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No. 2

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

WATER RESOURCES RESEARCH INSTITUTE
NATIONAL WATER RESEARCH CENTER
MINISTRY OF PUBLIC WORKS AND WATER RESOURCES
THE ARAB REPUBLIC OF EGYPT

SOUTH SINAI GROUNDWATER RESOURCES STUDY IN THE ARAB REPUBLIC OF EGYPT

SUPPORTING REPORT

MARCH 1999

PACIFIC CONSULTANTS INTERNATIONAL, TOKYO
IN ASSOCIATION WITH
SANYU CONSULTANTS INC., TOKYO

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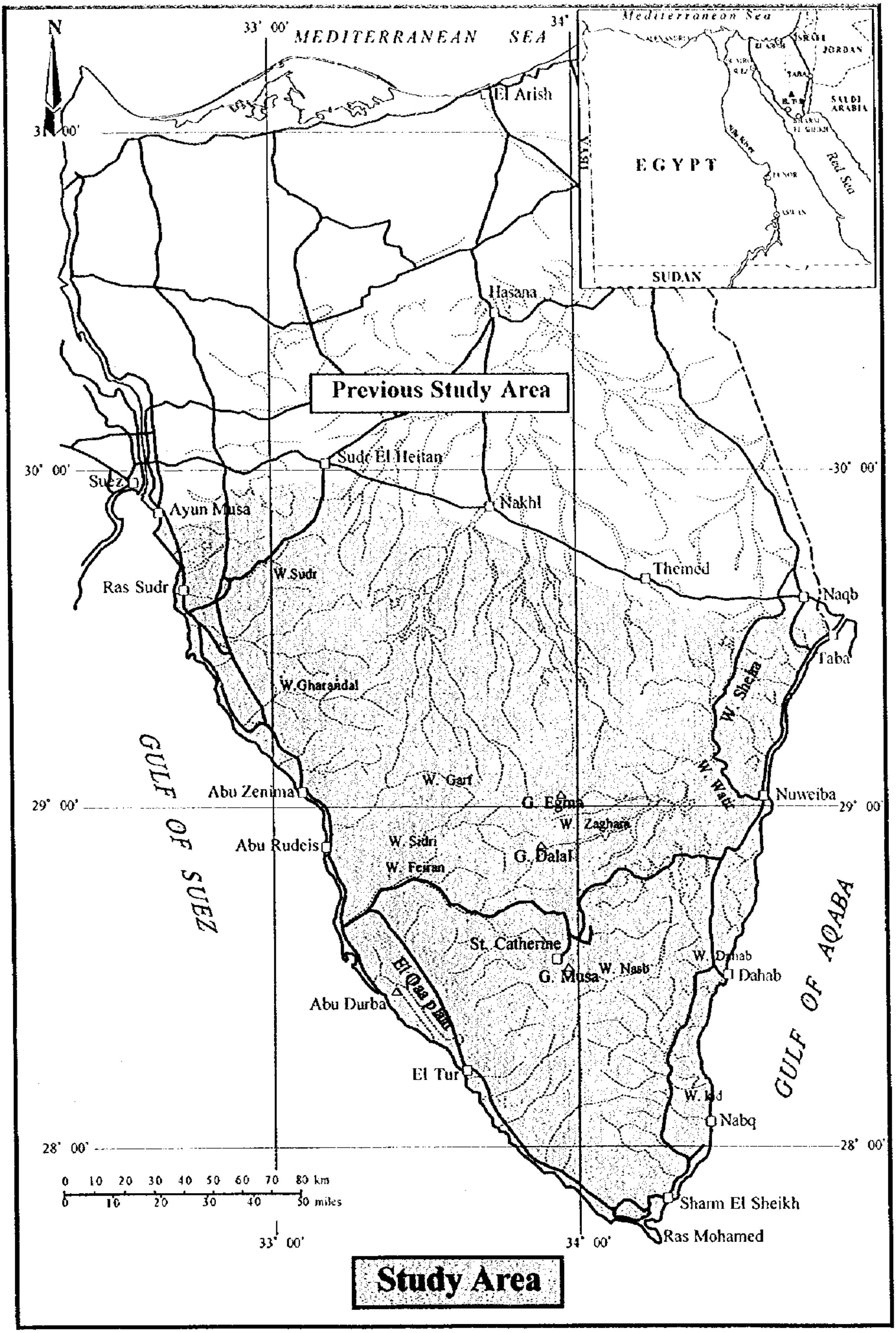
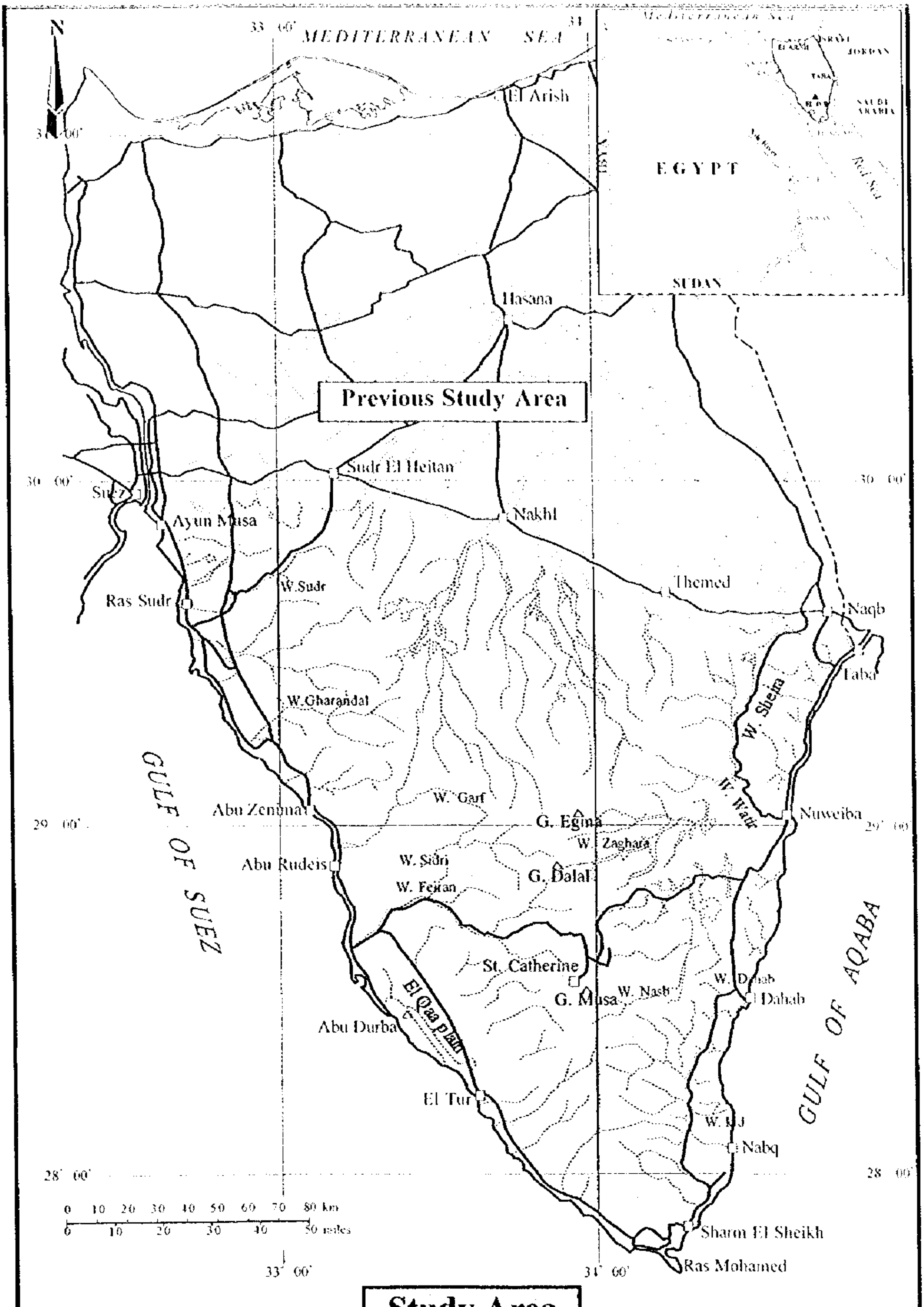


N
MEDITERRANEAN SEA
33° 00'
34°
31° 00'
El Arish
Mediterranean Sea
ISRAEL
JORDAN
SAUDI ARABIA
EGYPT
Red Sea
SUDAN
Hasana
Previous Study Area
Sudr El Heitan
30° 00'
Suez
Ayun Musa
Nakhl
Themed
W.Sudr
Ras Sudr
Naqb
Taba
W.Gharandal
W. Sheira
GULF OF SUEZ
W. Watir
W. Garf
Abu Zenima
G. Egma
Nuweiba
29° 00'
W. Zaghara
W. Sidri
Abu Rudeis
G. Dalal
W. Feiran
St. Catherine
W. Dahab
G. Musa
W. Nasb
Dahab
GULF OF AQABA
El Qaa plain
Abu Durba
El Tur
W. Kid
Nabq
28° 00'
0 10 20 30 40 50 60 70 80 km
0 10 20 30 40 50 miles
Sharm El Sheikh
Ras Mohamed
34° 00'
Study Area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W. Nash
W. Dahab
Dahab
Abu Durba
GULF OF AQABA
El Tur
W. Kid
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Ras Mohamed
EGYPT
SUDAN
30° 00'
29° 00'
28° 00'
33° 00'
34° 00'
0 10 20 30 40 50 60 70 80 km
0 10 20 30 40 50 miles
Study Area

TABLE OF CONTENTS

CHAPTER IV GEOMORPHOLOGY

CHAPTER V GEOLOGY

CHAPTER VI GEOPHYSICAL SURVEY

CHAPTER VII TEST WELL DRILLING AND PUMPING TEST

List of Tables

List of Figures

ABBREVIATION

ASL	: above the sea level
BGL	: below the ground level
BRGM	: Bureau de Recherches Geologiques et Minieres
CAPMAS	: Central Agency for Public Mobilization and Statistics
CBE	: Central Bank of Egypt
EC	: Electric Conductivity
EGSMA	: Egyptian Geological Survey and Mining Authority
ERSAP	: Economic Reform and Structural Adjustment Program
G.	: Gebel (Mountain)
GDP	: Gross Domestic Product
GPS	: Global Positioning System
GVA	: Gross Value Added
IMF	: International Monetary Fund
JICA	: Japan Intentional Cooperation Agency
LGU	: Local Government Unit
MAE	: Meteorological Authority of Egypt
NPDS	: National Plan for Development of Sinai
NSGRS	: North Sinai Groundwater Resources Study
RBA	: Roads and Bridge Authorities
RIWR	: Research Institute for Water Resources (Ex-WRRI)
SDS	: Sinai Development Study
SSGRS	: South Sinai Groundwater Resources Study
T	: Temperature
TDS	: Total Dissolved Solid
TEM	: Transient Electro Magnetic
USAID	: United States Agency for International Development
USGS	: United States Geological Survey
W.	: Wadi (Arid River)
WRRI	: Water Resources Research Institute
WRS	: Water Resources Study

CHAPTER I INTRODUCTION

1.1 Background of Study

Egypt is mainly covered by desert and only 4 % of its land is arable, mainly the alluvial plain of the Nile and its delta. In order to cope with the increasing population, the government of Egypt has been pressed into the development of the Sinai Peninsula, which have high potentials in mineral resources, tourism, and agricultural development. Under these circumstances, various kinds of international cooperation have been undertaken in the Sinai Peninsula.

The government of Egypt decided to implement the "National Plan for Development of Sinai" (NPDS) starting from 1994. The plan aims at achieving comprehensive development of Sinai over the period from 1994 to 2017.

The Sinai Peninsula is located in the east of Egypt and is totally composed of dessert except for the northeastern area. Because of its extremely low rainfall, no surface water is available. Only small amount of spring and groundwater are extracted for drinking and irrigation use.

Water transmission from the Nile, development of groundwater resources and desalination of sea water are considered to be the future water resources in the Sinai Peninsula. Out of the three, water transmission from the Nile is now under implementation.

It is indispensable to evaluate the potential of groundwater resources for the development of the Sinai Peninsula. The potential of groundwater resources in the Northern part of Sinai was estimated within the "North Sinai Groundwater Resources Study (NSGRS)" conducted by Japan International Cooperation Agency (JICA) in the period between 1988 and 1992. However, the potential of groundwater resources in South Sinai has not been evaluated because the available data are quite limited.

Under these circumstances, the Government of the Arab Republic of Egypt requested the Government of Japan to conduct a water resources development study to evaluate the water resources potential in South Sinai in order to cope with the increasing future water demand of the area.

1.2 Study Area

The study area was determined in the Scope of Work agreed upon between the both government on 10th October 1995. It covered the South Sinai Governorate (approximately 34,000 km^2) as shown in the opening page (location map of Study Area).

1.3 Objectives of Study

The objectives of the Study were defined in the above mentioned Scope of Work as follows;

(1) To prepare a series of water resources maps to evaluate groundwater potential in South Sinai.

(2) To formulate water resources development master plan in South Sinai.

(3) To perform technology transfer to Egyptian counterpart personnel in the courses of the Study.

(4) To up-date the hydrogeological map for North Sinai basically depending on the data prepared by WRRI.

1.4 Implementation of Study

The Water Resources Research Institute (WRRI) of the National Water Research Center (NWRC) was assigned as the counterpart organization from the Government of Egypt, while the Japan International Cooperation Agency (JICA) was assigned as the official agency responsible for the implementation of the technical cooperation program of the Government of Japan.

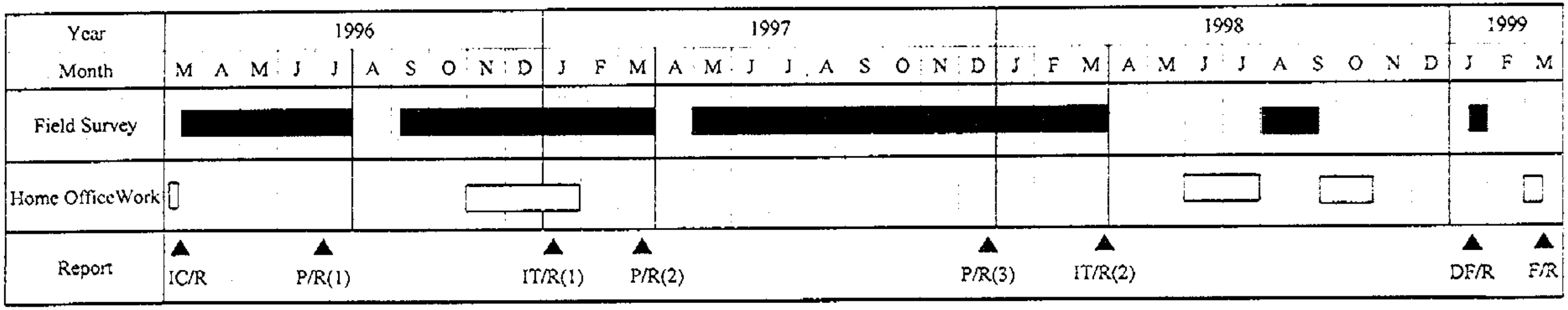
The Study was conducted by the Japanese Study Team dispatched by JICA together with the Egyptian counterpart staff.

Total schedule of the Study is shown in Table 1.4-1.

The members involved in the Study are listed below.

Name	Assignment
<JICA Study Team>	
Mr. Yasumasa YAMASAKI	Team Leader /Groundwater Development Planner
Mr. Norifumi YAMAMOTO	Hydrogeologist (A)
Mr. Yusuke OSHIKA	Hydrogeologist (B)
Mr. Motomu GOTO	Remote Sensing Expert
Dr. Mahbub A. K. M. REZA	Hydrologist/Water Balance Analyst
Mr. Yuichi HATA	Water Quality Expert
Mr. Masaru FUJITA	Geophysicist (A)
Mr. Kunio KIMURA	Geophysicist (B)
Mr. Mamoru NAKAMURA	Drilling Expert (A)
Mr. Satoshi ARAYA	Drilling Expert (B)
Mr. Katsuhiro FUJISAKI	Groundwater Simulation Expert
Mr. Hiroaki MIYAKOSHI	Water Supply Planning Expert
Mr. Jiro YABE	Implementation Planner/ Cost Estimator
Mr. Tatsuo TASHINO	Financial/Economic Analyst
Mr. Takashi KITAGUCHI	Environmental/ Ecological Expert
Mr. Takuya OMURA	Coordinator (Mar. 1996-May 1996)
Mr. Kyoichi SUGIMOTO	Coordinator (May 1996-Sep.1998)
<WRRI Staff>	
Prof. Dr. Mohamed Samir Mahmoud Farid	Director of WRRI (Team Leader)
Mr. Mohamed Tag El-Din El-Deftar	Senior Hydrogeologist (Assistant Team Leader)
Mr. Medhat El Bihery	Hydrogeologist (Groundwater Simulation Expert)
Ms. Hoda Sharaf	Hydrogeologist (Coordinator)
Mr. Mohamed Abd El-Haq	Geologist, El Tur Office (Hydrogeologist)
Dr. Ahmed Hassan Fahmi	Hydrologist (Hydrologist/Water Balance Analyst)
Dr. Abdel Hafez Hassan	Hydrogeologist (Water Quality Expert)
Mr. Shawky Hassan	Hydrogeologist (Drilling Expert)
Dr. Hatem Abd El Rahman Sayed Ahmed	Civil Engineer (Financial/Economic Analyst)
Mr. Abd El Azis Farouk Zaki	Civil Engineer (Environmental/ Ecological Expert)
Mr. Abdo Gasser	Geologist, El Arish Office (Geophysicist)
Mr. Mostafa Mohamed El Kharakany	Civil Engineer (Water Supply Planning Expert)

Table 1.4-1 Work Schedule



IC/R : Inception Report
P/R : Progress Report
IT/R : Interim Report
DF/R : Draft Final Report
F/R : Final Report

CHAPTER II REVIEW OF PREVIOUS STUDIES

Many groundwater resources development studies were undertaken in the Sinai Peninsula by various agencies. The major studies are Sinai Development Study (SDS) by USAID and Sinai Water Resources Study (SWRS) by RIWR in cooperation with EC. In addition to these, WRRI has been executed active groundwater resources studies in major wadis in South Sinai.

2.1 Sinai Development Study (SDS)

The study completed in 1984 was a comprehensive development study concerning Sinai Peninsula. The study proposed development schemes for the migration to Sinai from 1983 to 2000.

The volume 2 on water resources includes a preliminary cost estimation of groundwater development in accordance with the type of aquifers and recommended further detailed studies to evaluate the potential of water resources in Sinai.

The Study recognized seven (7) geomorphologic provinces; (1) Mediterranean Foreshore Province, Mobile Platform Province, (3) Northern Stable Platform Province, (4) Southern Stable Platform Province, (5) Southern Mountain Province, (6) Suez Rift Province and (7) Aqaba Rift Province.

Based on the above division, eight (8) geological units were identified as the aquifers; (1) Quaternary Deposits, (2) Sandstone of Miocene, (3) Limestone of Eocene, (4) Sedimentary Rocks of Upper Cretaceous, (5) Sandstone of Lower Cretaceous, (6) Sedimentary Rocks of Jurassic, (7) Sedimentary Rocks of Cambrian to Triassic and (8) Crystalline Rocks of Precambrian.

Although a certain degree of potential of surface water and groundwater was evaluated as available, the study recommended to transmit water from the Nile River.

2.2 Sinai Water Resources Study (SWRS)

The study has been implemented by RIWR in cooperation with EEC. It aimed to assess the groundwater resources in Sinai Peninsula. A large number of boreholes were drilled mainly in the Maghara area and the coastal plain of North Sinai area.

The study summarized the hydrogeological characteristics of aquifers and detailed study was concentrated on the Quaternary Aquifers in El Qaa Plain. According to that study, the main sources of recharge to the aquifers is the precipitation in the St. Catherine area and it reaches to the aquifers in the plain through faults and fissures. The amount of recharge is estimated at 19,800 m^3 in the northern part, 11,700 m^3 in the southern part and 35,500 m^3 by recycling of irrigation water.

Discharge from the plain is estimated as follows;

Maximum extraction by wells	:	14,000 m^3
Evaporation and flow out from the coast	:	15,000 m^3
Outflow to the Suez Bay	:	6,500 m^3

The El Qaa Plain is considered to store about 21 x 109 m^3 of groundwater in its basin. Sustainable amount of groundwater is estimated as 2.76 x 10^6 m3.

Numerical groundwater simulations concerning the Quaternary aquifers in El Qaa plain, El Arish area and Romana-Bir El Abd area have been carried out in this project. Hydrogeological condition in El Arish and Romana-Bir El Abd areas (North Sinai) were modeled using MARTHE (a multi-layered quasi-three dimensional groundwater flow model developed by BRGM). The Calibration of the model was completed comparing observed piezometric heads with calculated ones, and the groundwater balance based on the model was estimated.

In El Qaa plain, MODFLOW (a three-dimensional groundwater flow model developed by U.S.G.S.) was applied. A single aquifer model was applied and an interval of calculation nods was 2 km each. The distribution of the permeability was based on the results of 22 pumping tests. The source of recharge in the model was mainly the precipitation in the St. Catherine area. The mean rate of total groundwater abstraction was estimated to be approximately 10,000 m^3/day. The piezometric head calibration of the model was completed in the steady state condition. From the simulation study, it was concluded that the recharge of quaternary aquifer in El Qaa plain can be estimated between 20,000 and 30,000 m^3/day.

Also, a numerical modeling of the Lower Cretaceous aquifer was tried by RIWR in cooperation with EEC. However, the calibration of the model couldn't be completed, because of the lack of exact data in Negev area in Israel and the lack of information of the boundary conditions in Northern and Western Sinai.

2.3 North Sinai Groundwater Resources Study (NSGRS)

The study was executed by JICA during the period from 1988 to 1992. A total number of 19 test wells were drilled in North Sinai and seven (7) wells out of these were drilled into the Lower Cretaceous sandstone.

The study estimated the groundwater storage in the Lower Cretaceous and concluded that it was recharged in the South Sinai area approximately 20,000 years ago using C-14 dating of groundwater.

Furthermore, the study pointed out that water quality of South Sinai was supposed to be better than that of North Sinai and there is a possibility of plenty of groundwater storage in South Sinai.

As the results, the study prepared a series of hydrogeological maps for North Sinai and recommended to expand the study to South Sinai to evaluate the groundwater resources for the whole Sinai.

2.4 South Sinai Water Resources Development Project (SSWRDP)

The Study was conducted by WRRI under the finance by the Italian Government and concluded in 1996 directing the main emphasis to the Wadi Watir area from the hydrological and hydrological point of view. As the results of the Study, eight (8) reports were prepared: They are No.1 Geological Studies, No.2 Geophysical Investigation, No. 3 Hydrological Studies, No. 4 Groundwater Development Strategy, No. 5 Geochemical Investigations, No. 6 Environmental and Economical Aspects, No. 7 Design of Proposed Dams and No. 8 Tender Documents for proposed projects.

Finally three (3) major projects were proposed to utilize the water resources in the Wadi Watir area: To construct five (5) storage dams and 17 detention dams to prevent flood disasters, To construct seven (7) deep wells to develop Lower Cretaceous aquifer and To Develop and utilize Ain Furtaga spring.

2.5 Groundwater Resources Studies and Development by WRRI

WRRI has been conducting groundwater resources studies in South Sinai by geological and geophysical surveys. Based on the results of these studies, a number of production wells and piezometers were drilled penetrating into both Quaternary Aquifers and Pre-Quaternary Aquifers. The main study areas were El Qaa Plain, W. Feiran, W. Gharandal, W. Sidri, W. Sudr and W. Watir including Nuweiba coastal plain.

Hydrogeological characteristics of aquifers, namely facies and thickness of aquifers, and groundwater resources potential were revealed through these studies.

Furthermore, active groundwater development is going on in El Qaa Plain and other areas by WRRI or under the supervision of WRRI collecting many hydrogeological data.

CHAPTER III CLIMATE AND HYDROLOGY

3.1 Climate

3.1.1 Hydro-meteorological Network

There are two organizations namely, Meteorological Authority of Egypt (MAE) and Water Resources Research Institute (WRRI) have their own network in Sinai. Records show that network of MAE has started data collection since 1907 (El Arish). On the other hand network of WRRI is relatively very new and started its operation since mid 80s. Both organizations had a good network. According to the EC report (1995) MAE had 14 stations within Sinai but now only 10 are in operation (6 are in Study area). In 1989 EC has helped WRRI donating devices for setting up meteorological stations in Sinai, especially with a good number of rain gauge, water level recorder, rainfall totalizer etc. Existing number of stations (related to the Study Area) operated by WRRI is 12 (of which 4 are meteorological stations, rest are only rainfall stations). Both organizations (MAE & WRRI) collect data in field and send them to the main center where they are stored in the data base. In some cases, duplication with the MAE sites are also noticed. Density of rainfall recorders in the representative catchment areas, namely Wadi Sudr (upstream) and Wadi Feiran (upstream) is very high.

Existing stations in the Study Area (South Sinai)operated by both organizations are listed below and their locations are shown in Fig. 3.1.1-1

MAE stations in the Study Area

Station Name	Remarks
1. Ras Sudr	Weather station
2. St. Catherine	Weather station
3. El Tur	Weather station
4. Ras Nasrani	Weather station
5. Ras El Naqb	Weather station
6. Nuweiba	Weather station

WRRI stations in Study Area

Station Name	Remarks
1. Wadi Sudr	Weather station
2. Gharandal	Weather station
3. Malha	Rainfall recorder
4. Sahab	Rainfall recorder
5. Solaf	Rainfall recorder
6. St. Catherine	Weather station
7. Saal	Rainfall recorder
8. Nuweiba	Weather station
9. Wadi Watir	Rainfall recorder
10. Nakhl	Rainfall recorder*
11. Themed	Rainfall recorder*
12. Kuntella	Rainfall recorder*

(* O&M of these stations belong to North Sinai)

3.1.2 Existing Data

For the subject study, at first data available in WRRI were collected (some data are originally from MAE) and reviewed. And, supplemental data from MAE were collected and used in this Study. A list of collected data is presented below.

Sl. no.	Item	Stations
1	Rainfall	Themed, Nakhl, Naqb, Kuntella, Ras Sudr, St. Catherine, El Tur, Ras Nasrani, Nuweiba, Sheikh Attia
2	Temperature	Kuntella, Nakhl, Ras Sudr, St. Catherine, Nuweiba
3	Eaporation	Ras Sudr, St. Catherine, Nuweiba, Sharm El Sheikh
4	Wind Speed	Kuntella, Nakhl, Ras Sudr, St. Catherine, Nuweiba
5	Humidity	Kuntella, Nakhl, Ras Sudr, St. Catherine, Nuweiba
6	Sunshine	Nuweiba

3.1.3 Climate of Study Area

The climatological conditions of the Sinai Peninsula are similar to those which characterize desert areas in other parts of the world. They include extreme aridity, long hot rainless summer months and mild winter. During the winter months some areas of Sinai experience brief but high intensity of rainfall that makes Wadi beds to overflow and sometimes causes severe flush floods which damage the roadways and human lives. A brief description of some parameters of climate is presented below.

1) Temperature

The temperature of the air in Sinai is subject to large variations due to its geographical conditions such as extensive coast lines and high mountains. June and July are the hottest months. The temperature goes up to 36℃ in Nakhl and Kuntella areas (central Sinai) and in St. Catherine (relatively southern side) it is about 26℃. The coldest months are December and January. The average temperature goes down to 5℃.

2) Humidity

According to the collected data northern part of the Study Area (central part of Sinai) is more humid than the southern part. Humidity is higher in winter than in summer months. Average humidity in summer months varies approximately 35% to 45%, whereas in winter it is about 60 to 70%.

3) Evaporation

Being a desert area evaporation is very high all over the Study Area. In general, for the summer months average evaporation may be computed as 16-17mm/day. In the winter months it is about 5-6mm/day. But in case of Sharm El Sheikh, a city situated in the extreme south of the Sinai has a very high evaporation rate (12-26mm/day).

4) Wind Speed

Complete long term data of wind speed are in scarce. However, preliminary analysis shows that in the summer months average wind speed in Ras Sudr is about 5-6 m/sec and in the winter months it is about 4 m/sec. It was reported that in winter, high wind speed causes sand or dust storms and affect the normal activities in Sinai.

5) Sunshine Hours

Continuous long-term sunshine data were also very limited in the Study Area. However, data of Nuweiba (only three years) were collected. The summer months have longer sunshine hours which varies from 10-12 hrs per day. During the winter months it is about 8 hrs per day.

Table below shows the monthly average value of above mentioned meteorological parameters of selected stations.

Station	J	F	M	A	M	J	J	A	S	O	N	D
Temperature Unit: ℃												
Nakhl	9.6	11.1	15.8	20.2	24.2	29.1	27.4	30.9	28.5	25.0	16.8	18.7
St. Cath.	9.5	13.2	18.6	22.9	24.6	24.9	23.5	21.1	17.0	11.9	8.6	7.7
Humidity Unit:%												
Nakhl	67	71	55	42	47	37	49	52	68	63	60	68
St. Cath.	43	45	34	26	31	28	27	28	27	31	38	40
Evaporation Unit: mm/day												
St. Cath.	6.3	7.3	10.5	13.4	15.8	16.3	17.7	15.2	12.6	9.4	7.2	5.9
S.E.Sheikh	11.6	12.4	14.8	18.0	20.8	25.1	25.8	22.4	20.8	16.2	12.8	11.6
Wind Speed Unit: m/sec												
Nakhl	5.1	4.1	4.3	4.3	3.8	4.1	2.9	3.3	3.4	3.0	3.8	4.4
St. Cath.	4.0	5.4	5.0	5.3	5.3	5.2	5.0	4.1	4.5	4.2	4.2	3.6
Sunshine Unit: hr/day												
Nuweiba	7.5	9.0	9.8	10.0	10.3	12.4	12.4	12.0	10.4	9.2	8.7	8.2

3.2 Hydrology

3.2.1 Hydrological Conditions

Sinai is surrounded almost from all sides by large bodies of saline water of Red and Mediterranean seas. There is no natural streams flowing through the Sinai. The only source of fresh water in Sinai is rainfall which only falls in winter months. Therefore, hydrology of Study Area is governed mainly by the surface water flow through the Wadis due to this rainfall. This hydrological process depends on the rainfall parameters, such as depth, duration and intensities.

3.2.2 Rainfall

In a broad view, climate of Sinai may be categorized into two, such as dry and wet. Although annual rainfall is little, all of them occur in the wet season i.e. during the months of October through May. The wet season includes winter, spring and autumn seasons. In the summer i.e. June through September there is no rainfall at all.

There are two hydrological phenomena that responsible for the rainfall. One is the development of depressions over Cyprus in winter season. When it crosses over the Mediterranean forms cold fronts and causes rainfall in northern Sinai and also in the northern part of Egypt. The other one that causes rainfall events during the spring and autumn is due to the Monsoon depressions formed over Sudan and its movement over northern zones of Red Sea. Sometimes this movement coincides with another depression formed over the eastern part of Mediterranean and causes severe thunderstorms in the area.

From the review of collected data from the South Sinai area it was found that there are many years which have no rainfall and when there is some rainfall, the rainy days are very few, on the other hand rainfall intensity is very high and duration of storms is rather short. Although the duration is short the high intensity is the main reason for flush floods.

Analysis of the collected data show that average of annual rainy days (including 0.1mm) in Ras Sudr are 10, in Ras Nasrani it is 4, in El Tur it is 4, in St. Catherine and Naqb it is 13/year. On the other hand if only more than 5mm/day is considered it becomes only 1 to 3 days/year. Analysis also reveals that average annual rainfall of south Sinai varies from 5mm to 30mm. The annual total rainfall varies from 0.0mm to 123.2mm (in 1937, St. Catherine) and the highest daily maximum was recorded as 76.2mm (8th November 1937 at St. Catherine). However, daily maximum of some selected stations in recent years with their probabilities are tabulated below.

Station	Daily maximum	Month/Year	Probability
Ras El Naqb	35.3mm	Nov./1994	once in 14 year
Sheikh Attia	16.6mm	Feb./1991	(small data set)
Ras Sudr	26.7mm	Feb./1991	once in 30 year
St. Catherine	25.9mm	Mar./1991	once in 10 year
El Tur	18.6mm	Nov./1994	once in 15 year
Ras Nasrani	10.3mm	Oct./1989	once in 6 year
Nuweiba	10.9mm	Feb./1989	(small data set)

It is noteworthy to note that the above daily maximum rainfall might have occurred only by a single storm or few storms with high intensity, not from a continuous 24hrs rainfall.

Annual and monthly average rainfall of some stations is presented in the Fig. 3.2.2-1 and 3.2.2-2 respectively. Rainfall contours for south Sinai is shown in Fig. 3.2.2-3.

3.2.3 Drainage Catchment

As it is mentioned earlier that rainfall is the only source of freshwater in Sinai. Rain that falls in Sinai will ultimately change into three forms i.e. evaporation, infiltration as groundwater recharge and surface runoff. For planning purposes quantitative determination of these components are very important. The most accurate measurements can be achieved only through direct measurements in the catchment's outlet. However, number of catchments in the Study area is very large and Sinai lacks homogeneity. Therefore, surface runoff vary considerably from location to location and direct measurements in many catchments become more difficult.

So far, two attempts have been made in order to divide Sinai into number of catchments calculating the amount of surface runoff. One was done by USAID, known as 'Sinai Development Study (SDS)' about ten years ago. The other one is comparatively recent (1993) by EC as 'Sinai Water Resources Study (SWRS)'. In SDS, whole Sinai has been divided into 29 catchments and according to the SWRS, designated catchments are 52. However, for the subject Study both were reviewed and the Study Area was divided into suitable number of drainage catchments. The divisions are based on SWRS report and a topo map of 1:250,000 scale. The total number of catchments became 40, of which 16 lie in the eastern block and 24 lie in the western block. Apart from these two blocks, there are about 8,191 km^2 of Wadi El Arish catchment lie in the Study area. It is noteworthy to note that the runoff from El Arish catchment flow to the north Sinai. The list of drainage catchments with their respective areas are presented in Table 3.2.6-1 and Fig. 3.2.3-3 shows the drainage catchment divisions.

3.2.4 Main Wadis

Although there are 40 catchments in the Study area, however, active Wadis are not so many. In the western part, Wadi Sudr, Wadi Gharandal, Wadi Garf, Wadi Feiran and few Wadis in El Qaa Plain are mention-worthy. In the eastern part, Wadi Watir, Wadi Dahab and Wadi Kid are known as main active Wadis. A brief description of the main Wadis are given below.

(Western Group)

1) Wadi Sudr

This wadi has a catchment area of 712 km^2 lies in the northwest corner of the Study area. It starts from the boarder of Sudr Heitan and ends to the Gulf of Suez at Ras Sudr. The Wadi runs from northeast to southwest and has a total length of about 45 km. Highest elevation in the upstream is about 500mASL. Except the part of the delta near Ras Sudr this Wadi has a relatively very distinct waterway without famous tributaries. It is one of the very active Wadi in western group of Wadis. In an average three to four floods occur annually in this Wadi. There is a WRRI representative catchment in the upstream and a weather station in the middle part of the catchment. The area of the representative catchment is 25 km^{2}in the tributary called Wadi Meleiha. Floods are measured at two sites, one is at the outlet of the representative catchment and other is at a distance of 22 km from the Tunnel--El Tur road where the river cross section is equipped with a Parshal flume. The geological formations are sedimentary rocks of upper Cretaceous age. The catchment area of this Wadi is presented in Fig. 3.2.4-1.

2) Wadi Gharandal

This is also an active Wadi in the western group of Wadis. The drainage area of this Wadi is about 966 km^2 with a total length of about 60 km. The whole length of the catchment may be divided into 4-5 areas according to the characteristics of geology such as lime stone, sand stone etc. The upper part of the Wadi is known as wadi Abou Ghada. There are three oasis in the catchment area but do not have year round flow. The groundwater table in the wadi bed is comparatively low, about 25m below the ground surface. Wadi Gharandal is well known for its flush floods. Flush floods have damaged two dams constructed in this Wadi catchment. The main tributaries are Wadi Wata, Wadi Salva and Wadi El Garn. Fig. 3.2.4-2 shows the catchment area of Wadi Gharandal.

3) Wadi El Garf

This Wadi originates at the western foot of El Tih plateau. The upstream of this Wadi is consists of many fans. The catchment area of this Wadi is delineated as 742 km^2. The name of the main tributary is Wadi El Gharafi which joins from the northern side and a good contributor of surface flow. Fig. 3.2.4-3 shows the catchment area of this Wadi.

4) Feiran

This is a very important Wadi in the south Sinai. It originates in the rocky mountains of Moses and St. Catherine at an altitude of about 2,637mASL. It covers a total length of about 100 km when it meets the Gulf of Suez. The area that is drained through this Wadi is about 1,830 km^2. The geological formations are crystalline and metamorphic rocks. The middle part of Wadi has two oases namely, El Heiswa and Feiran. Flood records show that due to narrow cross section in these oases area the velocity rises very high and causes severe damage to the road and houses. The upper part of Wadi Feiran has three main tributaries and they are as follows:

(1) Wadi Solaf

This Wadi originates from the Gebel Catherine. It has a drainage area of 315 km^2 and covers the southern part of the upstream. Wadi Solaf joins Wadi Sheikh at a point of 45 km from the upstream.

(2) Wadi Sheikh

Out of three upstream tributaries Wadi Sheikh forms the middle part covering a drainage area of 328 km^2. There is a representative catchment with an area of 32 km^2 in this catchment.

(3) Wadi Akhdar

This wadi has a drainage area of 334 km^2. It descends from Egma-Tih complex from north and joins Wadi Sheikh at a point of 48 km. Below this point it takes the name of Wadi Feiran and flows down towards the Gulf. Fig. 3.2.4-4 shows the detail of Wadi Feiran.

5) El Qaa Plain

It is located in the western part of south Sinai covering a closed inland drainage basin area of about 3,900 km^2 extending north to south. The eastern border is formed by basement rocky mountains with an elevation of about 2,000 mASL. The western and northern borders are formed by sedimentary carbonate mountains. The average floor elevation of the Plain is about 100 mASL. The El Qaa Plain contains large Plain of desert and highly rugged mountains without almost any vegetation.

The plain has three geomorphic units namely, eastern basement rock mountainous unit, western sedimentary hilly unit and the central El Qaa Plain unit.

There are quite a few Wadis in El Qaa plain which flow from east to west. Among them Wadi Hibran, Wadi Mir, Wadi Sadik and Wadi Isla are very important. These wadis are only prominent only up to a certain distance from their mouths. Later, all of them spread towards the main plain as fans and as they come closer to the highway they form only one Wadi known as Wadi El Awag which ultimately flows into the gulf of Suez.

The Wadis are originated from the eastern basement rocky mountains. Usually there is no natural flow, flow occurs for a short period of time only when there is a rainstorm. At the Wadi mouths there are number of water-points/springs created by the water flows through the large open fissures and joints in the basement rocks. These waters are exploited by the villagers for domestic, livestock and limited agriculture.

Considerable effort has been made in order to know the potential of El Qaa plain, and its recharge mechanism by many organizations and individuals. Since all basins of El Qaa Plain are un-gauged researchers used representative catchment approach in order to know the hydrological characteristic of this Plain. Using the flood records in the representative catchments of Wadi Sudr and Wadi Sheikh annual runoff volume (in the form of flush floods) in the plain is estimated in the range of 0.8-1.2million m^3/year (Hatem, 1996). It was also observed that most of the runoff is generated in the eastern part of the Plain. Annual average recharge rate of the El Qaa Plain is estimated as much 66,000m^3/day (Dames and Moore, 1985), whereas in other estimates it is described as about 22,000 m^3/day (Hatem, 1996) and between 20,000-30,000 m^3/day (BRGM, 1994). Hatem also made groundwater reserves estimation for the Plain at 2.6×10^9 m^3. Fig. 3.4.2-5 shows the Plain with its Wadi system.

(Eastern group)

6) Wadi Watir

This Wadi has the largest catchment area of 3,516 km^2 and lies in the northeastern part of the Study Area. The total length is about 85 km. It is one of the most active Wadis in the south Sinai and famous for its destructive nature. The catchment area is covered by basement rocks, mainly highly fractured granite. It is also famous for its spring called Ain Furtaga from which water flows over the surface year round. The groundwater level varies from 8-12m below the ground surface around Sheikh Attia. This Wadi has many tributaries and can be divided into two groups, such as Western and Eastern. The Wadis in the western group are more prominent than the eastern group. Fig. 3.2.4-6 shows the Wadi Watir catchment with its important sub-catchments. A brief description of main tributaries is presented below.

(1) Wadi Khadeira

The catchment area of this Wadi is about 80 km^2. It originates from an elevation of about 1,200m of Gebel El Khoder and Ras El Khaitat. The length may be estimated at about 40 km. It joins Wadi Watir from the west at a point of 53 km from the Nuweiba outlet. The geology consists of limestone and shale.

(2) Wadi Sawana

The length of this Wadi is about 45 km with a catchment area of 84 km^2 and joins Wadi Watir from the west at a distance of 33 km from the Nuweiba outlet. It originates from an elevation of 1,280m of Gebel Om Froot and descends down to 430m. The geology may be described as limestone and shale.

(3) Wadi Zalaga

It is one of the most important tributary of Wadi Watir with a catchment area of 1,432 km^2. It originates from an elevation of 1,340m of Gebel El Barqa and traverse a total length of about 80 km before it joins Wadi Watir from the west at a distance of 30 km from the Nuweiba outlet. There is a spring with year round flow called Ain Umm Ahmed in this catchment. The geology of the catchment is consists of granite, limestone and shale.

(4) Wadi El Haithy

This is the only prominent Wadi in the eastern group of Wadi Watir. The catchment area is about 101 km^2. It originates from Gebel Shoaira at an elevation of about 960m. It traverses a length of about 44 km and joins Wadi Watir at a distance of 55 km from the Nuweiba outlet.

7) Wadi Dahab

Wadi Dahab has the second largest catchment area in the eastern group of Wadis covers an area of 2,067 km^2. In fact, Wadi Dahab has many tributaries and all of them contribute flows from the western side. The upper part of mainstream of Wadi Dahab is called as Wadi El Ghaghib and flows north to south. In the upstream of western part there are two groups of tributaries such as Saal-Genah-Hamam and Nasb-Zaghara groups. Almost every year flush floods occur in this Wadi system and causes damage to the shops/houses situated at the outlet of Wadi Dahab i.e. along the Dahab beach. The system of Wadi Dahab catchment is presented in Fig. 3.4.2-7. A brief description of this Wadi system is given below.

(1) Wadi Saal-Matamir-Hamam group

The Wadis that form this group are namely, Wadi Saal, Wadi Genah, Wadi Matamir and Wadi Akhri, and takes a new name called Wadi Sarfa at the meeting point. Further downstream it is called as Wadi Hamam and joins Wadi Zaghara.

(2) Wadi Zaghara-Nasb group

The Wadis in this group are Wadi Shalal, Wadi Nasb, Wadi Marikh and Wadi Zaghara. Wadi Shalal meets Nasb and then meets Wadi Zaghara. Wadi Marikh meets Wadi Zaghara from north at a point upstream of meeting point of Wadi Nasb and Zaghara. The lower part of this Wadi system is also called as Nasb pass.

8) Wadi Kid

Wadi Kid has the third largest catchment area in the eastern block and covers an area 1,090 km^2. It originates from the valley of Gebel Sheikh El Arab and Gebel Abou Masud.

Three tributaries namely, Wadi Maliha , Wadi Arhab and Wadi Lig meet together from the northern side and joins Wadi Kid as Wadi Madsus. In the eastern side the main tributaries are Wadi Es Mid and Wadi Gindhali meets together joins Wadi Kid as Wadi Magirat. The Wadi has a very distinct configuration up to a length of about 18 km from inter-section point with the highway. After this point the Wadi has a higher level of configuration with Oasis. There is seasonal surface flow and almost year round sub-surface flow from the Oasis at the point where configuration changes. Local Bedouins tap water by PVC pipe and accumulate them at a tank near the highway for selling purpose. Wadi Kid empties to the Red sea as Wadi Kabila. Fig. 3.2.4-8 shows the catchment area of Wadi Kid.

9) Wadi El Arish

This is the biggest Wadi system in the Sinai peninsula which has an area of 19,055 km^2 and flows from south to north. There is a dam of $3,000,000 m^3$ capacity in the down stream of this Wadi system. The upper part of the catchment may be divided in to three sub-basins and some parts fall within the Study area which is believed to be related to the recharge mechanism in the Nakhl-Themed area. The names of these sub-basins are:

(1) Wadi El Bruk

Forms the western part of the upstream of El Arish catchment and has an area of 3,345 km^2 of which 1,242 km^2 lies within the Study area.

(2) Wadi El Ruaq

This wadi shares the major part of the upstream covering an area of 6,481 km^2 of which 6,044 km^2 lie within the Study area

(3) Wadi El Aqaba

Shares an area of 2,839 km^2 in the eastern part of the upstream. The area within the Study area is 905 km^2.

3.2.5 Wadi Flows

1) Past Flood Records

According to the local people all main Wadis in the area experience flush floods of different magnitudes at least once in two years. Records also show that there are severe floods occurred in recent years in Wadi Feiran, Wadi Sudr and Wadi Watir. Before, 1989 no authentic records of floods were available. Since the installation of EC donated water level recorders by WRRI in few places some records are available in EC reports (at present no water level recorder exists in the area except Wadi Sudr). Therefore, any reliable conclusion regarding a rainfall-runoff relationship is very difficult with this limited set of data. However, some of the recorded floods in Wadi Sudr, Wadi Feiran and Wadi Watir are tabulated below.

Wadi Name	Date	Runoff Volume (m^3)	Remarks
Wadi Sudr	Jan. 26/90	237,000	below the weir
	Apr.02/90	279,000	below the weir
	Mar.05/91	25,000	below the weir
	Mar.06/91	328,000	catchment outlet
	Mar.22/91	2,925,000	below the weir
	Mar.23/91	1,107,000	below the weir
	Jan 23/97	240,094	below the weir
	Mar 03/97	195,048	below the weir
Wadi Feiran	Nov.05/89	255,000	at Feiran oasis
	Apr.26/89	22,000	at Watia pass
	Mar.22/91	11,400	catchment outlet
Wadi Watir	Oct.16/87	4,500,000	catchment outlet
	Apr.20/88	1,000,000	catchment outlet
	Oct.16/88	1,500,000	catchment outlet
	Oct.20/90*	3,500,000	catchment outlet
	May 16,17/97	440,640	catchment outlet
	May 28/97	27,720	upstream outlet
	Oct. 18/97	no record	-

(* this flood continued for 6 days (Oct. 19-24))

2) Flood in Wadi Watir and Wadi El Hathy Area

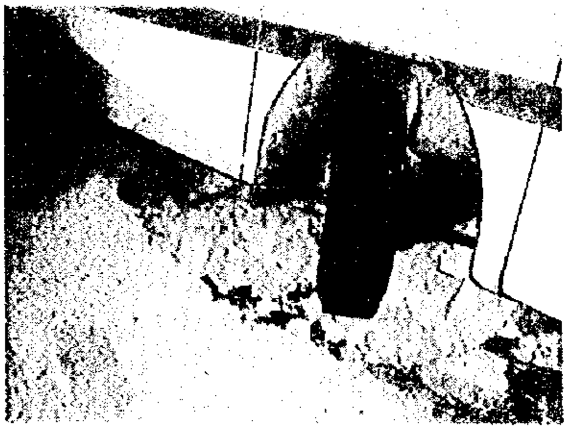
During this study, a rather large flood was happened in Wadi Watir and Wadi El Hathy Area in 1997. The outline of the flood is described as follows.

18th Oct. 1997

The local newspaper gave the first information about the flood as follows. "The flood was occurred in South Sinai on 17th, and the road in Wadi Watir and bound for St. Catherine Airport were closed." However, there's no more detail information.

The Study Team was near J-6 well by chance which was located at about 80Km west from Wadi Watir and Wadi El Hathy area and noticed a remarkably developed cumulonimbus cloud in the direction of these areas around 4 o'clock p.m. It is considered that the major impact of this flood is the heavy rain from the cloud.

The flood damage of the trunk road to Nuweiba or Taba started from near Naqb. There was a stuck bus of which the front wheel was slipped down into a hole of road shoulder because of the flood. Many traces of floodwater over the road began from Themed to Nuweiba through Wadi Watir.



Stack bus caused by destruction of the road shoulder

The seriously destroyed road was at 20km more ahead to the south, and there was no original form of the road structure for approximately 32Km up to Sheikh Attia.

Scattering asphalt fragments of road's pavement

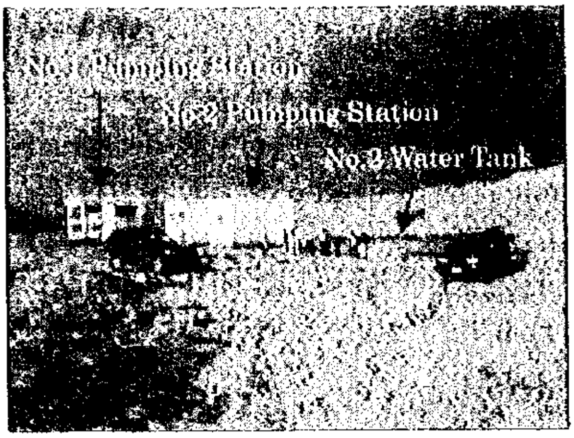
Taxi attacked by flood

As above mentioned, the newspaper reported the flood happened on 17th Oct., but the biggest flood occurred on 18th Oct. Another newspaper reported that a strong storm with several tens centimeter thick of hail attacked the south Israel on the same day. It seems that these abnormal happenings were due to the same weather conditions.

Hearing Survey on the Spot

Cafeteria in Wadi El Hathy

This cafeteria was located just out of damaged area and a victim asked here for help. He said that heavy rain began at 12:30 to 15:00 on 18th Oct. and light rain with hail continued to 19:00. The first flood was happened after one hour of the heavy rain.



Pumping station in Sheikh Attia area after flood on 21st Oct.

Mr. Uonese, Drilling Site Staff

He found the flood coming up in front of his car near Sheikh Attia on the way to the drilling site J-5 from Nuweiba at 3 PM on 18th.Oct. He made his small truck U-turn instantly and run away at a speed of 100Km/hr downstream. However, as the flood was following him at almost same speed, he drove on to a height nearby a roadside in order to let the flood go past. He had to stay there until the end of the main floods, namely at 7 Am on the next morning (20th. Oct.)

He said that the flood was about four meter in height at first but it became seven meter after half an hour. Such strong flood continued until next morning and moreover a weak flood 1m in height lasted until midday.

Field Survey for the Flood

Estimation of Precipitation

There is a meteorological station in Sheikh Attia, however, unfortunately no rainfall record could be taken. Then, it was paid attention that a water tank (12m x 12m x 3m= 432m^3) beside pumping station kept the hint of rain fall volume in this flood. No.1 water tank was filled up by floodwater. The elevation of flood trace on the wall of No.1 pumping station was equivalent to the top of this tank. It means that the water in the tank came from the floodwater and rainwater. On the other hand, No.2 water tank was filled up with clean water only 21cm in depth. Since No.2 water tank was located on slightly high level ground, the floodwater could not reach to the top of the tank. It seems that the most water was brought from rainfall during the flood. Because some mud cracks on the bottom of the tank suggested that it was dry up before the flood. If this presumption is true, a total rainfall during the flood is estimated at 210mm.

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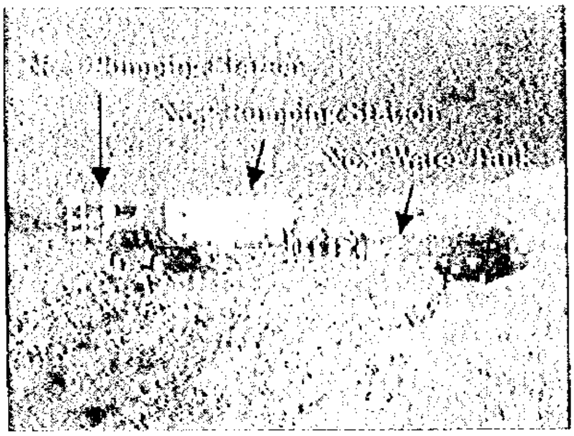

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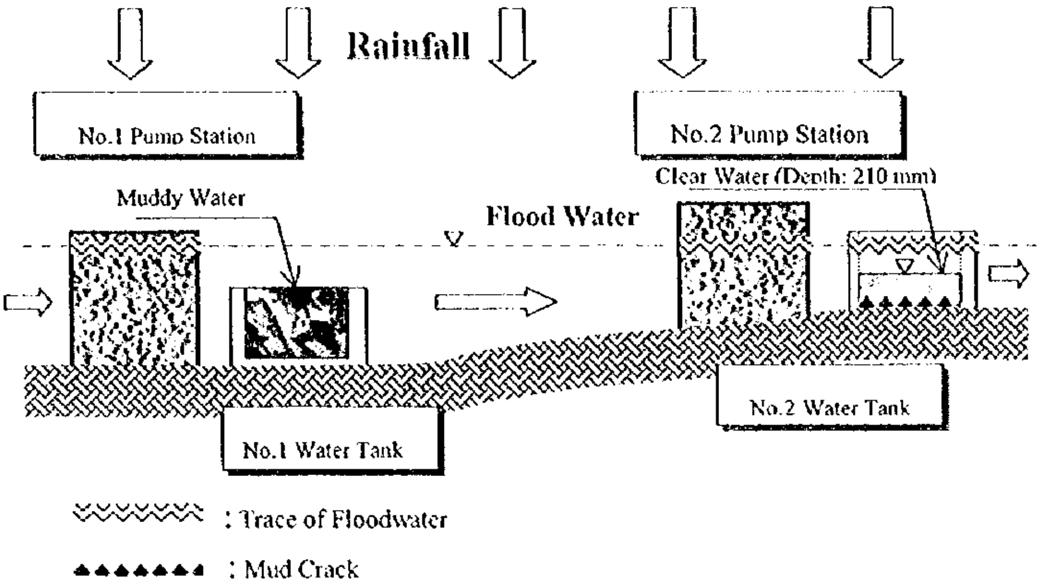

Conceptual Conditions for Rainfall Estimation

Damaged part of the road

The damaged load is the trunk road, which run from Cairo to Nuweiba through Suez Tunnel and crossing the middle of Sinai Peninsula. The damaged part of the road was mainly located in wadis where were somewhat wide. The road where was crossing the wadis had been taken some countermeasures against flood in every few years, for example culvert etc. however, this flood was seemed to be far larger scale than before. The serious damages were concentrated in such parts of the road.

3) Surface Runoff

In Sinai, the most difficult task still to be worked out is the calculation of runoff which is close to the observed one. In this connection, as long as long-term observed runoff data are not available the problem will remain unsolved. So far, WRRI has data for only few flood events in three major Wadis (W. Sudr, W. Feiran and W. Watir) but most of them are without any rainfall records. The Wadi that has records with rainfall data is Wadi Sudr. However, analysis show that the runoff coefficients of six flood events vary from 1.2 to 39.3 (Hatem, 1992).

Review of previous studies show that various attempts have been made for calculating runoff. In SDS (1985), emphcrical formulas were used for computing peak floods, flood volumes and flood duration. Recently, in 1993 WRRI has carried out a comprehensive study titled Surface Water Resources Study (SWRS, 1992) finance by the Commission for the European Communities. A part of the study (Sinai Water Resources Map) was entrusted on Engineering Faculty of Cairo University. Scarcity of suitable number of observed data, the Team used a set of equations focusing on the runoff governing parameters such as geology, slope, area, rainfall etc. Although high level of accuracy can not be obtained however, at the present stage this work may be considered as a complete work on Sinai hydrology which is simple and conceptually valid. Details of the equations are presented below.

$$V = R \times C \times A \times P$$

where, R is reduction facter
C is runoff coefficient
A is catchment area
P is rainfall depth

and the reduction factor R is given by

$$R = 1.05 - 0.0053\sqrt{A} \qquad (A \ \text{is in} \ km^2),$$

the runoff coefficient C is given by

$$C = \left(D\sqrt{9.81P}/G\right)^{10-S}$$

where, D is drainage density (km/km²)
P is rainfall in meters
G is an integer number representing geology (varies between 1 and 9)
S is land slope

Using these equations the Team prepared surface water resources maps for Sinai for the first time. Among them, map no. 12 represents the contours for average runoff and map no. 10 represents surface runoff coefficients contours.

Therefore, for the present Study, surface runoff was calculated using the contours for average runoff volume presented in the SWRS. According to the calculation the annual runoff volume was to be 12.28 and 40.64 x10^6 m^3/year for eastern and western blocks respectively, which makes a total of 52.92 x10^6 m^3/year. On the other hand, the El Arish catchment within the Study area will produce about 9.50x10^6 m^3/year. The calculated runoff volume for each Wadi is presented in Table 3.2.6-1 and the average runoff contour map is presented in Fig. 3.2.5-1.

3.2.6 Recharge to Groundwater

1) Review of Past Works

Although rainfall in Sinai is very little a part of it takes part in the process of aquifer recharge. Estimation of this recharge amount is a very difficult task where data on aquifer permeability, well yields and long term data for groundwater level are lacking. Regarding Sinai not many studies have done on subject of water balance. However, a review of the collected reports are presented below.

-Sinai Development Study (1986)

This is an elaborate study on the development of Sinai prepared by USAID. In this study an estimation of groundwater recharge for major aquifers has been made. According to the estimation recharge amount for whole Sinai is 413,000m^3/day. The report also stated that this amount is about half of the total recharge. The above mentioned amount may be divided according to the aquifers, such as

-Cambrian-to-Triassic and Cambrian-to-Cenomanian undifferentiated rocks	52,000m^3/day
-Lower Cretaceous rocks	38,000m^3/day
-Middle Cretaceous unit	192,000m^3/day
-Quaternary aquifers (Rafah area)	38,000m^3/day
-Quaternary aquifer (El Arish)	27,000m^3/day
-Quaternary aquifer (El Qaa plain)	66,000m^3/day

The report also calculated on the basis of north and south Sinai. Estimated average recharge in South Sinai is 282 m^3/day and rest i.e. 131 m^3/day is North Sinai.

-Sinai Water Resources Study (1993)

This study was financed by the European Economic Council (EEC). One of the study items was water resources and management in some selected areas. The areas includes two areas of the subject study. They are El Qaa Plain and Wadi Watir. For El Qaa Plain they performed a simulation study. In the study direct recharge by rainfall over El Qaa Plain was not considered, and the only recharge simulated in the model consists of under flow of the Wadis coming from the mountainous areas at the eastern boundary of the plain. The main conclusion of the study is that the recharge to El Qaa Plain quaternary aquifer can be estimated between 20,000 and 30,000m^3/day.

-Water Resources Potentials of the Gulf Region, Representative Catchment in Sudr Area, Sinai (1992)

This is a Thesis submitted to the Irrigation and Hydraulics Department, Cairo University by Eng. Hatem for the partial fulfillment of degree of Master's of Science. The objective of this three years study was to establish a general rainfall-runoff relationship in the Sudr representative area. It provides valuable information about the hydrological situation of the surface water and ground water of Sudr area.. The Wadi was divided into two parts upstream part and downstream (delta) part. The study concluded that the annual surface flow is about 13% of the average annual rainfall. The study also concluded that average groundwater recharge in the upstream of the Wadi is only 0.60% of the average inflow, whereas it equals to 29.2% in the delta part which has a very thick alluvial layer.

-Evaluation of Water Resources between Taba and El-Naqb (1994)

This study was performed by the Cairo University. The study area covers a 220 km long stretch along the Aqaba Gulf and included 28 Wadis. Among the many purposes, identification of groundwater reservoirs together with the rate and area for recharge. The study concluded that the area under study (wadi Watir) has two main groundwater reservoirs, one is in the basement rocks in the area surrounding Nuweiba city represented by Furtaga spring and the second one is sand stone reservoir. The estimated recharge for these two reservoirs are 62 and 43 million m^3/year totaling 105 million m^3/year.

-Water Resources Assessment and Utilization in El Qaa Plain, Sinai (1996)

A thesis submitted to the Cairo University by Eng. Hatem for the partial fulfillment of Ph.D. degree in civil engineering. A comprehensive study using models was carried out for five years in order to know the water resources situation in El Qaa Plain. The study concluded that in the limestone terrain recharge ranges 1.2-40% and in the basement terrain it ranges 0.89% to 7.8%. The thresh-hold rainfall producing runoff is 5mm. The estimated total recharge to El Qaa Plain as 7.77 million m^3/year which is about 21,000 m^3/day.

-South Sinai Water Resources Development Project (1996)

This two years project was carried by the WRRI with the financial help from Italian Commodity Fund. The study area mainly covers Wadi Watir area. The study proposed 17 potential sites for constructing detention dams and five sites storage dams. The estimated recharge rate for Ain Furtaga as 1,800m^3/day and for aquifer in the coastal delta as 750,000 m^3/year.

2) Calculated Amount of Recharge

As described in the earlier paragraphs, the recharge amount that have been estimated so far vary considerably. However, for the purpose of this study, a theoritical approach with few assumptions is used to calculate the amount of recharge for each Wadi catchment. The calculation was performed on an yearly average basis. The result shows that as percentage it varies from 10 to 70. And the total average amount was found to be $253x10^6m^3$/year. Of which about $100x10^6m^3$ in the El Arish catchment area and rest are in the eastern and western blocks.

On the other hand another calculation was performed by the WRRI using a tool developed HEC(Hydrologic Engineering Center) of USA army corps of engineers. JICA study team was provided with the calculated value(in the form of total of Runoff and Recharge). The review shows that in general, WRRI values are smaller than that of the Study team's. Direct interpretation of this difference is very difficult. However, it is assumed that the difference is due to the assumptions made for the input in the calculations. Table 3-2-6-1 shows the calculated results.

3.2.7 Wadi Risk

Although rainfall is scarce in Sinai peninsula, it is very famous for its flush floods with high velocity. Especially, the Wadis which have geological features of basement rock/shale. The Wadis which are famous for their activeness and causes damages to the infrastructures, disrupt the important communication system and sometimes to the human lives are Wadi Sudr, Wadi Gharandal, Wadi Feiran, Wadi Dahab and Wadi Watir. A brief description of risky areas are described below on the basis of the past records and field observations with the counterpart personnel. Approximate locations are shown in Fig. 3.2.7-1.

1) Wadi Sudr Catchment and Outlet

It is an active Wadi. In an average 3-4 floods occur per year. High flow velocity has caused severe damage to the hydraulic cross section at 22 km point from the Tunnel - El Tur highway where the side wall of the weir has been flushed away. The other areas which are under threat of this Wadi are the 10 to 11 km stretch, a stretch at a point 25 km, 33-34 km stretch from the highway where Wadi Sudr crosses the Sudr-Heitan road. On the other hand the downstream of this Wadi does not have a distinct flow regime but very wide fan and causes sedimentation problem on the highway.

2) Wadi Sudr Outlet-Abu Zenima

The stretch around the outlet of Wadi Sarbut Tal village experience flood damage almost every year. There are also two active Wadis in this stretch namely, Wadi Wardan and Wadi Gharandal. Their outlets are subject to damages. Inside the Gharandal catchment there are few stretches which are risky and subject to flood damage. The distance of these stretches from the highway are about 2 km point where Wadi crosses the road and 7 km point where road has already been destroyed (before the army camp).

3) Abu Zenima-Wadi Feiran Outlet

This stretch does not have a major problem but drainage congestion at the outlet of Wadi Feiran causes local flood around the entrance of Highway to St. Catherine and hence the highway is covered by sand, gravel and stones, and disrupt the traffic very badly.

4) Wadi Feiran Catchment

This Wadi is very famous for its activeness. Past records show that flood has destroyed many parts of the road, washed away the water level recorder. The damages are always more in two Oasis areas. The other stretches that are subject to damage are stretch of Tarfa village, the stretch where Wadi Sheikh, Wadi Solaf and Wadi Akhdar meets.

5) Wadi Feiran-El Tur

This stretch does not have any major problem, however, the surface flow from El Qaa Plain carries a lot of sediment and sometimes create a blockade on the main road. Also the point where Wadi El Awag crosses the highway near the El Tur city is a risky zone due to absence of any suitable structure to ease the flow path.

6) Sharm El Sheik-Naqb-Dahab

This stretch does not have a major problem. The normal flood water that is generated from the wadis such as Wadi Umm Razk, Wadi Lig, Wadi Madsus and Wadi Kid does not disrupt the normal life or traffic rather they help to recharge the underground aquifer.

7) Dahab Area

This area is situated at the downstream of an active Wadi called Wadi Dahab. It is quite a large Wadi and carry a huge amount of flood flow from the main tributaries such as Wadi Zaghara, Wadi Nasb and Saal.

8) Dahab Nuweiba Stretch

Only short Wadis are present in this stretch. Floods generated in this area go directly to the gulf of Aqaba without causing any major problems to the traffic or daily life.

9) Nuweiba Area (W. Watir Catchment)

The city of Nuweiba is situated at the downstream of Wadi Watir, the active Wadi in south Sinai. The Wadi itself is a short cut road from Naqb to Nuweiba and plays an important role in communication system of south Sinai. In fact, due to the activeness, the major portion of this road and the Nuweiba city is always under threat. Some protection works have been done, still there are many parts that are vulnerable to risk. Records show that high flow velocity destroy not only the road but also human lives.

10) Nakhl Area

There are many Wadis mainly tributaries of W. El Arish that cross Tunnel—Naqb high way at various locations. Among the locations, a stretch west of Nakhl city is always under threat, as because few tributaries such as Shibaya, Abu Adib, El Ruth and Ruaq pass through this stretch together and causes damage to the road almost every year

3.2.8 Groundwater Recharge Facilities

In south Sinai main groundwater reservoirs may be classified as: a) Shallow quaternary aquifer b) Upper cretaceous lime-stone aquifer and c) Lower cretaceous sand-stone aquifer. As a natural process these reservoirs are recharged by the rainfall that infiltrate to the ground. Although rainfall is scarce in Sinai still a huge amount of rainfall flow to the sea unused as surface runoff. Annual volume of this amount may be estimated $62x10^6$ m^3. It is believed that a major portion of this unused amount of runoff could be used in order to increase and accelerate the annual recharge mechanism of the aquifers.

To fulfill this target hydraulic structures of various types are the best ways. Therefore, in this Study, four storage dams, 24 detention dams and 4 diversion dams have been recommended in various locations of the Study area. In the selection of structure type and location geological, hydrological and physical parameters were taken into consideration. For example, storage dams are recommended in the locations were there is a suitable place for reservoir, presence of impervious layer and a good hydraulic section with high Wadi walls. Detention dams are recommended in the sites where there is a mild land slope with pervious soil. This kind of structures are already in use in Sinai by the Bedouins. Diversion dams are recommended near the outcrop areas in order to divert and spread the runoff water over the outcrop area for facilitating the infiltration process.

It is note worthy to mention that the locations/types/numbers of the recommended structures are not absolute one Therefore, before taking any decision for construction of these structures more detail study is necessary.

For Wadi Watir and Wadi Dahab detail studies have been carried out by the WRRI and number of dams have been proposed for construction. Total number of structures in Wadi Watir and Wadi Dahab are 22 and 11 respectively. Therefore, in this Study they were not included for consideration

A list of the dams is presented in Table 3.2.8-1 and locations are presented in Fig. 3.2.8-1.

Table 3.2.6-1 Caluculated Surface Runoff and Recharge

Code No.	Wadi Name	Area (Km^2)	Total Rainfall (1,000m^3/year)	Runoff (m^3/year)	Recharge (m^3/year)	JICA Study Team Runoff & Recharge (m^3/year)	WRRI Runoff & Recharge (m^3/year)
A. Eastern Block							
E-1	Nuweiba Taba Zone	526	10,520	3,071,840	4,818,160	7,890,000	790,000
E-2	Wadi Watir	3,516	70,320	14,116,740	38,623,260	52,740,000	52,700,000
E-3	Nuweiba-Dahab Zone	225	4,080	1,489,200	1,315,800	2,805,000	640,000
E-4	Wadi Mekamen	70	1,120	408,800	361,200	770,000	180,000
E-5	Wadi Amid	69	1,035	402,960	287,040	690,000	170,000
E-6	Wadi El Wadi	40	600	233,600	166,400	400,000	100,000
E-7	Wadi Dahab	2,067	28,938	9,807,915	8,795,085	18,603,000	31,000,000
E-8	Wadi Kena	121	1,694	706,640	382,360	1,089,000	300,000
E-9	Wadi El Kabila	193	2,509	1,127,120	416,880	1,544,000	1,450,000
E-10	Wadi Kid	1,093	13,080	6,365,600	1,264,400	7,630,000	2,730,000
E-11	Wadi Om Raka	39	468	85,410	187,590	273,000	0
E-12	Wadi Om Adawi	340	4,080	1,985,600	210,270	2,195,870	0
E-13	Wadi El Siga	86	860	219,730	284,490	504,220	0
E-14	Wadi El Marikha	116	928	63,510	121,500	185,010	0
E-15	Wadi El Atia El Sharki	150	1,200	328,500	276,225	604,725	0
E-16	Wadi Awaga	254	1,778	231,775	276,225	508,000	0
	Sub total	8,932	143,210	40,644,940	57,786,885	98,431,825	90,060,000
B. Western Block							
W-1	Wadi Sudr	712	10,680	259,880	6,860,120	7,120,000	1,100,000
W-2	Wadi Wardan	1,454	20,356	636,852	12,449,148	13,086,000	2,900,000
W-3	Wadi Seada	94	1,316	34,310	811,690	846,000	0
W-4	Wadi El Kalwat	126	1,764	22,995	1,111,005	1,134,000	0
W-5	Wadi Gharandal	966	13,524	528,885	8,165,115	8,694,000	7,200,000
W-6	Wadi Wst and Abu Meharat	172	2,408	81,614	1,466,386	1,548,000	0
W-7	Wadi Tal	117	1,638	51,246	1,001,754	1,053,000	1,200,000
W-8	Wadi Tiba	385	5,390	281,050	3,183,950	3,465,000	2,890,000
W-9	Wadi Khaboba	124	1,736	113,150	1,002,850	1,116,000	930,000
W-10	Wadi Baba	96	1,344	52,560	811,440	864,000	430,000
W-11	Wadi El Garf	742	11,130	812,490	6,607,510	7,420,000	3,710,000
W-12	Wadi Sidri	1,095	16,425	1,398,863	9,551,138	10,950,001	5,500,000
W-13	Wadi Feiran	1,830	34,770	2,671,800	22,948,200	25,620,000	13,000,000
W-14	Balaiem El Tur Zone	386	4,632	140,890	2,561,110	2,702,000	1,100,000
W-15	Wadi El Awag	1,934	25,142	3,529,550	11,942,450	15,472,000	5,800,000
W-16	Wadi Emlaha	236	2,596	215,350	1,200,650	1,416,000	710,000
W-17	Wadi Isla	386	3,860	366,314	1,563,686	1,930,000	390,000
W-18	Wadi Thiman	307	2,763	280,138	947,863	1,228,001	0
W-19	Wadi El Mhash	318	2,544	290,175	663,825	954,000	0
W-20	Wadi El Latehia	134	938	122,275	145,725	268,000	0
W-21	Wadi Agsha	140	980	127,750	152,250	280,000	0
W-22	Wadi Om Mrikha	73	511	66,613	79,388	146,001	0
W-23	Wadi Amik	111	777	101,288	120,713	222,001	0
W-24	Wadi El Ate El Garbi	101	707	92,163	109,838	202,001	0
	Sub total	12,039	167,931	12,278,201	95,457,804	107,736,005	46,860,000
	Total (A+B)	20,971	311,141	52,923,141	153,244,689	206,167,830	136,920,000
C. Wadi El Arish (within study area)							
Arish-1	(Wadi Bruk)	1,242	24,840	453,330	18,176,670	18,630,000	24,800,000
Arish-2	(Wadi Ruaq)	6,044	102,748	7,721,210	64,806,790	72,528,000	75,600,000
Arish-3	(Wadi Aqaba)	905	22,625	1,321,300	16,778,700	18,100,000	18,100,000
	Sub total	8,191	150,213	9,495,840	99,762,160	109,258,000	118,500,000
	Grand total (A+B+C)	29,162	461,354	62,418,981	253,006,849	315,425,830	255,420,000

Table 3.2.8-1 List of Recharge Facilities

Wadi Name	Rock Type	Slope	Type	Number	Objectives
Wadi Sudr	L.stone, Marl	Flat	Detention	3	U.cretaceous L.stone & alluviumaquifers
Wadi Wardan	L.stone, Shale	Steep	Detention	3	U.cretaceous L.stone & quaternary fan
Wadi Gharandal	S.stone, L.Stone, Sand, Gravel	Steep	Detention	4	L.cretaceous S.stone & U.cretaceous
Wadi El Garf	S.stone, Granite, L.stone, Marl.	Steep	Storage	1	Storage
Wadi El Sidri	Igneous, Volcanic, L.stone, Marl,	V. steep	Diversion	2	L.cretaceous S.stone
Wadi Feiran	Basement, Volcanic	V. steep	Diversion Detention	2 2	L.cretaceous S.stone & quaternary aquifer
El Qaa Plain	Igneous rock, S.stone	Flat	Detention	3	Quaternary reservoir
Wadi Isla	Igneous rock, Metamorphic	V. steep	Storage	1	Storage
Wadi El Mhash	Granite, Quaternary	V. steep	Detention	1	Quaternary aquifer
Wadi Om Adawi	Basement, Quatrernary	V. steep	Storage	1	Storage
Wadi Kid	Igneous, Volcanic, Metamorphic rock	V. steep	Detention Storage	2 1	Quaternary aquifer
Wadi El Arish	Lime stone	Mild	Detention	6	L.stone aquifer
Wadi Dahab	Basement, Shale	Steep	Detention Storage	7 4	Storage, S.stoneaquifer
Wadi Watir	Basement, Shale	Steep	Detention Storage	17 5	Storage, S.stoneaquifer