STATE OF QATAR

THE STUDY ON DRAINAGE IMPROVEMENT PLAN, DOHA CITY

MAIN REPORT

APRIL, 1987

JAPAN INTERNATIONAL COOPERATION AGENCY

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PREFACE

In response to the request of the Government of the State of Qatar, the Japanese Government has decided to conduct a study on the Drainage Improvement Plan in Doha City and entrusted the Study to the Japan International Cooperation Agency (JICA). JICA sent to Qatar a study team headed by Mr. Masami Ono, Yachiyo Engineering Co., Ltd., from December 1985 to December 1986.

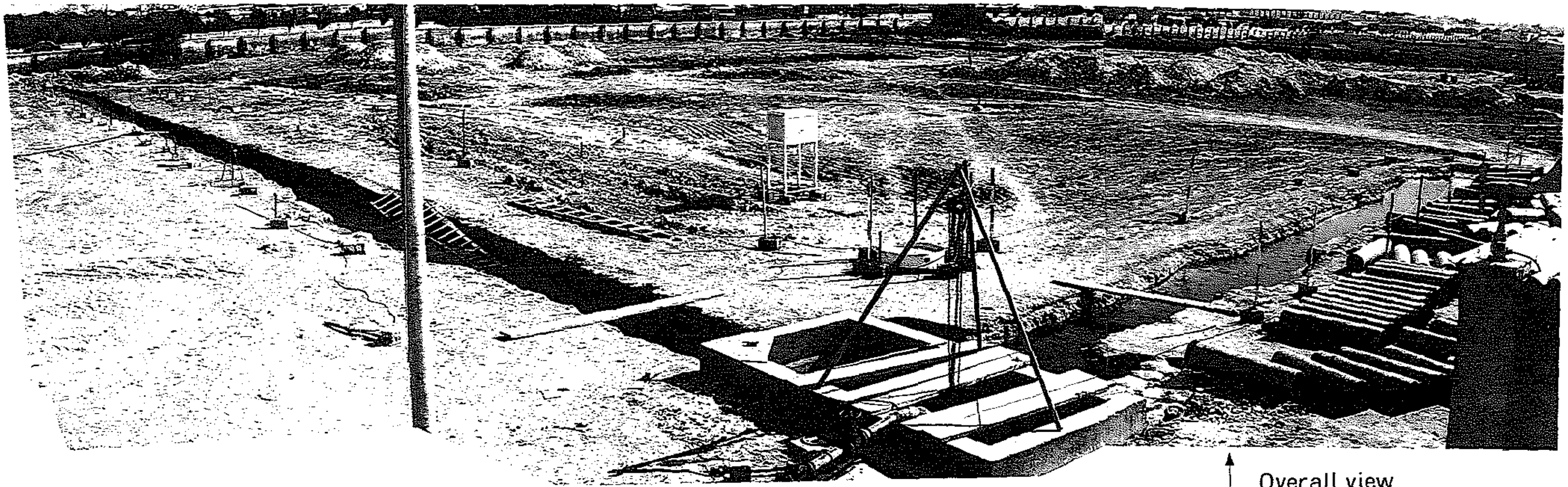
The team had discussions with the officials concerned of the Government of Qatar and conducted a field survey in the area. After the team returned to Japan, further studies were made and the present report has been prepared.

I hope that this report will serve for the development of the Project and contribute to the promotion of friendly relations between our two countries. I wish to express my deep appreciation to the officials concerned of the Government of Qatar for their close cooperation extended to the team.

April 1987

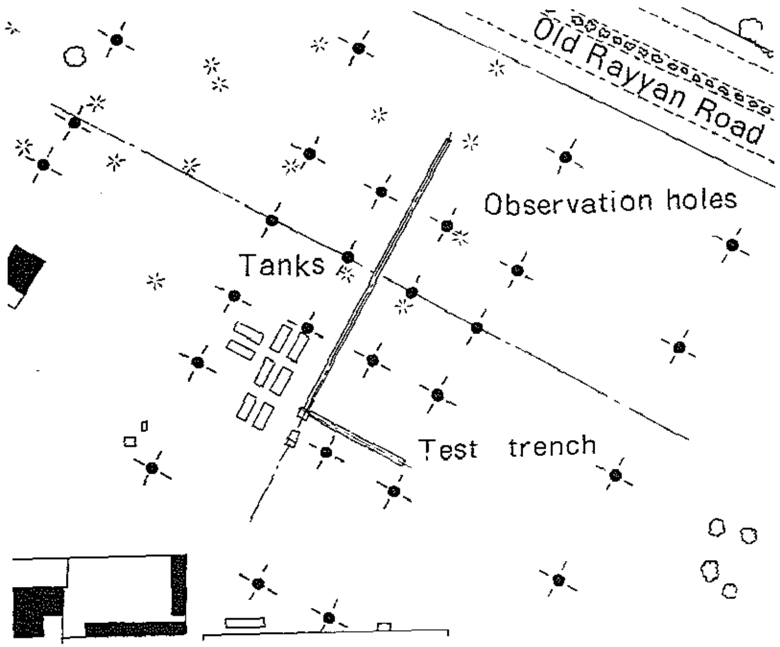
Keisuke Arita

Keisuke ARITA
President
Japan International Cooperation Agency

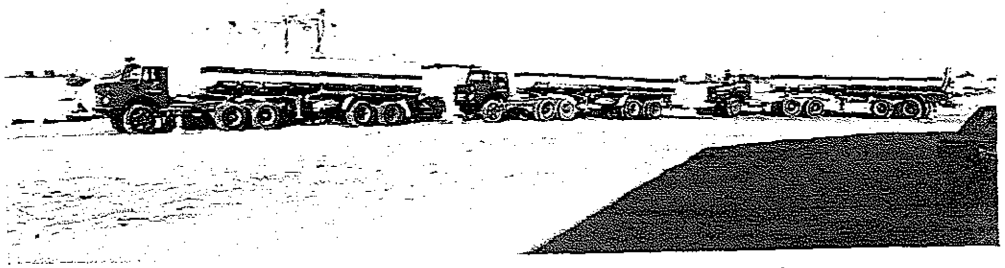


Overall view

Rayyan Test Work Site



Key Plan



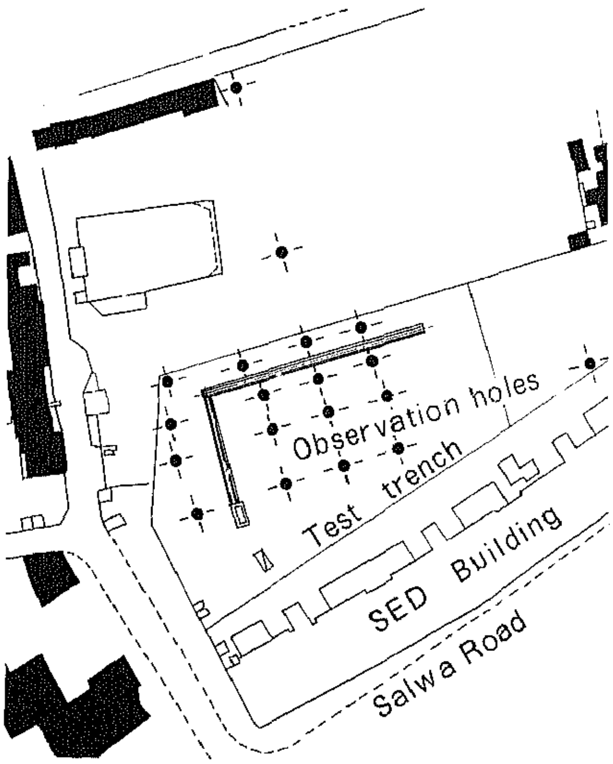
MPW Tankers transport abstracted groundwater from Rayyan site.

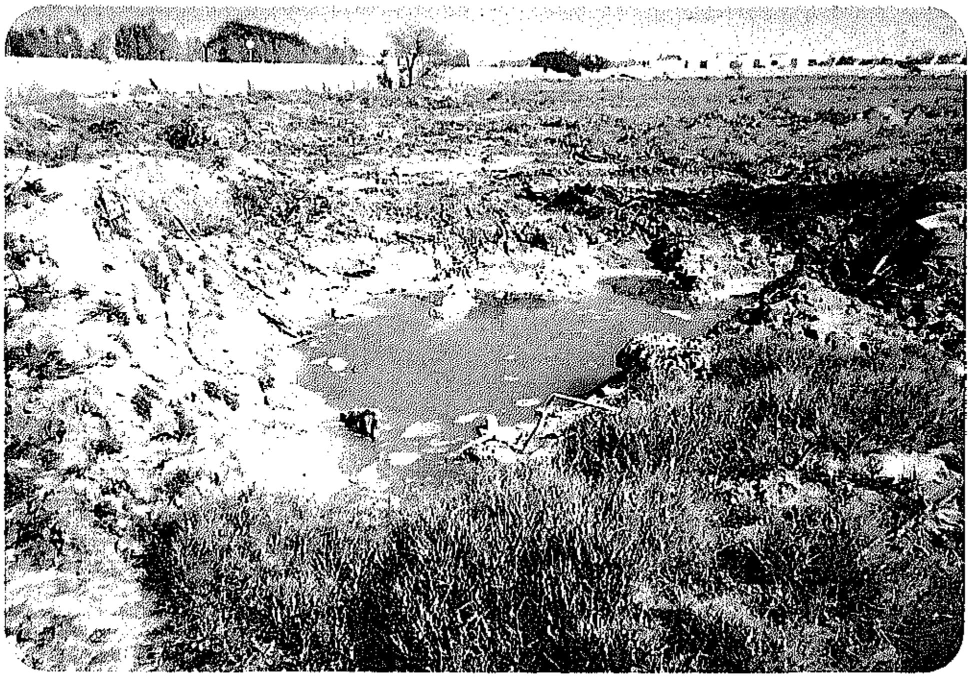
Test trench construction

Wadi Musherib
Test Work Site

Recovery Test

Key Plan

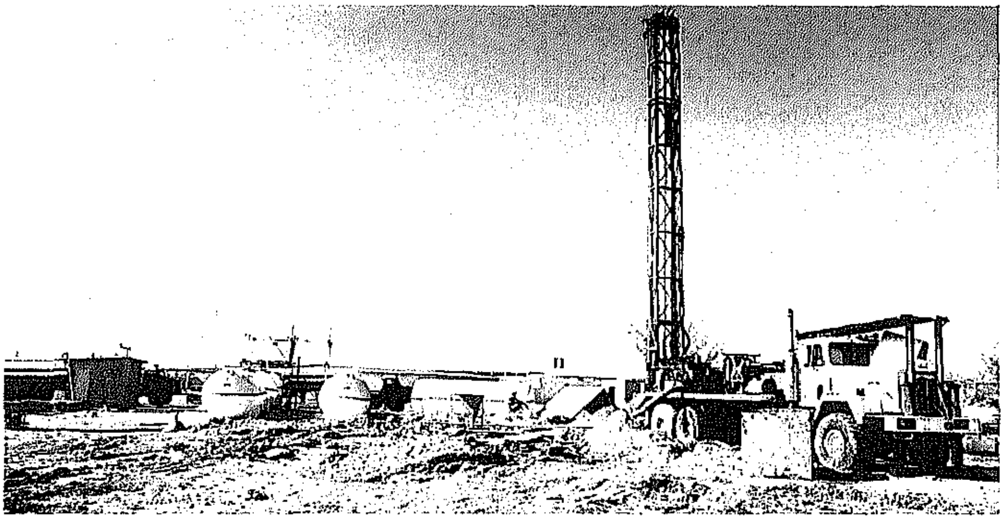




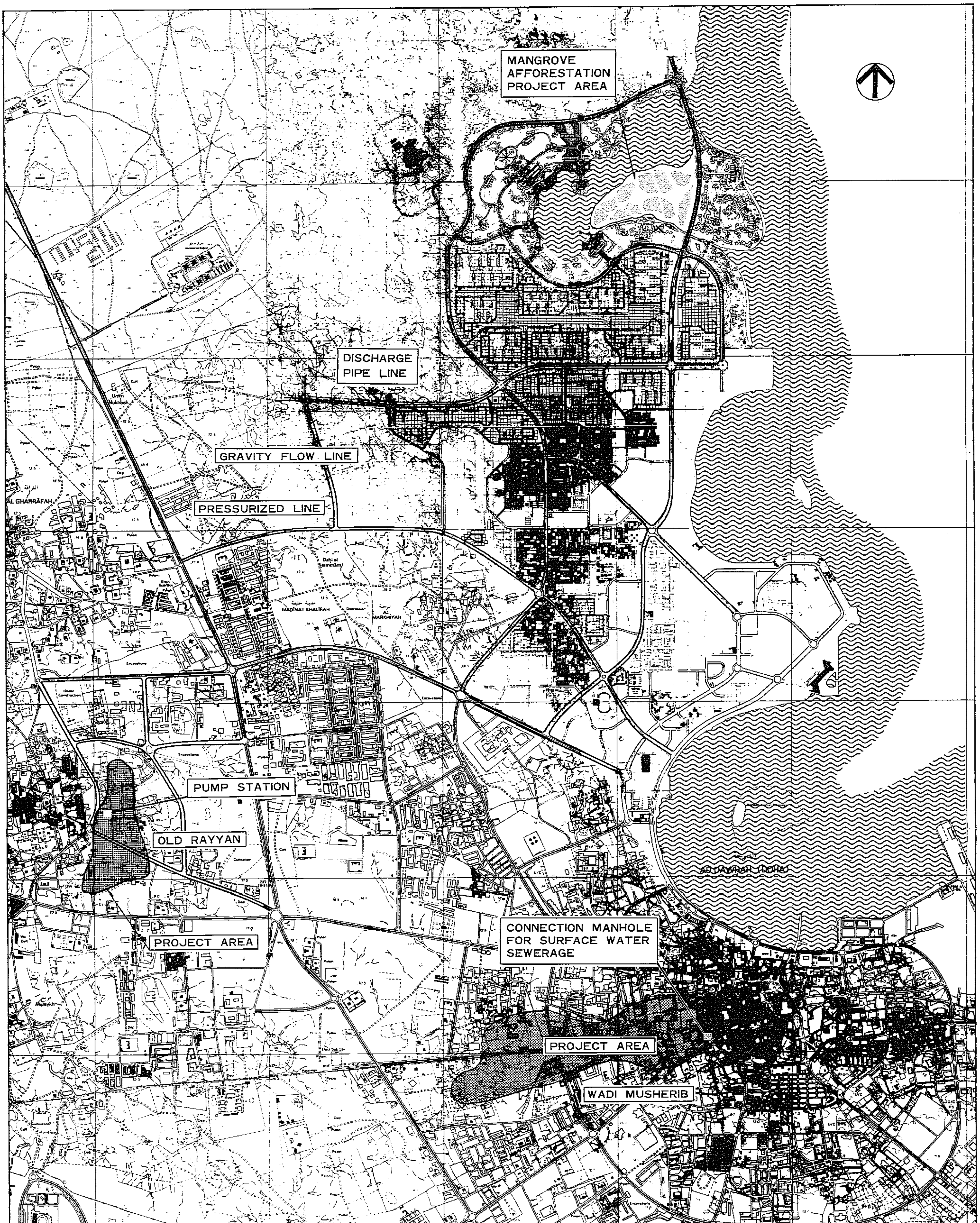
Standing Water at Rayyan farm later choosen
as site for Rayyan Test Trench

Standing Water near Musherib Dam

Core boring at Wadi Musherib Test Work site
executed by Amir Technical Office



Open hole drilling by MEW at Rayyan



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1. INTRODUCTION

1. INTRODUCTION

The study on drainage improvement plan in Doha City commenced in December 1985. The study activities included site data collection and test works, and design and analysis works in Japan. The Japan International Cooperation Agency formed the JICA Advisory Committee to supervise the execution of the sutdy by the JICA Study Team. The Government of Qatar formed the Technical Liaison Committee under the direction of the directors of MEW, CED and DM to maintain contact with the JICA Study Team. Members are as follows.

Qatar Steering Committee (Adhoc Committee in Services Committe)

Mr. M.Y. AL-ALI	Director of Electricity and Water Dept., MEW
Mr. R. AL-MANNAI	Director of Civil Engineeing Dept., MPW
Mr. A. M. AL-KHATER	Director of Doha Municipality

Qatar Technical Liaison Committee

Mr. J. LOCKERBIE	Chairman, Technical Office of H.H. AMIR
Mr. W. ATKINSON	Electricity and Water Dept. of MEW
Mr. B. ECCLESTON	Electricity and Water Dept. of MEW
Mr. I. BROWN	Civil Engineering Dept. of MPW
Mr. G. LAUDER	Civil Engineering Dept. of MPW
Mr. G. WISHART	Pencol/Civil Engineering Dept. of MPW
Dr. ABDUL BASIT	Doha Municipality
Mr. ABD AL AZIZ AL JABER	Doha Municipality

JICA Advisory Committee

Mr. Yasukazu KOMORI	Chairman
Mr. Masanori SHINAGAWA	Hydrology
Mr. Tadatoshi MATSUISHI	Drainage
Mr. Nobuyuki HORIE	Water Treatment
Mr. Shozo MATSUURA	JICA Official
Mr. Ryoma HIRAYAMA	JICA Official

JICA Study Team

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Dr. Mashio YAMAHA	Water Treatment
Dr. Yoshiyuki UEMURA	Groundwater
Mr. Motoharu TAKAGI	Geophysical Sounding
Mr. Ryousuke TERANISHI	Drainage System
Mr. Noboru SAEKI	Civil Construction
Mr. Yoosuke SASAKI	Hydrology
Mr. M.S. RIAD	Coordinator

We would like to take this opportunity to express our appreciation to the Laboratory of Doha South Sewage Treatment Works, MPW, Department of Meteorology, MCT, Well Fields Section and Drilling Section, MEW, Planning Section, Doha Municipality and the Technical Office of H.H. the Amir for their assistance during various stages of the Study.

2. SUMMARY OF THE STUDY

2. SUMMARY OF THE STUDY

2.1 Background of the Study and Basic Policy

In the State of Qatar, in recent years the groundwater table has been rising within Doha City and its surrounding vicinity. Consequently some areas are suffering during construction and maintenance of civil and building works, and electric and telephone cable works. Damage due to salt accumulation is occurring at the ground surface.

In order to solve this problem, many studies have already been executed by various concerned authorities, however up to the present concrete countermeasures have not yet been executed.

The following three study areas in Doha City and its vicinity, where significant groundwater rising is recognized in lowlying parts and damage mainly by salt accumulation is occurring, were selected and the basic policy for urgent groundwater drainage plan was established.

1. Wadi Musherib area (typical wadi lowlying area)
2. Rayyan area (typical inland depression)
3. New District (typical coastal plain area)

The study team executed the following activities at each study area, 1) understanding characteristics of groundwater rising mechanism, 2) investigating actual damage, 3) executing test works at Wadi Musherib and Rayyan area for groundwater drainage plan, 4) studying the possibility of reuse and method of water treatment and 5) establishing concrete and effective countermeasures with preliminary designs.

At the same time suggestions and recommendations regarding this groundwater rising problem were also presented.

The detailed contents of the study and flow chart are shown in Fig.2.1.1.

2.2 Hydrogeology and Groundwater Quality

Topography of Doha, including the three study areas (namely Doha city, Rayyan, and New District) consist of wadis, depressions, escarpment, etc. which in turn are characterized by two groups of basin-shaped lands with linear alignment which may be observed at almost right angles with each other. This is considered to relate to the geological structure lines with faults.

The existing two groundwater mounds of Khalifa and Khayl are recognized as these structural elements.

In order to understand the relation between rising groundwater level and recharge amount, and the forecasting of discharge volume required in the subject areas, quasi-three dimensional unsteady groundwater analysis was carried out to simulate the groundwater behaviour from 1983 to 1986 and obtain sufficient numerical information.

Regarding water quality, EC (electric conductivity) values of water at Dammam Layer show considerably high values between 7,000 - 13,000 micro mhos/cm and have shown a tendency to gradually decrease from the values measured in 1982. pH values are approximately 7. In the meantime COD values at Rayyan are relatively high but are generally considered less than 5 ppm and not highly polluted.

2.3 Rate of Groundwater Rising and Damage

Outside of the 'C' Ring Road in Doha and in the inland lowlying part at Rayyan, an annual groundwater rise of 0.3 to 0.5 m was observed and moreover 11.2 ha of standing water appeared at the lowlying part of Rayyan in the rainy season of 1986.

Due to the groundwater rise direct damage to underground facilities, basements of buildings, roads and vegetation are occurring as follows;

- Appearance of highly corrosive layer by salt accumulation
- Increase of maintenance work in number and cost due to decrease of function and quality of facilities
- Increased costs due to short machine life
- Deterioration of reinforced concrete of underground foundations and structures
- Increase of construction time and cost for foundation
- Salinity hazard to vegetation

2.4 Mechanism of Groundwater Rising and Preliminary Study on Method of Lowering Groundwater Table

Regarding growth and shape of groundwater mound, mounds appear at the places of high gross recharge. From the point of groundwater flow, peaks of mounds remain at the places of low permeability in aquifer and shape of mounds moderately flattens at high permeability zone.

In order to curb the growth of groundwater mounds, alleviation of gross recharge amount should be seriously considered as a long term countermeasure, however the project to eliminate the direct damage which is appearing at lowlying part and shows a tendency of increase should be immediately commenced.

In order to alleviate the direct damage in such lowlying areas, it is inevitable to lower the groundwater table from 1.0 - 1.5 m below ground surface.

As methods of lowering groundwater table, land drainage, vertical drainage and tunnel drainage can be considered. As a result of preliminary analysis problems in application of vertical and tunnel methods have been identified and are mentioned hereunder.

Questions for Vertical Drainage Method

- Contamination of lower aquifer (UER layer)
- Allowable water amount injection in UER layer
- Reliability of lower Dammam layer overlaying UER layer as cap rock
- Necessity of pretreatment plant for bacteria, suspended solids, fine sand etc.
- Pressurizing process

Questions for Tunnel Method

- Risk of flooding accident during construction
- Occurrence of sudden reduction phenomena in partial groundwater table
- Topographical restriction to secure earth covering above tunnel

Therefore lateral drainage method was adopted having the superior points of

1. Applicability as an urgent countermeasure
2. Prooven reliability of the method
3. Safety as construction method

2.5 Pumping Test at Test Works

At each of Lower Wadi Musherib and Old Rayyan an 'L' shape lateral drain of depth 4 - 5 m and length 90 - 110 m was excavated and pumping tests were conducted over a duration of time.

Results of the test work are summarised in the tables below.

Responding to the drawdown in test trenches at Wadi Musherib and Rayyan i.e. 3.3 m and 2.9 m respectively, drawdown values of surrounding area are 0.7 - 0.8 m for Wadi Musherib and 0.5 - 0.7 m for Rayyan at 30 m distance from trenches. Therefore the drawdown effects to the vicinity are considered to be almost the same on both sites.

On the contrary, discharge quantity of 0.75 - 1.00 m^3/min at Rayyan is 3 - 4 times larger than that of 0.20 - 0.28 m^3/min at Wadi Musherib. This shows that permeability at Rayyan site is higher than that of Wadi Musherib, and this fact was also confirmed from the result of two dimensional vertical plane groundwater analysis.

Regarding water quality, EC values at Wadi Musherib show low figures of 3,500 - 5,000 micro mhos/cm as well as low COD values, and abstracted groundwater under present conditions can be used as irrigation water.

In the meantime groundwater at Rayyan shows considerably high EC values of 12,500 - 18,000 micro mhos/cm and reuse for irrigation water is limited. COD values at Rayyan are also relatively higher than Wadi Musherib. Therefore when considering disposal to the sea, application of buffer zone such as contact aeration zone or mangrove afforestation is recommended.

Table 2.1.1 Drawdown of Groundwater Table around Test Site by Pumping Test

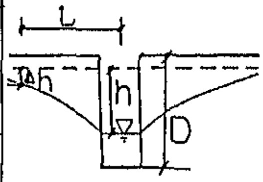
Test Site	Discharge (m3/min)	Depth of Trench (D)	Drawdown at Trench (H)	Drawdown (Δh) (m) at Distance (L)		
Musherib	0.20-0.28	5.0	3.3	L=10 m	L=30 m	
				1.4-1.7	0.7-0.8	
Rayyan	0.75-1.00	4.0	2.9	L=30 m	L=90 m	
				0.5-0.7	0.1-0.2	

Table 2.1.2 Quality of Abstracted Water

Test Site	PH	EC (micro mhos/cm)	COD (mg/l)
Musherib	7 - 9	3,500 - 5,000	1 - 4
Rayyan	7 - 8	12,500 - 18,000	4 - 15

Table 2.1.3 Permeability Coefficient by Two Dimensional Groundwater Flow Analysis

Lithological Classification		Permeability Coefficient (m/sec)	
		Musherib Site	Rayyan Site
1st layer	Upper Dammam strongly wheathered layer	2.7×10^{-5}	8.4×10^{-5}
2nd layer	Upper Dammam weakly wheathered layer	1.3×10^{-5}	7.8×10^{-5}
3rd layer	Lower Dammam wheathered layer (Midra Shale)	9.8×10^{-6}	3.3×10^{-5}

2.6 Reuse of Abstracted Groundwater

Considering the conditions of demand, quality, intake and discharge points the following reuse plans were proposed.

- Abstracted water from Musherib area
  Irrigation water for Hamad General Hospital, Sadd garden and other greening plans in the vicinity.

- Abstracted water from Rayyan area
  Irrigation water for Mangrove afforestation plan in the "Natural Reserve Area" featured in the New District "Regional Park" plan.

2.7 Urgent Drainage Plan

For the two areas suffering from direct damage by groundwater rising, namely Wadi Musherib and Rayyan low lying areas, alternatives were comparatively studied, and preliminary designs were prepared for the recommended plan for each area.

In the case of Wadi Musherib, the project area was divided into two, upstream and downstream, in order to implement staged construction which enables modification on 2nd phase design after obtaining the actual discharge quantity and quality.

The General plan and summary of the urgent drainage plans are shown on the Drawings DRP-1001, 2001 and Table 2.1.4 respectively.

No significant damage directly caused by the groundwater rising at New District is recognized and therefore New District was excluded from the object of the urgent drainage plan. The groundwater table in this area is almost the same as seawater level and is considered to be influenced by tidal fluctuation. For this area, some local counter-measures were recommended for reference such as protection of vegitation from salinity hazard, soil stablizing cement method and salt resistant construction materials.

2.8 Applicability of JICA Study to Other Similar Areas

For other lowlying areas where shallow groundwater table is causing damage or damage is predicted in the future, application of JICA Study can be made possible by classifying such areas typically into Wadi lowlying Area Type, Inland lowlying Area Type or Coastal lowlying Area Type. Each of the three types is represented in the Study by Wadi Musherib, Rayyan and New District areas respectively.

Nevertheless, preliminary investigation such as geological investigation by core boring study on hydrogeological features, and analysis of groundwater quality continue to be necessary for new areas so as to identify any differences in regional characteristics which may exist between different areas of the same type.

2.9 Summary of Recommendation

For the government of Qatar to effectively deal with the groundwater problems in Doha city and other cities and proceeding with the urgent drainage plan proposed by the JICA Study, the establishment of an efficient organization to bring together the independent efforts of individual departments, and utilize their respective technical and administrative functions is recommended.

For total solution of groundwater problem, the accumulation, arrangement and analysis of basic data is essential and therefore a built-up data-base linked to the monitoring system is recommended.

At the same time from the long and medium range points of view, preventive measures to curb the groundwater recharge, i.e. water saving and education campaigns, charge system, leakage detection system etc. are also necessary. Some examples applied in Japan are introduced in this report for reference.

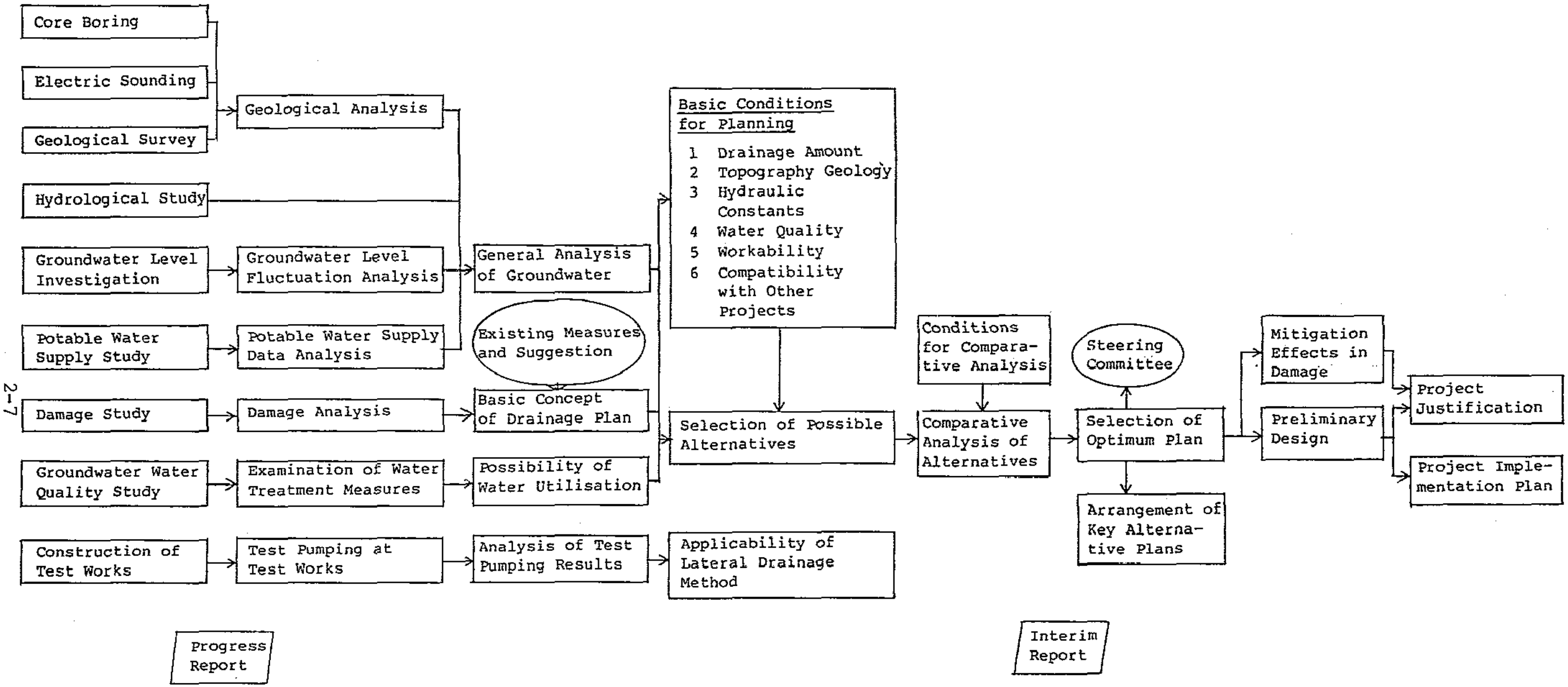


Fig. 2.1.1 Flow Chart of the Study

Table 2.1.4 Facility Outline and Construction Cost *for* Urgent Drainage Plan

Urgent Drainage Area	Lateral Drainage System	Discharge Pump Station	Discharge Pipe Line	Disposal Point	Estimated Construction Cost
Wadi Musherib depression area (150 ha, discharge amount 1,500,000 m^3/year)	Perforated pipe in perimeter arrangement ø300-450 mm L=12,875 m (two-phase construction)	Gravity flow piping	Connection pipe ø450 mm (L=30 m)	1 Tanker filling station (2 nos.) for irrigation 2 Wadi Musherib stormwater trunk line	37 x 10^6 QR
Rayyan depression area (70 ha, discharge amount 3,000,000 m^3/year)	Perforated pipe in perimeter arrangement ø300-600 mm L=5,904 m	Horizontal double suction volute pump, 3 units (1 unit for stand-by) Total head: 122 m Actual head: 21.4 m Discharge volume: 2.85 x 2 units = 5.7 m^3/min	1 Pressure pipe Ductile cast iron pipe ø250 mm L=6,700 m 2 Gravity flow pipe Ductile cast iron pipe ø350 L=7,700 m	Sea by way of Mangrove lagoon at West Bay	52 x 10^6 QR

3. PRINCIPAL FINDINGS OF BASIC STUDY

3. PRINCIPAL FINDINGS

3.1 Background and Consideration of Previous Studies

3.1.1 Serial Trend Observed in Previous Studies

The previous studies on the rising groundwater level in Doha, conducted by the Qatar Government, are listed below in chronological order.

(1) 1981 (Dec.)	:	Doha Stormwater and Land Drainage Master Plan (MPW - Pencol)
(2) 1982	:	Hydrogeology of Qatar, part of the Project Technical Report, No. 5 (FAO, B.L. Eccleston and I.E. Harhash)
(3) 1983 (May)	:	Rising Water Table Project (MEW - ASCO)
(4) 1984 (Jul.)	:	Report on Flooding in the Musherib Wadi (MPW - CED - Sewerage Division)
(5) 1984 (Aug.)	:	Concerted Action for Water Management of Doha/Qatar (MPW/MTPW Netherlands)
(6) 1985 (Mar.)	:	Doha Stormwater and Groundwater Management Action Report (MPW - CED - Pencol)

(1) With the progress of development in Doha, the capacity and area for storing surface water or to allow its permiation has been reduced. As a result, despite little annual rainfall, stormwater is frequently seen in the area's lowland when torrential rain occurs. The "Doha Stormwater and Land Drainage Master Plan" was prepared by Pencol in December, 1981 on the instructions of the MPW in view of the local development plan in regard to the necessary stormwater discharge facilities for the excessive rainwater causing stormwater and their associated land drainage system as part of groundwater control.

Pencol's report consisted of an initial review of the situation in already developed areas, the collection and examination of data on rainfall, flooding, groundwater and weather conditions, etc. and the appropriate criteria for the design of stormwater and land drainage network.

In regard to areas prone to flooding by stormwater, it was found that stormwater often occurs near main roads as the natural run-off is cut off by these roads and that the depth of the groundwater table is much nearer the surface than in 1959 although the actual depth varied from 1m in coastal areas to 4.6m in Doha's lowland areas. Based on these findings, the methods for the collection and disposal of the flooding stormwater were presented and the planning for the land drainage system for flooded areas was also proposed. In addition, the economic benefits of the drainage network and the combination with the existing stormwater sewerage were examined and the application scope and the type of drainage network suitable for Doha's future development were decided in view of the social requirements. Furthermore, substitute plans were proposed and evaluated and the preliminary design was presented. While the hydrogeological survey confirmed the main sources for the groundwater recharge, the report suggested that a further study on aquifers and the groundwater flow be conducted.

(2) The report entitled "Hydrogeology of Qatar" by B.L. Eccleston and I.E. Harhash was issued as a separate volume of the Project Technical Report No.5 "Resources of Qatar and Their Development" in 1982, which was in turn based on the FAO's project assistance program with the Ministry of Industry and Agriculture, ongoing since 1971. The geological formations and the structure of the Qatar Peninsula, including the historical formation of aquifers and hydrogeological characteristics of aquitards and aquicludes were described in this report and groundwater contour maps for 1980 and 1985 covering almost the entire Peninsula were presented. In addition, the groundwater flow was examined and a hydrogeological model presented for the hydrogeological estimation of the water balance (this report provides the basis for JICA's approach to the study of geological and hydrogeological conditions).

(3) Doha rapidly expanded from a coastal town with a population of 15,000 in 1948 to a large city with a population of 220,000 in 1981. The groundwater level also showed a rapid rise due to the increased recharge which was in turn caused by the increased consumption of desalinated water and water supply from well fields including leakage from the potable water distribution system. Consequently, the groundwater which had formerly flowed with a gentle gradient from 1 m QND to sea-level now formed groundwater mounds at a maximum 9 m QND. The groundwater level rose by as much as 8 m in less than 10 years at the Rayyan and Hitmi townships. Unfortunately, however, data on the groundwater volume causing this rising groundwater level problem and on the consequences of this phenomenon were unavailable at that time.

On the instructions of the MEW, ASCO carried out a study in December, 1981 and prepared the "Rising Water Table Project" report in May, 1983 which is known as the ASCO Report. ASCO analysed the causes and origin of the groundwater recharge and confirmed the annual gross recharge causing the groundwater level to rise and form mounds. ASCO also carried out the following;

- o Groundwater level survey using bore holes to clarify the formation and variations of the groundwater table and study on the characteristics of aquifers by means of test pumping from the bore holes.

- o Water quality analysis to clarify the origin of the recharge.

- o The analysis and appraisal of the characteristics of aquifers obtained from the hydrogeological and engineering data and also development of a simulation model for the water balance determined by such related factors as the recharge and outflow.

The report proposed immediate and long-term groundwater level control measures, together with the necessity of conducting a study on the project cost and its economic feasibility. The following immediate remedial measures in particular were proposed for the Lower Wadi Musherib and Montazah area.

- o Renewal of the stormwater drainage facilities to allow the free infiltration of the groundwater and the suggestion of lateral and vertical drainage measures.

o Introduction of a pilot scheme at the Musherib well field to examine the drainage system.

In regard to long-term control works and measures, the following were proposed.

o Examination of an integrated drainage system to maintain the groundwater level observed in 1982 based on the results of the above pilot drainage scheme.

o Appraisal of the groundwater volume to be abstracted for reuse.

o Examination of a possible method to reduce the gross recharge through a simulation study, etc.

Furthermore, policy measures in regard to data accumulation, the continuance of chemical analysis and the education of the public in view of saving water, were proposed.

(4) Although the groundwater level has tended to show a declining tendency in the Qatar Peninsula in general, the rising trend continues in Doha and has reached the ground surface in Wadi Musherib, causing various damage. The Sewerage Division of the CED conducted a study on the causes of the rising groundwater level and the measures to be taken and subsequently prepared the "Report on Flooding in the Musherib Wadi" in July, 1984. Based on an annual groundwater level rise of 22cm for 18 years and a gross recharge in the Musherib and 'A' Ring Road areas exceeding 1,000mm per year in 1982 (both referred to in the 1983 ASCO Report), studies on the leakage from potable water pipes, the over-irrigation of gardens and parks and such origins of recharge as septic tanks, sewage and rainfall were carried out.

The study results showed that the main causes of the groundwater recharge were the overflow from septic tanks and the leakage from potable water pipes. The report proposed the continuance of the rainwater drainage trunk channel network expansion work, in progress in Wadi Musherib by the MPW following Pencol's recommendation in 1981, and the early implementation of a plan to connect household septic tanks and sewage pipes which had been under examination by the Sewerage Division.

(5) The Dutch Ministry of Transport and Public Works sent a Reconnaissance Mission to Qatar in August, 1984 in response to the request made by the MPW of Qatar for advise on Doha's groundwater problem and the accumulation of salt on the track course surface at the West Bay Football Stadium. The Mission carried out a field survey on the groundwater problem and examined the past studies.

The Mission's report proposed the setting up of a consultative committee consisting of the departmental heads of the Qatar Government in view of the fact that the groundwater problem did not appear to have been considered as a common problem for all related government departments despite the conclusion of the ASCO Report. In addition, the following suggestions were made.

As stormwater drainage network was in progress in the lowland critical areas, similar work could be extended to high ground as Phase II of the project depending on the good results in the low-land areas. Additional measures should also be introduced for low-land areas at the Phase II stage depending on the result of monitoring for the groundwater level. As the groundwater was polluted by sewage, the report suggested that the drained water should be treated by a special facility. Open drains, such as ditches and channels, should be provided along the original coastline in the New District.

(6) In view of the steady rise of the groundwater level in Doha, almost reaching the ground surface in lowland areas and taking serious dimensions in those areas where flooding frequently occurred after heavy rain, Pencol prepared the "*Doha Stormwater and Groundwater Management Action Report*" in March, 1985 at the request of the MPW - CED. Given the serious dimensions of the problem, Pencol confirmed the existing data and analysed the existing proposals to solve the problems relating to the rising groundwater level and stormwater flooding.

i) Confirmation of Existing Data

The existing data such as stormwater (rainfall and run-off), groundwater recharge, groundwater outflow, and groundwater balance were examined.

ii) Analysis of Existing Proposals

1 Stormwater Disposal Methods

- o Discharge of run-off via surface water sewers to the sea
- o Soakaways
- o Artificial recharge
- o Discharge to sewerage system
- o Removal by tanker

2 Items to be considered to Control Groundwater Recharge and Increase Outflow

- o Potable water leakage, recharge from sewage, rainfall and over-irrigation
- o Land drainage
- o Vertical drainage
- o Collection of groundwater for potable supply
- o Associated problems (i.e. land subsidence)

3 General Policy Proposals

- o Concerted action by governmental departments
- o Public education
- o Data collection (rainfall, groundwater and water consumption)

3.1.2 Technical Information from Previous Studies

(1) Topography and Hydrogeology

The topography of the Qatar Peninsula has gentle undulations in harmony with the two folds running in the N-S and NNW-SSE directions. The Study Area is located on the east wing of the Qatar Central Pericline and has a geological structure gently inclining towards the east and two series of basins in the NNW-SSE and ENE and WSW directions.

The dissolution of hard plaster in the Lower RUS formation caused the collapse of the formations above it, producing the many depressions which characterise Qatar's topography.

The order of the formations in the Study Area and their hydrogeological characteristics are as follows.

Formation	Permeability	Permeability Coefficient
Superficial Deposits		
Upper Dammam Dolomites	Aquifer	11 - 370 m/d
Lower Dammam - Midra Shale	Aquitard	
Upper Rus Dolomites	Poor Aquifer	0.01 - 0.03 m/d
Lower Rus Anhydrites	Aquiclude	
Umm-er-Radhuma Dolomites	Aquifer	

The facies of the Upper Dammam aquifer where the groundwater mounds are formed are rather complicated and show large changes in the hydrological characteristics in both the lateral and vertical directions.

The Lower Dammam formation has a thickness of 5 - 10 m and is formed by a combination of shales and clay layers. Each shale contains silts, etc. and is less than 1 m in thickness. This formation is usually called the Midra Shale and is believed to be an aquitard.

The Upper Dammam formation has a thickness of 20 - 30 m and is the aquifer causing the problem of the rising groundwater level. The Midra Shale, which is in effect an aquitard, is located below the Upper Dammam formation and blocks the permeation of the recharge water into the Rus Dolomite formation below and, therefore, the increase of the volume of water stored in the Upper Dammam formation causes the rise of the groundwater level.

The Midra Shale consists of soft, developed shale with a lamina structure and is yellow-brownish to grey-greenish in colour. Clay and mudstone are intercalated and exfoliation is easy. The distribution of the Midra Shale is complicated as the original formation was destroyed or deformed by the subsidence of the Rus formation below it. The topography shaped by the weathered sections of the Upper Dammam formation roughly reflects the state of the Midra Shale.

The 300 m thick UER formation generally starts 85 m below the surface in the Study Area and its upper part forms an aquifer, possibly containing fresh water, with a high production index. Its head is lower than the groundwater level of the Upper Dammam formation (aquifer).

Two groundwater mounds have been formed in the Upper Dammam formation on both sides of the Wadi Musherib lowland. As the gradient of the groundwater table is generally gentle, the groundwater is as shallow as less than 2 m in parts of the lowland areas of Wadi Musherib and Montazah.

Although the mounds in Doha correspond to an area of high gross recharge, the mound in Khalifa does not necessarily correspond to the distribution of the gross recharge. In view of this, it is believed that the local shape of the groundwater table depends on the "Midra High".

(2) Mathematical Model of Groundwater Flow

A mathematical model was introduced to simulate the groundwater flow in the Study Area using a quasi 3-dimensional method with the Upper Dammam formation as the subject formation in view of its direct relation to the groundwater problem. The Lower Dammam formation (Midra Shale) was treated as an aquitard (foundation) to simplify the model.

In the model, the Upper Dammam formation was divided into 2 layers in terms of the respective structures, namely

Unit 2 - Upper Layer ..... Upper Weathered Layer
Unit 1 - Lower Layer ..... Middle and Lower Composite Layer

As a result of repeated tests on the 5 different permeability combinations of these 2 layers, the 2 layer structure with an upper layer permeability coefficient of 200 m/d and a lower layer permeability coefficient of 40 m/d was found to be the best combination and these figures did not contradict the hydrological constants obtained by the field survey.

(3) Water Balance

The water balance was calculated using the QATS zones corresponding to the administrative zones, taking into consideration the five recharge related items and the seven outflow related items and assuming the shape of the groundwater table in 1982. These QATS zones were introduced in view of simplifying the quantitative understanding of the recharge items.

Gross Recharge to Aquifer in 1982	33.824 million m^3
Total Outflow to Aquifer in 1982	32.109 million m^3

The difference of 1.717 million m^3 (5.4% of the gross recharge) is the additional stored volume in the aquifer which raised the groundwater level in the Study Area by an average of 0.28 m for that year.

In short, 33% of the total volume of natural water and water originating from human activities (106.36 million m^3) was recharged to a shallow aquifer in the Study Area, of which 5.4% (1.7 million m^3) was stored in the acquifer in 1982.

The breakdown of the gross recharge (33.826 million m^3) by the five recharge sources is as follows.

a. Irrigation 13.715 million m^3 (40.6%)
b. Potable Water Distribution System 9.238 million m^3 (27.3%)
c. Sewage 6.415 million m^3 (19.0%)
d. Rainfall 4.206 million m^3 (13.0%)
e. Treated Sewage Effluent (TSE) Distribution System 0.250 million m^3 (0.1%)

The breakdown of the total outflow (32.109 million m^3) by the seven types of outflow is as follows.

a. Seepage to Sea 14.487 million m^3 (45.4%)
b. Farm Abstraction 6.181 million m^3 (19.2%)
c. Drainage of Groundwater to Sewerage System 5.292 million m^3 (16.5%)
d. Stormwater Drainage 2.000 million m^3 (6.1%)
e. Abstraction for Blending 1.834 million m^3 (5.7%)
f. Groundwater Outflow Inland 1.815 million m^3 (5.5%)
g. Groundwater Evaporation 0.500 million m^3 (1.6%)

(4) Water Quality of the groundwater

Based on the comprehensive studies on the hydrochemical process and solutions many findings were made and the characteristics of the groundwater in Doha city were clarified to some extent. These findings include the EC values of the groundwater in Doha city, the problems on the saturation of plaster, density of salinity in the groundwater and accumulation of salinity in soils.

a. Samples and results of the water quality analyses

The results of water quality analyses on the 88 samples carried out by ASCO are summarized in the Supporting Report, Section C. The samples include not only the groundwater, but also fresh water and rainwater. About 40 samples (about 50%) of the total number were collected from the ASCO Project Test Wells. From the geological view point, most of the samples, 50 number (57%) in total were taken from the groundwater in the Dammam Formation. The sampling points are counted to be 52 in total, as more than two samples were collected from some sampling points. The samples by ASCO are classified as follows.

Table 3.1.1 Classification of Samples for Water Quality Tests by ASCO

Item	Dammam (D) Formation	Rus (R) Formation	D & R Formation	Others	Total
Project Test Wells	31	9	-	-	40
Boring Holes	8	6	13	2	29
Uncasted wells	1	-	-	-	1
Pits & Trenches	10	-	-	2	12
Fresh Rainwater	-	-	-	6	6
Total	50	15	13	10	88

b. EC values

The groundwater in Doha city is characterized by the EC values. The character of the groundwater can be exactly assumed by observing the EC value. A linear relationship is recognized between the Total Dissolved Solids (T.D.S) of salt and the EC values. (EC value of 10,000 micro mhos/cm equals about 7,500 ppm).

The EC values of the natural groundwater in Doha city area are stable between 7,000 and 13,000 micro mhos/cm. The groundwater with an EC value of more than 13,000 micro mhos/cm is found in the deeper soil layer. If the EC value of the groundwater is less than 7,000 micro mhos/cm, it is assumed that the groundwater is diluted with the urban water and polluted. The distribution of the EC values of the ASCO samples is shown in Table 3.5.

Table 3.1.2 Distribution of the EC Values of the ASCO Samples

EC Values micro mhos/cm	Dammam (D) Formation (N=49)	Rus (R) Formation (N=16)	D & R Formation (N=13)	Total (N=78)
< 7,000	(21)	(2)	(1)	(24)
< 10,000	(11)	(6)	(5)	(22)
< 13,000	(7)		(5)	(12)
< 16,000	(2)	(2)	(2)	(6)
< 19,000	(2)	(1)		(3)
< 22,000	(1)			(1)
< 25,000	(1)	(1)		(2)
> 25,000	(4)	(4)		(8)
EC<7,000	43%	13%	8%	31%
7,000<EC<13,000	37%	38%	77%	44%

About 40% of the samples collected from the groundwater in Dammam Formation show an EC value of less than 7,000 micro mhos/cm. This fact indicates that the groundwater in Dammam Formation is diluted with fresher waters of anthopogenic origin and considerably polluted.

c. Present condition of groundwater pollution

The groundwater in the central part of Doha city or inside of the 'B' Ring Road is seriously polluted. The value of K, NO_3 and PO_4 show extremely high levels. The groundwater is located about 1 m below the ground surface in the low land areas of Souq, and Cable and Wireless roundabout in Wadi Musherib. It is clear from the five basic indices (PO_4, NO_3, Na, SO_4, Cl) that the groundwater in the above area is contaminated with the sewage water from sewage system, septic tanks and cesspits. Some groundwater in the areas contains the obnoxious smell of H_2S.

3.1.3 Summary of Proposals and Recommendations

The proposals, recommendations and/or suggested policies given in the past study reports are summarised in Table 3.1.3.

Table 3.1.3 - Summary of Proposals, etc. for Groundwater Drainage in Doha

	Emergency Measures	Long-Term Measures	Required Policies
Subject Area	(1) Wadi Musherib/ well field areas (2) Montazah Park/ roundabout area	Doha city and Umm Said areas	Doha city and Umm Said areas
Objectives	(1) Lowering of groundwater level in subject areas (2) Implementation of pilot tests (3) Provision of information and materials for long-term measures	(1) Prevention of further rise of two groundwater mounds from their 1982 levels (2) Eradication of areas where groundwater level is less than 2 m below ground surface	Encouragement of contribution by administrative sectors to promote measures and projects to solve groundwater problem
Project Measures or Policies	(1) Renewal of rainwater drainage facilities with added lateral drainage of groundwater (2) Vertical drainage of excessive groundwater (3) Local drainage of groundwater using wells	In addition to those measures described as emergency measures (1) Utilisation of abstracted groundwater: retreatment and irrigation use (measure to reduce gross recharge) (2) Water saving type irrigation system	(1) Government committee for water resources adjustment (2) Promotion of pilot test plan for vertical drainage (3) Preservation of data-base and introduction of mathematical model

(4) Implementation of groundwater drainage pilot test plan Place: well field of Wadi Musherib Contents: lateral and vertical drainage	(3) Renewal of drainage pipes, asbestos pipes, etc.	(4) Early warning system based on monitoring
	(4) Leakage detection system for drainage pipes, etc.	(5) Early detection and repair system for damaged pipes, etc.
(5) Points to Note; Avoidance of negative influence on building foundations and underground structures due to groundwater drainage or lowering of its level (method, level and speed of groundwater level lowering)	(5) Elimination of cesspits and septic tanks	(6) Groundwater drainage in West Bay area (land drainage)
	(6) Expansion of sewerage system	(7) Artificial embankment fill using reclaimed land
	(7) Review of future utilisation of TSE	(8) Replacement of blending by groundwater by introducing carbonating device
		(9) Use of abstracted groundwater for public irrigation
		(10) Introduction of deep root and salt resistant plants
		(11) Obligatory safety measures as parts of building approval process
		(12) Introduction of water charge system
		(13) Public relations activities to promote water saving

3.2 Damage due to Rising Groundwater

Although the severity of the groundwater problem has been recently recognized by the officials of the related governmental agencies, no drastic damage has so far occurred, and the problem does not yet have the wide recognition among the citizens.

The spread of standing water is unavoidable if the rising rate of groundwater in Rayyan, presently at 0.3 to 0.5 meter annually continues. Damage will also increase in Wadi Musherib if the extent of the Khayl groundwater mound is not checked.

An investigation through field reconnaissance and hearing survey was conducted in order to determine the damage caused by the rising groundwater. The following are the findings and conclusions of that investigation.

3.2.1 Field Reconnaissance

The first approach to the rising groundwater problem addressed the visual objects such as standing water and dead trees. Second approach was to inspect actual damage not only due to the rising groundwater but also caused by specific hydraulic facilities.

(1) Standing Water

The first survey was conducted on Feb. 6-10, 1986 just after a rainfall of 7.4 mm when many streets were affected by standing water. During the second survey of March 23-24, 1986, most of the same streets were dry.

From the comparison of the two standing water areas, the standing water origins can be divided into two categories; stormwater and groundwater, as shown in Fig. 3.2.1.

As the standing water caused by storm water depends on the rainfall amount and its distribution, Fig. 3.2.1 represents only one configuration of the storm water flooding area which varies with time.

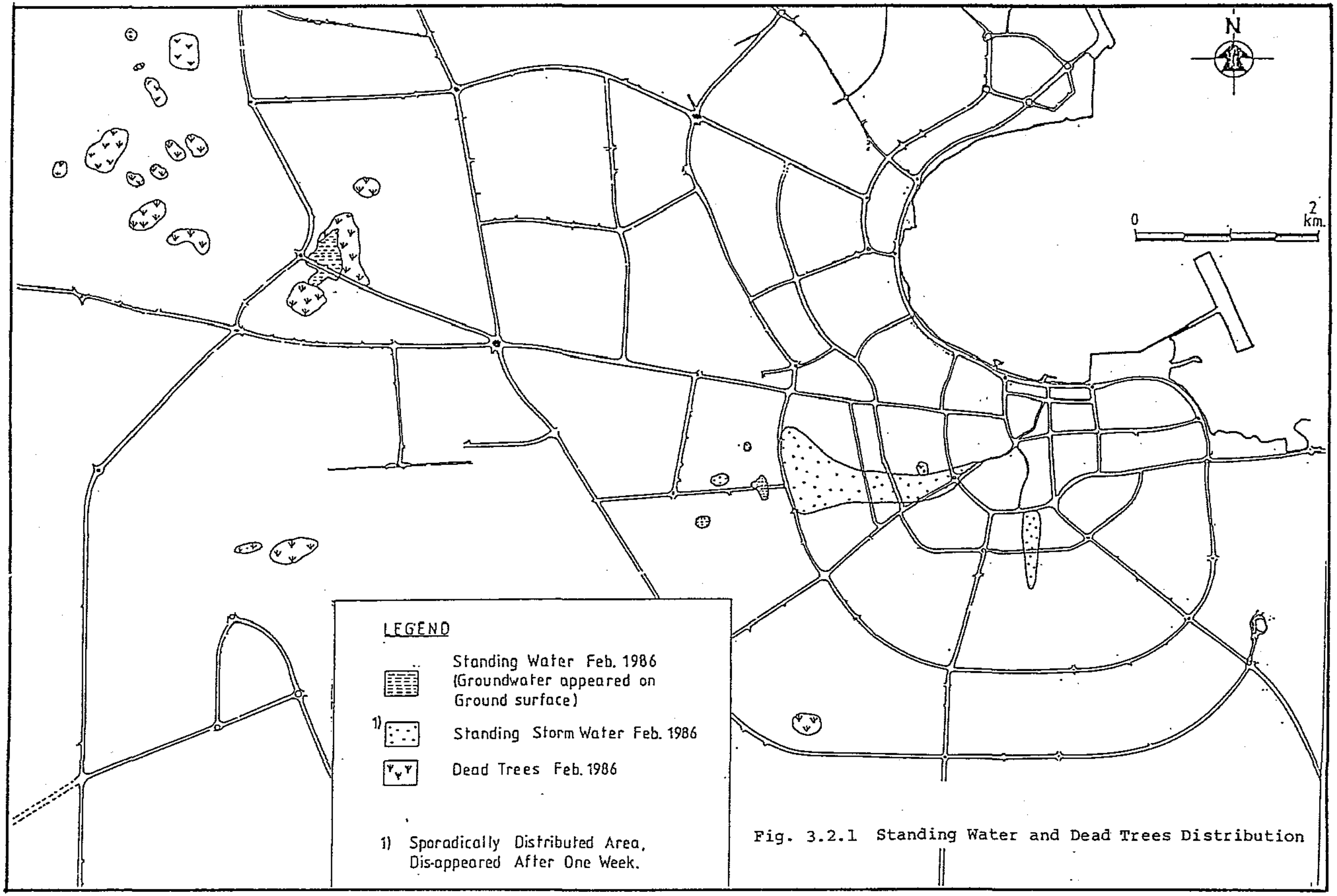


Fig. 3.2.1 Standing Water and Dead Trees Distribution

Standing water due to groundwater is found at the following areas:

- Rayyan
- Abu Sadirah just downstream of the Wadi Musherib Dam
- Right bank located 700 to 800 m upstream of the Wadi Musherib Dam
- Abandoned farm near Al Ahli Sports Club
- Abu Hamour

(2) Dead Tress

A reconnaissance of dead trees was carried out from Feb. 1 to 25, 1986 and their distribution is shown in Fig. 3.2.1.

The first impression from the dead trees seemed to be that the problem was caused by the rising groundwater, however the reasons for their death could be one of many, as discussed in item 3.2.2 (7).

(3) Building Basement, Road and Underground Service Facilities

To measure the extent of damage to basements, roads and underground service facilities, due to the rising groundwater, governmental organizations were visited and some actual damage was inspected.

Almost all of the underground structures encountering groundwater are affected and, thus, maintenance and installation of new works have become necessary.

In underground structures, where waterproofing is insufficient leakage has become inevitable with the rise in groundwater level. Salt particles are deposited on the basement wall surfaces indicating unsaturated seepage flow. Corrosion of metallic parts due to groundwater is widespread, suggesting the possibility of corrosion of reinforcing steel in concrete structures. Fig. 3.2.2 shows the locations and brief descriptions of some of the damaged sites visited.

Regarding the road construction, it is considered that the strength of subgrade has been reduced by the rising water saturation and frequent repair or maintenance is required.

SITE	STATUS	DAMAGE
1) Qatar National Museum	Completed	Leaks in aquarium which is underground. Pencol prepared a report for remedy.
2) Ministry of Finance & Petroleum	Completed	Leakage in basement. White, Young & Partners consultants investigated and concluded leakage due to tidal water. Remedial work executed.
3) Al Khaleej Insurance Bldg.	Under Construction	Costly dewatering operations during foundations construction raised foundations costs by about 1.5 times.
4) Abdallah el Attiyah Bldg.	Under Construction	Leakage in basement due to insufficient insulation. At time of construction start groundwater was not at shallow depths. Owner having problems sealing basement and cannot receive completion certificate. 4 consultants have been requested to help in addition to Doha Municipality.
5) Exchange Chamber, QNTS	Completed	Groundwater leakage at points of entry of cables into chamber, despite many efforts to seal. 3 years ago chamber was filled with water causing service disruptions. Sump pit and pump installed recently.
6) Abdallah Sherif Bldg.	Completed 9 - 10 years	Leakage is occurring in basement from two opposite walls. Behind one wall is a sewerage cess pit, and there is a garden behind the other. Residents complain water sometimes reaches 15 cm above basement floor.
7) Ahmed Bin Mohd. Al Thani Bldg.	Constructed 6 - 7 years ago	Leakage of basement. In mid 1985 extra thickness of concrete was poured on basement floor to a ht. of @ 50 cms, and since then no leakage has been reported. Groundfloor occupied by shops and car showrooms. Completion certificate withheld by Doha Munic. because of exceeding ht. limits and leakage problems.
8) Commercial Offices Bldg.	Under Construction, finishing stage. Construction started 3 years ago	Leakage appeared during winter 1985 at lift pits, and was repaired by sand & cement spray under pressure over wire mesh. In Feb. 1986, after some heavy rain leakage appeared in basement floor construction joints. Water samples were taken from pit dug beside the basement wall where water level was at a depth of 1.4 m.
9) Montazah Park Swimming Pool Pump Room	Constructed about 19 years ago. Room all underground. Dims. 10x10 m	Leakage at wall which is opposite common wall between swimming pool and pump room. No insulation applied at time of construction. Room floor damp and salt contamination appearing on walls. Consultants have been called in but no remedial decision has been reached.
10) National Theater	Completed	Leaks in basement. White, Young & Partners consultants investigated and remedial work executed. Leakage due to tidal water, consultants believe. It is also believed that irrigation water is also to blame.

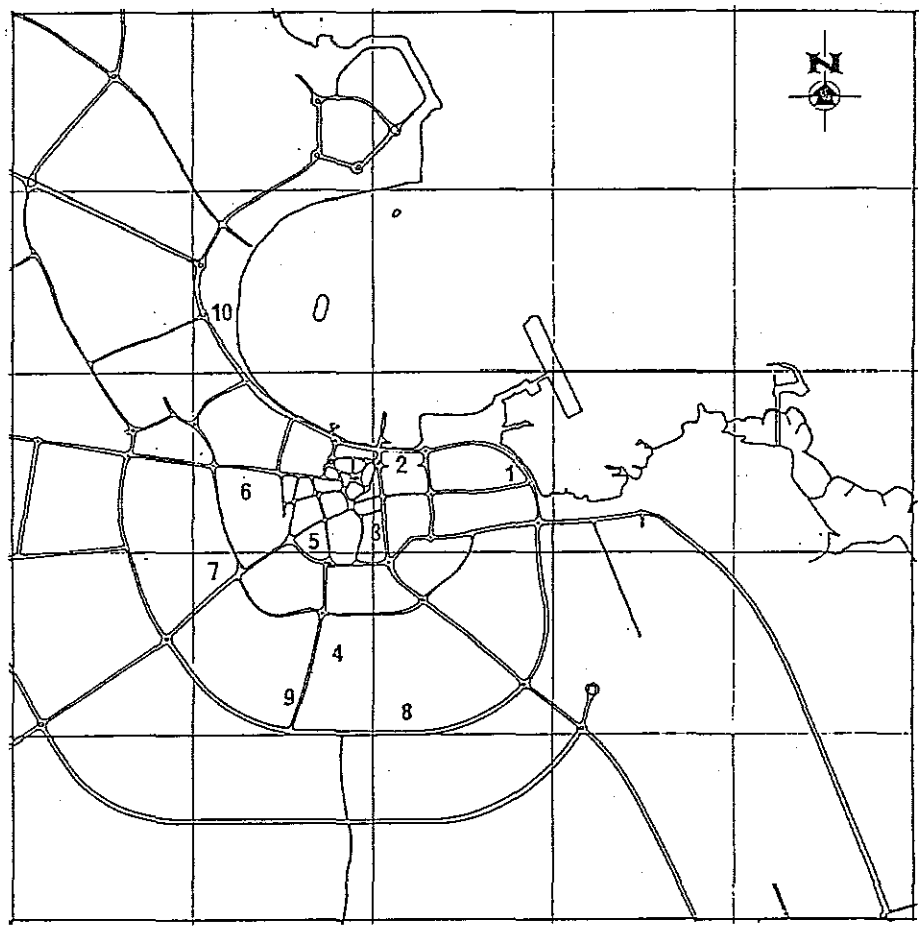


Fig. 3.2.2 Location of Some Structures Effected by Rising Groundwater

3.2.2 Hearing Survey on Damage

The hearing survey aimed at identifying the extent of the damage created to the city's services and other activities by the rising groundwater. Hearings began on 24th February and lasted for one month, ending on 23rd March 1986. Supplementary hearings were conducted during the second half of November 1986. Officials in the Qatari Government, members of the Technical Liaison Committee, farm owners, private consultants and contractors were interviewed.

The damage and opinions described below were expressed by these parties. In some cases damage was confirmed by site inspection.

(1) Electric Power Distribution Network

a. Increase in cost and time during maintenance and repair works.

b. Washing out of trench fill material.

c. Damage to old parts of network where waterproofing measures may have become ineffective, or were insufficient from the start.

d. Fear of possible contribution to settlement and cracks in substations.

(2) Qatar National Telephone Service (QNTS)

a. Groundwater is running through PVC ducts enclosing cables and filling manholes with water.

b. Extra time and cost are incurred when executing jointing or repair operations in manholes full of water.

c. Leakage of groundwater into main exchange chamber located underground in front of the Cable and Wireless headquarters, and salt particles observed on the chamber walls.

d. Presence of hydrogen sulphide in water filling some of the manholes creates a health hazard to QNTS workers.

(3) Sewerage Network

a. Groundwater intrusion into the sewerage network is about 30% of the total flow.

b. Extra cost of tanking and GRP lining of old and new manholes.

c. Increase in costs of installation and maintenance works in high groundwater areas.

d. Shortening of pump life due to increased flow in the network.

e. Corrosion of pump impellers by high saline groundwater.

f. Salinity of Treated Sewage Effluent.

g. Bad odour and corrosion by hydrogen sulphide in water.

(4) Potable Water Distribution Network

a. Increase in installation costs where dewatering operations are necessary.

b. Potential corrosion effect on ductile iron pipes and copper service connections.

c. Water Department's Distribution Section investigates many false complaints of damaged pipes, a situation costly in both time and money.

d. Fear of groundwater intrusion into the system in areas of the city under restricted supply of potable water.

(5) Roads Network

a. Damage of old roads in the city and Rayyan.

b. Groundwater level is directly below tarmac in some roads in Wadi Musherib.

c. Additional cost due to increased subbase thickness for roads in West Bay, as protection against groundwater.

(6) Standing Water

a. In Rayyan, standing water in abandoned farms is a source for bad odor and a breeding place for mosquitoes.

b. Some streets in Wadi Musherib are covered with water for one week after heavy rain.

(7) Cultivation

a. Salt contamination of soil in Rayyan.

b. Some Rayyan farmers said that palm trees began dying when water started to rise above the ground surface 6 - 12 months ago (March 1986).

c. As other reasons, unconnected with groundwater were heard during the hearing survey, and the lack of any study into this problem, the Study Team cannot conclude that death of palm trees and vegetation is connected to groundwater.

(8) Safety of Structures

a. The situation where old buildings badly constructed with poor quality materials are located in high groundwater area is causing concern. These three factors combined may cause failures.

b. Leakage in basements, salt contamination of basement walls and corrosion of embedded reinforcement is wide spread.

c. Construction costs for foundations have increased in shallow groundwater areas. Many developers avoid construction of high buildings or basements to reduce costs.

d. Existing Qatari building codes include specifications to protect underground structures against groundwater, however compliance to these specifications is in many cases either not done or else done poorly.

   It is believed by many interviewed, as well as the JICA Study Team that more strict control is needed in the checking of drawings and structural calculations, and construction supervision. The extent of the groundwater in some areas of the city deems this necessary.

3.2.3 Systematic Classification of Damage

Damage was classified into direct damage and indirect damage, according to the following concept:

Direct damage : Damage attributed directly to the rising groundwater
Indirect damage: Damage derived from direct damage

(1) Evaluation criteria

An evaluation of the damage was necessary in order to determine the extent of the damage caused by the rising groundwater table.

Attempts were made to obtain data in order to quantitatively evaluate the damage in terms of cost, however required figures were not available from the different authorities responsible for the services. The reasons the officials explained for being unable to provide such information included that budget breakdowns are unavailable or confidential.

Therefore JICA Study Team attempted to evaluate the damage in terms of the influence such damage creates. In case of direct damage the following criteria were used:

i) Lowering of service level
ii) Increase of maintenance and repair costs
iii) Increase of construction costs
iv) Increase of running costs
v) Health hazard
vi) Shortening of facilities and equipment life
vii) Decrease in quality

In case of indirect damage, criteria used were as follows:

i) Decrease of land use possibilities
ii) Traffic disturbances during maintenance or installation works
iii) Decrease of land property values
iv) Degradation of amenity between human and groundwater

(2) Evaluation

Table 3.1.1 in the Supporting Report describes in detail the damages effecting each sector, and its evaluation in terms of its influence.

The contents of the table regarding direct damage, grouped under evaluation criteria headings are as follows:

i) Lowering of service level, or quality
- QNTS : Leakage in Exchange Chamber
- Electricity : Groundwater intrusion into cables damaged by other services
- Sewerage : 30% groundwater intrusion into network

ii) Increase of maintenance costs
- QNTS : Dewatering manholes
- Electricity : Dewatering trenches
- Sewerage : Dewatering trenches, corrosion of pump impellers, increased wear of pump
- Roads : Roads damaged in city area and Rayyan, removal of standing water from roads
- Structures : Dewatering of basements having leaks

iii) Increase of construction costs
- QNTS : Dewatering manholes
- Electricity : Dewatering trenches
- Sewerage : Dewatering trenches, tanking and GRP lining of new manholes
- Potable Water: Dewatering trenches at West Bay
- Roads : Additional subbase layer for roads in West Bay
- Structures : Dewatering site

iv) Increase of running costs
- QNTS : Continuous dewatering of Exchange Chamber
- Sewerage : 30% groundwater intrusion into network

v) Health hazard to maintenance crews
- QNTS : Groundwater mixed with sewage in some manholes, having a very high rate of hydrogen sulphide
- Standing Water: Source for breeding of mosquitoes and emission of odour

vi) Shortening of facilities and equipment life
- Electricity : Corrosion of armour wire, subsidence of cables, settlement of old substations
- Sewerage : Shortening of pump life, subsidence of ducts
- Potable Water : Potential corrosive effect
- Dewatering Equipment : Wear and shortening of equipment life

vii) Decrease in quality
- Potable Water : Possible groundwater intrusion into network
- Structures : Deterioration of concrete
- Vegetation : Salt contamination of soil, increased salinity of groundwater used for irrigation

In the case of indirect damage the table contents are as follows:

i) Decrease of land use possibilities
   - Alteration in designs of future construction projects

ii) Traffic disturbance during maintenance or installation works
   - Use of sections of streets for placing dewatering equipments

iii) Decrease of land and building property values
   - Salt contamination of top soil layer

iv) Degradation of amenity between human and groundwater
   - Unpleasant situation of standing water, regarding odour and mosquitoes
   - Problem at recreational locations

3.2.4 Relationship between Groundwater Level and Damage

(1) Groundwater Level and Types of Damage

Damage caused by the groundwater rising is classified into three groups, as shown in Fig. 3.2.3, depending on the actual groundwater level.

1. Standing Water Areas: Areas where damage is caused by the appearance of standing water.

2. Capillary Wet Areas: Areas where the capillary fringes reach the ground surface, resulting in a high salt accumulation due to the hot and dry weather. Salinity of soil moisture is higher than sea water.

3. Areas of Rising Groundwater Level: Areas where neither standing water nor wet areas by the capillary effect are observed but damage is caused by the general rise of the groundwater level.

(i) Damage in Standing Water Areas

1) Disturbance to Traffic

Smooth traffic flow is disturbed when roads are flooded. This occurs at Wadi Musherib immediately following rainfall. In Rayyan, the problem of flooding scarcely arises as the major road are raised above the ground level. However, unpaved roads on private land are often flooded, becoming impassable due to the muddy conditions.

2) Damage Caused by Propagation of Insects and Microbes

The occurrence of standing water changes the ecosystem, therefore contributing to the propagation of insects and microbes and thereby causing the danger of introducing a species which is harmful to human life. It is generally recommended that tilapia be kept to prevent the breeding of mosquitoes when the utilisation of surface water is intended.

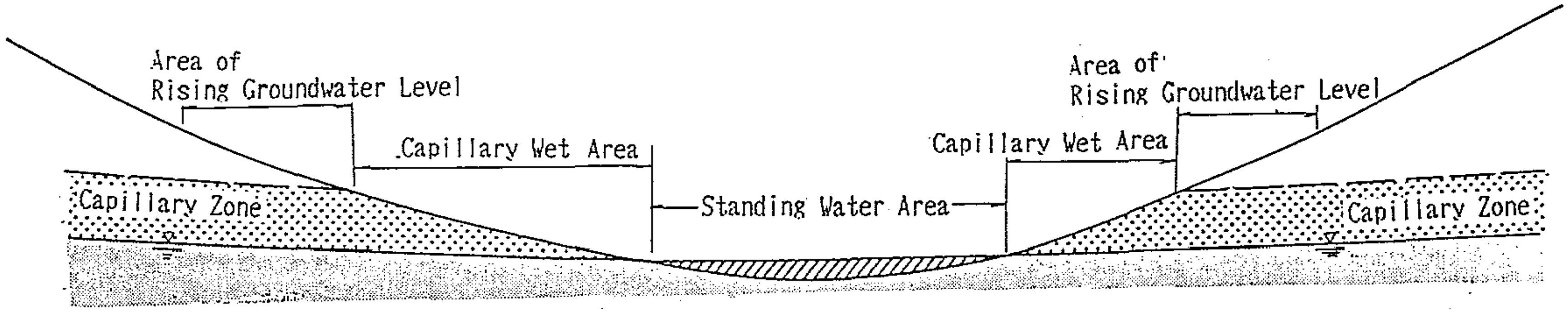
3) Pollution of Groundwater Resources by High Salt Content of Standing Water

When standing water emerges, its salt content rises due to strong evaporation caused by solar radiation and this highly salinated water may permeate due to its high density. If this highly salinated water spreads into the groundwater, a situation may arise where the groundwater which has so far been utilised becomes unfit for use.

(ii) Damage in Capillary Wet Areas

1) Salt Accumulation in Soil

As evaporation from the ground surface is conspicuous in dry areas with a high temperature, the salt content which has moved upwards due to the capillary effect is deposited on the ground surface. When this accumulation of salt advances too far, the area tends to be abandoned. Restoration of the area to its original state involves major civil engineering work since excavation of the soil where the salt has accumulated and placement of new soil is required.



(1) Damage in Standing Water Area

1 Disturbance to Traffic

2 Propagation of Insects and Microbes

3 Pollution of Groundwater Resources by High Salt Content of Standing Water

(2) Damage in Capillary Wet Areas

1 Salt Accumulation in Soil

2 High Saline Soil Moisture

3 Reduced Permeability of Top Soil

4 Increased Wetting Phenomenon

5 Softened subsurface and Deformed Subsurface

(3) Damage in Area of Rising Groundwater Level

1 Lowered Function of Septic Tank

2 Increased Groundwater Inflow

3 Generation of Uplift

Fig. 3.2.3 Relationship between Groundwater Level and Damage

2) High Saline Soil Moisture

The salt content of the soil moisture increases in hot and dry weather. As the osmotic pressure changes in accordance with changes in the salt content of the soil moisture, it becomes increasingly difficult for plants to take water through their roots. Leaching is, therefore, necessary to reduce the salt content of the soil moisture.

In addition, as the salt content of the soil moisture becomes higher than the salt content of the groundwater, it corrodes those concrete foundations, structures and iron pipes, etc. which are not salt-resistant, thus shortening their lives. It becomes necessary, therefore, to protect underground structures by waterproofing walls and using salt-resistant cement, etc.

3) Reduced Permeability of Top Soil

When the salt deposits itself in the pores of soil, both the air and water permeabilities are reduced because of the narrowed passages.

The deteriorated air permeability results in an inadequate oxygen supply which has an undesirable effect on vegetation. Deep ploughing is required to improve the air permeability. Moreover, control of the salt content in the soil moisture by means of irrigation and drainage facilities is also required in order to prevent the salinity hazard in the soil.

Poor top soil permeation may also result in lasting standing water after rainfall or a reduction in the leaching effects on vegetation.

4) Increased Wetting Phenomenon

With the rise of the capillary fringe, concrete walls may get wet and reinforcing bars may be corroded due to water penetrating through the cracks in the concrete. Coating should prove effective to prevent this phenomenon.

The efficiency of the functions of underground facilities may be reduced by the wet condition and such measures as coating and dewatering, etc. should be employed depending on the case in question.

5) Possible Deformation of Subsurface

With a rise in the soil moisture, the clay content which fills and binds the soil may be softened, causing a reduction in the soil strength.

Damage to buildings is generally caused by multiple reasons and a softened subsurface seldom proves to be the main reason for damage. However, it can still act as an auxiliary factor and should, therefore, not be ignored. There have been cases where the salt which has accumulated in the soil has dissolved after contact with highly dissolving water such as potable water and this has caused a reduction in the soil strength due to changes in the soil structure. In addition, deformation of the local subsurface may result due to leakage from potable water pipelines.

(iii) Damage in the Area of Rising Groundwater Level

1) Lowered Function of Septic Tank (Diminution of Unsaturated Zone)

The septic tank performs the purification of sewage water by utilising the soil absorption effect and bacteria activities as sewage water permeates underground. With a rise in the level of the groundwater, the depth of the soil between the bottom of the septic tank and the groundwater level becomes inadequate for the required function to be performed. In an extreme case, no permeation from the septic tank can be expected and the sewage water overflows onto the ground surface causing problems of odour and health.

In general, the function of the septic tank is restored with a lowering of the groundwater level. It is, however, preferable that a house connected sewage system cover all the city in order to create a better environment.

2) Increased Groundwater Inflow

With a rise of the groundwater level, the cost of foundation work (introduction of waterproofing and gravel, dewatering, etc.) becomes higher. The cost of maintaining underground facilities also increases as more days are needed to drain the extra volume of water. There are two possible measures for this, i.e. local dewatering and a lowering of the groundwater level over a wide area.

The flooding of underground structures can be dealt with by water proofing and the installation of dewatering facilities.

As far as the increased volume for sewage treatment due to the inflow of groundwater to the sewage system is concerned, preventive measures should be considered in addition to improvements in the sewage treatment capacity.

3) Generation of Uplift

With the rise of the groundwater level, uplift acts against underground structures, resulting in cracks or uneven subsidence. This uplift should be examined from the design stage depending on the expected degree of damage to the structures concerned.

(2) Measures to Reduce Groundwater Level

(i) Necessity of Introducing Groundwater Level Lowering Measures

Table 3.2.1 shows the necessary groundwater level lowering measures depending on the damage caused by the rising groundwater level.

Damage caused by the rising groundwater level is most extensive in the case of standing water areas, followed by capillary wet areas and groundwater rising areas in that order.

When urgent measures are contemplated, it appears that the highest priority should be given to solving the problem of water logging in agricultural terminology.

Those problems concerning the occurrence of standing water and the salt accumulation by the capillary effect are known as water logging problems in the agriculture field. Water logging completely deteriorates the soil.

(ii) Relations between the Groundwater Level and the Laid Depth of Underground Structures etc.

In order to grasp the laid depths of principal underground facilities, structures, root of plants and so on, the field survey and hearings were carried out and these results are summarized in Table 3.2.2.

(iii) Desirable Groundwater Level

The question of the desirable groundwater level should also be examined in order to solve the problems in standing water areas and capillary wet areas.

Salt accumulation due to the capillary effect is mostly manifest upto a depth of 30 cm below the ground surface which is strongly affected by the hot and dry weather.

When the salt content of the soil moisture increases, the salt content deposits itself in the spaces in the soil, strengthening the capillary effect due to the narrowed spaces. Therefore, salt accumulation due to the capillary effect tends to occur in accordance with the higher salt content in the soil moisture.

It is generally believed that the capillary effect operates upto 1 - 1.5 m when the salt content of the groundwater is below 1 - 2 gr/l (0.1 - 0.2%) and upto 2 - 3 m when the salt content reaches 10 - 15 gr/l (1.0 - 1.5%).

Since the field investigation showed a capillary effect of approximately 1 m in depth, the level of the groundwater required to eradicate the wet areas by the capillary effect is considered to be 1 - 1.5 m below the ground surface.

Although a deeper groundwater level is generally more preferable, the engineering cost to achieve such a deep groundwater level is high because of the necessity of constructing drainage facilities in deep locations. In addition, groundwater found in deeper depths is of high salt content than that in shallow depths, which may be a disadvantage in case of reuse of abstracted groundwater.

Since the problems in those areas where the groundwater is 1 - 2 m below the ground surface are insignificant in comparison with the problems in those areas where the groundwater level is 0 - 1 m, the suggestion is made here that a desired groundwater level of 2 m be introduced in order to lower the present groundwater level by 1 - 1.5 m.

- Critical Groundwater Level .... 1 - 1.5 m
- Desirable Groundwater Level .... 2.0 m

Table 3.2.1 Damage Caused by Groundwater Rising and Countermeasures

Area	Phenomenon	Type of Damage	Selected Countermeasure
Standing Water	Occurrence of Standing Water	Disturbance to Traffic	A
	Propagation of Insects & Microbes	Possible Outbreak of Diseases	A
	High Salt Content of Standing Water	Reduced Value of Ground-water Resource	A
Capillary Wet	Salt Accumulation in Soil	Negative Effect on Land Use	A
		Diminished Spaces in Soil	B
	Salination of Capillary Water	Damage to Vegetation	A
		Chemical Reaction of Concrete & Iron Pipes, etc.	C
	Poor Permeability	Poor Leaching Effect	A
	Increase of Wetting Phenomenon	Reduced Function of Under-ground Facilities	B
	Softened or Deformed Subsurface	Cracks & Subsidence	B
	Diminished Unsaturated Zone	Reduced Function of Septic Tank	B
Rising Groundwater Level	Increased Groundwater Flow	Increase Cost of Foundation Construction	B
		Increased Maintenance Cost of Underground Facilities	B
		Flooding of Underground Structures	B
		Increased Volume for Sewage Treatment	B
	Generation of Uplift	Occurrence of Cracks & Uneven Subsidence, etc.	C

A: Items where measures to lower the groundwater level over a wide area are particularly effective.

B: Items where local measures are expected to show considerable effect.

C: Items where the established damage is difficult to repair.

Table 3.2.2 Assumed Desirable Groundwater Level at Wadi Musherib and New District

Main facilities and structures which seem to have bad effects due to rising of groundwater	Assumed depth of cover (m)	Assumed desirable groundwater level for each facility
(1) Pipes and manholes of sewerage network	1.2 - 6.0	
(2) Septic tanks and soakaways	* Bottom elevation of soakaways 3.0 - 4.0	3.5 - 4.5
(3) Cables and chambers of telephone distribution network	0.4 - 2.0	2.0
(4) Cables and chambers of electric power distribution network	0.4 - 1.5	2.0
(5) Pipes and chambers of potable water distribution network	0.9	1.4
(6) Pipes and manholes of surface water sewer	1.2 - 3.0	2.0 - 3.5
(7) Pipes and chambers of TSE distribution network	1.0	1.5
(8) Roads	* Bottom elevation of base course 0.3 - 1.0	1.5
(9) Buildings	* Bottom elevation of foundation 1.0 - 1.5 * Bottom elevation of basement 4.0 - 4.5	1.5 5.0
(10) Plants	* Roots of grass 0.3 - 0.5 * Roots of trees ? (Depends on kinds of trees)	?

3.3 Hydrogeology

3.3.1 Objective of the Study

Hydrogeological studies are the most important basic studies for solving the fundamental problems of drainage scheme for the areas requiring drainage. Studies include investigations of regional geological structure, hydrogeological characteristics and their distribution conditions.

As the most suitable and effective measure to cope with the rising groundwater level, a solution known as lateral drainage scheme has been selected as an urgent improvement measure. To carry out this scheme, two test work sites, one each at Wadi Musherib and Rayyan, were established. The effectiveness of the lateral drainage method was verified by the test work.

In consideration of the above-mentioned background, the two major objectives of the present hydrogeological study were as follows:

1 Clarification on all required hydrogeological conditions and geological structures of the study area for the purpose of preparing a groundwater drainage improvement plan.

2 Understanding the hydrogeological structures of the test work sites.

The hydrogeological study executed consisted of fieldwork, electrical soundings, geological observations of test work site excavation trench walls, core borings, and Lugeon tests. The results of the hydrogeological analyses are reflected in the basic concept of the drainage scheme.

3.3.2 Topography and Geology

(1) Topography

The principal topographic feature of the Qatar Peninsula is the low to moderate reliefs of gently undulating low lying plains with the highest hills around 100 m in the southern part. According to the existing report (FAO 1982), the land mass of Qatar was reported to have been formed around the Tertiary Eocene time.

There are fold structures running in the N-S and NNW-SSE axes in the Qatar Peninsula. As if in harmony with these, gently rolling plains make up the topographic feature. The study area is situated in the eastern wing of the Qatar Central Pericline, possessing geological structure gently sloping toward the eastern side.

As illustrated in the summit level map (Fig. 3.3.1), the topography of the study area can generally be divided into two major regions: 1) the extremely gentle upland of 8 - 16 m above sea level and 2) the coastal plain of less than 2 m above sea level.

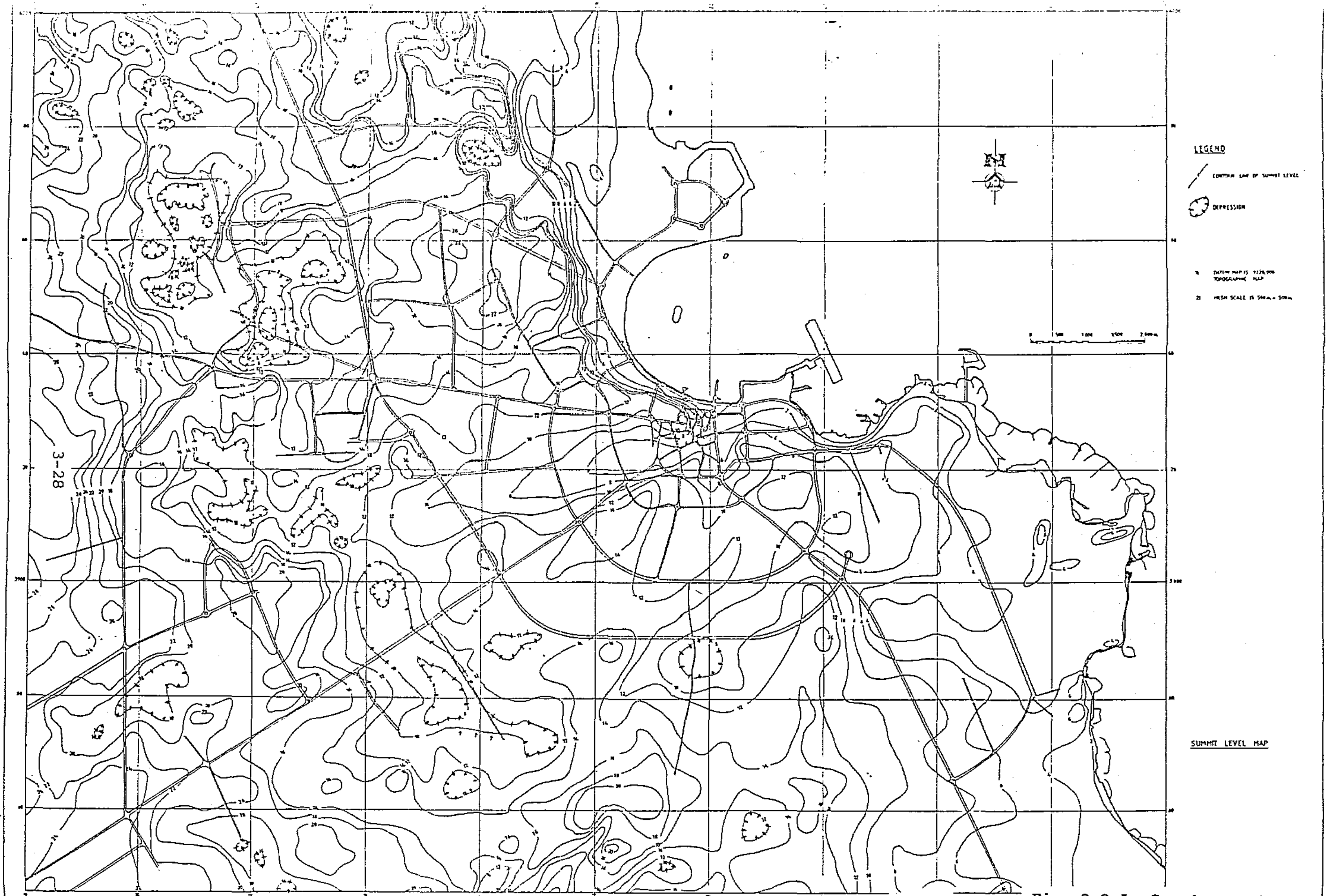


Fig. 3.3.1 Summit Level Map

In the upland, as illustrated in the summit level map, basin-shaped land extending in arc-shape toward NNW-SSE and another basin land extending nearly directly across it toward ENE-WSW can be acknowledged. Among these the most prominent topography which can be observed is the basin land in linear alignment in the direction of NNW-SSE along Garrafa-Rayyan-Markiyah-Abu Hamour-Naeejah. The lowest points of the basin land are 6 - 8 m above sea level which are anywhere between 6 - 8 m lower than their surrounding highland surface.

This basin land was not formed as a result of erosion process, but it is rather a conspicuous reflection of the geological structure and as such there is hardly any river system which drains to the sea.

In the boundary area between the highland lying in the west of the study area and the coastal plain lying in the east, an escarpment of 10 m in relative height is observed extending nearly due NNW-SSE.

According to a past report, this escarpment was thought to be part of a cylindrical collapsed cliff. Although the real cliff is observed in the vicinity of Doha Bay curving gently in an arc-shaped formation; however, in the northern region, since escarpment is seen extending in nearly over a straight line, it would be possible to conclude that it is eroded cliff or cliff of geological nature (fault cliff and/or fold terrace).

Moreover, in the city limits of Doha City two lowlands can be observed as shown in Fig. 3.3.2, one along Wadi Musherib and another in Montazah district. These two lowlands are presumed to be structural in nature as they compare closely with the geological structure of lower elevation layer.

Situated in the northwest section of the study area, the coastal plain, currently undergoing urban development, has variously been referred to as New District or West Bay. The coastal plain, a flat lowland of no more than 2 m above sea level (mostly less than 1 m), is a reclaimed land even today being filled with dredged sand and earth transported from the interior.

In the present report, a basin-shaped land without drainage to the sea shall be defined as "basin", while the one with drainage as "lowland".

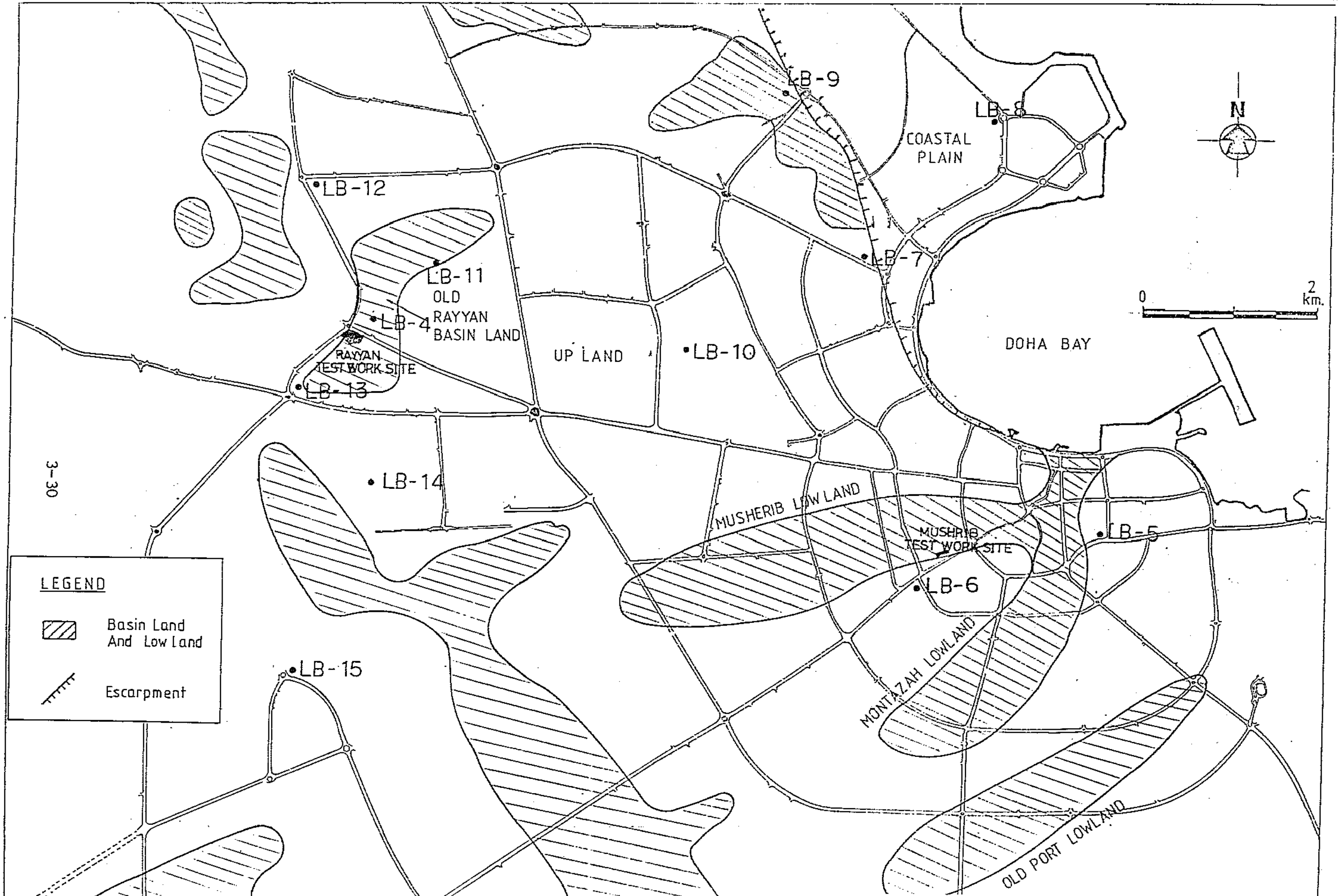


Fig. 3.3.2 Topographic Features of Study Area

(2) Geology

The Qatar Peninsula, for the most part, is composed of calcareous layer. The most ancient layer, situated at a depth of 1400 m below the ground surface, is of the Upper Jurassic which corresponds to the Arab Formation of Saudi Arabia. The Upper Jurassic formation is overlain in sequence by Cretaceous, Paleogene and Quaternary deposits.

In the Qatar peninsula, there are two fold structures along the axes of N-S and NNW-SSE. Related to these geological structures in the northern side of the central district of the peninsula is an accumulation of a seam of carbonate layers rich in shallow water sediments; in the southern side a sulfate layer rich in deep water sediments; and finally intercalated between the said two layers is a layer of residual sulfate facie.

An outstanding hydrologeological phenomenon, related to the aforementioned characteristic of variations in lithofacies, is a depression formed as a result of leaching of sulfate found in the layer of sulfate facies distributed in the district. As this depression is related to the Midra Shale, the depression phenomenon is not very striking where Midra Shale is present, while it is rather conspicuous where Midra Shale is absent. Along the boundary facies, the dissolution scarp was formed as shown in Fig. 3.3.3.

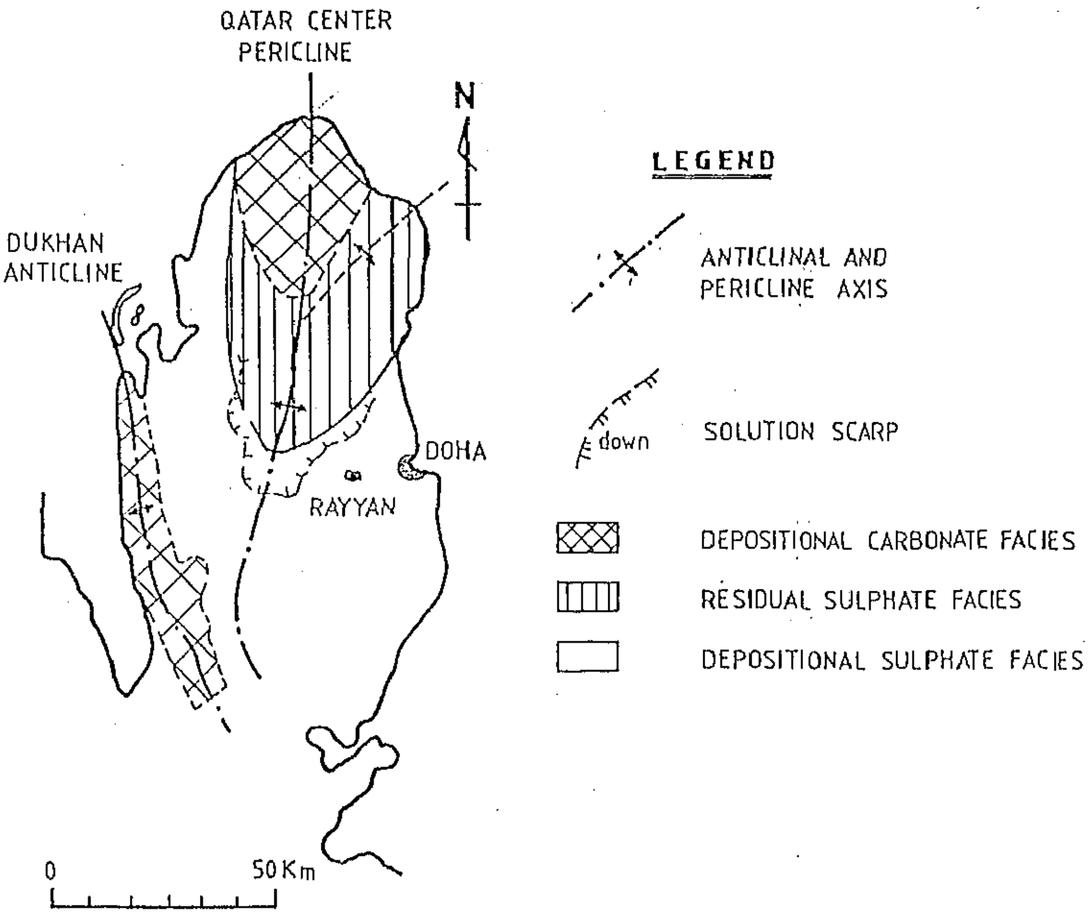


Fig. 3.3.3 Principal Geological Structure and Formation Facies Map (simplified from FAO, 1981, Fig. 3.13 and Fig. 3.10)

The sequence of geological layers observed in the study area is shown in Table 3.3.1. The critical layer in connection with the groundwater problem in Doha City is the Dammam Formation. As this is a water containing layer, the present study's efforts shall be concentrated in this layer.

The Dammam Formation is made of 4 units, from the top: Simsima limestone, dolomite layer, Alveolina limestone layer, and Midra Shale. In terms of hydrogeology, it is composed of 3 zones: I) Upper Zone (severest weathered), II) Lower Zone (slightly weathered), and III) Midra shale. However, since the thickness of the Midra shale is not as thick as has been reported in the previous report and is intercalated with limestone containing sandy-silty layer, the second and third zones shall be together called the Lower Dammam Formation.

Moreover, in part of Rayyan district calcareous sandstone layer was observed on top of the Dammam Formation.

(i) Sandstone layer

The sandstone layer is observed distributed only in part of the New District and Rayyan in the study area. In both districts it is a calcareous sandstone layer.

The distribution of sandstone in the Rayyan area has been acknowledged by fieldwork and boring at LB-4. Thickness has been determined to be approximately 5 m. However, from the results of electrical soundings, the distribution is determined to be narrow, being confined to the Rayyan area only.

As the New District is overlain with a layer of fill sand, the distribution and accurate thickness of sandstone layer could not be ascertained; however, from boring at LB-8, appreciable concretion can be acknowledged.

(ii) Upper Dammam Formation

The distribution of the Upper Dammam Formation throughout the entire study area has been acknowledged by fieldwork and by well study and is considered to be a generalized layer. This layer is mainly dolomitic limestone with accompanying limestone and sandy limestone.

From the results of boring, the top surface of this layer has been determined to be strongly weathered with well developed fissures which are filled with reddish-brown clay and other materials. However, toward the lower position the degree of weathering tends to weaken.

(iii) Lower Dammam Formation

The Lower Dammam Formation is widely distributed in the study area. The contour of top of the Lower Dammam Formation is shown in Fig. 3.3.4. The elevation at the top surface of the Lower Dammam Formation is -10 to -15 m(QND) in the low lying areas, and in the surrounding areas, the elevation is around +5 m(QND). The shape of the area is harmonious with the general characteristic topography of the area.

Table 3.3.1 Lithostratigraphic Sequence and Hydrogeological Significance

AGE	FORMATION	SUB FORMATION	MEMBER	THICKNESS (m)	LITHOLOGY	HYDROGEOLOGICAL SIGNIFICANCE
Oligocene	-	-	-	-	Absent; major unconformity	Period of diagenetic alteration of Simsima Limestone to Dolomite enhancing permeabilities.
Eocene	-	-	-	-	Absent; major unconformity	
- middle	Dammam	Upper Dammam	Simsima Limestone and Dolomite	30	Originally, very variable but basically chalky limestone. Diagenetic dolomite replacement general through of variable thickness (up to 10m).	Forms 80% of Qatar land surface. Both facies important aquifers where phreatic levels near surface in coastal belt etc.
	Dammam	Lower Dammam	Alveolina Limestone	1	E_1 marker; white compact fossiliferous chalky limestone	Lower Dammam, consisting largely of shale, has confining influence on Rus groundwater. Absence from northern 1/3 of Qatar of great recharge significance and controlling factor in removal of gypsum from underlying Rus Formation
Eocene - middle	Dammam	Lower Dammam	Midra Shale	10	Laminated, sub-fissile brown-yellow shale. Fossiliferous (sharks teeth) and with limonite and phosphate nodules.	(See above)
			Fhaihil Velates Limestone	1	White crystalline compact fossiliferous limestone	
Eocene - lower	Rus	-	Unit- 1 "Chalky Limestone"	25+		<u>Anhydrite facies</u> aquiclude,
			Unit- 2 "Anhydrite"	60+	<u>Sulphate, Facies</u> thick; anhydrite up to 50% with marl and some thin limestones.	
			Unit- 3 "Dolomitic Limestone"	? Abs		
Palaeocene	Umm er Radhuma	-	-	300+	Thick, alternating sequence of limestones and dolomites. Top 30-50m karstic dolomite. Marl content increasing downwards.	Upper unit excellent aquifer of very high storage coefficient and porosity. Remainder variable.

(After, Cavalier, 1970, IDTC 1980 and FAO, 1981)

From ASCO Report, 1983 Table 2.1

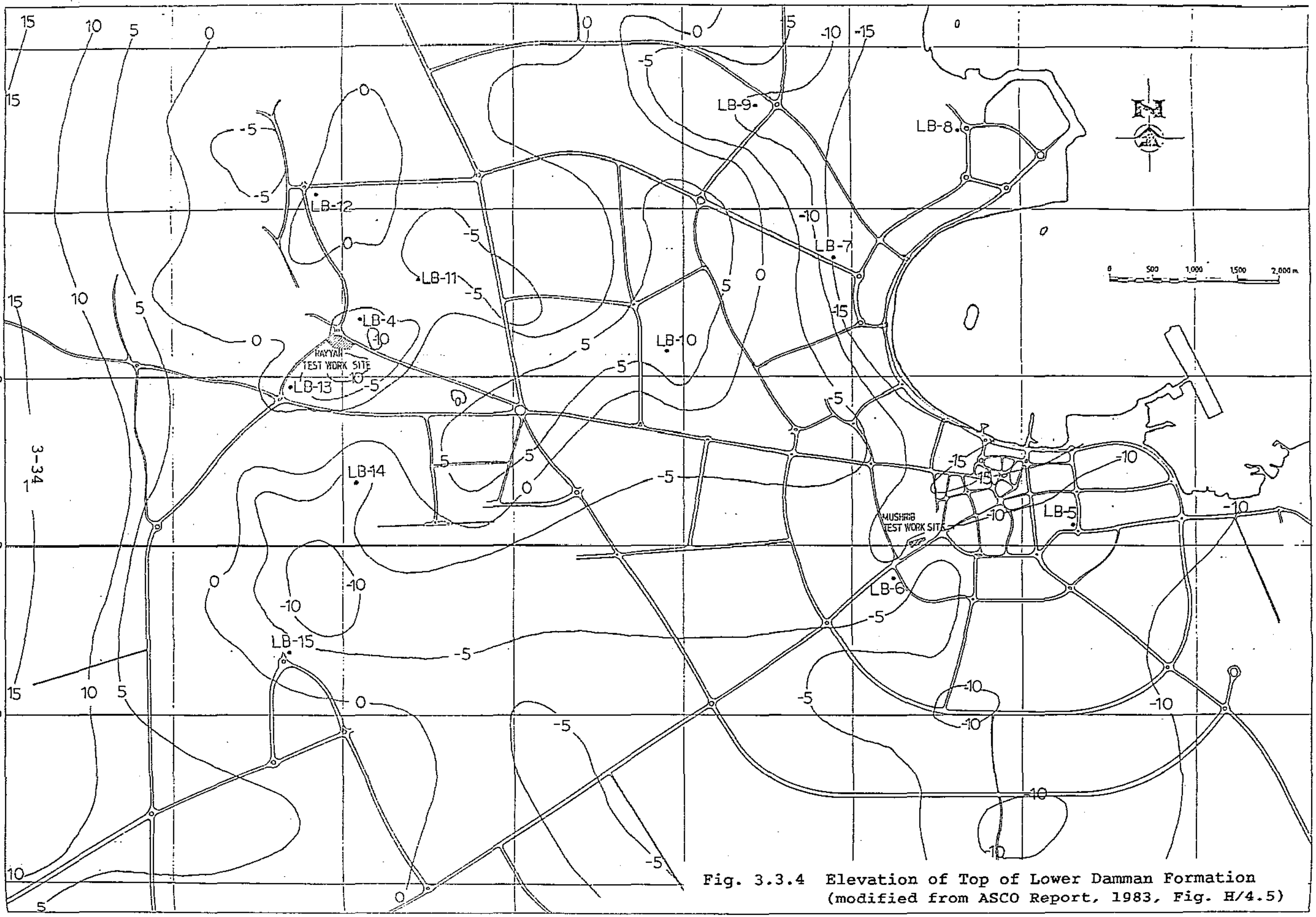


Fig. 3.3.4 Elevation of Top of Lower Damman Formation (modified from ASCO Report, 1983, Fig. H/4.5)

The Lower Dammam Formation is mainly composed of dolomitic limestone, limestone and sandy-silty limestone with shale (Midra Shale) interposed in between.

Observed in the Midra Shale are from 1 to 4 layers of shale whose individual thicknesses are several centimeters. While it is thicker at the upper section of the Lower Dammam Formation, it becomes thinner towards the lower section. Also the horizontal continuity cannot be recognized to be by all means good. Moreover, numerous well developed horizontal fissures at intervals of several millimeters have been observed.

While dolomitic limestone forming the main feature of this formation is very conspicuous at the upper section, the change to sandy-silty limestone toward the lower section can be observed.

Moreover, anhydrite-gypsum can be frequently observed in the middle section of the formation in various shapes, some imbedded horizontally in layer shape, others irregularly imbedded in vein-like shape, and still others imbedded in mottled shape. Anhydrite is observed mostly imbedded in layer shape, while the trend is that gypsum is increasingly more likely to be observed in vein-like and mottled shapes. Some anhydrite in layer shape may be as much as 20 cm in thickness, but their continuity cannot be recognized.

(iv) Rus Formation

The Rus Formation could not be confirmed in the present study. However, as can be recognized by boring carried out in the present study, the lower part of the Lower Dammam Formation changes to sandy-silty limestone with part of the section interposed with chalky limestone. This is rather quite similar to the lithofacies of Unit 1 of the Rus Formation. Moreover, since the Rus Formation is overlain apparently confirmably by the Lower Dammam Formation , the Rus Formation can be assumed to be present immediately beneath boring LB-6 and TB-30 of the present study.

Accordingly, armed with the results of the present study in addition to the results from the past studies, a surface contour map of the Rus Formation was prepared as shown in Fig. 3.3.5. The distribution of topographically low lands and the lower elevation surface of layers expressed as either "Depression" or "Low" seem to correspond.

(3) Geological Structure of the Study Area

According to the observations of layers exposed in dug wells (Arabic Wells), a deformation of layers can be recognized at several points scattered within the Rayyan basin area. The deformation of these layers is presumed to preserve pre-depression structural elements. According to this, the directions of minor anticlial and synclinal axis, joints and minor faults are all aligned in the directions of depression topography in correspondence with the two directions of NW-SE and NE-SW to ENE-WSW. This phenomenon can only indicate the presence of tectonic movement somehow related to the structural elements incorporated in the layer in the district which includes the depressions located in the Rayyan area. From the fact that the alignment extends in the

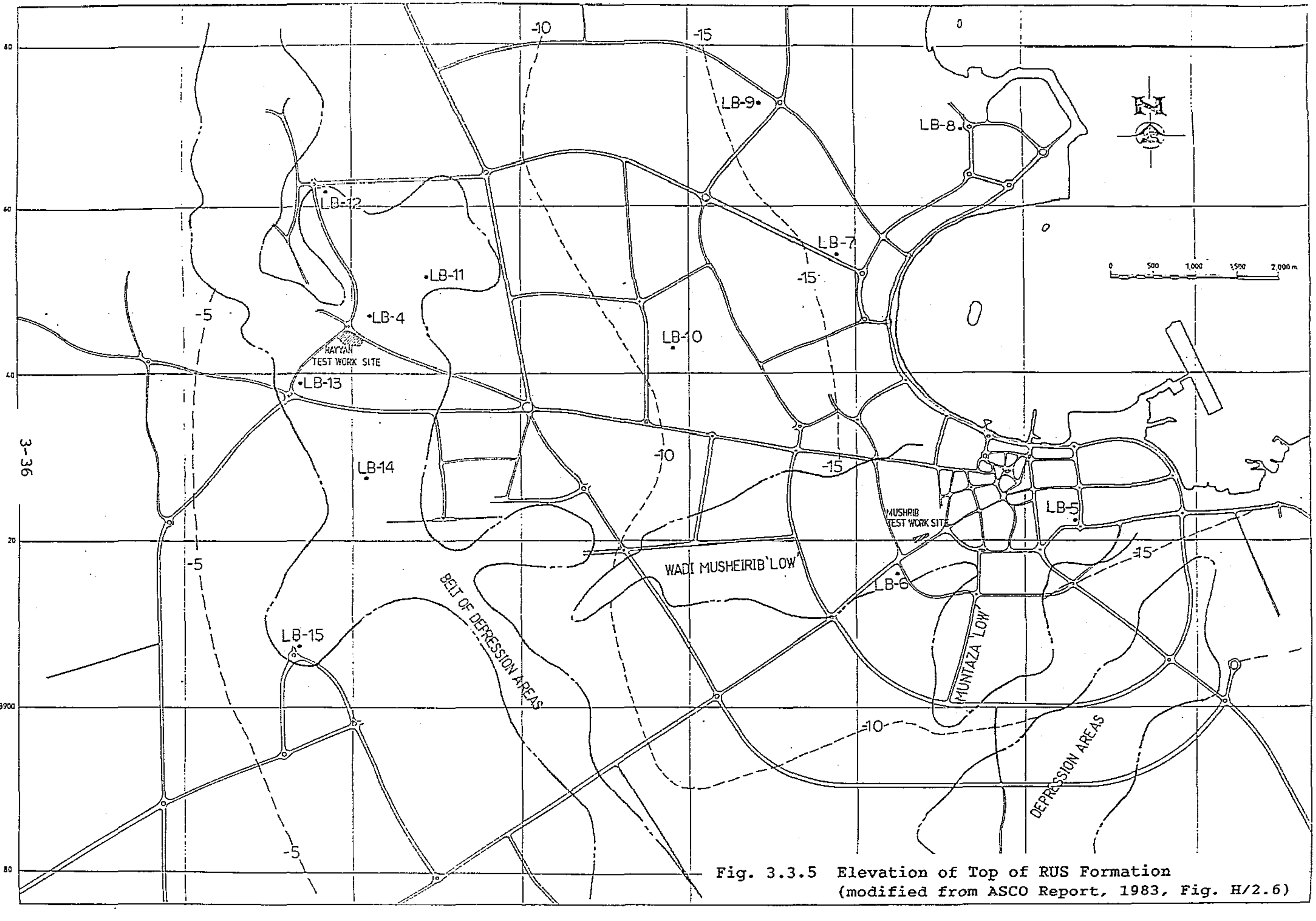


Fig. 3.3.5 Elevation of Top of RUS Formation
(modified from ASCO Report, 1983, Fig. H/2.6)

direction of tectonic line (fold axis, joint and fault), the formation of depression topography is certain to be related to the tectonic movement, and also indicates that it is regulated by geological structure.

Besides, the thickness of the strongly weathered zone of the Upper Dammam Formation in the depression is quite substantial. This is presumed to be the result of weathering of the layer caused by infiltrating rain water after the formation of the tectonic line. The grade of weathering, being different depending on the extent of the tectonic line and differences in lithofacies, is presumed to have advanced selectively. Especially, leaching caused by seepage water is apt to take place in the layer located in the study area and adjacent environ. Advancing weathering in the upper part, as it were, hastens leaching deformation of the underlain layer in the lower part. The deformation in the lower section layer, in turn, causes deformation and collapse in the upper part layer, thus further hastening the weathering process. The repetition of these processes is presumed to have contributed toward the formation of depressions in the study area.

In consideration of the above-mentioned assumptions, the following process of geological structural development can be advanced as shown in Fig. 3.3.6.

1) Fracture systems in the direction of NW-SE and NE-SW to ENE-WSW was formed.

2) In order for groundwater to infiltrate and flow along the fractures region, anhydrites and other materials in this region had to be leached and cavities began to be formed, thus causing the formation of depressions along the feature.

3) Finally, the present condition of topography characterized by low lands and depressions aligned in the direction of the tectonic line was formed.

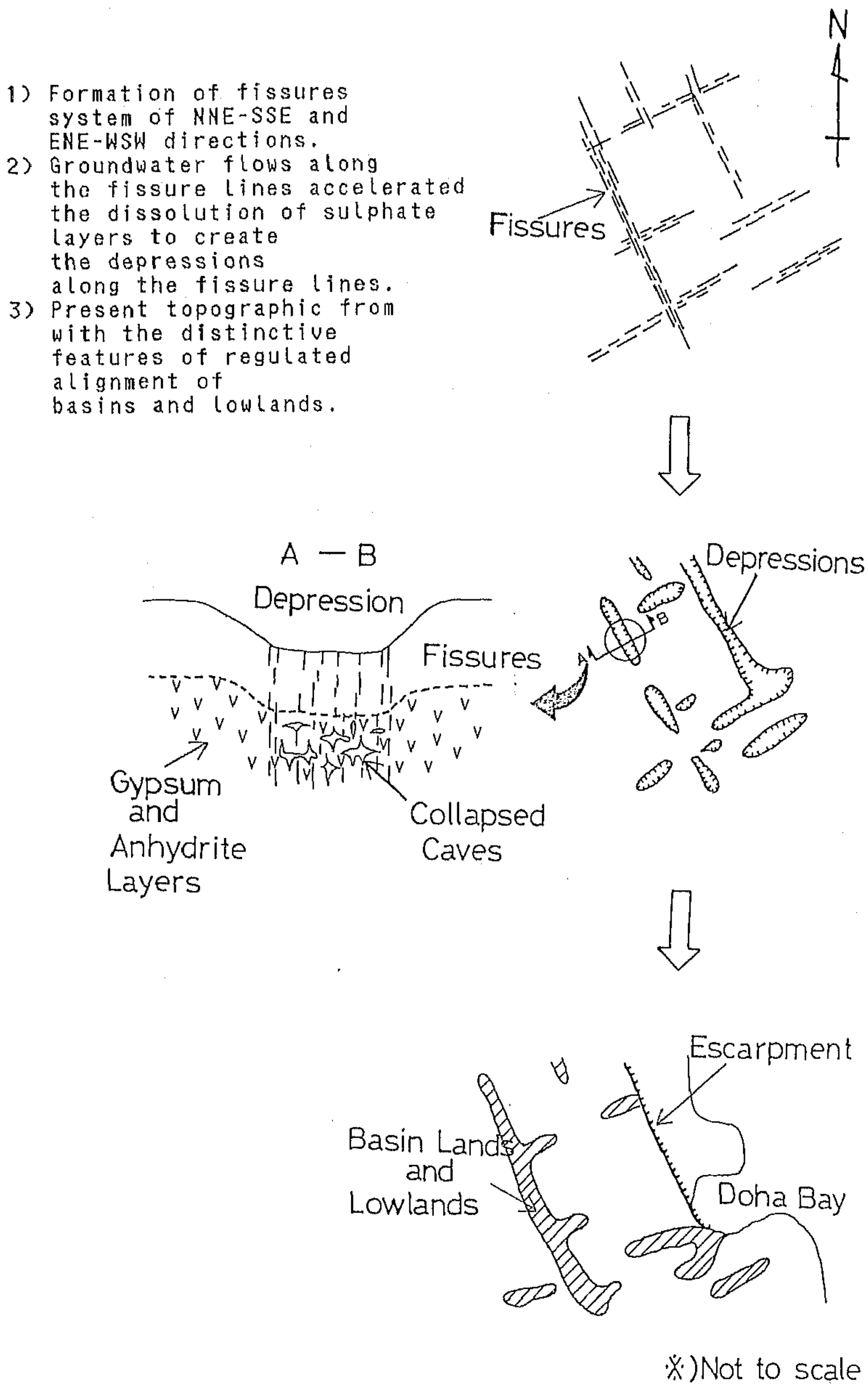


Fig. 3.3.6 Development of Depression Structure

(4) Hydrogeology

In terms of hydrogeology, the geological layers can be divided into 3 layers from the top as I, II, and III. The characteristics of each of the three layers shall be described below.

(a) Composition and Characteristics of Each Layer

(i) Layer I

This layer is composed of sand and strongly weathered zone of the Upper Dammam Formation. Although clay is interposed in the upper part of the Upper Dammam Formation, since fissures are dominant due to severe weathering, high permeability can be presumed. In the superficial layer in Rayyan, sandstone is distributed; because the degree of consolidation is low, and high water permeability can be presumed, in terms of hydrogeology, this layer shall not be classified as strongly weathered zone of the Upper Dammam Formation, but it shall be included in Layer I.

Although this layer is widely distributed throughout the entire area, the tendency is for it to be thick in the lowland, gradually becoming thin in the highland. This layer is thick in Musherib lowland and Rayyan basin. At the lowest elevation of the two areas, the thickness of Layer I reaches as much as 5 - 6 m, but in the surrounding areas, it thins out to 1 - 2 m. On the LB-13 coreboring located South-West of Rayyan area Layer I could not be observed.

In Layer I, Lugeon value (Lu) obtained through the Lugeon test was generally large with values greater than 20 Lu and there are no few instances where the values exceeded 100 Lu.

(ii) Layer II

This layer is composed of slightly weathered zone and fresh part of the Upper Dammam Formation. In the lower part of the Upper Dammam Formation, a fresh limestone layer can be seen because of weaker weathering; however, fissures in either the horizontal or perpendicular direction could be observed. However, water permeability is presumed to be somewhat less than that found in the severely weathered part.

Layer II has been observed distributed throughout the entire study area in 5 - 10 m thickness.

In Layer II, there were few test values indicating 100 Lu, and in general it was smaller in comparison with Layer I.

(iii) Layer III

This layer is composed of the Lower Dammam Formation. The Lower Dammam Formation is interposed with layers of shale whose thicknesses range from 1 m to several centimeters. The water permeability in this layer is presumed to be less than either Layer I or Layer II.

In Layer III, Lugeon value was less than 100 Lu and although the frequency of 20 Lu or less became bigger, this layer in terms of water permeability could be classified as an impermeable layer.

(b) Hydrogeological Structure

Two groundwater mounds can be recognized in Doha City.

This is because the direction of elongation of the groundwater mound is due NW-SE in the northern part and due NE-SW in the southern part. This direction corresponds with the alignment of depression topography; in other words the geological structure. This phenomenon is schematically drawn in Fig. 3.3.7. The areas in which the shape of the mound has collapsed or has expanded, have large spaces between groundwater level contour lines and it is presumed that the underground permeability is high. In the study area, the groundwater table is situated in the I or II layer, the Upper Dammam formation where permeability is relatively high. Especially, the groundwater table is situated in the I layer.

As result of that, the shape of the groundwater table in the study area is well reflected on the hydrogeological structure.

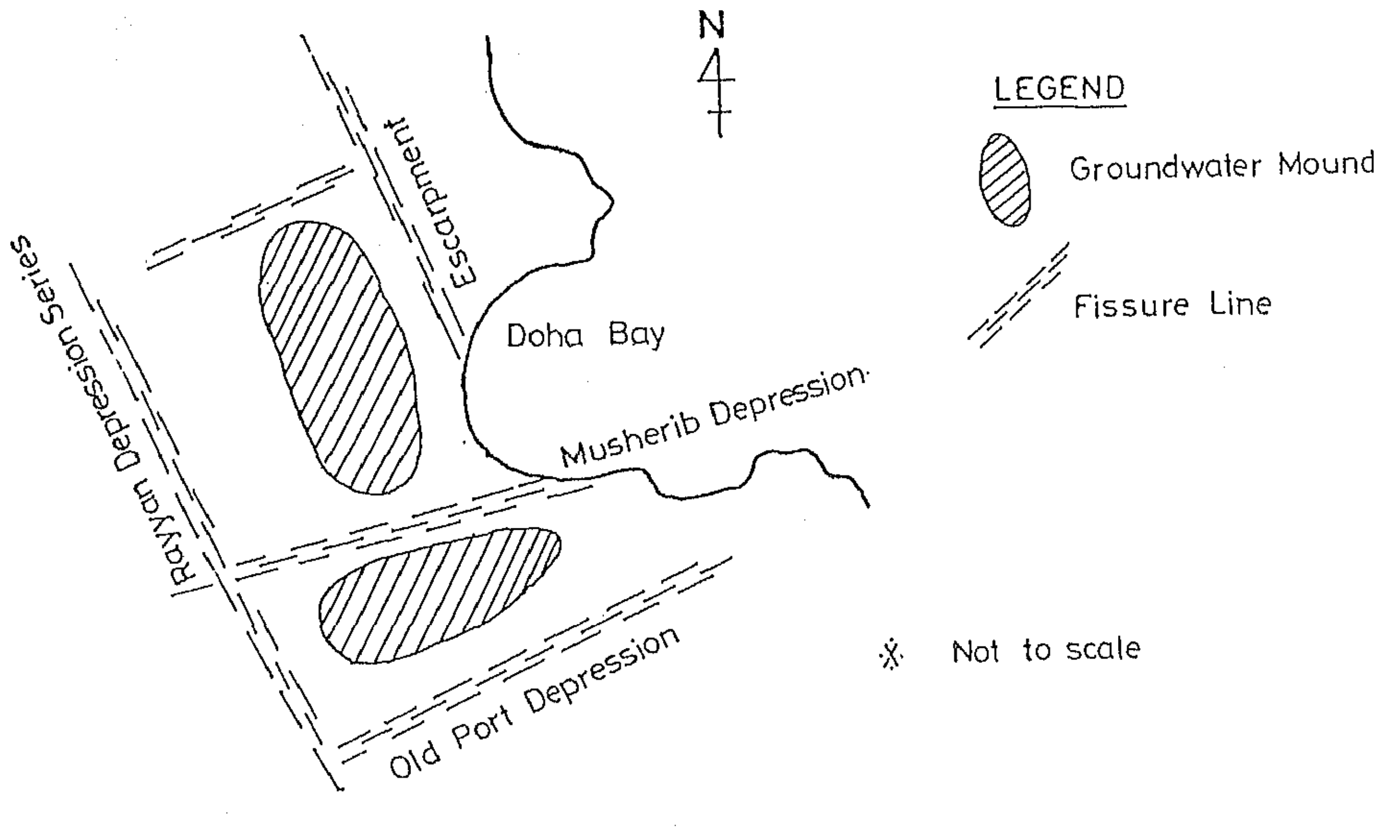


Fig. 3.3.7 Schematic Drawing of Relationship between Groundwater Mounds and Geological Structures

3.3.3 Hydrogeology of the Study Areas

(1) Musherib Area

Musherib area where electrical soundings were carried out is situated about central part in the Wadi Musherib lowland.

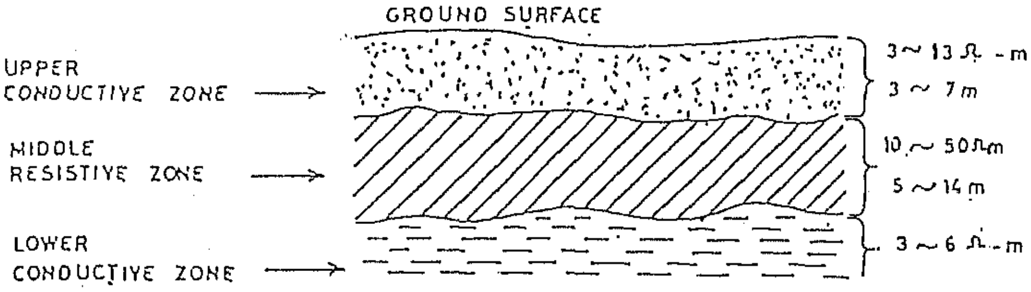


Fig. 3.3.8 Schematic Drawing of Electrical Soundings Results at Musherib Area

From the previous study of boring results, for structure foundation survey and so on, topsoil is extremely thin of less than 1 m thickness. The Upper Conductive Zone shown in the cross section of Fig. 3.3.8 is presumed to correspond to the upper weathered zone of the Upper Dammam Formation. This crust is the strongly weathered (diagenesis action) dolomitic limestone containing much clay. Although extremely low permeability is expected in the shallow part along the Musherib lowland, as a result of electrical soundings, very similar 3-layer structure in the other areas can be observed.

The Middle Resistive Zone is presumed to correspond to the relatively fresh lower layer with few fissures of the Upper Dammam Formation.

The Lower Conductive Zone corresponds either to Midra shale of the Lower Dammam Formation or adjacent formation.

As a result of the above, hydrogeological structure of the Musherib lowland could be considered in the following manner.

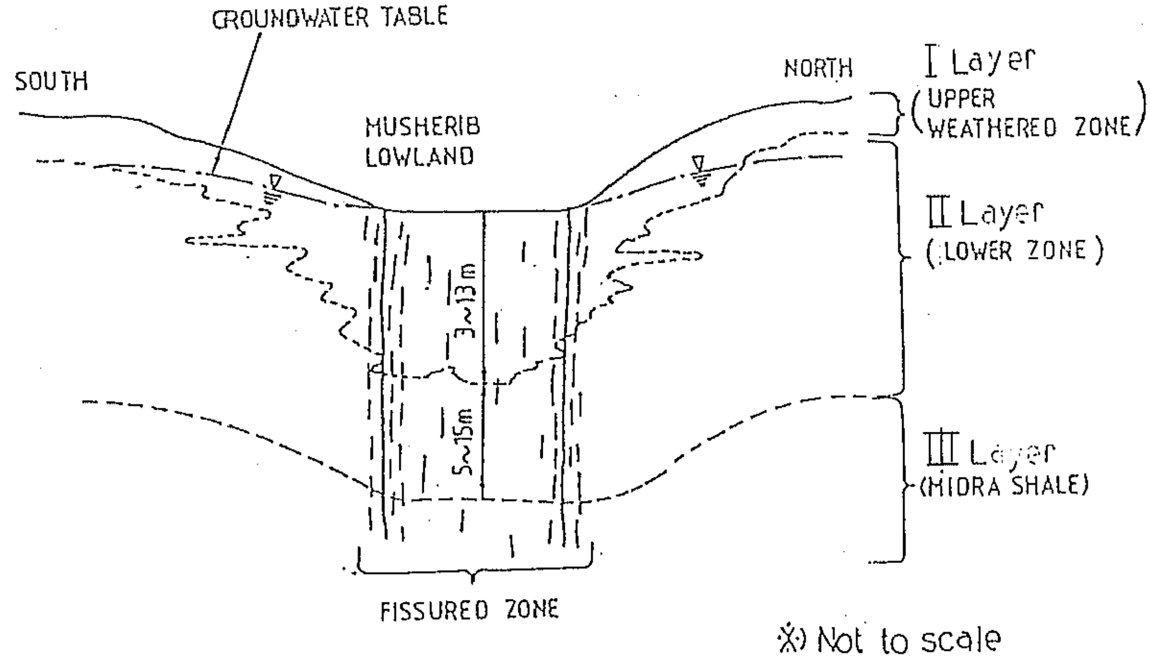


Fig. 3.3.9 Schematic Cross Section of Musherib Lowland

(2) Rayyan Area

The Rayyan area is one of the group of depressions which extends NW-SE direction in the western part of Doha City. The elevation of the bottom of basin is the lowest, which is less than 6 m above sea level. The schematic drawing of this area is shown in Fig. 3.3.10. For details, see the summit level map, Fig. 3.3.1.

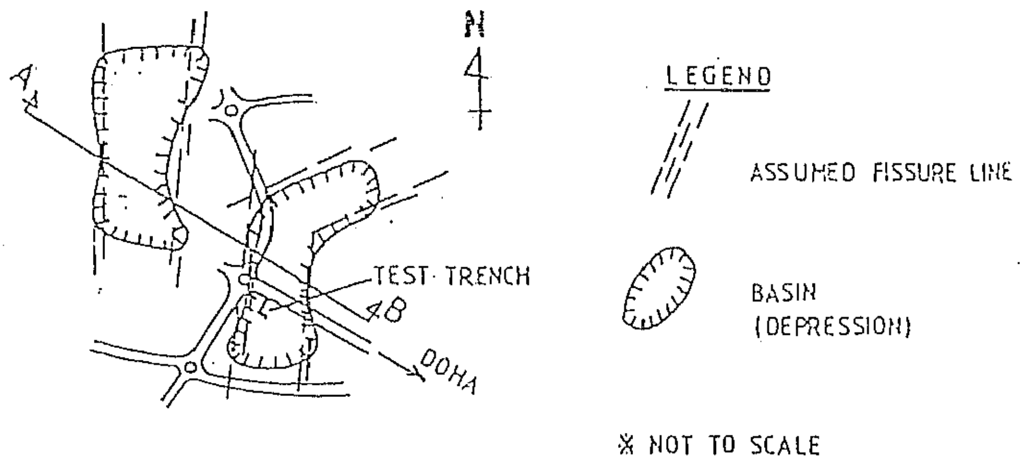


Fig. 3.3.10 Geotechtonical Feature of Rayyan Area Depression

The results of electrical soundings are shown in Fig. 3.3.11. Fig. 3.3.11 is the schematic cross section showing the features along A-B line of Fig. 3.3.10.

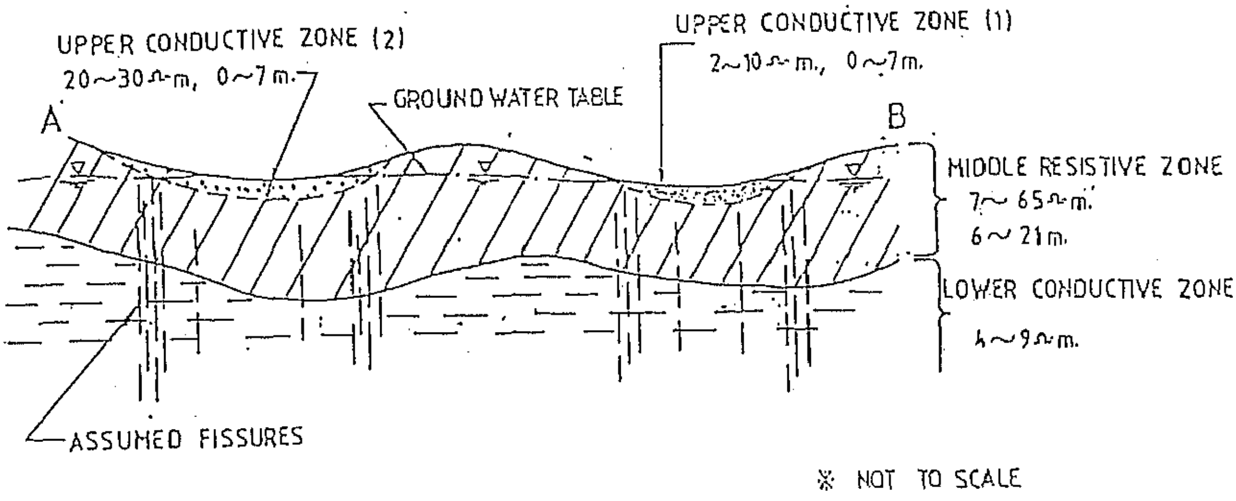


Fig. 3.3.11 Schematic Drawing of Electrical Sounding Results in Rayyan Area

The Upper Conductive Zone (1) is a conspicuously low resistive layer with resistivity value in the range between 2-10 ohm m. As a result of the on-site reconnaissance, it became clear that this layer is extremely brittle vesicular calcareous sandstone. This layer shows quite a high transmissivity coefficient and is distributed centrally in both depression areas with its thickness assumed to be in the neighborhood of 7 m at the maximum.

The Upper Conductive Zone (2), being similar to the Upper Conductive Zone of the Musherib presumed to be the superficial weathered zone of the Upper Dammam Formation, is dolomitic limestone containing much clay and fissures.

Being similar to the Musherib lowlands, the Middle Resistive Zone and Lower Conductive Zone are presumed to correspond, respectively, to relatively new Simsima dolomitic limestone with few fissures and the Lower Dammam Formation (Midra shale or its surrounding layer).

The geological structure and topography as hypothesized from the results of electrical sounding in the Rayyan area agree rather closely with the cross section. Moreover, a number of fracture systems presumed to have played an indirect role in the formation of depression areas can be recognized around the marginal zones of the areas.

(3) New District Area

The New District area, a so-called Coastal Plain situated in the northern part of Doha City, is a lowland located on the eastern side of the escarpment which extends on NWN-SES direction. The results of electrical soundings carried out in this area are outlined in Fig. 3.3.12.

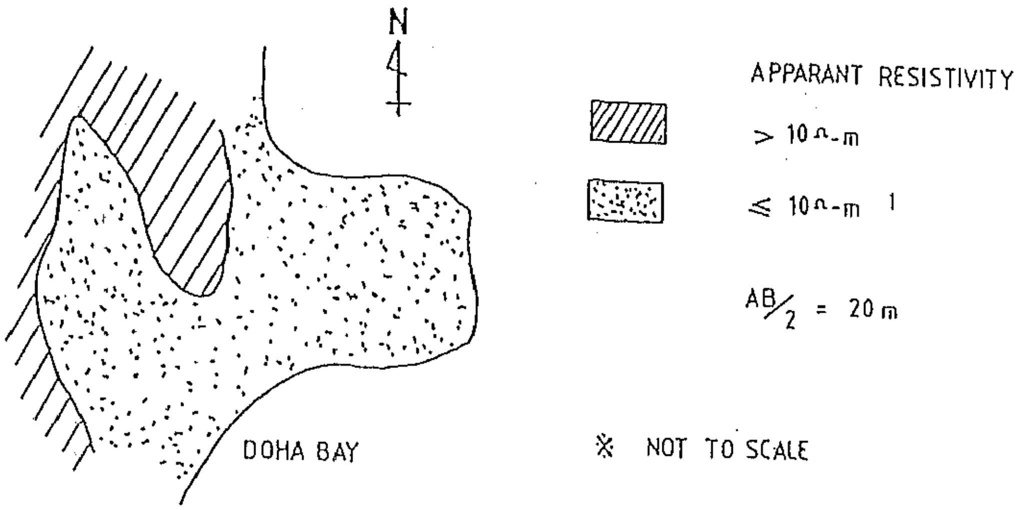


Fig. 3.3.12 Schematic Apparent Resistivity Map in New District Area of Doha

The results of Fig. 3.3.12, correspond well with the summit level map, the topography matches the mountain region as long as the value of apparent resistivity is 10 ohm m or greater. From the results of fieldwork, territories with apparent resistivity values of 10 ohm m or greater correspond with outcropping areas.

As there is infiltration of sea water of exceedingly low resistivity, it would be quite difficult to make proper estimations with respect to geological structure from the results of electrical soundings in the study area. It would be highly probable to find distributed the so-called Sabkha deposits which are extremely weak sediments from lagoon (N value, 1 - 2) high in salt concentration underneath the surface of the sea.

Bordering on the western limits of the New District area, the geological structure of the escarpment is thought to be not especially distributed depending on the results of electrical soundings carried out in this area, as shown in Fig. 3.3.13.

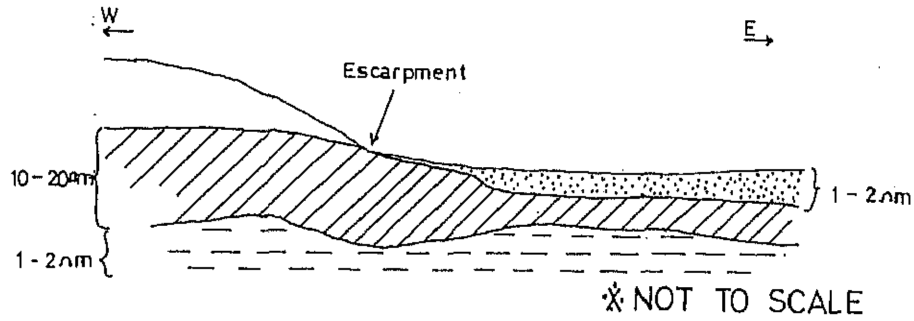


Fig. 3.3.13 Schematic Cross Section of New District Area

From the facts that: 1) this Escarpment extends in nearly the same alignment in the direction of a group of depression basins found in the inland, 2) though found to be few in number from the observation of joints in the excavation surfaces which cut across the cliff, a number of joints have been recognized extending in the same direction as that of the cliff, and finally 3) as the detection of a layer which seems to be dipping slightly to the east, the existence of fractures at the foot of this cliff in the same direction of the cliff could be considered a likely possibility.

3.3.4 Hydrogeology of Test Work Sites

(1) Musherib Test Work Site

The geology of the Musherib test work site consists of filling materials as overburden and dolomitic limestone as bedrock.

The bedrock of Musherib test work site is gray to white mottled dolomitic limestone and generally strongly weathered, as shown in Fig. 3.3.14. The bedrock is mostly clay of blueish green to reddish brown colour and in part it is brecciated structure interposed with a mixture of clay and unweathered rock fragments.

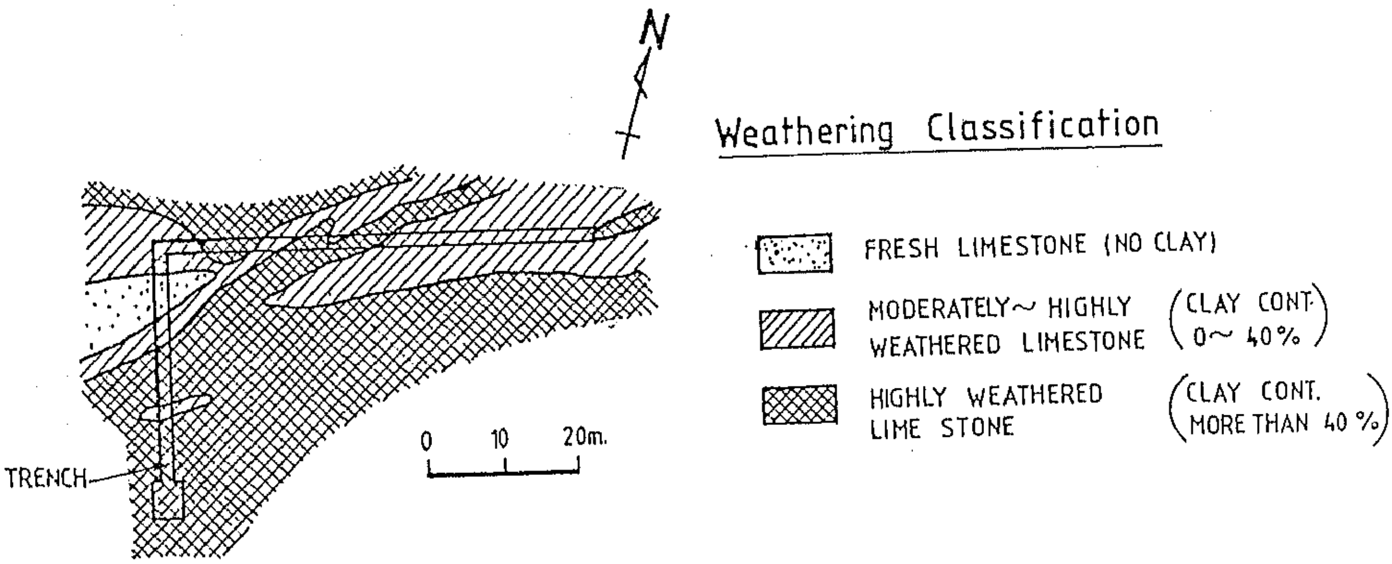


Fig. 3.3.14 Weathering Classification of Limestone of Musherib Test Site

In the fresh limestone, fossils are rarely observed and gypsum is present in nodular forms. As a large number of such gypsum nodules have dissolved, cavities of 1~5 cm have been created.

The filling materials are composed of sand, gravels, clay and waste materials which include rags, steel bars, concrete, plastics, etc. The thickness of the filling material is 1~1.5 m.

The characteristics revealed by a close observation of the weathering conditions in the trench shall be discussed below.

1) As is shown below, a collection of rock fragments are believed to be unweathered relics which are distributed vertically in the clay zone.

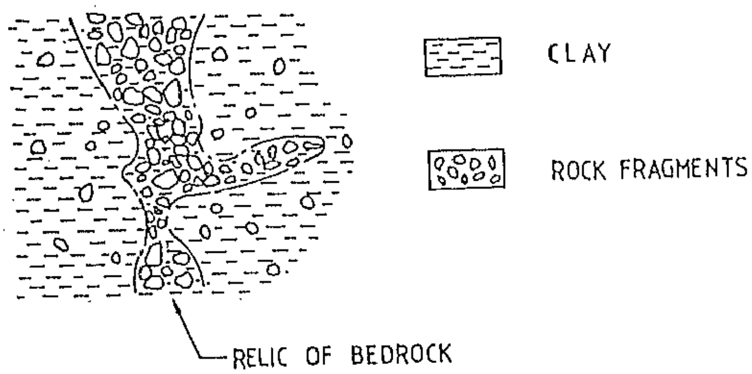


Fig. 3.3.15 Schematic Drawing of Vertical Alignment of Bedrock Relic

2) The direction of the weathered zone of the test work site shown in Fig. 3.3.15 is prominently due ENE-WSW-NE-SE. As has been stated in the preceding section, the weathering phenomenon suggests that it has all the more strongly been constrained by the linear structural elements in agreement with the direction of the Musherib lowland.

   According to previous studies reports, the weathered zone is reported to get thicker along the Musherib lowland. In the lowland, the weathering phenomenon has advanced into depths along the fissures which had been formed previously.

The bedding plane of dolomitic limestone is due NE-SW direction and is dipping 10° 15° toward NW. (This direction is toward the central Musherib lowland.)

Although no clear evidence exists of either fissure or fault in the test work site, vertical small-scaled lineament or clay veins could be observed in places. The vertical structural arrangement of weathering zone corresponds to the Musherib lowland which runs due ENE-WSE. Considering this, in the test work site, structural elements such as fissures have become quite difficult to recognize because of strongly weathering of dolomitic limestone.

At the longer leg of the trench, the groundwater has been observed spurting in large quantity. Also from the bedding planes and places where clay veins are present irregularly, spurting is observed in small quantity.

(2) Rayyan Test Work Site

The geology of the Rayyan test work trench consists of dolomitic limestone and topsoil.

According to the data on adjacent area, dolomitic limestone in the Rayyan test work site can be correlated to Simsima limestone and Dolomite Member of Upper Eocene. The dolomitic limestone is divided into two portions in terms of the degree of weathering.

The superficial dolomitic limestone has been strongly weathered turning in to white to gray clay containing limestone fragments in places. This portion, also containing much plant roots, is 0.5 - 2 m in thickness, with the average at 1 m. The stratification and joints could not be recognized.

This strongly weathered portion is underlain by strongly to moderately weathered dolomitic limestone which is composed of a hard limestone, dolomitic limestone layer and white-green clay layer. As these layers are found interposed in nearly horizontal manner, it can be presumed that these had been created along the original bedding plane of the dolomitic limestone.

In the strongly to moderately weathered portion, a weak stratification structure in the intervals of 5 - 30 cm can be observed.

The topsoil in the Rayyan test work site is composed of brown clay which contains silt and sand with gravel. The thickness of the topsoil is 10 15 cm. This layer is assumed to have been transported and deposited by wind (aeorian deposits).

In the Rayyan test work trench, 7 joints and minor faults were observed. All of them were small, with even the largest ones being not more than 10 cm in width. Along these joints, dolomitic limestone have transformed into gray to brown clay of several centimeters. It is quite characteristic that most of these joints and faults are nearly in the same direction (i.e. E-W to NW-ES).

In the trench, there were relatively large volume of groundwater flowout discharge at numerous locations. In terms of areas of water spurting, two classes can be identified: 1) spurting along the joints, and 2) spurting along the fissures. Especially numerous are water spurting out of the fissures along the minor axis of the trench. In case of water spurting along the joint surface, the quantity of flow increases as the joints get closer to the fissures. From these considerations, the following can be assumed.

a) The main flow of groundwater is along either the joints or bedding planes.

b) As far as the flow of groundwater is concerned, a more significant role is played by joints than the bedding planes.