 2,403 million cubic meters per year for the Dispersed Strategy, of which 2,283 million cubic meters per year would be Nile water. The comparable figure for all the All Coasts Strategy is 641 million cubic meters per year, of which 570 million would consist of Nile water. Unlike the other strategies, the Frontier Strategy proposes no pipeline to the Southwest Subregion for the purposes of land reclamation; only modest land reclamation would take place in the El Qaa Plain under this strategy, based on exploitation of the Quaternary aquifer. A relatively small-diameter pipeline carrying Nile water to Abu Rudeis for domestic and industrial purposes is recommended under the Frontier Strategy. The Recommended Strategy calls for 1,590 million cubic meters of water per year for agriculture, of which 1,500 million cubic meters would be from the Nile system.

All strategies assume that groundwater will continue to be used for irrigation in El Arish and the Sheikh Zuwayid-Rafah Strip area, about 10 million cubic feet per year in each location. However, no increase in groundwater withdrawal in these areas is recommended, pending establishment of, and evaluation by, an El Arish-Rafah groundwater management agency, as proposed in Section 5.4. The Consultant recommends that additional land reclamation in these areas be based on the supply of Nile water.

Under all strategies, many settlements will continue to be largely dependent on groundwater and surface water, including Nakhl, El Themed, El Kuntilla, Taba, St. Catherine, Nuweiba, and Dahab. Desalinization of brackish groundwater supplies will probably be necessary and economically feasible in the tourist centers of Nuweiba, Dahab, and Sharm El Sheikh. In addition, Sharm El Sheikh will continue to receive by pipeline at least a limited supply of potable groundwater from El Tor. Both Frontier and Dispersed Strategies include increased use of well water for livestock watering, which is also emphasized in the Recommended Strategy.

Significant use of runoff water for agriculture was considered mainly under the Dispersed Strategy and is also given priority in the Recommended Strategy. Under these plans cultivation of isolated patches of land located in the Uplands (Gebel El Maghara, Gebel Yelleq, and Gebel El Halal areas) would take place based on techniques for conserving and concentrating runoff water, as described in Section 2.2.2. The primary emphasis would be on the increased use of spreader dykes on runoff farms, including microcatchments, initially on an experimental basis. A total of at least 2,000 feddans of land under such cultivation is envisaged for the year 2000.

The study team agrees with the stated policy of the Ministry of Irrigation that the groundwater potential of Sinai should be thoroughly explored and evaluated before allocating large quantities of Nile water to Sinai. In this regard, the groundwater exploratory drilling program in Sinai is presently being carried forward in an expeditious manner by the Institute of Water Resources. But because of the urgency of Sinai development, the simultaneous initiation of prefeasibility studies on Nile water transfer to Sinai (such as those described in Section 5.5.4) is recommended

5.2.2 Water Conservation and Reuse

Two general approaches can be adopted to optimize water use under the Recommended Strategy.

- The establishment of practices to limit future water use
- Water recycling or reuse of waste and drainage waters.

5.2.2.1 Improving Water-Use Efficiency

Improving water-use efficiency involves the dissemination of techniques for effective water use and management, combined with the establishment of incentives to apply the water-saving technology. In the agricultural area, water for irrigation may be applied in excess of crop and leaching requirements. Information is needed regarding the best irrigation methods and the optimal quantities of irrigation water required for various crops under Sinai conditions. The agricultural research stations, recommended in Volume III and Working Paper No. 35, have as one of their objectives the determination of maximum yields available for each crop per unit of water. This involves determination of the optimum times of irrigation for each crop, along with the applicable quantities. With this information, it is possible to produce the maximum quantity of foodstuffs with a limited water supply, such as exists now at El Arish. Once the technology of irrigation water management in Sinai has been determined, an information and dissemination system and procedure is needed to teach them to the farmers.

The next step is to provide the incentives or sanctions that encourage water users to apply water-saving techniques. With respect to groundwater, the scope of a water management agency would include review of applications for new wells, issuance of permits for wells, determination (measurement) of well discharges, and possible establishment of water fees. Such an agency could, of course, exercise direct control of well discharges and the groundwater diverted for irrigation. Alternatively, it could apply control solely through appropriate pricing of the water pumped. Users, having to pay for water, would have an incentive to use the water wisely. In the reclamation areas to be irrigated by Nile water, control over water use could be handled in a similar fashion.

In setting a water fee schedule, differentials should be considered for different types of uses, and for different regions. Fee subsidies may sometimes be justified but even then the fee level should be high enough to ensure that the water will be used sparingly. The entire matter of fee-setting is a policy matter to be decided by the National Government after considering the analysis and recommendations of the proposed Sinai Water Authority and its policy board.

5.2.2.2 Water Reuse

Recycling and reuse of both wastewater and irrigation drainage water should be considered. It is recommended that a sewage treatment system be established at El Arish (and other cities as they develop) to include recharge of the treated wastewaters into the Quaternary aquifer. Several types of secondary and tertiary treatment have been used throughout the world in preparing wastewater for groundwater recharge.

In the Dan region sewage reclamation project in Israel, use is made of a system of stabilization ponds that consist of aerobic facultative recirculated ponds. The effluent from the stabilization ponds undergoes lime treatment in an upflow solid-contact clarifier for removal of algae, and then enters detention ponds for ammonia stripping and pH balancing. The effluent is then pumped to recharge spreading basins located in the sand dunes, where it recharges the local aquifer. The organic load permitted in the ponds in 1972 was 23 grams of biochemical oxygen demand (BOD) per square meter of pond area. The cost of this type of treatment is said to be less than that for more conventional plants involving mechanical equipment. (0755)

Careful management of the recharge basins will ensure maximum intake rates. The size of the area dedicated to the recharge basins will be a function of the design flow for the treatment system and the final infiltration rate of the soils, to be determined by field tests. The area selected should be large enough to allow for the regular "resting" or drying of the recharge basins in rotation, followed by mechanical scarification and possible chemical treatment -- all required to maintain as high an average intake rate as possible. The selection of areas for recharge basins should be guided by the available subsurface stratigraphic data, so that the hydraulic connection between the recharge basins and the underlying aquifer can be reasonably assured.

A treatment process similar to that described for the Dan region is probably appropriate for El Arish. Preliminary design concepts for such a system should be prepared and evaluated.

Once the wastewater reuse system envisioned has been established at El Arish and the results have been reviewed for a year or more, similar systems -- appropriately modified -- could be considered for El Tor, Ras Sudr, Abu Rudeis, and other towns expected to grow to city size.

The reuse of irrigation drainage water is dependent on topographic and soil characteristics. Under certain topographic conditions, it may be impractical to collect and pump the collected drainage water to potential points of use. Irrigated soils often contain a large amount of soluble salts that tend to leach out with the drainage waters. If the resulting salt content of the drainage water is too high, it may be difficult to use, even after mixing with a large portion of fresh water. A productive reuse of drainage water under certain conditions is aquacultural in tanks or cisterns. Halophytic plants, including date palms and barley, can be grown on recycled saline drainage water.

The reuse of irrigation drainage water may be practical in both large and small proposed reclamation areas. The conveyance systems and pumping stations in these areas should be designed to permit the recovery of drainage waters and their mixing with Nile water for use on the crops. Recycling and reuse may receive the highest priority in those areas listed in 5.2.1 as relying permanently on ground and surface water, principally in the eastern Uplands and the Southeast subregion.

5.3 WATER MANAGEMENT

Efficient management of water resources involves the optimum exploitation and use of water resources whereby the water needs for Sinai development are met and, at the same time, each water resource is conserved and protected to the extent possible. This management of water resources consists of the control and allocation of each water supply on a rational basis that takes into consideration both present and future development needs of Sinai as well as the whole of Egypt. Efficient management will involve the flexible allocation and reallocation of water from all the available water sources, each particular pattern of allocation depending to a large extent on both the availability of each water supply and its relative cost.

Information Base

An essential component of the management system herein proposed for Sinai is the information base on water-resource availability, quality, and use rates. Such a water information base needs to be continuously updated and renewed. A good starting point for such an information base can be found in the current Sinai data-collecting activities of the Institute of Water Resources, the files and publications of the Desert Institute, and the information brought together for the present report.

Groundwater Conservation

The management of groundwater would form an integral part of the overall management of the peninsula's water resources. In each location, groundwater-use quotas would be established for each aquifer, based on an evaluation of the safe yield in the given area. Safe yields would be arrived at by a thorough analysis of the available groundwater data for the area. For the purposes of water management in Sinai, the following definitions may be used:

- Safe yield -- the maximum withdrawal rate from an aquifer, which will result in neither significant deterioration of groundwater quality nor excessive lowering of the pumping water level in wells
- Excessive lowering -- beyond a maximum acceptable pumping cost
- Significant deterioration -- salinity beyond the water-quality requirement for the major expected use in a given area.

In certain cases, a policy decision could be made that the computed safe yield for an aquifer may be exceeded for a specified period of time in order to provide more water for some development purpose, provided such excessive pumpage involves only a decline in the water levels and no unacceptable deterioration in quality. In this case, government may take into consideration the increased pumping costs involved and provide subsidies to cover these costs. Only in rare cases, however, would it be advisable to plan to withdraw essentially all the economically extractable groundwater from any of the aquifers in Sinai, which are recharged only very slowly.

The scientific evaluation of groundwater, performed by experienced hydrogeologists, is a vital element of water management.

5.3.1 Functions of Sinai Water Management

The Consultant presents water management suggestions under the general heading of "The Sinai Water Authority." This is one option amongst several for management of this resource. The functions discussed hereafter could also be assigned to more than one agency, since the water problems vary from one subregion to another. Alternatively, these functions could be assigned to a water department within a comprehensive development agency.

The primary functions of a Sinai water authority would include the following:

- Collect, process and monitor information
- Establish and manage water allocations
- Plan and possibly implement new water-development projects
- Maintain water-supply civil works
- Establish and enforce a system of incentives and/or sanctions
- Provide education in good water management techniques.

Information System and Monitoring

This function involves the collection, analysis, and storage of routine field data and monitoring data as well as performance of certain exploratory and research programs related to water-resource development. Information would be obtained and maintained in six general sectors:

- Rainfall and dew
- Local surface-water supplies
- Groundwater
- Desalinization
- Nile-water supply
- Waste and drainage water

For local surface water a system of runoff-measurement gaging stations would be established in conjunction with a network of raingage stations. Rainfall-runoff relationships would be established initially on the basis of intensive studies on selected small basins, such as are now underway by the Institute of Water Resources. Based on this information, estimates of runoff yield and release rates from possible reservoirs at selected sites in Sinai would be made. The analysis of meteorological data leading to the design and performance of cloud-seeding experiments would be performed, and the results of such experiments and their interpretation would form a part of the water information base.

For groundwater, information on the areal extent, yield potential, water quality, recharge from agricultural and urban uses, and trends in pumpage and water levels would be maintained for each major aquifer -- most particularly for those listed below:

- The Quaternary aquifers of El Arish, Rafah, and the El Qaa Plain
- Miocene Sandstone aquifers in certain areas
- The Middle Cretaceous unit
- The Lower Cretaceous and older contiguous sandstone
- The Crystalline aquifers of South Sinai.

Trends in groundwater quality or water-level fluctuations would be identified and the documentary data, with conclusions, communicated to the authority responsible for setting groundwater quotas.
Also included here are the groundwater exploratory functions in which test drilling and aquifer tests would be performed and documented. Data would include well logs, pumping-test results and results of water-quality analyses.

Detailed spring and water-well field inventories would be undertaken to extend the knowledge of aquifer characteristics, supplementing the water-point inventories reported in this volume and those performed by the Desert Institute. In addition, rates of groundwater withdrawal and recharge would be recorded for each major well at regular intervals. Based on the perceived needs for increased groundwater development in the area, consideration could be given to the possibility of performing computer-based groundwater modeling of aquifers on which there are sufficient data.

A relatively small but important function of the information system would involve maintaining up-to-date process and cost data on the different methods and commercial units developed for desalinization. Details on plant-unit energy requirements, capital investment costs, and other pertinent specifications would be maintained in an easily retrievable form.

Details on existing Nile water supply systems in Sinai, including diversions, gates, and pumping stations as well as quantities of flow, would be maintained and updated on a rigorously regular basis as a portion of the national Nile water management program. Frequent monitoring of the Nile water supply systems would permit the regular updating of information on the condition and maintenance schedules of canals, pipelines, pumping stations, and other appurtenances.

Regular monitoring of waste and drainage water quantity and quality will be a vital link in the Sinai water information system, as a regular and/or reserve resource. For instance, reprocessed wastewater might normally be used to irrigate crops; in an emergency it could be subject to further processing and used for consumption.

Information on Sinai water resources, including regular monitoring data, may be stored in an electronic data processing (EDP) system. Such a system should permit easy entry and updating of data and provide for easy retrieval of the information in the form of simple tables and charts. In addition to the technical information appropriate for each of the six sectors mentioned above, cost data should be obtained and updated on all aspects of water-development and water-use capital costs as well as on operation and maintenance costs.

Water-Supply Development and Control

This function includes the following elements;

- Establishment and management of water allocations
- Planning and implementation of new water development projects
- Maintenance of water-supply civil works

As part of the water allocation function, water-diversion quotas would be set by the Authority, based on information and recommendations provided from the information-system section. Such quotas would be based on the availability and quality of surface water, groundwater, and Nile water supplies. As their quality or availability varies, as monitored, the quotas would be adjusted appropriately. Permits would be issued to qualified users and these would specify the quantities and times of diversion or groundwater pumpage that would be allowed. Authority staff would make frequent, but unannounced, field inspection visits to insure compliance with the permit requirements.

The planning and implementation of new water-supply projects requires technical feasibility studies and financial analyses for those projects appearing to offer the best chances for success -- whether a surface-water, groundwater, desalinized water, wastewater, or Nile water supply project. At the implementation stage, the water authority would provide for engineering design, the necessary procurement for the selected project, and supervision of the works involved.

Regular inspection and maintenance of all the civil works connected with water supply would be established on a schedule for each type of works. Data on work performed and condition of the works during each visit would be provided to the information system for review, and evaluation of feasible modifications in the review schedule.

Enforcement of Incentives and/or Sanctions

This is an optional function. The need and advisability of charging for water should be considered. From the purely financial point of view, it may be desirable to set some reasonable fee to charge water users to recover, at least in part, the money invested in the water-supply works and required for their operation and maintenance. As an alternative or complement to water fees, penalties for misuse of water may be set and enforced.

Education

A water-use education program might well be a regular function of the Sinai Water Authority. Water costs and use are quite different in the peninsula as compared to Nilotic Egypt, and new immigrants or pioneers will need orientation to a new water regime. Education will encourage responsible use of water and water equipment.

5.3.2 Organizational Structure

The Sinai Water Authority might have an organizational structure such as that discussed below. Three departments would be responsible for the following major functions:

- Water-resources information and monitoring
- Water-supply development and control
- Enforcement of good water practices.

The water-resources information/monitoring department would be closely linked with the water-supply development and control department. The latter would depend heavily on the information and the results of analysis from the former department, both for setting water-diversion quotas as well as for planning and implementing new projects.

The policies under which the authority would operate (e.g., regarding use enforcement and criteria for undertaking new water-supply projects) may be established by a supervisory policy board. The charter of the board would include the stipulation that the policies subsequently set forth by the board would be consistent with national Water Master Plan. The membership of the supervisory policy board might include the following:

- Minister of Irrigation
- Minister of Defence
- The Five Sinai Governors
- Director of the Sinai Development Authority
- The President of the Suez Canal Authority

The Sinai Water Authority would be headed by a director who would have full responsibility for the activities of the authority. He would report directly to the supervisory policy board on all policy matters and would be responsible for carrying out the policy decisions of that board. On all other matters, such as those dealing with staffing, organizational concerns, and technical requirements of the authority, he might report to the Minister of Irrigation. The heads of each of the three departments would report directly to the director.

5.3.3 Staffing

The senior staff of the water authority should be recruited from knowledgeable and proficient professionals who have had considerable experience in Sinai or similar areas. The director should be an individual with demonstrated professional experience in water-resources administration and management involving groundwater as well as large-scale distribution and use of surface water.

The water-resource information and monitoring department should be staffed by scientists and engineers of proven professional ability, possibly recruited from several Ministries or Institutes. For example, surface-water hydrologists and modelers may be recruited from the Institute of Water Resources, hydrogeologists from the Desert Institute, and a meteorologist from the Meteorological Authority. Experienced engineers from the Ministry of Irrigation and professional hydrogeologists will be required to staff the Nile water supply system branch as well as the New Projects Branch. Skilled managers, administrators, and accountants are needed for the water-allocation branch as well as the education and enforcement sections.

It is recommended that all the staff be permanently located in Sinai. Adequate incentives -- including attractive salaries as well as suitable housing and schooling facilities -- would ensure that high-caliber personnel are induced to join the authority. Centrally located, Bir El Thamada might be considered as a temporary control office location. Two or more field or subregional offices may be advisable, particularly for staff involved in monitoring and in the collection of water-resources data.

In addition to the senior and professional staff needed for the supervisory, analytical, and evaluation functions, a range of technicians, mechanics, and compliance field staff would be required. These staff would be involved, respectively, in the collection and compilation of water-resources data, including monitoring data; the maintenance and repair of the civil works associated with the water-supply systems; and the inspection of water-diversion compliance relative to permit authorization. The authority would probably have to establish a central workshop for facilitating the repair of various components of the water-supply system, including pumps and engines.

5.4 GROUNDWATER MANAGEMENT/MONITORING PROPOSAL FOR SELECTED GROUNDWATER BASINS

One of the first programs that should be undertaken is the institution of a systematic groundwater monitoring and pumpage control program for specific areas where it is known that overpumping of aquifers is occurring or is likely to occur in the near future. Primary locations for such a program are the El Arish-Rafah area and the El Qaa Plain, where several irrigation wells have recently been drilled in the Quaternary aquifer by REGWA. Groundwater monitoring and control in the El Arish-Rafah area is an immediate concern. First steps in establishing a groundwater monitoring system for El Arish were undertaken by the Institute of Water Resources in 1983.

5.4.1 El Arish-Rafah Groundwater Management Agency

A temporary agency (the El Arish-Rafah Groundwater Management Agency) could be created under the Sinai Development Authority, or the North Sinai Governorate, with the guidance of the Desert Institute, could perform this function.

It is recommended that the proposed temporary El Arish-Rafah agency comprise a monitoring/data-processing branch and a groundwater allocation branch. The monitoring/data-processing branch would be responsible for the regular collection, analysis, and interpretation of groundwater data, particularly with respect to trends in groundwater levels, groundwater quality, and groundwater pumpage. Data on all new wells drilled in the area would also be collected, processed, and interpreted. The groundwater allocation branch would be responsible for establishing groundwater pumpage quotas, issuing permits to qualified well owners and performing compliance inspection to ensure that the permitted pumpage quotas are not exceeded. The pumpage quotas would be set initially by the agency for each area and for each well within the area, and would be reviewed from time to time as more information becomes available. In establishing groundwater quotas, trends in water-level declines and in groundwater quality would be considered along with estimates of groundwater recharge for each aquifer. In certain cases, the groundwater allocation branch might be able to recommend certain well designs or coastal gallery designs that would permit efficient but limited withdrawal of groundwater.

The El Arish-Rafah groundwater management agency would be administered by a director or head, who would have demonstrated professional experience in all aspects of hydrogeology and in administration. The monitoring/data-processing branch would be staffed by professional hydrogeologists, preferably with some previous experience in the hydrogeology of the El Arish-Rafah area. They would be assisted in the field collection of data by technicians trained in groundwater monitoring and sampling techniques. The groundwater allocation branch would be involved in detailed analysis; quota establishment and permit compliance would require a range of qualified professionals from analytical hydrogeologists to competent managers.

The El Arish-Rafah area aquifers that require immediate monitoring and management are the Quaternary aquifer of El Arish, the Pleistocene aquifer in the Rafah area (which may be hydraulically connected with the El Arish Quaternary aquifer), and the surficial coastal-sand aquifer, probably of recent origin. In all three aquifers, groundwater quality deterioration is a concern, and it appears such deterioration is linked to excessive pumping in many cases.

The deterioration of groundwater quality in the El Arish Quaternary aquifer in an area to the southeast of El Arish was discussed in Section 2.2.3. A line of 35 shallow coastal wells tapping the surficial coastal-sand aquifer was drilled by REGWA in 1983 between Sheikh Zuwayid and Rafah. These wells deserve careful monitoring and control, so that individual pumping rates and the withdrawal rate from the whole system do not become excessive. That is, the withdrawal rates and the pumping schedules must be set so that the salinity of the pumped water does not increase significantly, and so that the nearby land (about 1,000 feddans) cultivated by the "Mawasi" method (soil water supplied by a shallow groundwater table) is not adversely affected by the well pumpage.

The groundwater quality associated with the Rafah Pleistocene aquifer appears to be marginal for many uses, and there is some evidence that its quality decreases in the westward direction, south of Sheikh Zuwayid. The relationship between water quality in this aquifer and location, on the one hand, and pumping rates, on the other, should be investigated by the agency professionals.

The monitoring aspect of the program should include water-level monitoring, water-quality monitoring, and the monitoring and measurement of well pumping rates. Pumping rates should be determined on a daily and seasonal basis for all wells in the vicinity of each well selected for monitoring water levels and water quality. The rates can be determined by flow meters on the discharge line, or by more approximate methods, such as the trajectory method. Initially, water levels should be measured monthly in perhaps 10 to 20 selected wells in each aquifer, and automatic water-level recorders established at 3 key wells in each aquifer. Water-table (or piezometric) contour maps for each aquifer should be prepared from each complete set of water-level data, and the map should indicate the average pumping rate for all nearby wells during the period involved. After 12 months of data have been collected and analyzed, the interval of water-level measurements may be increased from 1 to 2 months.

Water quality sampling should be performed monthly in 10 representative wells in each aquifer, and quarterly in the 10 to 20 wells selected for water-level measurements. The water samples collected monthly should be analyzed only for pH, chloride content, and specific conductance. Samples collected quarterly will be analyzed for the major mineral constituents -- carbonates, bicarbonates, chlorides, sulfates, sodium, calcium, and magnesium, in addition to pH and specific conductance.

Quarterly or semiannual reports should be prepared as part of the monitoring program. They should describe and interpret groundwater conditions as inferred from the collected data, and recommend management practices.

The groundwater monitoring program will require accurate well locations and elevations of the water-level reference point, such as top of well casing. The Institute of Water Resources of the Ministry of Irrigation has recently surveyed many of the wells near El Arish, including the new land reclamation wells. Similar surveying will be required for the wells selected for monitoring in the Sheikh Zuwayid-Rafah strip.

5.4.2 Groundwater Management/Monitoring in the El Qaa Plain

A groundwater management/monitoring program for the Quaternary aquifer of the El Qaa Plain is second in importance only to that for the El Arish-Rafah area.

The REGWA program of drilling 12 irrigation wells in the El Qaa Plain was completed recently, and withdrawals from the aquifer are expected to increase significantly over the next 12 months.

The present water quality of the aquifer appears to be good in most places, but may not always remain so unless careful management of new well construction and well discharges is established. As is the case with the El Arish-Rafah area, a groundwater monitoring program will be a necessary requirement of sound groundwater management. The program should provide the information necessary to set limits on the magnitude and areal distribution of groundwater withdrawals. The aim of such limits is to prevent drastic lowering of water levels and deterioration of groundwater quality as a result of excessive pumping. Initially, all active production wells in the area should be inventoried and surveyed. Accurate coordinates and reference-point elevations should be provided for each well.

The elements of the groundwater management/monitoring program would be essentially the same as those outlined for the El Arish-Rafah area.

For the time being, the necessary data collection, monitoring, and quota-setting functions could be performed by one experienced hydrogeologist employed by the South Sinai Governorate. This individual, together with his functions, would be absorbed into the Sinai Water Authority after its formation.

5.5 IMMEDIATE AND NEAR-TERM WATER-SUPPLY INVESTIGATION PROJECTS

To provide an adequate information base to permit the optimal exploitation and conservation of present and future water resources of Sinai, a series of studies for completion in the very near future is recommended. These projects may be grouped under the major sources of water supply -- groundwater, Nile water, rainfall and dew, and surface-water:

- Groundwater
  - -- Exploratory well-drilling and testing program
  - -- Geophysical surveys in the El Arish-Rafah area
- Nile water
  - -- Prefeasibility studies comparing the use of large pipelines and canals for land reclamation in Sinai
  - -- Prefeasibility studies comparing various take-off points for Nile and drainage water for selected land reclamation candidate areas
- Rainfall and dew
  - -- Improvement of Sinai meteorological network
  - -- Prefeasibility study of cloud-seeding in Sinai
  - -- Prefeasibility study of dew harvesting in the high mountains
- Surface water
  - -- Runoff gaging stations
  - -- Hydrologic studies on small basins
  - -- Evaluation of potential large and small dam sites.

These projects are discussed in the following subsections in the same order as presented above, which is the order of their recommended priority.

In addition to these projects, which may be considered relatively urgent, the establishment of the management/monitoring agency for the El Arish-Rafah area described in Section 5.4.1 should have the highest priority. A sizeable population in this area already relies on groundwater for both domestic and irrigation uses, so it is essential that this resource be both exploited and protected in the optimal manner.

5.5.1 Exploratory Well-Drilling and Testing Program

A preliminary drilling program for Sinai was submitted to the Ministry of Development on February 1, 1981. In May 1981, the MOD was provided with cost estimates for the preliminary drilling program. After reviewing these estimates, it was generally agreed that the expected cost for the drilling was too high to permit implementation of the program in the very near future.

Since that time, considerable additional data on the potential aquifers in Sinai have been collected and evaluated. The drilling program has been modified in certain aspects to reflect the increased understanding of hydrogeologic conditions in Sinai and new cost and strategy considerations, which are discussed in Chapter 4.

The program presented herein has been revised to limit the well depths and minimize the number of deep wells. Moreover, the importance of designing the drilling program to fit the needs of the overall development strategy chosen for Sinai is recognized. This concern led to a further modification of the program--recommended siting of the exploratory wells in locations where, if the wells prove successful, water can be supplied directly to proposed facilities or projects. This program should be further modified following the evaluation of the results of the ongoing exploratory well-drilling program being performed in Sinai by the Institute of Water Resources with external financial assistance from the European Economic Community and perhaps other sources.

A total of 44 exploratory wells is recommended, of which 25 have been given a Priority I rating. The total drilling envisioned amounts to 9,340 meters, for an average of 212 meters per well. The depth per well ranges from 50 to 700 meters. These figures can be compared with the 11,200 meters of drilling planned under the preliminary program, in which the average well depth would have been 303 meters.

A total drilling of 5,230 meters is proposed for the 25 Priority I wells -- at an average depth of 209 meters. In the preliminary program, 19 Priority I wells were proposed -- with a combined depth of 6,200 meters. The average well depth was 326 meters.

Based on the foregoing comparisons, the costs of the modified drilling program should be 80 to 85 percent of that estimated for the preliminary program. In making this rather rough estimate, it is assumed that the additional costs due to increased drill-rig mobilization (because of more wells), plus the incremental costs due to inflation over the past two years, are essentially offset by the incremental savings due to construction of shallower wells.

The remaining 19 wells are classified as Priority II. It is recommended that the drilling program be divided into two phases. The first phase should consist of drilling the 25 Priority I wells. After evaluation of the results of the first phase, the drilling of Priority II wells could be undertaken with appropriate modifications.

The purpose of any water supply resulting from groundwater development relates directly to the water demands arising from the recommended development strategy presented in Volume I. The exploratory wells are located in areas where at least one of the strategies discussed in Chapter 4.0 calls for groundwater use. Therefore, if the wells prove successful and are later converted to production wells, they can provide water directly to the proposed project, community, or facility. In certain cases, it may be useful to equip the successful exploratory wells with experimental windmills to evaluate the feasibility of a wider use of that power source.

It is recommended that the following procedure be implemented for determining the exact location for each exploratory well site:

- Evaluation of the terrain and the relevant geologic structures by analysis of stereo-pair aerial photos of the proposed site area

- Inventory of existing wells within a 0.5- to 1-kilometer radius of the site area

- Inspection and visual evaluation of the site area, leading to a final site selection.

The importance of the proposed exploratory well-drilling program in the evaluation of Sinai's water resources cannot be overemphasized. It is the essential first step for developing the new groundwater supplies required by the development strategy, particularly the rural development and farms and sections of the Uplands and Southeast Subregion.

5.5.2 Geophysical Surveys in the El Arish-Rafah Area

The Consultant recommends performance of surface resistivity surveys in the El Arish-Rafah area to evaluate the extent of seawater intrusion in the El Arish Quaternary aquifer and in the surficial coastal-sand aquifer in the area between Sheikh Zuwayid and Rafah. Additional surface resistivity surveys should be performed southeast of El Arish town and over the area underlain by the Rafah Pleistocene aquifer to provide clues to the source of relatively poor quality groundwater.

Existing well logs and the known groundwater quality for selected key wells in these areas would be used for calibration and interpretation of the results. Several vertical soundings will probably be required along the coast and in the areas of poor-quality groundwater. In addition, surface-resistivity traverses, at fixed electrode spacings, would be performed in each area. One crew of three to four persons, including a geophysicist, would be required for 20 to 30 working days in each of the three areas--El Arish, the Sheikh Zuwayid-Rafah coastal strip, and the area around Rafah and westward (several kilometers south of the coast). The field surveys would be followed by office analysis and data interpretation.

5.5.3 Detailed Pipeline versus Canal Feasibility Studies for Conveyance of Nile Water

In Section 5.2 it was recommended that, in most cases, large pipelines rather than canals be used for conveyance of Nile water in Sinai (up to 2-meter diameter). The basis for this recommendation lies in the results of this study's land capability analysis (Volume IV) which indicates the likelihood that land suitable for reclamation will be found in relatively small tracts, each of which may be relatively isolated from one another. Hence, to avoid significant water losses through seepage and evaporation from canals during the conveyance between adjacent tracts, the use of large pipelines was tentatively recommended.

The final recommendation regarding the use of large pipelines or canals cannot be made until the ongoing REGWA soil survey in northwest Sinai is complete, and until similar soil surveys are performed in other areas of Sinai, including the Gifgafa, Wadi El Bruk, and Middle Wadi El Arish areas in North-Central Sinai, and in the Abu Rudeis, Wadi Feiran delta and El Qaa areas in the south.

While soil surveys are underway and their results are being interpreted, a prefeasibility study should be undertaken to compare the use of large pipelines versus canals to convey Nile water to each of the tracts identified for reclamation. Such a prefeasibility study(s) should include comparative cost analyses, estimated construction schedules, and the environmental and social effects of canals and large pipelines for each proposed corridor.

At the same time, a prefeasibility study of alternative take-off points from the Nile and various canals should be undertaken for each of the major land reclamation cluster areas; take-off points studied should include Minia, Beni Suef, Maadi, Cairo, Ismailia, and Suez.

5.5.4 Improvement of Meteorological Network

As mentioned in Section 2.2.1, the available meteorological data and the pre-1982 network of meteorological stations are inadequate for a reliable assessment of Sinai water resources. Hence, upgrading and expansion of the present meteorological network are recommended.

As a part of its Sinai water-resources investigation, the Institute of Water Resources is undertaking a program to perform the recommended upgrading and expansion of the meteorological network. We understand that new first-order stations have already been established at the following locations: El Qantara, El Arish, Nakhl, Ras Sudr, and Abu Rudeis. An additional first-order station will be established at St. Catherine in the near future. Phase Two of the Institute's program in meteorology will involve establishment of additional first-order stations located east of the former Camp David withdrawal line.

This meteorological program should be expanded to satisfy the need for detailed meteorological data for each representative area in Sinai including Dahab, Ras Taba, El Quseima, and Gebel El Maghara.

5.5.5 Detailed Feasibility Study of Cloud-Seeding in Sinai

As described in Section 2.3.3, the next step in a detailed assessment of the cloud-seeding potential in Sinai should involve the collection and analysis of available meteorological data pertinent to cloud-seeding, along with a thorough review of the pertinent literature on weather modification.

Data collection will involve the collection and organization of all available data on rain, wind, and cloudiness in Sinai, with emphasis on the Northeast Coast and Uplands. Maps and profiles should then be prepared depicting detailed topographic and plant-cover characteristics for areas selected for possible cloud-seeding experiments.

The last component of this project would involve a preliminary design of cloud-seeding experiments in Sinai. The experimental design should specify the areas of most potential; the recommended methods and times of cloud-seeding; the raingage grid spacing; the schedule for the preparation for and performance of the experiments; and detailed cost estimates.

5.5.6 Runoff-Gaging Stations

Reliable measurements or estimates of runoff on some of the major wadis, and near significant settlements in lesser wadis, are important for establishing control and regulation. Gaging or runoff-estimation stations should be established on the lower reaches of Wadi El Arish, Wadi Sudr, Wadi Sidri, Wadi Feiran, Wadi El Gerafi, and near Taba and Sharm El Sheikh.

Because of the sporadic character of runoff and the fact that the wadis are dry most of the time, normal stream-gage calibration will need to be modified. The recording of flood heights will pose difficulties since flow of any level occurs so infrequently. Nevertheless, it is highly important to establish some type of gaging station at the locations mentioned, with suitable sturdy equipment and reliable attendance.

5.5.7 Hydrologic Studies on Small Basins

The study of rainfall-runoff relationships and evapotranspiration on a few small basins in Sinai is another important project. The information obtained from several years of records on small basins may be extrapolated to larger basins and can supplement the runoff estimates for large wadis, discussed in Section 5.5.6. Moreover, the information obtained from small basins will aid in providing estimates of groundwater recharge, as well as other components of the Sinai water balance. This study should include at least one high mountain basin for the study of dew formation.

It will be necessary to select three or four representative basins of a size ranging from perhaps 5 to 25 square kilometers. Appropriate devices and equipment should be established in each basin study area, including rain gages, runoff-measuring weirs, recorders, and evaporation pans. Once the instrumentation is complete, continuous measurements should be made for a period of not less than 5 years, and possibly for as long as 10 to 15 years. When measurements in one basin are terminated, the instruments could possibly be set up in another basin for another extended series of measurements, under different meteorological, geological, and topographic conditions.

The Institute of Water Resources has initiated a plan to study six small basins in Sinai as part of its overall water resources investigation of Sinai. Currently, a study of a basin in the Gebel El Maghara area has begun, and we understand the necessary instrumentation has already been provided there. Full details on the small-basin study program of the Institute should be available in the near future.

5.5.8 Evaluation of Potential Dam Sites

Five dam sites should be evaluated in a more detailed manner than was possible as part of SDS-I.* As mentioned in Section 2.2.2, the following sites are recommended -- El Daiqa Gorge, Lahfan Gorge, Wadi Sudr, and Wadi El Hadira (near Bir El Thamada), and Wadi Gerafi (near El Kuntilla), the latter as two examples of a small reservoir. The locations of these sites are given on Figure 2.2 earlier in this volume (see also Plate 5-3 in Working Paper No. 45, the Preliminary Map Portfolio).

The proposed studies should consist of two parts -- a careful field appraisal of each of the sites and a preliminary benefit-cost analysis of each project, to include not only the dam itself but also all associated works, pipelines to points of use, and end-use facilities. It should be borne in mind that until runoff data have been obtained for a 5- to 10-year period (Sections 5.5.6 and 5.5.7), no final benefit-cost analysis can be performed, as the potential yield of any basin, particularly the small ones, will be highly uncertain.

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*These additional investigations were initiated by the Government of Egypt in 1982; by 1984 tentative conclusions had been reached as far as El Daiqa and Lahfan Gorges are concerned and no further development at these sites is planned in the foreseeable future.

APPENDIX A: ADDITIONAL WATER TABLES

TABLE A-1

Estimated Water Use in Sinai During Late 1981, by Source

Area or Community	Local Groundwater: Total Groundwater Currently Withdrawn (m^3/day)	Aquifer and Location	Wells or Springs	Uses: Public Supply (m^3/day)	Uses: Irrigation (m^3/day)	Uses: Exported to Other Areas (m^3/day)	Exported to Other Areas: Destination	Nile Water for Irrigation: Amount (m^3/day)	Nile Water for Irrigation: Origin	Piped Water for Domestic Supply: Amount (m^3/day)	Piped Water for Domestic Supply: Origin	By Truck for Domestic Supply: Amount (m^3/day)	By Truck for Domestic Supply: Origin	Total (m^3/day)
El Arish	25,000	Quaternary aquifer	Wells	8,100	14,300	2,600	Gifgafa and Wadi Umm Khisheib, also El Quseima	0	--	0	--	0	--	25,000
Rafah-Sheikh Zuwayid	15,000	Quaternary aquifers	Wells	Mostly from Israel National Carrier	15,000[a]	0	--	0	--	10,000[b]	Israel[c] National Carrier	0	--	25,000
Abu Aweigila	120	Wadi alluvium	Wells	20[a]	100[a]	0	--	0	--	600	El Arish[c] groundwater	0	--	720
El Quseima	310	Eocene or Cretaceous limestone	Well and springs	10[a]	300[a]	0	--	0	--	600	El Arish[c] groundwater	0	--	910
Bir El Abd	250	Sand dune aquifer	Wells	250[a]	0	0	--	0	--	0	--	16	Nile water at El Qantara	266
Negila	30	Sand dune aquifer	Well	30[a]	0	0	--	0	--	0	--	28	Nile water at El Qantara	58
Rabaa	200	Sand dune aquifer	Wells and trench	20[a]	180	0	--	0	--	0	--	16	Nile water at El Qantara	216
Romana	30	Sand dune aquifer	Wells	30[a]	0	0	--	0	--	0	--	16	Nile water at El Qantara	46
Baloza	0	--	--	0	0	0	--	0	--	0	--	25	Nile water at El Qantara	25
Gilbana	100	Sand dunes or Pleistocene aquifer	Wells	100[a]	0	0	--	0	--	0	--	30(?)	Nile water at El Qantara	130
El Qantara East	0	--	--	0	0	0	--	0	--	500	Nile water, from across Suez Canal	0	--	500

[a]Estimated.

[b]Approximately 7,000 m^3/day of this quantity is believed to have been used for irrigation.

[c]Discontinued during summer of 1982.

TABLE A-1 (cont'd)

Area or Community	Local Groundwater: Total Groundwater Currently Withdrawn (m³/day)	Aquifer and Location	Wells or Springs	Uses: Public Supply (m³/day)	Uses: Irrigation (m³/day)	Uses: Exported to Other Areas (m³/day)	Uses: Exported to Other Areas: Destination	Nile Water for Irrigation: Amount (m³/day)	Nile Water for Irrigation: Origin	Piped Water for Domestic Supply: Amount (m³/day)	Piped Water for Domestic Supply: Origin	By Truck for Domestic Supply: Amount (m³/day)	By Truck for Domestic Supply: Origin	Total (m³/day)
New Mit Abul Kom, Heroes' Village and Youth Farms, East Bitter Lakes area	0	--	--	0	0	0	--	55,000	Nile water via Suez Irrigation Canal and siphons south of Ismailia	0	--	0	--	55,000
Gifgafa	10	Lower Cretaceous aquifer (?)	Military well	10[a]	0	0	--	0	--	100	El Arish[c] groundwater	0	--	110
"Early warning station" at Wadi Umm Khisheib	0	--	--	0	0	0	--	0	--	1,200[d]	El Arish groundwater	0	--	1,200
El Hema (Bachdad)	0	--	--	0	0	0	--	0	--	100	El Arish groundwater	0	--	100
El Hasana	130	Wadi alluvium, Paleocene formation, and basalt dykes	Wells	130[a]	0	0	--	0	--	0	--	24	El Hema pumping station (El Arish groundwater)	154
Bir El Thamada	12	Wadi alluvium	Wells	12[a]	0	0	--	0	--	0	--	10(?)	El Hema pumping station (El Arish groundwater)	22
Nakhl	100	Wadi alluvium and Lower Cretaceous	Wells	100[a]	0	0	--	0	--	0	--	0	--	100
El Shatt	0	--	--	0	0	0	--	0	--	0	--	2	Nile water from El Qantara	2

[d]Some of this flow was reportedly used for agriculture at the Wadi Umm Khisheib station.

TABLE A-1 (cont'd)

Area or Community	Local Groundwater: Total Groundwater Currently Withdrawn (m^3/day)	Local Groundwater: Aquifer and Location	Local Groundwater: Wells or Springs	Uses: Public Supply (m^3/day)	Uses: Irrigation (m^3/day)	Uses: Exported to Other Areas (m^3/day)	Uses: Exported to Other Areas: Destination	Nile Water for Irrigation: Amount (m^3/day)	Nile Water for Irrigation: Origin	Piped Water for Domestic Supply: Amount (m^3/day)	Piped Water for Domestic Supply: Origin	By Truck for Domestic Supply: Amount (m^3/day)	By Truck for Domestic Supply: Origin	Total (m^3/day)
El Kuntilla	60	Wadi alluvium	Wells	60[a]	0	0	--	0	--	0	--	0	--	60
El Themed	75	Wadi alluvium and Middle Cretaceous aquifer	Wells	75[a]	0	0	--	0	--	0	--	0	--	75
Ayun Musa	500-1,000[e]	Miocene and Lower Cretaceous aquifers	Flowing wells and springs	0	0	0	--	0	--	0	--	1	Nile water from El Qantara	1
Ras Misalla	150	Basal Miocene and Cretaceous	2 wells	0	0	150[a]	Ras Sudr	0	--	0	--	0	--	150
Ras Sudr and Abu Suweira	500	Quaternary	Wells	0	500[a]	0	--	0	--	150[a]	2 wells at Ras Misalla	40	Nile water from El Qantara	690
Wadi Gharandal	102	Quaternary	Wells	2	100[a]	0	--	0	--	0	--	0	--	102
Abu Zenima	50	--	--	50[a]	0	0	--	0	--	0	--	4	Nile water from El Qantara	54
Abu Rudeis	900	Quaternary	Wells (~8 km away in Wadi Sidri)	100[a]	0	0	--	0	--	0	--	8	Nile water from El Qantara	908
		Quaternary	Nearby wells	800[f]										
Feiran and Belayim oil-fields	0	--	--	0	0	0	--	0	--	1,300[f]	Wells in Wadi Feiran located 10-12 km from sea	0	--	1,300

[e]Estimated free flow from springs and flowing wells at Ayun Musa. The water is apparently not put to use; total dissolved solids (TDS) reported to range from 2,500 to 13,000 mg/l.

[f]Estimated use for oilfields.

TABLE A-1 (cont'd)

	Local Groundwater													
				Uses				Nile Water for Irrigation		Piped Water for Domestic Supply		By Truck for Domestic Supply		
						Exported to Other Areas								
Area or Community	Total Groundwater Currently Withdrawn (m^3/day)	Aquifer and Location	Wells or Springs	Public Supply (m^3/day)	Irrigation (m^3/day)	(m^3/day)	Destination	Amount (m^3/day)	Origin	Amount (m^3/day)	Origin	Amount (m^3/day)	Origin	Total (m^3/day)
Wadi Feiran (10-12 km from Gulf of Suez)	1,300	Miocene sandstone and possibly Quaternary	3 wells	0	0	1,300[f]	Feiran and Belayim oil-fields	0	--	0	--	0	--	1,300
Feiran Oasis	1,400	Wadi alluvium	Wells	50	1,350[a]	0	--	0	--	0	--	0	--	1,400
Wadi El Sheikh (between Feiran Oasis and Watia Pass)	210	Wadi alluvium	Wells	10	200[a]	0	--	0	--	0	--	0	--	210
Gebel Katherina area	100	Quaternary and crystal-line units	Wells and springs	60	40	0	--	0	--	0	--	0	--	100
El Tor area	2,800	Quaternary	Wells	700	100	2,000	Sharm El Sheikh	0	--	0	--	4	Nile water	2,804
Sharm El Sheikh	10	Miocene sandstone	Wells	10	0	0	--	0	--	2,000	El Tor wells	0	--	2,010
Nebq	50	Quaternary	Wells	50	0	0	--	0	--	0	--	0	--	50
Dahab	50	Quaternary	Wells	50	0	0	--	0	--	100[a]	Springs in crystalline rock located a few kilo-meters west	0	--	150
Nuweiba/ Wasit	50	Quaternary	Wells	50	0	0	--	0	--	100[a]	Springs in crystalline rock located a few kilo-meters west	0	--	150
TOTAL	49,099[g]	--	--	10,879	32,170	6,050	--	55,000	--	16,750	--	224	--	121,073

[g]Excludes unused free discharge at Ayun Musa.

SOURCE: Calculations by the Consultant.

TABLE A-2

Inventory of Dams in Sinai[a]

Name	Description	Reference
A. Rawafaa Dam	Arched masonary dam located on Wadi El Arish, about 52 km south of El Arish; capacity about 3,000,000 m^3; reported to be silted up.	1268, 1350
B. El Gudeirat Dam	Masonry dam, located about 9 km west of the Israeli border; built by the Turks in World War I, but presently silted up.	1268
C. Perkins Dam	Masonry dam on Wadi El Gudeirat located on Wadi Sad, one of the short wadis draining the southeastern flank of Gebel Dalfa (east of Gebel El Halal).	1268
D. Wadi Gharandal Dams	Two small diversion dams in Wadi Gharandal, located 10-12 km from the Gulf of Suez; used for irrigation; the uppermost one ponds back 300-400 m^3 of slightly brackish water; presumably an earthen structure in both cases.	0230
E. Wadi Nefuz Dam	Wadi Nefuz flows from Gebel Banat to Wadi Feiran and is located north of the Oasis of Feiran; the dam is located in the upper part of this wadi, where it flows through a red granite canyon, exhibiting springs; the dam is filled with eroded soil.	1335
F. El Wadi Dam	A large dam built by the Bedouins at El Wadi, north of El Tor, for irrigation purposes; it was subsequently washed away.	1335
G. Wadi Shellal Dam	Formerly supplied piped water to Umm Bugma.	1333

[a] Locations of these dams are shown on Figure 2.2

SOURCE: Information from various sources as noted in reference column.

TABLE A-3

Possible Dam Sites in Sinai

Location[a]	Wadi	Possible Purpose	Possible Problems
H. El Daiqa Gorge	El Arish	Supply of water to El Arish town; flood protection for El Arish town.	Deprivation of downstream areas; requires long conveyance system; evaporation loss relatively high.
I. Mitmetni Gorge	El Arish	Supply of water to El Arish town; flood protection for El Arish town.	Deprivation of downstream areas; requires long conveyance system; evaporation loss relatively high.
J. El Lahfan Gorge	El Arish	Supply of water to El Arish town; flood protection for El Arish town.	Possible foundation problems; long dam required; seepage losses could be high.
K. Gebel El Halal	El Hadira	Supply of irrigation water to El Arish flood plain south of Gebel El Halal.	Expected yield is relatively low.
L. 5 km west of Ain Sudr	Wadi Sudr	Public supply at Ras Sudr; irrigation supply for Wadi Sudr delta; cultivation in bed of reservoir.	Rate of siltation expected to be high; evaporation loss relatively high; expected yield is not high.
M. Near Gebel Maghara (South Sinai)	Wadi Sidri	Public supply for Abu Rudeis; irrigation water for Wadi Sidri Plain.	Rate of siltation expected to be high; evaporation loss relatively high; expected yield is not high.
N. Upstream of the Oasis of Feiran	Wadi Feiran	Flood protection for oasis; irrigation supply to the oasis and to northern El Qaa Plain.	Rate of siltation expected to be high; evaporation loss relatively high.
O. Near Kuntilla	Wadi El Gerafi	Irrigation supply; groundwater recharge.	Rate of siltation and evaporation expected to be high; modest yield; would require negotiations with Israel.

[a] Locations of these dams are shown on Figure 2.2.

SOURCE: Derived from SDS-I analysis of topographic characteristics of Sinai as described in Section 3.2.5 of Working Paper 33.

TABLE A-4

Summary of Information on Groundwater Availability Areas in Sinai

No.	Area[a]	Aquifer	Well Depth (m)	Discharge Rate Per Well (l/sec)	Estimated Long-Term Groundwater Withdrawable (m^3/day)	Estimated TDS of Water (mg/l)[b]	Cost of Groundwater (LE/m^3)	Average Degree of Confidence[c]
1	Rafah	Quaternary coastal aquifers	40 - 90	9 - 17	30,000	400 - 4,000	0.02 - 0.07	2.4
2	El Arish	Quaternary coastal aquifers	40 - 60	3 - 28	25,000	1,000 - 6,000	0.01 - 0.06	1.2
3	North coastal strip	Dune sand	5 - 8[d]	2[d]	6,000	2,500 - 5,000	0.12	2.2
4	Rabaa	Pleistocene	70 - 110	11 - 23	10,000	5,000 - 7,000	0.02 - 0.06	2.8
5	Masagid Basin	Quaternary	30 - 50	1 - 9	3,000	1,500 - 3,000	0.05 - 0.21	3.8
6	East side of Gebel El Maghara	Middle Cretaceous	50 - 250	2 - 14	5,000	2,000 - 5,000	0.02 - 0.42	3.4

[a]Refer to Figures 2.5, 2.6 and 2.7 of this volume (and Plates 6-1 and 6-2 of Working Paper No. 45, the Map Portfolio) for location of areas.

[b]TDS = total dissolved solids.

[c]The number "1" indicates the highest degree of confidence; the number "4" indicates the lowest degree.

[d]Trenches about 15 meters long or large-diameter wells are assumed to be the primary means of groundwater development.

TABLE A-4 (cont'd)

No.	Area[a]	Aquifer	Well Depth (m)	Discharge Rate Per Well (l/sec)	Estimated Long-Term Groundwater Withdrawable (m^3/day)	Estimated TDS of Water (mg/l)[b]	Cost of Groundwater (LE/m^3)	Average Degree of Confidence[c]
7	Gebel El Halal	Middle Cretaceous	50 - 250	2 - 14	5,000	1,500 - 4,000	0.02 - 0.39	3.4
8	Gebels Yelleq and Fallig	Middle Cretaceous	50 - 250	2 - 14	9,000	1,500 - 4,000	0.02 - 0.40	3.4
9	Gebels Hamra and Giddi	Middle Cretaceous	50 - 250	2 - 14	2,000	2,000 - 6,000	0.02 - 0.41	3.6
10	Gebel Kherim	Middle Cretaceous	50 - 250	2 - 14	600	2,000 - 4,000	0.02 - 0.38	3.6
11	Gebels Burga and Taliat El Bedan	Middle Cretaceous	50 - 250	2 - 14	2,000	2,000 - 4,000	0.02 - 0.38	3.4
12	Central Sinai	Middle Cretaceous	250 - 450	2 - 14	10,000	1,500 - 4,000	0.05 - 0.65	3.6
13	El Quseima	Eocene	25 - 75	3 - 17	3,000	500 - 3,000	0.01 - 0.14	3.0
14	Great Bitter Lake to Ras Misalla	Miocene sandstone	150 - 550	6 - 23	10,000	1,000 - 8,000	0.02 - 0.31	2.4
15	Wadi El Arish upstream Gebel El Halal	Wadi alluvium	30 - 40	2 - 17	3,000	2,000 - 4,000	0.02 - 0.19	3.0

TABLE A-4 (cont'd)

No.	Area[a]	Aquifer	Well Depth (m)	Discharge Rate Per Well (l/sec)	Estimated Long-Term Groundwater Withdrawable (m^3/day)	Estimated TDS of Water (mg/l)[b]	Cost of Groundwater (LE/m^3)	Average Degree of Confidence[c]
16	Wadi El Gayifa	Wadi alluvium	30 - 40	2 - 9	3,000	1,500 - 2,500	0.03 - 0.17	3.0
17	Wadi El Gerafi	Wadi alluvium	30 - 50	2 - 12	7,000	1,500 - 3,000	0.02 - 0.19	3.0
18	Wadi Geraia	Wadi alluvium	20 - 40	2 - 9	500	1,500 - 3,000	0.03 - 0.17	2.8
19	Wadi El Aqabah	Wadi alluvium	25 - 45	2 - 9	1,500	1,500 - 4,000	0.03 - 0.18	3.0
20	Wadis El Bruk and El Arish	Wadi alluvium	25 - 45	2 - 9	2,500	2,500 - 6,000	0.03 - 0.18	2.8
21	Wadi Sudr Delta	Wadi alluvium	20 - 30	3 - 14	1,200	2,500 - 5,000	0.02 - 0.11	2.2
22	Wadi Wardan Delta	Wadi alluvium	20 - 30	3 - 14	1,200	2,000 - 7,000	0.02 - 0.11	2.2
23	South Central Sinai	Middle Cretaceous	150 - 350	2 - 14	12,000	1,500 - 4,000	0.03 - 0.50	3.6
24	Gebel Somar to Gebel Igma	Middle Cretaceous	50 - 200	3 - 23	12,000	1,000 - 3,000	0.01 - 0.23	3.0

TABLE A-4 (cont'd)

No.	Area[a]	Aquifer	Well Depth (m)	Discharge Rate Per Well (l/sec)	Estimated Long-Term Groundwater Withdrawable (m^3/day)	Estimated TDS of Water (mg/l)[b]	Cost of Groundwater (LE/m^3)	Average Degree of Confidence[c]
25	El Themed to Ras El Gineina	Middle Cretaceous	50 - 200	1 - 9	12,000	2,000 - 6,000	0.03 - 0.63	3.2
26	Wadi Gharan-dal	Wadi alluvium	15 - 35	0.5 - 2	600	2,000 - 5,000	0.10 - 0.53	2.8
27	Southern Mountains	Crystalline	40 - 120	1 - 7	30,000	200 - 2,500	0.03 - 0.47	3.0
28	Wadi Baba, El Markha Plain	Wadi alluvium	50 - 200	2 - 14	1,200	1,500 - 4,000	0.02 - 0.33	2.8
29	Wadi Sidri and Delta	Wadi alluvium	40 - 80	1 - 9	900	1,000 - 3,000	0.03 - 0.44	2.6
30	Abu Rudeis to El Qaa Plain	Miocene sandstone	30 - 80	2 - 17	2,000	2,500 - 8,000	0.01 - 0.20	2.8
31	Wadi Feiran and Wadi El Sheikh	Wadi alluvi-um and lake deposits	10 - 55	0.5 - 6	5,000	300 - 700	0.03 - 0.69	1.6
32	Gebel Kathe-rina area	Wadi alluvium	30 - 60	0.5 - 4	1,400	200 - 400	0.10 - 0.62	2.4
33	El Qaa Plain	Quaternary	80 - 150	12 - 35	30,000	600 - 2,500	0.01 - 0.10	1.6

TABLE A-4 (cont'd)

No.	Area[a]	Aquifer	Well Depth (m)	Discharge Rate Per Well (l/sec)	Estimated Long-Term Groundwater Withdrawable (m^3/day)	Estimated TDS of Water (mg/l)	Cost of Groundwater (LE/m^3)	Average Degree of Confidence[c]
34	Sharm El Sheikh	Miocene sandstone	20 - 30	0.5 - 2	600	2,000 - 7,000	0.07 - 0.41	3.0
35	Sharm El Sheikh	Wadi alluvium	40 - 100	2 - 12	1,000	1,500 - 4,000	0.02 - 0.21	3.6
36	Wadis Kid and Umm Adawi; Nebq area	Wadi alluvium	40 - 100	2 - 12	1,500	600 - 3,500	0.02 - 0.21	3.4
37	Wadi Nasb	Wadi alluvium	25 - 40	0.5 - 7	3,000	300 - 1,500	0.03 - 0.59	3.2
38	Wadi El Ghaib and Dahab area	Wadi alluvium	15 - 40	1 - 9	1,600	2,000 - 4,000	0.02 - 0.31	3.0
39	Wadi Watir and Nuweiba area	Wadi alluvium	15 - 40	1 - 9	1,200	1,000 - 3,500	0.02 - 0.31	3.2
40	Gebel El Maghara area	Lower Cretaceous sandstone	50 - 450	2 - 23	6,000	1,200 - 6,000	0.01 - 0.67	2.6
41	Risan Aneiza area	Lower Cretaceous sandstone	50 - 550	2 - 23	2,400	2,000 - 7,000	0.01 - 0.78	2.6

TABLE A-4 (cont'd)

No.	Area[a]	Aquifer	Well Depth (m)	Discharge Rate Per Well (l/sec)	Estimated Long-Term Groundwater Withdrawable (m^3/day)	Estimated TDS of Water (mg/l)[b]	Cost of Groundwater (LE/m^3)	Average Degree of Confidence[c]
42	Gebel El Halal	Lower Cretaceous sandstone	50 - 450	0.3 - 9	1,000	1,000 - 3,000	0.02 - 1.99	2.4
43	Gebel Kherim	Lower Cretaceous sandstone	100 - 450	3 - 17	400	1,500 - 2,500	0.03 - 0.45	3.0
44	Central Sinai	Lower Cretaceous sandstone	650 - 950	2 - 14	10,000	1,500 - 2,500	0.12 - 1.50	2.6
45	South-central Sinai	Lower Cretaceous sandstone	350 - 650	2 - 14	10,000	1,500 - 2,500	0.08 - 1.22	3.0
46	South Sinai	Nubian[f]	100 - 450	2 - 14	7,000	1,500 - 3,500	0.03 - 1.00	3.2
47	East Sinai, Gebel El Hamra area	Lower Cretaceous sandstone	200 - 650	2 - 14	2,000	1,500 - 3,000	0.05 - 1.15	3.2

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[e]Refers to Lower Cretaceous sandstone and older contiguous sandstones.

Source: Calculations by the Consultant; see Working Paper No. 33 for details.

TABLE A-5

Summary of 1981 Information on Existing or Proposed Water Pipelines, Primarily for Domestic Supply

No.	Water Source	Place of Origin[a/]	Destination[a/]	Distance (km)	Pipe Diameter (mm)	Pipe Material	Approximate Flow Rate (m^3/day)	Number of Pumping Stations	Purpose of Pipeline
1	Nile Water via Ismailia Canal and Suez Irri-gation Canal	1 km north of El Qantara; crossing Suez Canal by means of siphon	Bir El Abd	75	300	Asbestos cement	4,000	3, Mosalas, Gilbana, Romana	Primarily domestic supply to El Qantara East, Gilbana, Baloza, Romana, Negila, and Bir El Abd[b/]
2	Military water wells at El Arish	El Arish	Gifgafa and early warning station at Umm Khisheib	110 to Gifgafa; an additional 40 to Umm Khisheib	200 to El Hema pumping station; 150 for the remainder	Steel	1,400 up to El Hema station; 1,300 for remainder	3, El Arish, El Hema, Gifgafa	Domestic water supply for Gifgafa and Umm Khisheib.
3	Military water wells at El Arish	El Arish	Quseima	75[b]	150 or 200	Steel	1,200	1, El Arish	Domestic water supply for Abu Aweigila and Quseima.[c/]
4	National Water Carrier	Israel	Rafah-Sheikh Zuwayid area	?	500	?	10,000	1, Near Hod Abu Rad (Sadot)	To provide water for public supply and irrigation.[d/]
5	3 water wells at Ras Misalla (tapping Lower Miocene and Middle Creta-ceous units)	Ras Misalla	Ras Sudr	25	200	Steel	150	None, Water flows by gravity	Industrial and domestic uses at Ras Sudr; not potable with further treatment.
6	3 wells in alluvium in El Qaa Plain near El Tor	El Tor	Sharm El Sheikh	90	250	Steel	2,000	1, El Tor (pressure devel-oped = 265 m of water)	Domestic water supply for Sharm El Sheikh.

[a/] Refer to Figure 3.1 of this volume (and Plate 6-3 in Working Paper No. 45 in the SDS-I project files) for the locations of these pipelines.

[b/] Estimated capital cost LE 5.2 million.

[c/] Discontinued during summer 1982.

[d/] Estimated capital cost LE 30.4 million. Construction began in 1982.

[e/] Estimated capital cost LE 10.4 million on the basis of preliminary technical studies.

[f/] Unused in 1981 but in good condition.

SOURCE: Data collected by Dames & Moore, mainly in 1981.

TABLE A-5 (cont'd)

No.	Water Source	Place of Origin[a]	Destination[a]	Distance (km)	Pipe Diameter (mm)	Pipe Material	Approximate Flow Rate (m^3/day)	Number of Pumping Stations	Purpose of Pipeline
7	Unknown	Gifgafa	Baloza and east side of canal from Ismailia	130 (total length)	100	Steel	1,000[b]	1, Out of use; located 50 km south of Baloza	Water supply to northwest Sinai.
8	Nile water; water to be treated at El Qantara West	El Qantara	El Arish	150	700	Steel	28,000	4	Domestic water needs of El Arish.[d/]
9	Water wells at El Arish	Pumping station at El Hema, about 35 km south of Bir El Lahfan	El Hasana	25	150	Steel	500	--	Potable and domestic water supply to El Hasana.
10	Nile water via Ismailia Canal and Hamdi Tunnel	Hamdi Tunnel (treated water from Suez treatment plant)	Abu Rudeis	150	300 to 500	Steel	4,000	4	Supply potable water to Ayun Musa, Ras Sudr, Abu Zenima, and Abu Rudeis.[e/]
11	None	Gifgafa	Bir El Thamada	?	300	Steel	--	--	Supply potable water.[f/]
12	None	Eilat	Ras El Naqb Airport	?	?	?	--	--	Supply potable water to airport.

Table A-6

Estimated Water Requirements for Domestic Purposes, Industries, Mining and Tourism in the Year 2000, by Subregion, for the Recommended Strategy and Three Alternatives

(a) Domestic Water Demand and Reference Population

Subregion	Domestic Water Demand[a/] (million m^3/yr)				Estimated Population, Year 2000 (000)			
	RS	FR	DI	AC	RS	FR	DI	AC
Northwest	4.2	7.1	6.3	4.5	167.1	238.6	225.3	180.5
Northeast of which Uplands	20.2 (2.1)	19.8 b/	21.3 b/	17.9 b/	623.8 (170.0)	668.4 b/	727.4 b/	599.1 b/
Southwest	5.3	2.0	4.1	5.8	137.5	117.3	174.2	198.1
Southeast	1.2	1.6	1.6	1.6	44.7	89.0	91.1	85.2
TOTAL	30.9	30.5	33.3	29.8	973.1	1,113.3	1,217.9	1,062.9

(b) Requirements for Industries, Mining and Tourism[c/]

	Estimated Water Demands (million m^3/yr)					
	Tourism			Industries and Mining		
	RS	FR	DI	RS	FR	DI
Northwest	1.6	0.62	2.50	0.03	0.04	0.17
Northeast of which Uplands	6.5 (0.4)	1.30 b/	0.54 b/	0.17 (0.01)	0.04 b/	0.32 b/
Southwest	78.2	4.72	5.92	0.05	0.06	0.10
Southeast	0.3	0.53	0.01	0.17	0.11	0.37
TOTAL	86.6	7.17	8.97	0.41	0.29	0.96

FR, DI, and AC represent Frontier, Dispersed and All Coasts alternative strategies considered at an early stage in the 1983 analysis. RS is the Recommended Strategy proposed by the Consultant after discussions with the Steering Committee and further analysis. The Recommended Strategy is summarized in Volume I of this Report.

[a/] Includes water demands for commercial enterprises.

[b/] Uplands requirements not reported separately when alternative strategies were being reviewed.

[c/] Industries, mining and tourism requirements were not reported separately for the All Coasts alternative, which was superseded by the Consultant's Recommended Strategy.

Source: 1983 project memoranda and internal working papers.

TABLE A-7

Projection of Feddans Likely to be Suitable for Irrigated Agriculture and Estimated Year 2000 Water Duties, Using Nile Water or Local Groundwater, by Subregion and Areas, for the Recommended Strategy and Three Alternatives

(a) Proposed for Irrigation with Nile Water

	Subregion and area	Thousands of Irrigated Feddans RS	FR	DI	AC
	Northwest, subtotal	71.0 a/	35.1	39.1	32.0
1.	El Tina Plain	20.0	--	1.1	--
2.	Qantara-Baloza	16.0	15.1	16.0	12.0
3.	East Bitter Lakes	30.0 a/	15.0	16.0	14.0
4.	East of Suez (joins SW-1)	5.0	5.0	6.0	6.0
	Northeast, subtotal	52.0	45.6	52.0	35.0
1.	Romana - El Mazar	20.0	17.0	20.0	15.0
2.	Sheikh Zuwayid-Rafah	15.0	14.5	15.0	10.0
3&4.	Lower Wadi El Arish	17.0	14.1	17.0	10.0
	Uplands, subtotal	51.0	102.0	133.5	10.0
1.	Gifgafa	16.0	6.0	16.0	--
2&3.	Wadi El Bruk	25.0	64.0	65.0	--
4.	El Sirr Plain	10.0	--	10.0	10.0
5.	Wadi El Hema	b/	--	--	--
6.	El Hasana	b/	4.0	20.0	--
7.	Middle Wadi El Arish	b/	23.0	22.5	--
8.	Wadi El Gayifa/El Quseima	b/	5.0	b/	b/
9.	Wadi El Gerafi/El Kuntilla	b/	--	b/	--
	Southwest, subtotal	15.0	b/	47.0	12.0
1.	East of Suez (joins NW-4)	1.0	--	--	--
2.	Ramlet Himeiyir Plain	b/	--	8.0	--
3.	Abu Rudeis	6.0	b/	8.0	2.0
4.	Wadi Feiran Delta	8.0	--	10.0	--
5.	El Qaa Plain	b/	b/	21.0	10.0
	Southeast b/	b/	b/	b/	b/
	Total feddanage	189.0 a/	182.7	271.6	89.0

TABLE A-7 (continued)

Subregion and area		Water Duty (million cubic meters per year) RS	FR	DI	AC
	Northwest, subtotal	544.8	255.4	282.3	188.0
1.	El Tina Plain[c/]	180.0	--	7.0	--
2.	Qantara-Baloza[c/]	115.8	111.4	115.8	69.0
3.	East Bitter Lakes[d/]	213.0	108.0	115.7	84.5
4.	East of Suez[e/]	36.0	36.0	43.8	34.5
	Northeast, subtotal	372.8	338.2	372.8	221.2
1.	Romana - El Mazar[c/]	155.0	152.5	155.0	86.2
2.	Sheikh Zuwayid-Rafah[c/]	88.8	95.9	88.8	57.5
3&4.	Lower Wadi El Arish[c/]	129.0	89.8	129.0	77.5
	Uplands, subtotal	411.3	827.7	1,084.8	57.5
1.	Gifgafa[d/]	121.3	43.7	121.3	--
2&3.	Wadi El Bruk[d/]	212.5	526.0	552.5	--
4.	El Sirr Plain[c/]	77.5	--	77.5	57.5
5.	Wadi El Hema[f/]	--	--	--	--
6.	El Hasana	--	26.0	144.0	--
7.	Middle Wadi El Arish	--	192.5	189.5	--
8.	Wadi El Gayifa/El Quseima	--	39.5	--	--
9.	Wadi El Gerafi/El Kuntilla	b/	--	b/	--
	Southwest, subtotal	170.6	b/	542.6	103.4
1.	East of Suez[e/]	7.8	--	--	--
2.	Ramlet Himeiyir Plain[d/]	--	--	89.3	--
3.	Abu Rudeis[d/]	69.8	--	93.0	17.2
4.	Wadi Feiran Delta[d/]	93.0	--	116.2	--
5.	El Qaa Plain[g/]	b/	--	244.1	86.2
	Southeast[b/]	--	--	--	--
	Total water duty	1,499.5	1,421.1	2,282.5	570.1

TABLE A-7 (continued)

(b) Proposed for Irrigation with Local Groundwater

Subregion and area		Thousands of Irrigated Feddans			
		RS	FR	DI	AC
	Northwest[h/]	--	--	--	--
	Northeast, subtotal	4.0	4.0	4.0	4.0
1.	Romana - El Mazar[i/]	--	--	--	--
2.	Sheikh Zuwayid-Rafah	2.0	2.0	2.0	2.0
3&4.	Lower Wadi El Arish	2.0	2.0	2.0	2.0
	Uplands, subtotal	2.9	0.1	2.9	0.1
1.	Gifgafa[i/]	i/	--	--	--
2&3.	Wadi El Bruk[i/]	i/	--	--	--
4.	El Sirr Plain[i/]	i/	--	--	--
5.	Wadi El Hema[j/]	j/	--	--	--
6.	El Hasana	j/	i/	i/	--
7.	Middle Wadi El Arish	j/	i/	i/	--
8.	Wadi El Gayifa/El Quseima	0.1	0.1	0.1	0.1
9.	Wadi El Gerafi/El Kuntilla	0.6	--	0.6	--
10.	Nakhl (Research Station)	0.2	--	0.2	--
11.	Gebels El Maghara, Yelleq and El Halal	2.0	--	2.0	--
	Southwest, subtotal	4.3	4.4	4.6	0.3
1.	East of Suez	i/	--	--	--
2.	Ramlet Himeiyir Plain	j/	--	i/	--
3.	Abu Rudeis	i/	0.1	i/	i/
4.	Wadi Feiran Delta	i/	--	i/	--
5.	El Qaa Plain	4.0	4.0	4.0	i/
6.	Wadi Feiran upstream	0.3	0.3	0.6	0.3
	Southeast, subtotal	1.7	0.6	0.7	0.8
1.	Wadi Watir (northwest from Nuweiba)	0.6	0.2	0.2	0.2
2.	Wadis El Ghaib and Nasb (north and west of Dahab)	0.4	0.2	0.3	0.3
3.	Three wadis west of Nebq	0.7	0.2	0.2	0.2
	Total feddanage	12.9	9.1	12.2	5.2

TABLE A-7 (continued)

Subregion and area		Water Duty (million cubic meters per year) RS	FR	DI	AC
	Northwest[h/]	--	--	--	--
	Northeast, subtotal	20.0	20.0	20.0	20.0
2.	Sheikh Zuwayid-Rafah	10.0	10.0	10.0	10.0
3&4.	Lower Wadi El Arish	10.0	10.0	10.0	10.0
	Uplands, subtotal	15.2	0.7	15.2	0.7
8.	Wadi El Gayifa/El Quseima	0.7	0.7	0.7	0.7
9.	Wadi El Gerafi/El Kuntilla	5.1	--	5.1	--
10.	Nakhl (Research Station)	1.4	--	1.4	--
11.	Gebels El Maghara, Yelleq and El Halal	8.0[k/]	--	8.0[k/]	
	Southwest, subtotal	44.2	45.4	46.0	1.8
3.	Abu Rudeis	--	1.2	--	--
5.	El Qaa Plain	42.4	42.4	42.4	--
6.	Wadi Feiran	1.8	1.8	3.6	1.8
	Southeast, subtotal	11.1	3.9	4.6	5.3
1.	Wadi Watir (northwest from Nuweiba	3.9	1.3	1.3	1.3
2.	Wadis El Ghaib and Nasb (north and west of Dahab)	2.6	1.3	2.0	2.0
3.	Three wadis west of Nebq	4.6	1.3	1.3	2.0
	Total water duty	90.5	70.0	85.8	27.8

TABLE A-7 (continued)

RS = Recommended Strategy; FR, DI and AC are Alternative Development Strategies considered earlier in the planning process -- namely, Frontier, Dispersed and All Coasts respectively.

a/ Includes 14,000 feddans already being developed, for which a water duty of about 100 million cubic meters per year is estimated, assuming two crops each year.

b/ Initial development only with local groundwater, generally combined with drip or "controlled environment" (greenhouse) agriculture.

c/ Proposed Source: El Qantara or El Salaam Canal.

d/ Proposed Source: Imailia Canal.

e/ Proposed Source: Ismailia Canal or Maadi-Suez pipeline.

f/ Initial development recommended with local groundwater and managed runoff; an option to the Recommended Strategy would extend the pipeline system from Ismailia beyond Gifgafa to the Wadi El Hema area.

g/ The Consultant recommends thorough study of the possibility of bringing Nile water to Southern Sinai, especially the El Qaa Plain which appears to have considerable agricultural potential, by pipeline under the Gulf of Suez. This could be considered in association with a conduit bringing Nile Water from Upper Egypt to the coastal areas of the Red Sea Governorate.

h/ Development foreseen mainly with Nile Water until exploration verifies reliable sources of groundwater. Agriculture based on managed runoff is also recommended in the mountain passes of the southeastern corner of this subregion.

i/ Development foreseen mainly with Nile Water until exploration verifies reliable sources of groundwater.

j/ Number of feddans and extent of agriculture cannot be determined until exploration determines the quantity and quality of available groundwater.

k/ Includes 2,000 feddans to be developed with "managed runoff" with an estimated water duty of 8 million cubic meters per year.

Source: Estimates by the Consultant summarized in project memoranda on file.

TABLE A-8

Projected Water Supplies to Meet Domestic, Industrial and Tourism Demands for Freshwater by the Year 2000, by Subregion, for the Recommended Strategy and Three Alternatives

Subregion	Estimated Population	Domestic Water Demands mn m^3/yr	Domestic Water Demands PWS	Industrial and Mining Water Demands mn m^3/yr	Industrial and Mining Water Demands PWS	Tourism Water Demands mn m^3/yr	Tourism Water Demands PWS	Combined Water Demands mn m^3/yr
		(a) The Recommended Development Strategy						
All Sinai	973,074	30.94	PN	86.61	--	0.42	--	117.97
Northwest	167,065	4.25	PN & LG	1.61	PN	0.03	PN	5.89
Northeast	453,822	18.07	PN & LG	6.12	PN & LG	0.17	PN & LG	24.36
Uplands	170,004	2.10	PN & LG	0.38	PN & LG	*	PN & LG	2.48
Southwest	137,486	5.34	PN & LG	78.23	PN & LG	0.05	PN & LG	83.62
Southeast	44,699	1.18	LG(D) & PG	0.27	LG(D)	0.17	LG(D),T,PG	1.62
		(b) The Frontier Strategy						
All Sinai	1,113,310	30.47	--	7.17	--	0.25	--	37.89
Northwest	238,630	7.05	PN	0.62	PN	0.04	PN	7.71
Northeast a/	668,420	19.84	PN & LG	1.30	PN & LG	0.04	PN & LG	21.18
Southwest	117,290	2.02	PN & LG	4.72	PN & LG	0.06	PN & LG	6.80
Southeast	88,970	1.56	LG(D) & PG	0.53	LG(D)	0.11	LG(D),T,PG	2.20
		(c) The Dispersed Development Strategy						
All Sinai	1,217,880	33.30	--	8.97	--	9.96	--	43.23
Northwest	225,350	6.29	PN	2.50	PN	0.17	PN	8.96
Northeast a/	727,380	12.30	PN & LG	0.54	PN & LG	0.32	PN	22.16
Southwest	174,080	4.08	PN & LG	5.93	PN & LG	0.10	PN & LG	10.11
Southeast	91,070	1.63	LG(D) & PG)	*	--	0.37	LG(D),T,PG	2.00
		(d) The All Coast Development Strategy						
All Sinai	1,062,990	29.77	--	b/	--	b/	--	b/
Northwest	180,530	4.53	PN					
Northeast a/	599,140	17.87	PN, LG, LG(D)					
Southwest	198,110	5.82	PN, LG, LG(D)					
Southeast	85,210	1.55	PG, LG, LG(D)					

PWS = Principal Water Source; PN = Piped Nile Water; PG = Groundwater piped from another area of Sinai; LG = Local groundwater; LG(D) = Local groundwter, desalinized; T = Tanker

*Less than 5,000 cubic meters per year.

a/ Includes Uplands.

b/ Estimates of industrial, mining and tourism demands for freshwater were not completed, since the All Coasts alternative strategy was superseded by the Recommended Strategy.

Source: Calculations by Consultant in project memoranda on file.

TABLE A-9

Water Well Operational and Maintenance Costs (Including Pumping)

Depth to Pumping Level (meters below ground)	Well Discharge Rate (m^3/day)[a,b] 100		300		700		1,000		2,000		3,000	
	(LE/yr)	(LE/m^3)	(LE/yr)	(LE/m^3)	(LE/yr)	(LE/m^3)	(LE/yr)	(LE/m^3)	(LE/yr)	(LE/m^3)	(LE/yr)	(LE/m^3)
(a) At a Diesel Fuel Price of LE 0.025 per Liter												
10	209	0.017	227	0.006	263	0.003	290	0.002	380	0.002	471	0.001
20	217	0.018	252	0.007	321	0.004	372	0.003	544	0.002	717	0.002
30	225	0.019	276	0.007	378	0.004	454	0.004	709	0.003	963	0.003
50	242	0.020	326	0.009	493	0.006	618	0.005	1,037	0.004	1,455	0.004
70	258	0.021	375	0.010	608	0.007	782	0.006	1,365	0.006	1,947	0.005
100	283	0.023	449	0.012	780	0.009	1,029	0.008	1,857	0.008	2,686	0.007
130	307	0.025	522	0.014	952	0.011	1,275	0.010	2,350	0.010	3,424	0.009
160	332	0.027	596	0.016	1,125	0.013	1,521	0.012	2,842	0.012	4,163	0.011
200	365	0.030	695	0.019	1,354	0.016	1,849	0.015	3,498	0.014	5,147	0.014
240	398	0.033	793	0.022	1,584	0.019	2,177	0.018	4,155	0.017	6,132	0.017
280	431	0.035	892	0.024	1,814	0.021	2,505	0.021	4,811	0.020	7,116	0.020
320	463	0.038	990	0.027	2,044	0.024	2,834	0.023	5,467	0.023	8,101	0.022
(b) At a Diesel Fuel Price of LE 0.18 per Liter												
10	240	0.020	320	0.009	481	0.006	601	0.005	1,003	0.004	1,404	0.004
20	274	0.023	423	0.012	721	0.009	944	0.008	1,688	0.007	2,432	0.007
30	309	0.025	526	0.014	961	0.011	1,287	0.010	2,374	0.010	3,461	0.010
50	377	0.031	732	0.020	1,441	0.017	1,972	0.016	3,745	0.015	5,517	0.015
70	446	0.037	937	0.026	1,920	0.023	2,658	0.022	5,116	0.021	7,573	0.021
100	549	0.045	1,246	0.034	2,640	0.031	3,685	0.030	7,172	0.029	10,658	0.029
130	651	0.054	1,554	0.043	3,360	0.039	4,714	0.039	9,229	0.038	13,743	0.038
160	754	0.062	1,863	0.051	4,080	0.048	5,743	0.047	11,285	0.046	16,828	0.046
200	891	0.073	2,274	0.062	5,039	0.059	7,114	0.058	14,027	0.058	20,940	0.057
240	1,028	0.084	2,685	0.074	5,999	0.070	8,485	0.070	16,769	0.069	25,054	0.069
280	1,165	0.096	3,097	0.085	6,959	0.082	9,855	0.081	19,511	0.080	29,166	0.080
320	1,303	0.107	3,508	0.096	7,919	0.093	11,226	0.092	22,253	0.091	33,279	0.091

[a] For each well discharge rate, annual operation and maintenance costs are given in the first column; the operation and maintenance costs of water per cubic meter are given in the second column.

[b] Indicated discharge rates are assumed to occur on the average for only 8 hr/day.

SOURCE: Calculations by Consultant.

TABLE A-10

Cost Details on Planned or Possible Desalinization Units in Sinai

A	B	C	D	E	F	G	H	0	J	K	L	M
Unit No.	Location	Purpose	Proposed Type of Unit[a]	Feedwater (TDS in mg/l)[b]	Capacity (m^3/day)	Estimated Plant Investment Cost (LE x 10^3)	Annualized Investment Cost (LE x 10^3)[c]	Estimated Operating Expenses (LE x 10^3)[d]	Estimated Total Annual Costs for Desalinization (LE x 10^3)	Estimated Cost of Desalinizing Water (LE/m^3)	Estimated Cost of Supplying Groundwater as Feedwater (LE/m^3)	Total Estimated Cost of Desalinized Water (LE/m^3)
1-4	El Arish[e]	Potable supply	RO	Local groundwater (2,000-4,000)	1,600 (4 units)	1,340 (4 units)	142	115	251	0.46	0.06	0.52
5	El Masaid[f]	Potable supply	RO	Local groundwater (3,000-6,000)	200	165	18	22	40	0.57	0.06	0.63
6	Bir El Abd[f]	Potable supply	RO	Local groundwater (5,000-8,000)	200	165	18	22	40	0.57	0.06	0.63
7	Ras Sudr[g]	Domestic supply	RO	Local groundwater (3,000-5,000)	625	343	36	54	90	0.42	0.10	0.52
8	Abu Zenima (possible site)	Domestic and industrial supply	RO	Seawater	1,200	3,000	315	318	633	1.70	--	1.70
			RO	Groundwater, piped from 15 km east (3,000-5,000)	1,200	606	64	96	160	0.39	0.30	0.69
9	Abu Rudeis (possible site)	Domestic and industrial supply	RO	Local groundwater (3,000-5,000)	2,000	947	100	152	252	0.36	0.06	0.42
					5,000	2,100	223	344	567	0.33	0.06	0.39

[a]ED = electrodialysis, RO = reverse osmosis. For RO (seawater), the assumed plant load factor is 0.85; for other RO plants and for ED plants, the assumed plant load factor is 0.95.

[b]In each case, the expected total dissolved solids (TDS) level of the output water is about 500 mg/l.

[c]Assumed plant life is 30 years; discount rate is 10 percent.

[d]Including labor, materials, chemicals, membrane replacement, and power.

[e]These units are essentially already installed.

[f]Plans are underway to purchase and install these units.

[g]A reverse osmosis unit already exists at Ras Sudr, but its installation has to be completed.

TABLE A-10 (continued)

A Unit No.	B Location	C Purpose	D Proposed Type of Unit[b]	E Feedwater (TDS in mg/l)	F Capacity (m^3/day)	G Estimated Plant Investment Cost (LE x 10^3)	H Annualized Investment Cost (LE x 10^3)[c]	I Estimated Operating Expenses (LE x 10^3)[d]	J Estimated Total Annual Costs for Desalinization (LE x 10^3)	K Estimated Cost of Desalinizing Water (LE/m^3)	L Estimated Cost of Supplying Groundwater as Feedwater (LE/m^3)	M Total Estimated Cost of Desalinized Water (LE/m^3)
10	Sharm El Sheikh (possible site)	Domestic and tourism supply	RO RO	Seawater Local groundwater (4,000-7,000)	1,200 1,200	3,000 783	315 83	318 112	633 195	1.70 0.47	-- 0.15	1.70 0.62
11	Nebq (possible site)	Domestic and tourism supply	RO	Local groundwater (4,000)	1,000	517	55	82	137	0.39	0.10	0.49
12	Dahab (possible site)	Domestic and tourism supply	RO	Local groundwater (2,000-4,500)	1,000	517	55	82	137	0.39	0.10	0.49
13	Nuweiba (possible site)	Domestic and tourism supply	RO	Local groundwater (2,000-3,500)	1,000 1,500	517 737	55 78	82 118	137 196	0.39 0.38	0.10 0.10	0.49 0.48

SOURCE: Calculations by Dames & Moore.

Note: Since those estimates were prepared an additional desalinization plant has been planned for Sinai, to be located at Ras Taba.

TABLE A-11

Estimated Cost of Nile Water Conveyed by Canal to Five Sinai Reclamation Areas included in the Water Master Plan[a]

Reclamation Area Number	No. of Feddans	Total Annual Water Duty (million LE/m^3)	Source of Water	Estimated Cost of Water Delivered to Farm (LE/m^3)[b]
1	265,000	1,855	El Salaam Canal	0.019
2	250,000	1,250	Salhia Canal (from the Ismailia Canal)	0.023
3	135,000	945	El Salaam Canal	0.019
4	30,000	150	Suez Irrigation Canal	0.019
5	55,000	275	Suez Irrigation Canal	0.023
TOTAL	735,000	4,475		0.021 average

[a] Figure 2.11 shows the location of reclamation areas proposed for Sinai in the Government's Master Plan for Water Resources Development, published in 1981. Plate 5-3 in Working Paper No. 45, the Map Portfolio, illustrates the same information on a scale of 1:750,000.

[b] Estimated by Consultant. Costs per cubic meter will increase if the number of feddans to be irrigated is reduced significantly. The following elements of cost were considered when preparing these estimates:

- General works replacement and operation west of the Suez Canal
- Pumping drainage water for Reclamation Areas 1 and 3 (assumed to make up 40 percent of the total flow)
- Widening of the Ismailia and El Salaam Canals to accommodate water for Sinai
- Pumping water into the main canals in Sinai
- Constructing and maintaining all siphons and major delivery canals (or pipelines) in Sinai

SOURCE: Derived primarily from the Water Master Plan (references (0859), (0862), (0863), Volume V, prepared for the Ministry of Irrigation under a grant from the United Nations Development Programme.

TABLE A-12

Results of Cost Analysis for Major Pipelines Planned or Under Construction

No.	Water Source	Place of Origin	Destination	Capacity (m^3/day)	Purpose of Pipeline	Estimated Capital Cost (LE x 10^6)	Annualized Capital Cost (LE/yr x 10^6)[a]	Estimated Operating Cost (LE/yr x 10^6)	Total Annual Cost (LE/yr x 10^6)	Water Cost (LE/m^3)
1	Nile water via Ismailia Canal and Suez Irrigation Canal	1 km north of El Qantara	Bir El Abd	4,000	Domestic supply to El Qantara East, Gilbana, Baloza, Romana, Negila, and Bir El Abd	5.25	0.58	0.19	0.77	0.53
8	Nile water via Ismailia Canal and Suez Irrigation Canal	El Qantara	El Arish	28,000	Domestic supply for El Arish	30.4	3.35	0.46	3.81	0.37
10	Nile water via Suez Irrigation Canal and Hamdi Tunnel	Hamdi Tunnel	Abu Rudeis	4,000	Domestic supply to Ayun Musa, Ras Sudr, Abu Zenima, and Abu Rudeis	10.4	1.14	0.24	1.38	0.95
11[b]	Nile water via a pipeline from Maadi to Suez	Maadi	East of Suez Canal (Reclamation Area No. 5)	500,000	Irrigation of a major fraction of Reclamation Area No. 5	136.5	14.1	11.1	25.2	0.14

[a] Assuming an effective pipeline life of 25 years, at a discount rate of 10 percent.

[b] Only those costs applicable for the Sinai capacity flow are shown. Costs attributable to the supply of water to Suez are excluded.

SOURCE: 1983 Project Memoranda on file.

TABLE A-13

Summary of Costs of Nile Water by Pipeline For The Recommended Strategy and Two Alternatives

A. For The Recommended Strategy[d/]

	Subregion and Reclamation Area[a/]	Origin of Pipeline	Capital Cost (LE x 10^6)			(Cost of Water (LE/m^3)[b/]					
			Primary Pipeline[c/]	Secondary Pipeline	Total	Primary Pipeline		Secondary Pipeline		Total	
						L	B	L	B	L	B
	Northwest										
1.	El Tina	El Salaam Canal	70	50	120	0.03-.06	0.05-.10	0.03	0.04	0.06-.09	0.09-.14
2.	Qantara to Baloza	El Qantara	45	32	77	0.03-.08	0.05-.13	0.03	0.04	0.06-.11	0.09-.17
3.	East Bitter Lakes	Basic conveyance system already in place; costs not included in estimates of additional conveyances required to implement the Recommended Strategy.									
4.	East Suez (includes 1000 feddans in SW)	Ismailia	62	9	71	0.16-.22	0.25-.33	0.02	0.03	0.18-.24	0.28-.36
	Northeast										
1.	Romana to EL Mazar	El Qantara	141	37	178	0.08-.23	0.14-.35	0.03	0.03	0.11-.26	0.17-.38
2.	Sheikh Zuwayid to Rafah	El Qantara	208	26	234	0.28-.35	0.50-.57	0.03	0.04	0.31-.38	0.54-.61
3.+4.	Lower Wadi El Arish	El Qantara	282	30	312	0.26-.35	0.45-.60	0.03	0.03	0.29-.38	0.48-.63
	Uplands										
1.	Gifgafa	Ismailia	210	29	239	0.23-.31	0.39-.52	0.03	0.03	0.26-.34	0.42-.55
2.+3.	Wadi El Bruk	Ismailia	477	53	530	0.33-.46	0.56-.70	0.03	0.04	0.36-.49	0.60-.74
4.	El Sirr Plain	El Qantara	193	18	211	0.33-.36	0.57-.62	0.03	0.03	0.36-.39	0.60-.65
	Southwest										
3.	Abu Rudeis	Ismailia	198	11	209	0.36-.39	0.63-.67	0.02	0.02	0.38-.41	0.65-.69
4.	Wadi Feiran Delta	Ismailia	273	16	289	0.40-.45	0.70-.75	0.02	0.02	0.42-.47	0.72-.77
	Industral Area north of Ras Sudr	Ismailia	76	-	76	0.12-.14	0.23-.28	-	-	0.12-.14	0.23-.28
	TOTAL		2,235	311	2,546						

TABLE A-13 (continued)

B. For The Frontier Strategy

Subregion and Reclamation Area[a/]	Origin of Pipeline	Capital Cost (LE x 10^6): Primary Pipeline[c/]	Capital Cost (LE x 10^6): Secondary Pipeline	Capital Cost (LE x 10^6): Total	Cost of Water (LE/m^3)[b/]: Primary Pipeline L	Primary Pipeline B	Secondary Pipeline L	Secondary Pipeline B	Total L	Total B
Northwest										
NW-2 (Qantara to Baloza)	El Qantara	50	26	76	0.03-0.08	0.05-0.13	0.028	0.033	0.06-0.11	0.08-0.16
NW-4 (East of Suez)	Ismailia	57	7	64	0.18-0.24	0.26-0.35	0.02	0.03	0.20-0.26	0.29-0.38
Northeast										
NE-1 (Romana to El Mazar)	El Qantara	145	32	177	0.08-0.21	0.13-0.34	0.025	0.029	0.10-0.23	0.16-0.37
NE-2 (Sheikh Zuwayid to Rafah)	El Qantara	230	26	256	0.29-0.36	0.50-0.60	0.032	0.037	0.32-0.39	0.54-0.64
NE-3 & 4 (along Lower Wadi El Arish)	El Qantara	235	22	257	0.26-0.46	0.44-0.70	0.029	0.033	0.29-0.49	0.47-0.73
Uplands										
UP-1 (Gifgafa area)	Ismailia	85	9	94	0.24-0.31	0.40-0.52	0.02	0.03	0.26-0.33	0.43-0.55
UP-2 & 3 (Wadi El Bruk)	Ismailia	1,265	141	1,406	0.37-0.39	0.62-0.67	0.03	0.04	0.40-0.42	0.66-0.71
UP-6 (El Hasana area)	Ismailia	85	5	90	0.40-0.48	0.69-0.79	0.02	0.03	0.42-0.50	0.72-0.82
UP-7 (Middle Wadi El Arish)	Ismailia	550	51	601	0.42-0.44	0.73-0.79	0.03	0.04	0.45-0.47	0.77-0.83
UP-8 (Wadi El Gayifa El Quseima)	Ismailia	140	8	148	0.47-0.56	0.82-0.94	0.02	0.03	0.49-0.58	0.85-0.97
TOTAL		2,842	327	3,169						

TABLE A-13 (continued)

C. For The Dispersed Strategy

Subregion and Reclamation Area[a]	Origin of Pipeline	Capital Cost (LE x 10^6)			Cost of Water (LE/m^3)[b]					
		Primary Pipeline[c]	Secondary Pipeline	Total	Primary Pipeline		Secondary Pipeline		Total	
					L	B	L	B	L	B
Northwest										
NW-2 (Qantara to Baloza)	El Qantara	52	28	80	0.03-0.08	0.05-0.12	0.03	0.03	0.06-0.11	0.08-0.15
NW-4 & SW-1 (East of Suez)	Ismailia	63	9	72	0.16-0.22	0.25-0.33	0.03	0.03	0.19-0.25	0.28-0.36
Northeast										
NE-1 (Romana to El Mazar)	El Qantara	145	37	182	0.08-0.16	0.14-0.29	0.03	0.03	0.11-0.19	0.17-0.32
NE-2 (Sheikh Zuwayid to Rafah)	El Qantara	230	26	256	0.30-0.34	0.52-0.59	0.04	0.04	0.34-0.38	0.56-0.63
NE-3 & 4 (along Lower Wadi El Arish)	El Qantara	280	30	310	0.26-0.35	0.44-0.59	0.03	0.03	0.29-0.38	0.47-0.62
Uplands										
UP-1 (Gifgafa area)	Ismailia	215	29	244	0.24-0.31	0.40-0.52	0.03	0.03	0.27-0.34	0.43-0.55
UP-2 & 3 (Wadi El Bruk)	Ismailia	1,335	146	1,481	0.33-0.40	0.56-0.68	0.03	0.04	0.36-0.43	0.60-0.72
UP-4 (El Sirr Plain)	El Qantara	192	18	210	0.33-0.36	0.56-0.61	0.03	0.03	0.36-0.39	0.59-0.64
NE-6 (El Hasana area)	Ismailia	400	40	440	0.37-0.44	0.65-0.75	0.03	0.04	0.40-0.47	0.69-0.79
UP-7 (Middle Wadi El Arish)	Ismailia	605	49	654	0.42-0.45	0.73-0.78	0.03	0.04	0.45-0.48	0.77-0.82

TABLE A-13 (continued)

Subregion and Reclamation Area[a]	Origin of Pipeline	Capital Cost (LE x 10^6) Primary Pipeline[c]	Capital Cost Secondary Pipeline	Capital Cost Total	Cost of Water (LE/m^3)[b] Primary Pipeline L	Primary Pipeline B	Secondary Pipeline L	Secondary Pipeline B	Total L	Total B
Southwest										
SW-2 (Ramlet Himeiyir)	Ismailia	330	17	347	0.50-0.54	0.86-0.95	0.023	0.028	0.52-0.56	0.89-0.98
SW-3 (Abu Rudeis area)	Ismailia	255	16	271	0.37-0.40	0.64-0.69	0.021	0.024	0.39-0.42	0.66-0.71
SW-4 (Delta of Wadi Feiran)	Ismailia	340	21	361	0.40-0.42	0.70-0.73	0.022	0.026	0.42-0.44	0.73-0.76
SW-5 (El Qaa Plain)	Ismailia	1,085	61	1,146	0.48-0.52	0.83-0.92	0.025	0.031	0.50-0.54	0.86-0.95
TOTAL		5,527	527	6,054						

a/ Area numbers revised for the Final Report (1985).

b/ L = using the local price of diesel fuel in 1981 (LE 0.025 per liter); B = using the border price of diesel fuel in 1981 (LE 0.18 per liter).

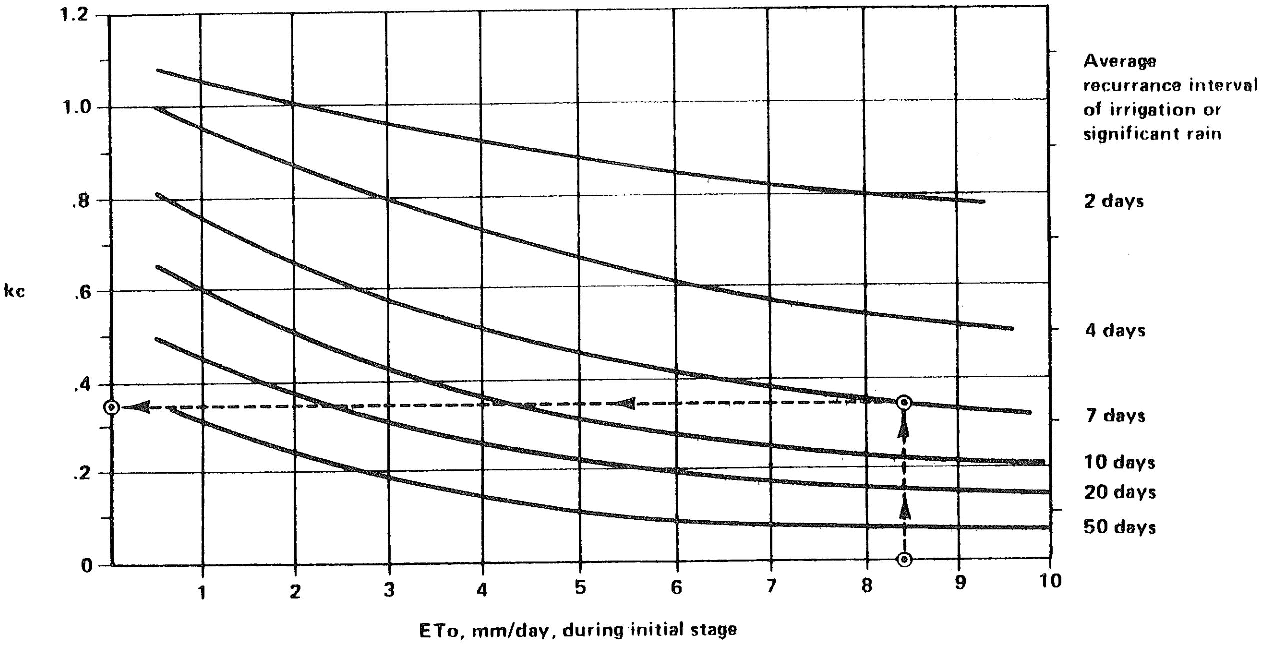
c/ Public supply, industrial, and tourism requirements are included, as well as those for land reclamation.

d/ Calculation for Recommended Strategy reviewed and revised slightly, January, 1985.

SOURCE: Calculations by the Consultant in Project memoranda on file.

Figure A.1

Relationship of Actual Evapotranspiration to the Reference Rate and the Frequency of Rainfall (or Irrigation)



ET_0, measured along the horizontal axis in millimeters per day, is the reference evapotranspiration rate, calculated by the Penman method, taking into account radiation, temperature, wind velocity, humidity and other climatological factors for any particular place.

Actual evapotranspiration will be a function (kc) of the reference rate (ET_0) and the average frequency of irrigation (and/or significant rainfall). Medium-textured soils are assumed; for light-textured soils, the kc value should be reduced by about 30 percent.

In the example on this graph (●------▶), the reference evapotranspiration rate for Cairo is about 8.4 mm/day; if irrigation is on a weekly (seven-day) rotation, the kc is seen to be about 0.35.

Clearly, a place with a lower reference rate than Cairo or a more frequent than weekly watering schedule (whether by irrigation or rainfall) would have a "kc" closer to unity. For instance, a place with a reference ET_0 of 5 mm/day and watering weekly could expect its "actual" evapotranspiration rate to be just under half of its reference rate (5 mm/day x 0.47 or, say, 2.35 mm/day; and Cairo with irrigation every two days would have an actual evapotranspiration rate of about 80 percent of its reference rate (8.4 mm/day x 0.8 or, say, 6.72 mm/day).

Common sense tells us that the more frequent the watering, the greater the water "loss" through evapotranspiration; the graph allows us to estimate just how much that "loss" might be under various circumstances.

SOURCE: Food and Agriculture Organization, Crop Water Requirements, Irrigation and Drainage Paper No. 24 (Revised 1977), p. 38. The curve representing a 50-day interval between significant waterings was estimated by the Consultant.

APPENDIX B

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