- Initial Condition

  $h(xi,o) = h(xi)$ .... (3.2.4)
- Boundary Condition

  $h_{\Gamma}(xi,t) = h\ (xi,t)$ .... (3.2.5)

where, Γ : Subscript which expresses the coordinates
: Subscript which expresses the boundary of calculation domain.

iv) Calculation Method

The calculation method used is the finite element method, introducing the following trial function;

$h(xi,t) = Nn(xi)\ hn(t)$ .... (3.2.6)
$(n = 1, 2, \ldots\ldots\ldots)$

where, Nn(xi) : Function Determined by the coordinates
hn(t) : Unknown Parameter in Function of Time

The residual (R) expressed by Eq. 3.2.7 which is obtained by the substitution of Eq. 3.2.6 into Eq. 3.2.1 is minimised by the trial calculation in each time step to satisfy the convergency condition.

$$\nabla \cdot T\nabla(Nn(xi)hn(t)) - \frac{\partial}{t}(Nn(xi)hn(t)) - qn(t)Nn(xi) = R \quad \ldots\ldots \quad (3.2.7)$$

3.2 Numerical Analysis of Groundwater at Wadi Musherib

3.2.1 Data Preparation

The following materials were used to prepare the input data:

1 Source Term

- Land use classification map : Fig. 3.2.1
- Groundwater recharge amount by QATS (ASCO)
- Evaporation amount

2 Aquifer Thickness

- Topographical map (1:5000)
- Contour map of weak weathered layer top : Fig. 3.2.2
- Contour map of lower Dammam formation top: Fig. 3.2.3
- Contour map of Rus Formation top : Fig. 3.2.4

3 Hydraulic Constants

- Calculation results of steady model (ASCO)
- Lugeon test
- Pumping test results at Test Works

4 Groundwater Level

- 1983 Groundwater level contour map (ASCO) : Fig. 3.2.5
- 1986 Groundwater level contour map : Fig. 3.2.6

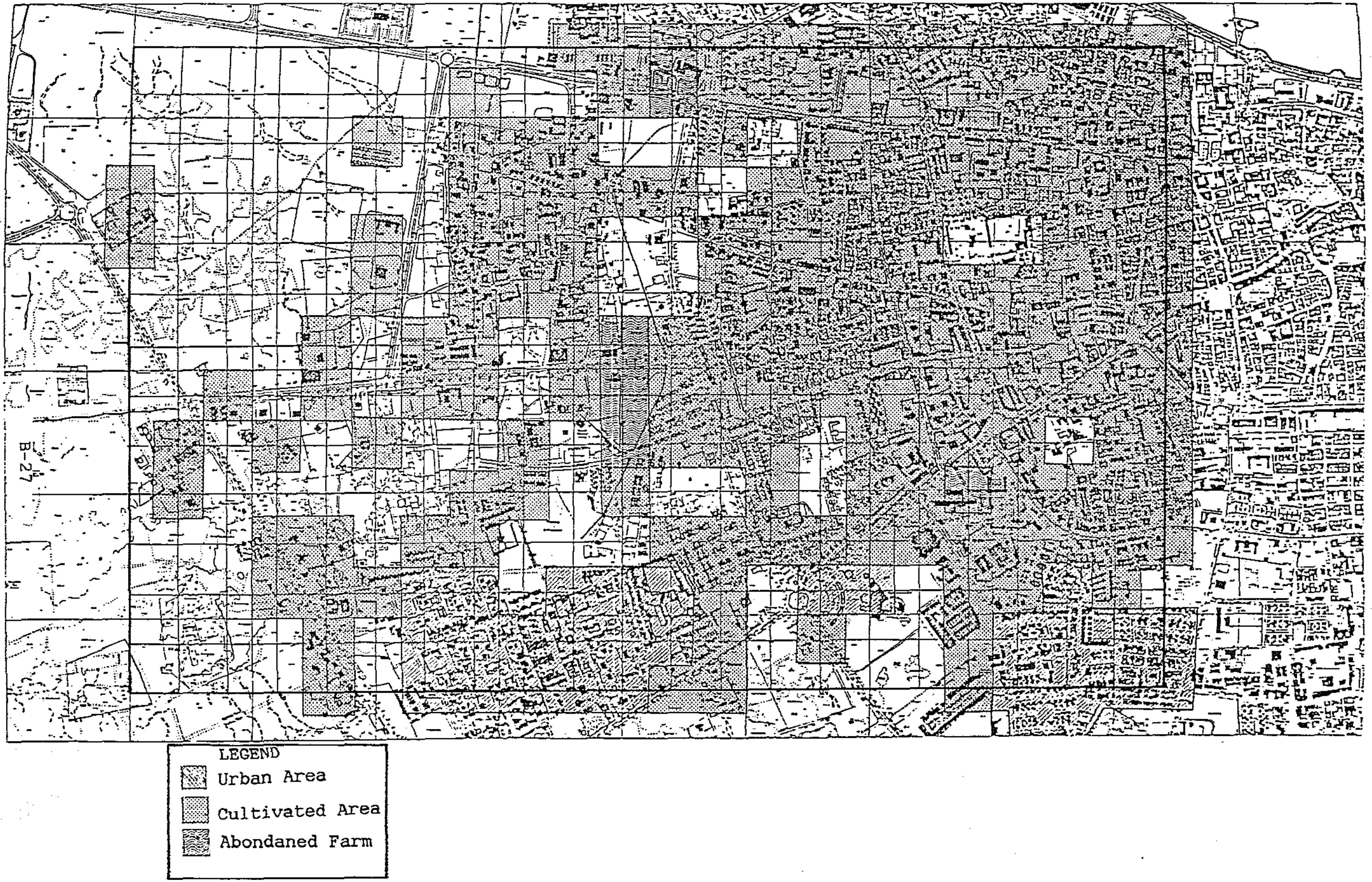


Fig. 3.2.1 Land Use Classification Map of Wadi Musherib

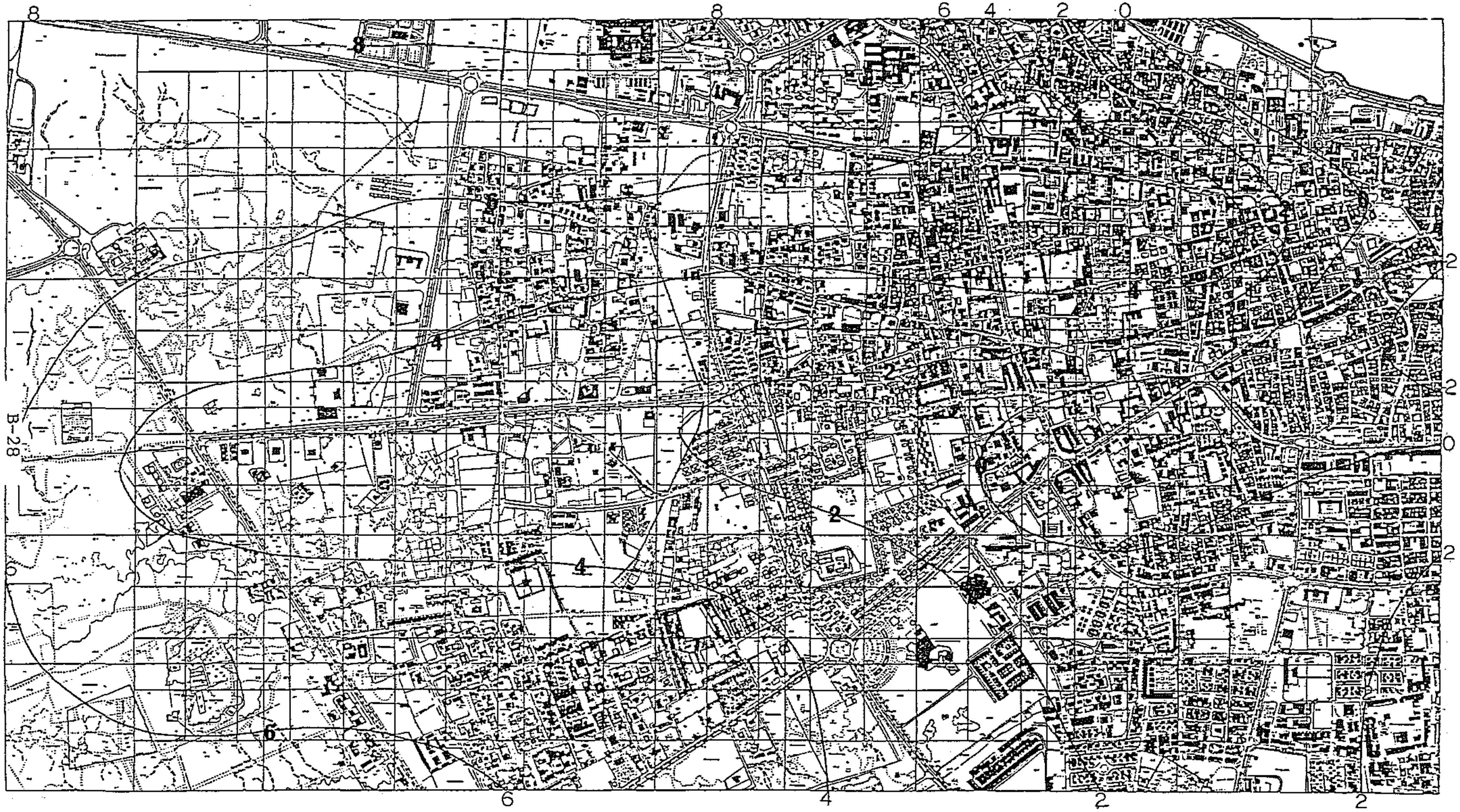


Fig. 3.2.2 Contour Map of Weak Weathered Layer Top of Wadi Musherib

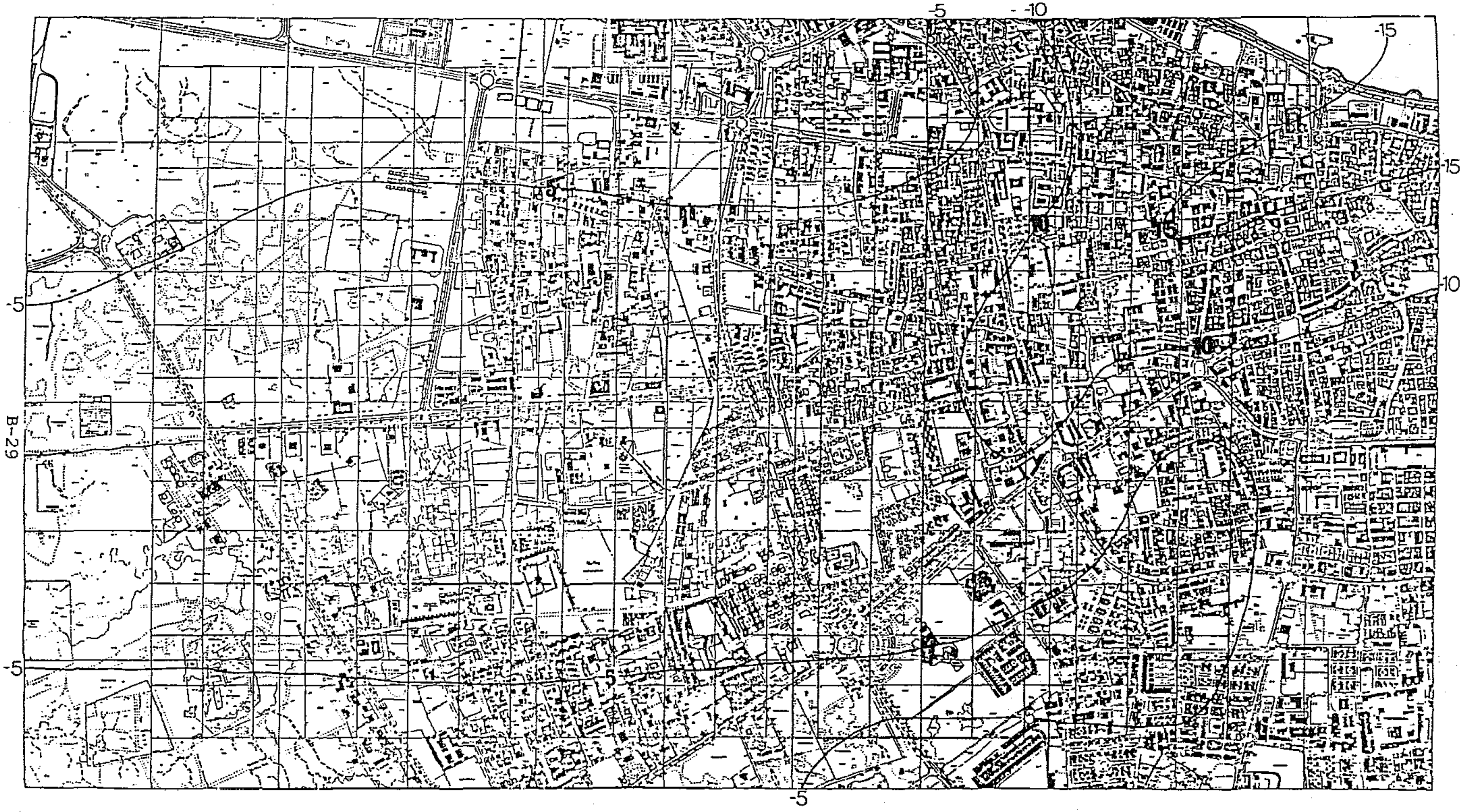


Fig. 3.2.3 Contour Map of Lower Dammam Formation Top of Wadi Musherib

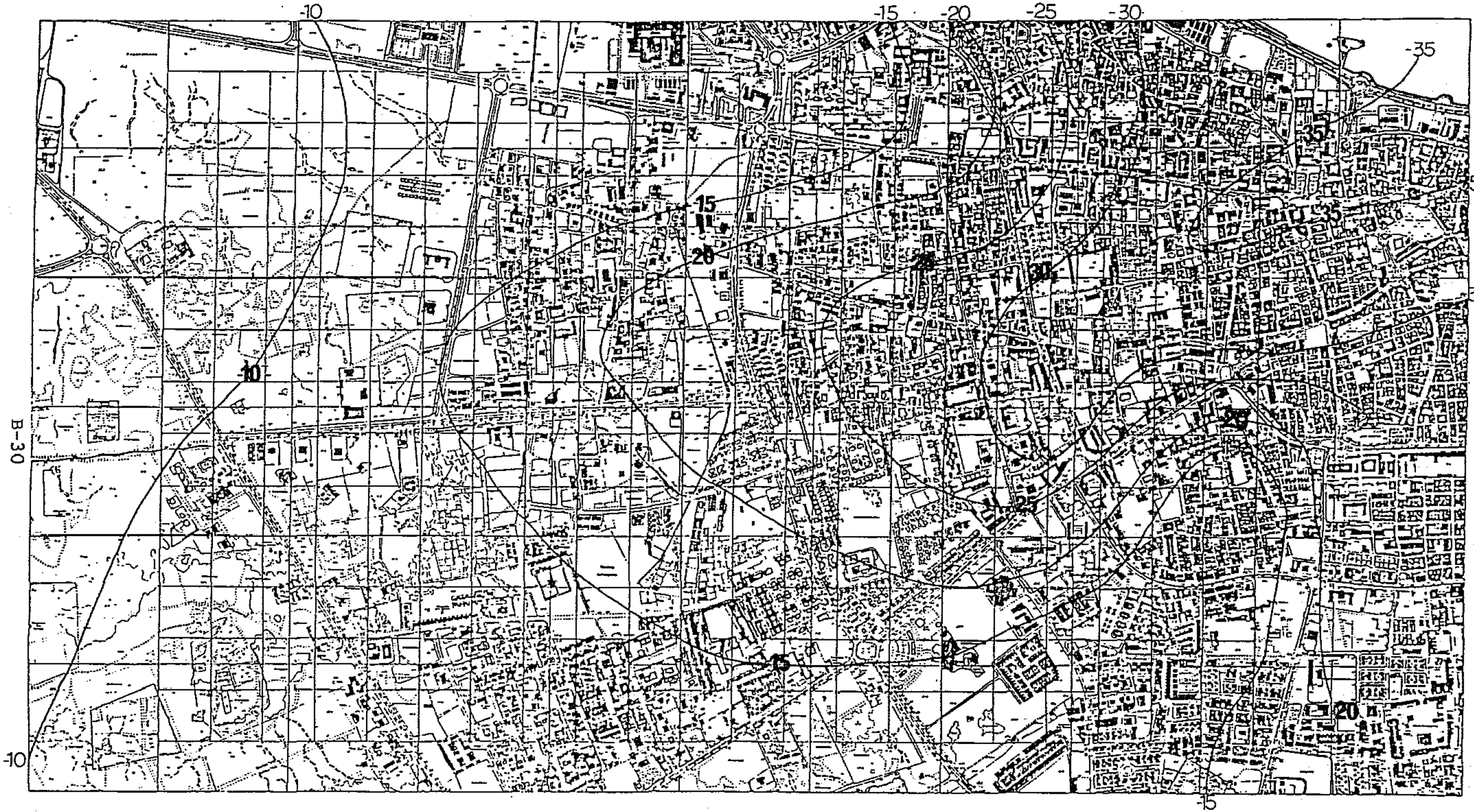


Fig. 3.2.4 Contour Map of Rus Formation Top of Wadi Musherib

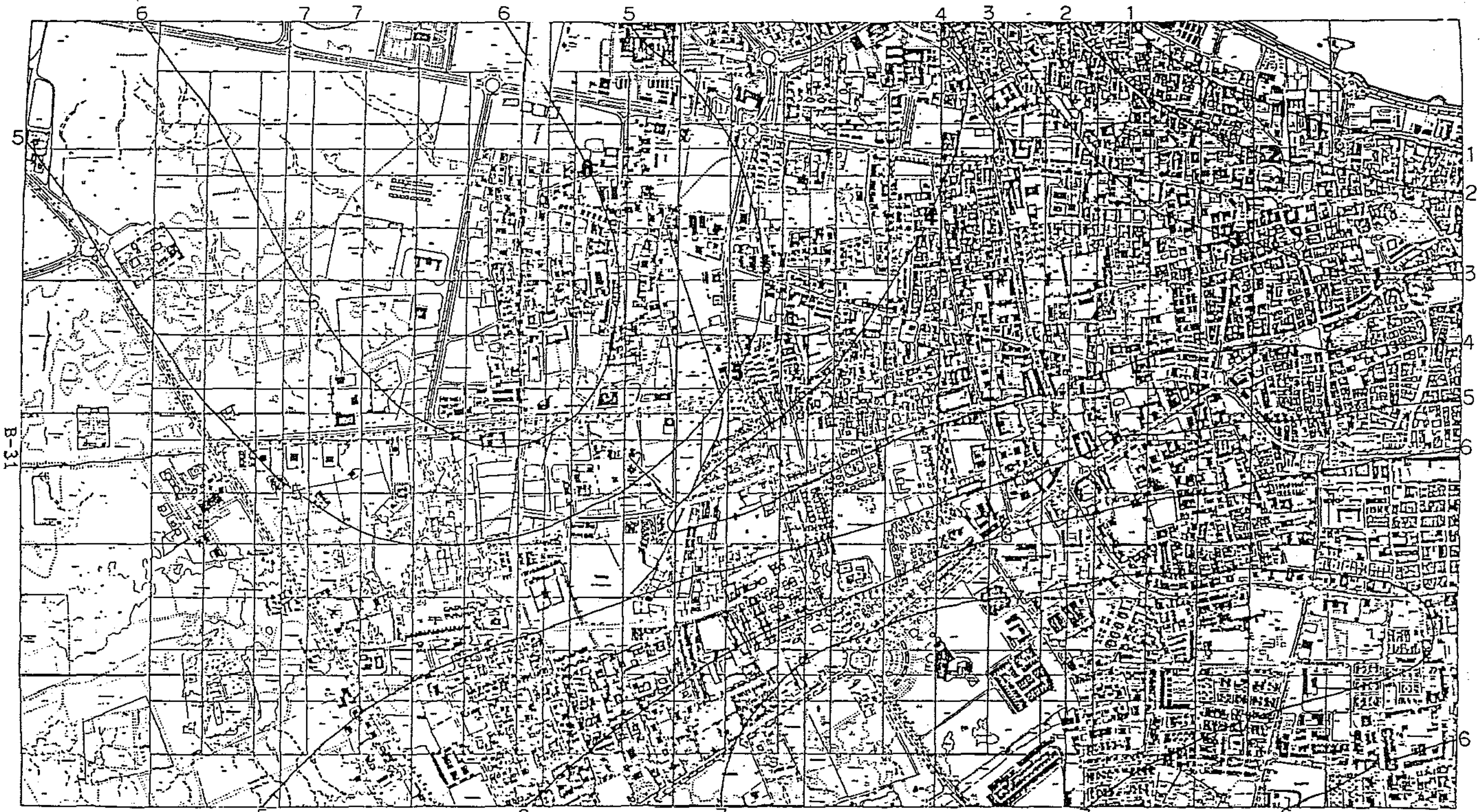


Fig. 3.2.5 Groundwater Level Contour Map of Wadi Musherib: 1983

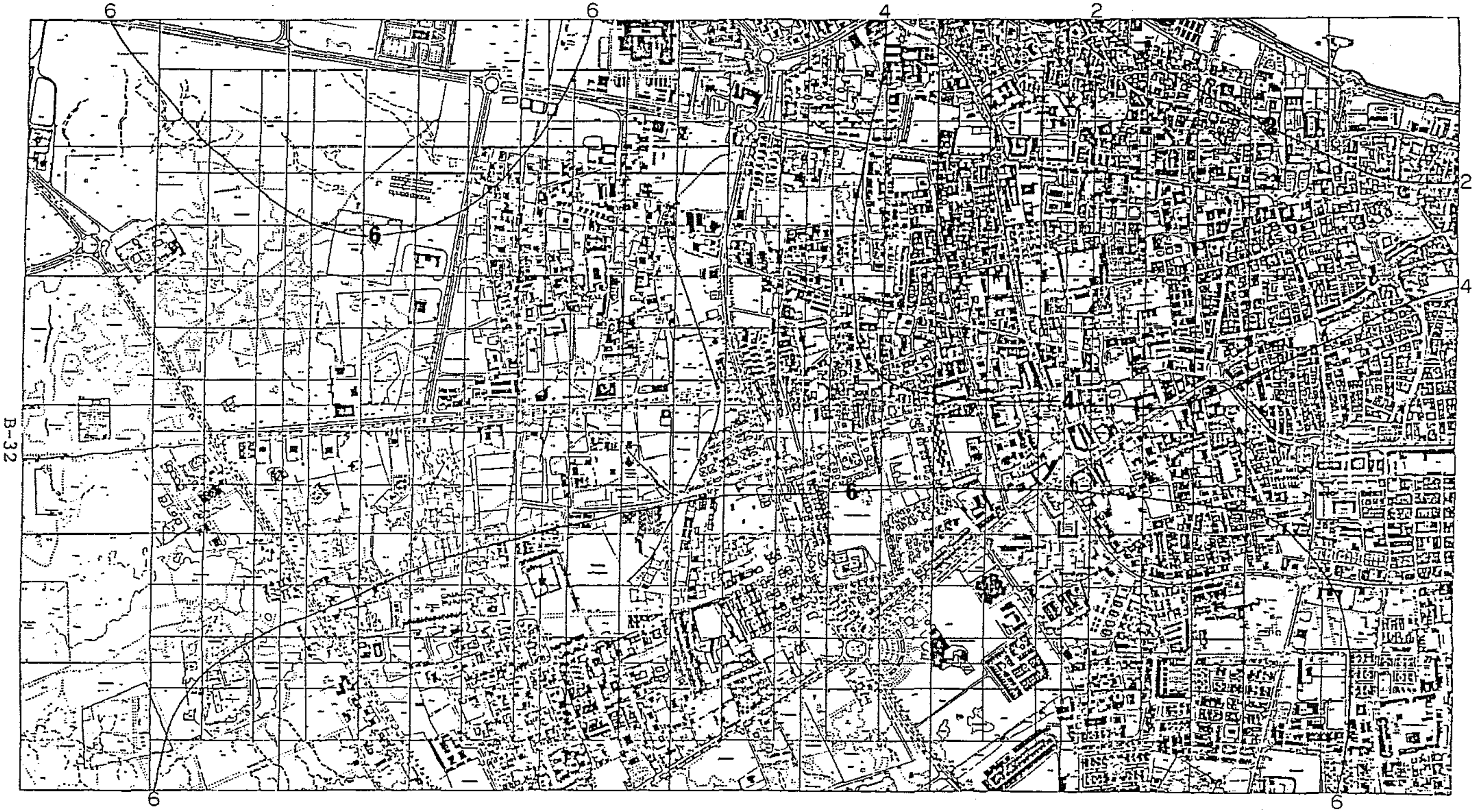


Fig. 3.2.6 Groundwater Level Contour Map of Wadi Musherib: 1986

The calculation domains for Wadi Musherib were determined to sufficiently cover the respective influence areas which were affected by the drawdown of the lateral drainage. Its grid system is shown in Fig. 3.2.7.

Evaluation data of ground surface, geological boundaries and groundwater tables at each nodal point were made by digitizer reading. Aquifer thickness was calculated from the elevation data. Evaporation amount and transmissivity were calculated in the function of groundwater level at each time step of unsteady analysis. Groundwater recharge amount from surface was initially estimated from the land use classification and the previous calculation results of ASCO.

Starting relationship between land use and groundwater recharge amount from surface is as follows:

- High class residential area	:	700 - 1000 mm/yr
- Urban area	:	400 - 700 mm/yr
- Cultivated area (groundwater extraction)	:	-700 - 0 mm/yr
- Open space	:	0 mm/yr

Taking into account trial simulation results of groundwater level variation from 1983 to 1986, recharge amount was modified by trial and error method.

3.2.2 Calculation Results

(1) Simulation of Groundwater Level

According to the numerical analysis of groundwater level from 1986 for Wadi Musherib as shown in Fig. 3.2.8, groundwater movement can be interpreted as follows;

- The existence of a groundwater divide may be expected in the upstream of Wadi Musherib dam. Groundwater east of this divide flows to sea, while groundwater west of this divide flows inland.

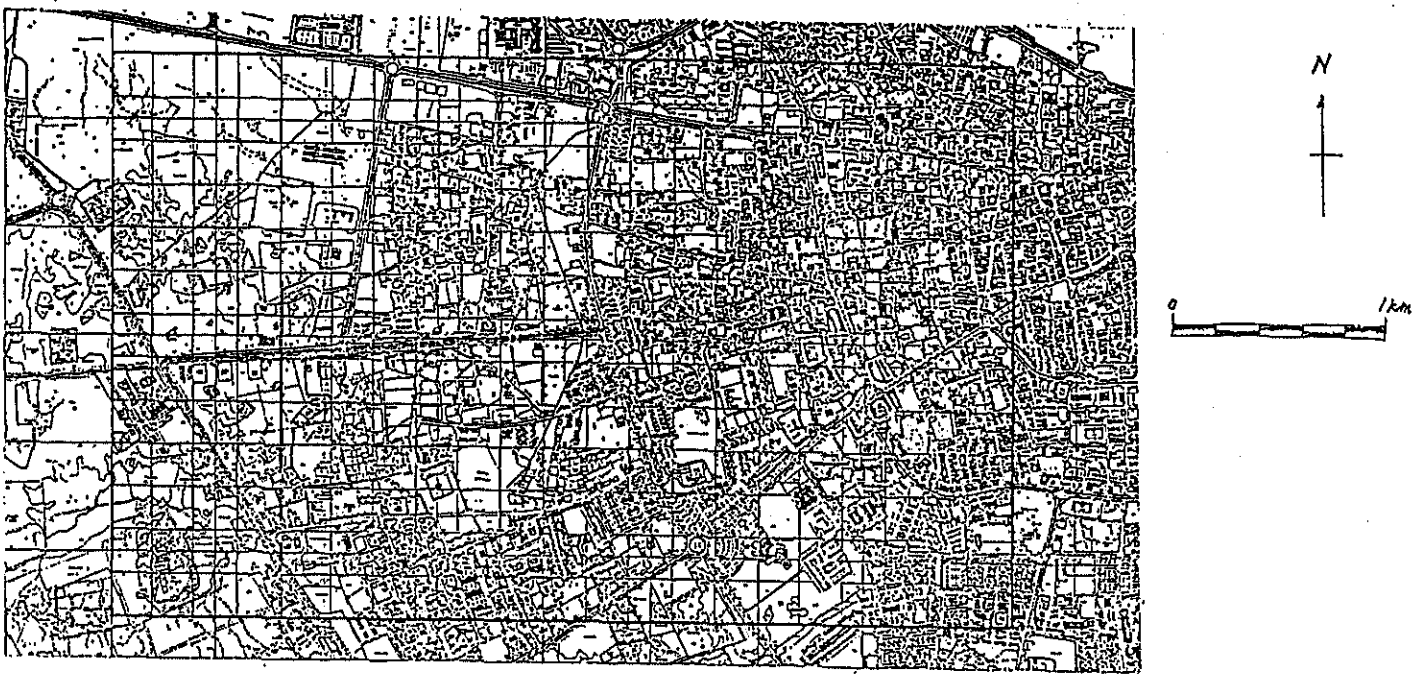
- Groundwater inflow from Khalifah mound towards Wadi Musherib is smaller than that from Khayl mound.

- Wadi Musherib seems to be situated nearly at the lateral periphery of Khayl mound and is collecting an important volume from this mound.

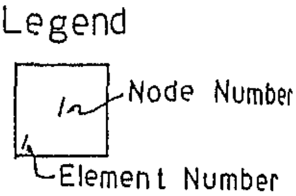
(2) Forecasting of Groundwater Inflow Amount

The groundwater inflow amount from outside the design collection area is examined by sensibility analysis based on the following conditions using a quasi three dimensional groundwater analysis.

a. Inner boundary condition (dummy degree of groundwater level lowering by trenches): 3 cases (0.5 m, 1.0 m and 2.0 m)



Key Map



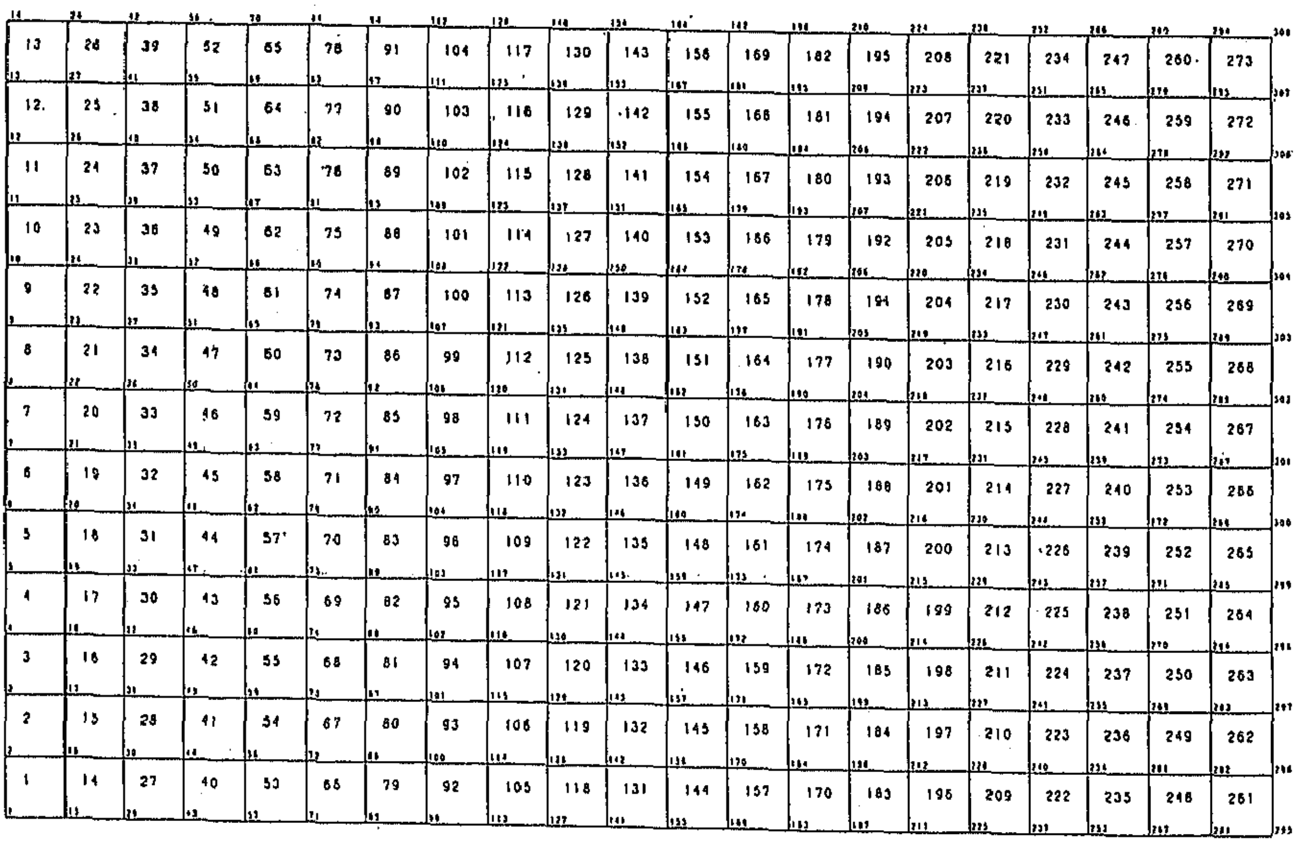
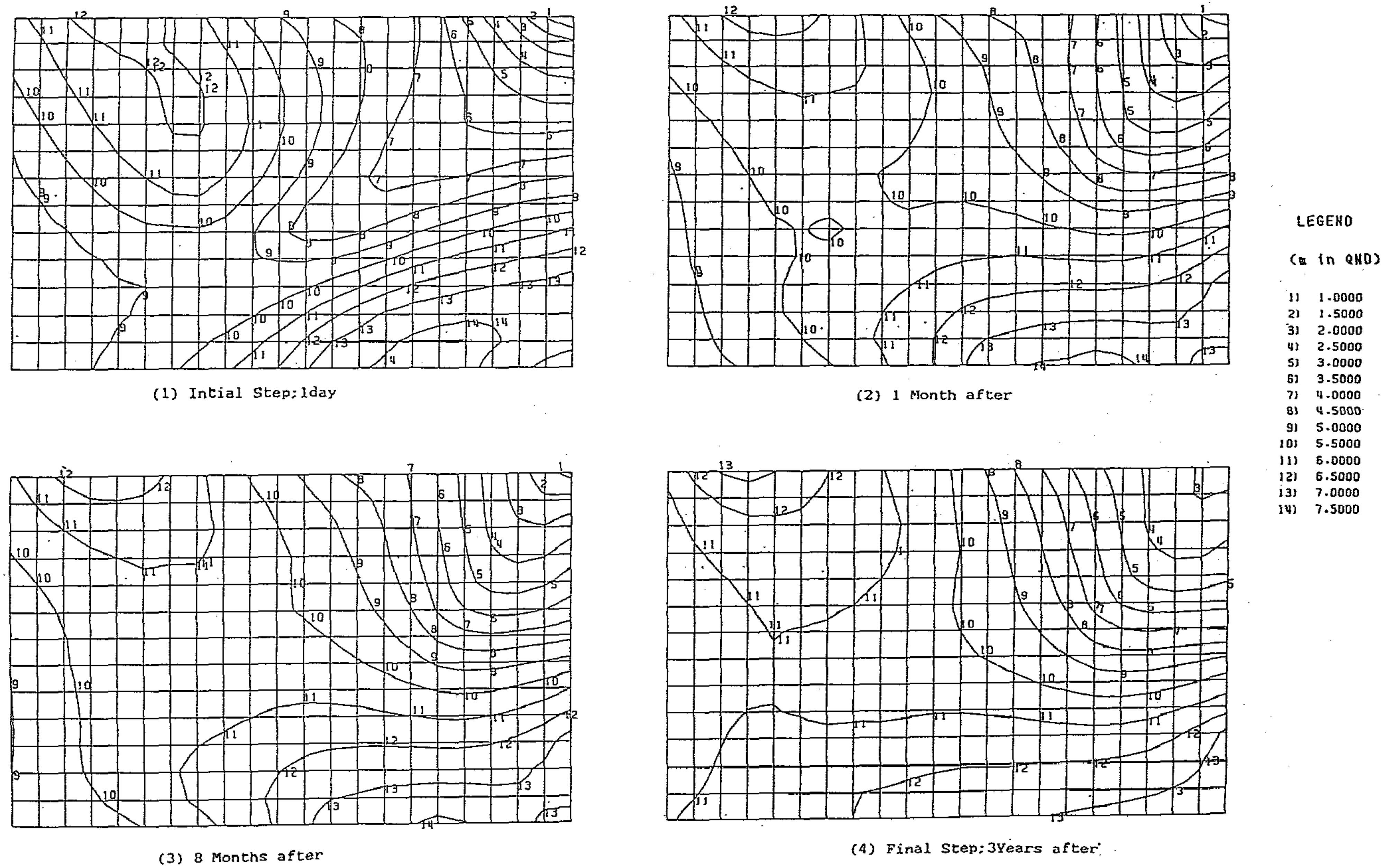


Fig. 3.2.7 Grid System of Quasi Three Dimensional Analysis for Wadi Musherib



(1) Intial Step;1day

(2) 1 Month after

(3) 8 Months after

(4) Final Step;3Years after

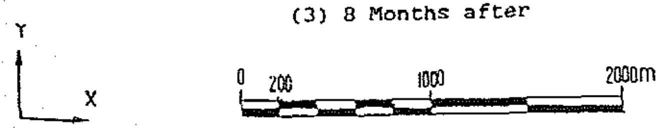


Fig. 3.2.8 Simulation of Groundwater Level from 1983 to 1986 for Wadi Musherib

b. Groundwater level at the periphery of the calculation area: groundwater level in February, 1986

c. Hydrualic parameters are identified by the discharge amount obtained from test site.

The calculation results of sensibility analysis are shown in Table 3.2.1

Table 3.2.1 Groundwater Inflow Amount to Collection Facility : Wadi Musherib

Case No.	Inner Boundary Condition	Estimated Groundwater Inflow Volume
1	0.25 m	1.05 million m^3/year
2	0.5 m	1.17 "
3	1.0 m	1.45 "

The test run results of these 3 cases show the strong sensitivity in the area between the profile A-A" and B-B" given in Fig. 3.2.9, reflecting a high velocity of groundwater flow table from Khayl groundwater mound to Wadi Musherib. The effect on the south side at the collection facility is small.

The estimated inflow volume of Case 1 and Case 2 are 1.05×10^6 m^3/year and 1.17×10^6 m^3/year respectively. As Case 3 generates large inflow into the above-mentioned area of high sensitivity and, thus, causes a strong influence on the outer boundary condition, the solution in Case 3 can not be adopted. In the present Project, the inflow volume (Q_1) of 1.17×10^6 m^3/year is adopted as the drainage volume.

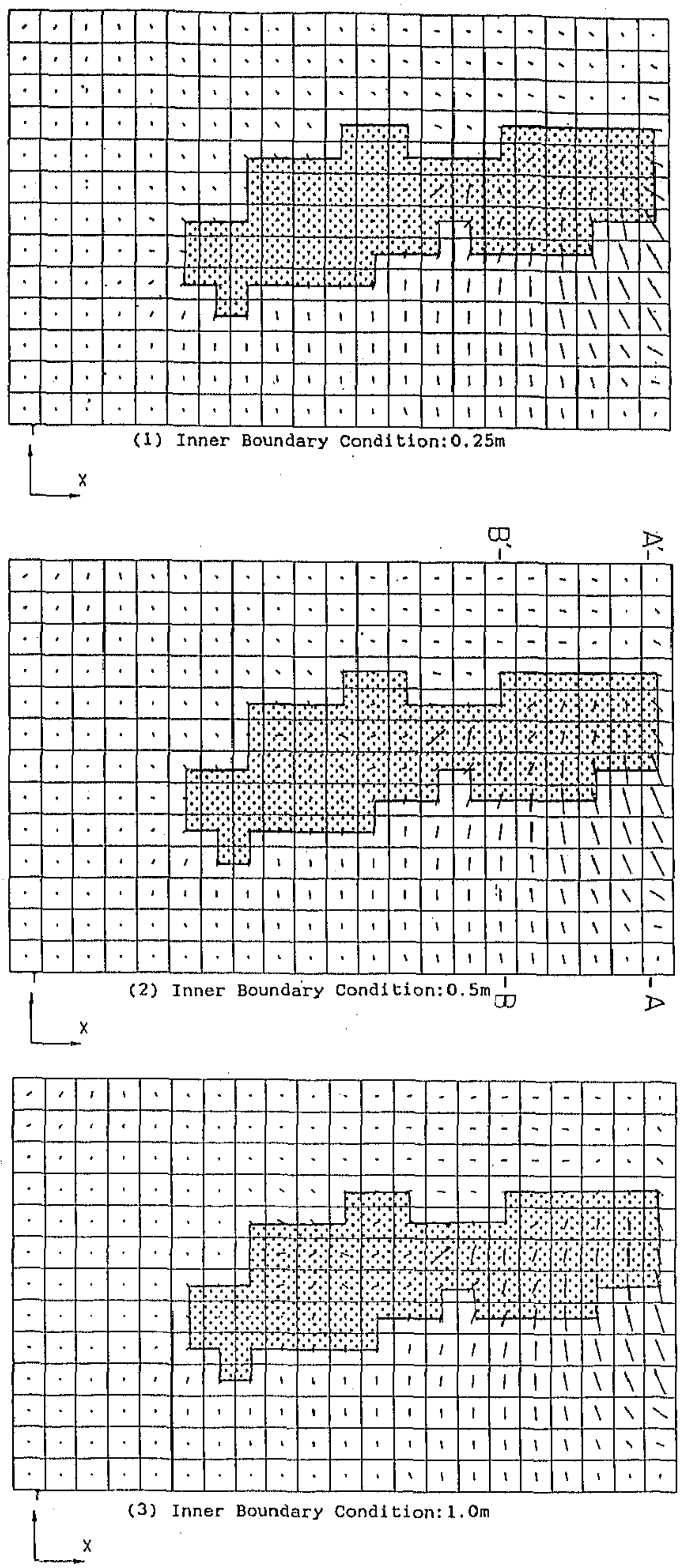


Fig. 3.2.9 Groundwater Flow Vector Map of Sensibility Analysis for Wadi Mushrib

3.3 Numerical Analysis of Groundwater at Rayyan

3.3.1 Data Preparation

The following materials were used to prepare the input data:

1 Groundwater Recharge
- Land use classification map : Fig. 3.3.1
- Groundwater recharge amount by QATS (ASCO)
- Evaporation amount

2 Aquifer Thickness
- Topographical map (1:5000)
- Contour map of weak weathered layer top : Fig. 3.3.2
- Contour map of lower Dammam formation top : Fig. 3.3.3
- Contour map of Rus Formation top : Fig. 3.3.4

3 Hydraulic Constants
- Calculation results of steady model (ASCO)
- Lugeon test
- Pumping test results at Test Works

4 Groundwater Level
- 1983 Groundwater level contour map (ASCO) : Fig. 3.3.5
- 1986 Groundwater level contour map : Fig. 3.3.6

The calculation domain for Rayyan was determined to sufficiently cover the respective influence areas which were affected by the drawdown of the lateral drainage. Its grid system is shown in Fig. 3.3.7.

The following items were considered in the parameter identification process.

1 Simulation of rising groundwater level behavior
2 Simulation of expected discharge amounts near the Test work sites

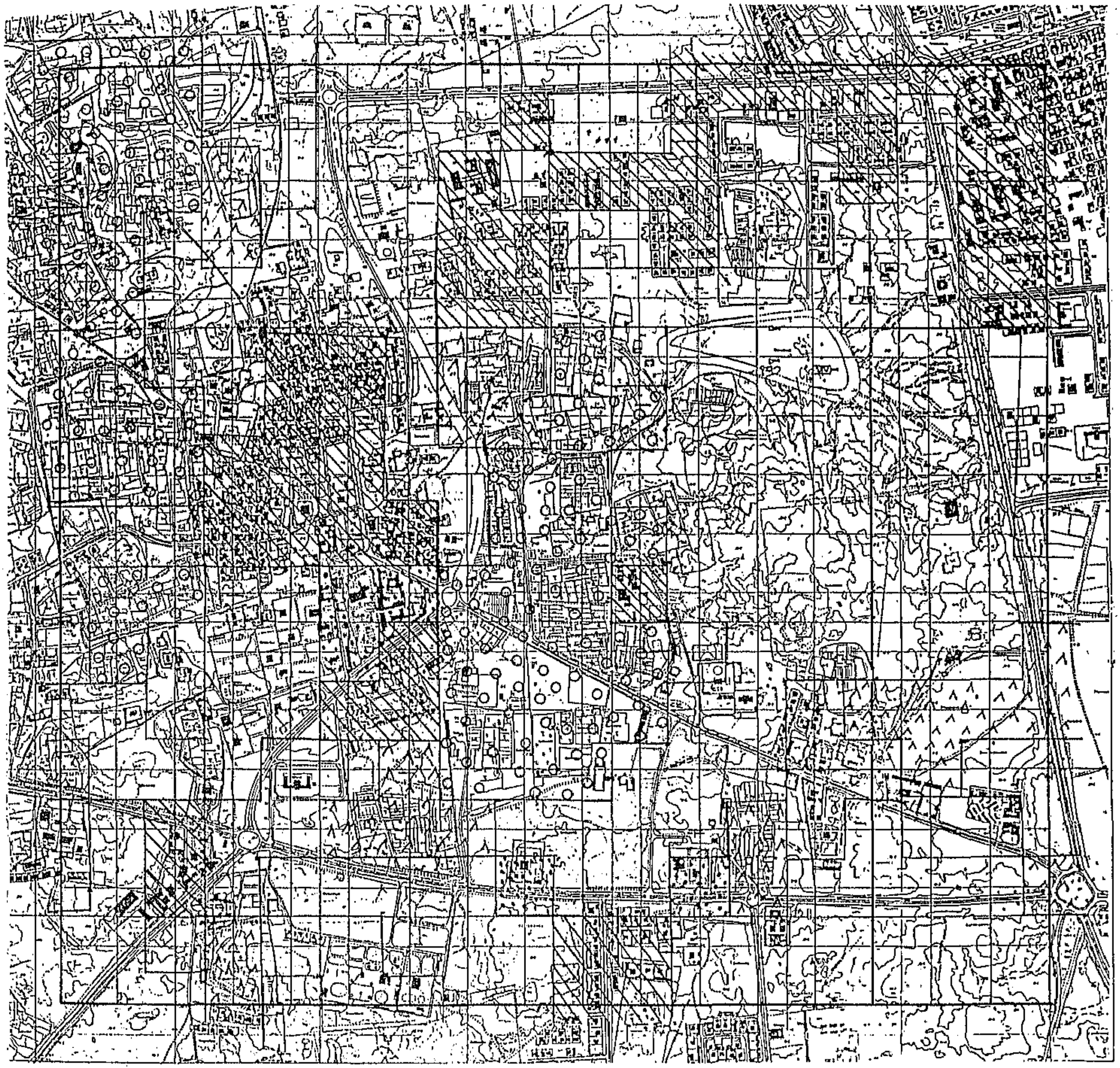
Collection and modification were mainly made on the source term by the trial and error method.

3.3.2 Calculation Results

(1) Simulation of Groundwater Level

Simulation of Groundwater level from 1983 to 1986 for Rayyan is shown in Fig. 3.3.8.

According to the numerical analysis, the source term of node falling in the standing water area varies strongly from 1983 to 1986; especially the evaporation amount becomes important.



LEGEND

- High Class Resident Area
- Urban Area
- Cultivated Area
- Abondaned Farm
- Bare Land

Fig. 3.3.1 Land Use Classification Map of Rayyan

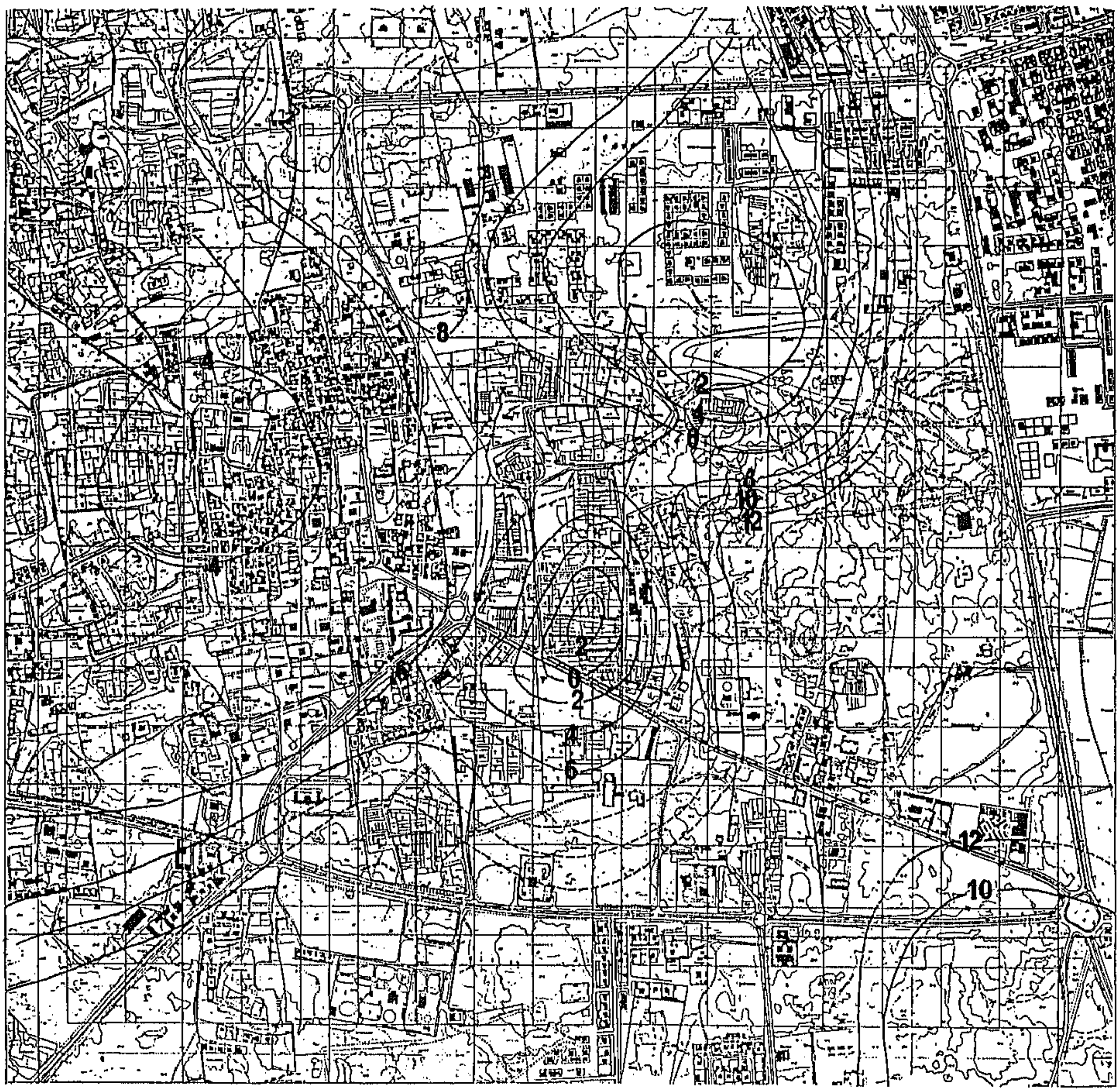


Fig. 3.3.2 Contour Map of Weak Weathered Layer Top of Rayyan

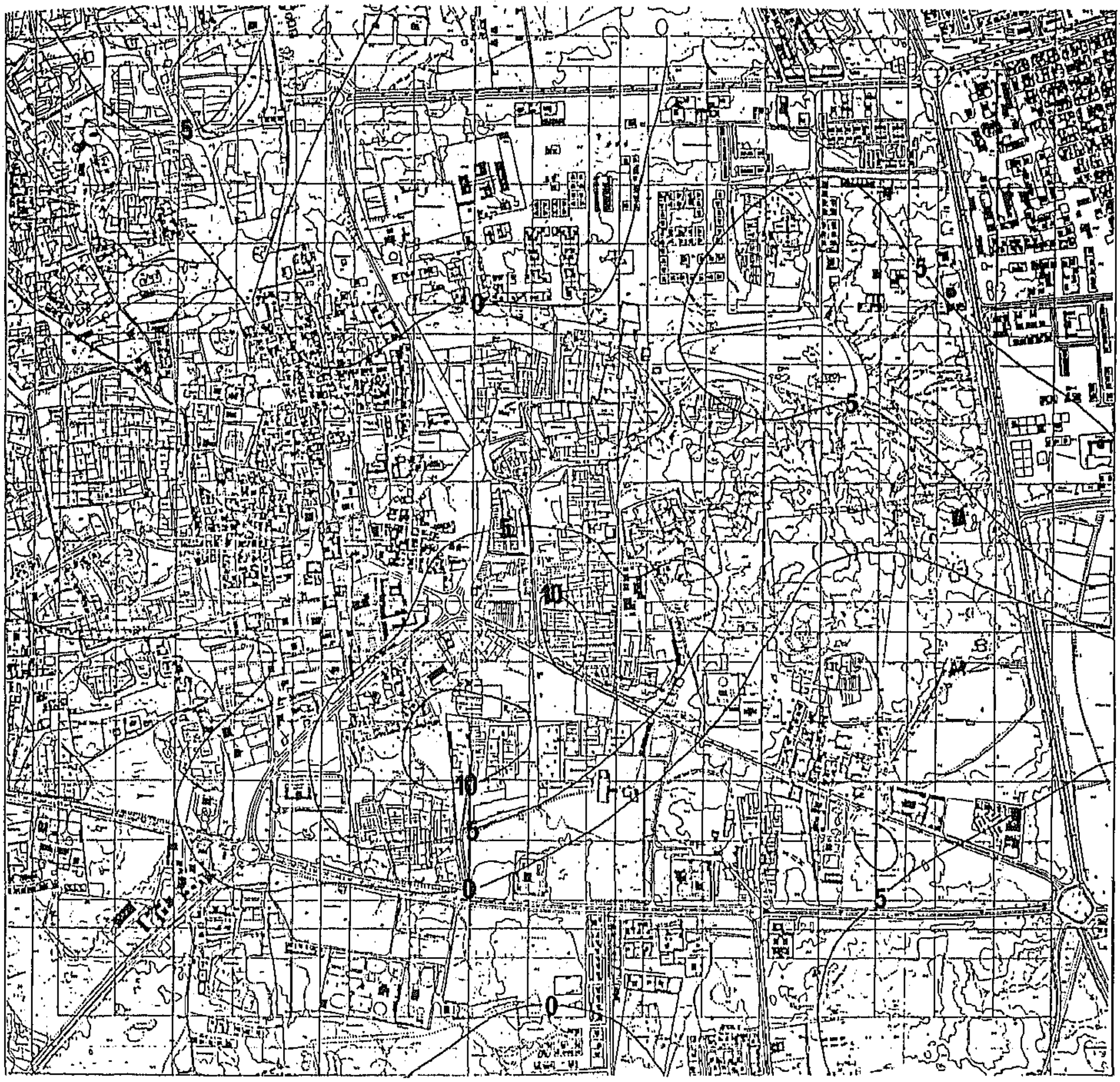


Fig. 3.3.3 Contour Map of Lower Dammam Formation Top of Rayyan

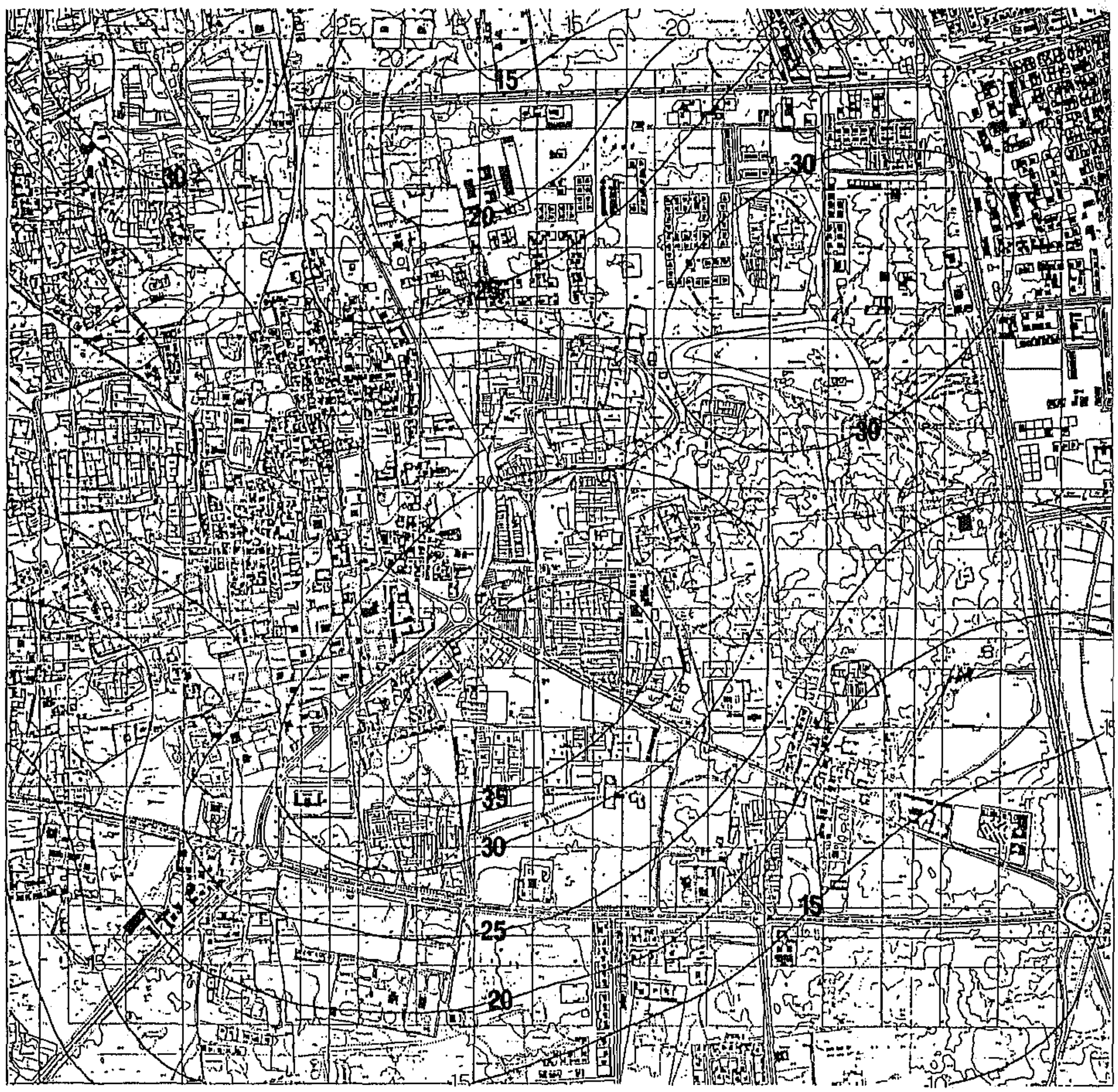


Fig. 3.3.4 Contour Map of Rus Formation Top of Rayyan

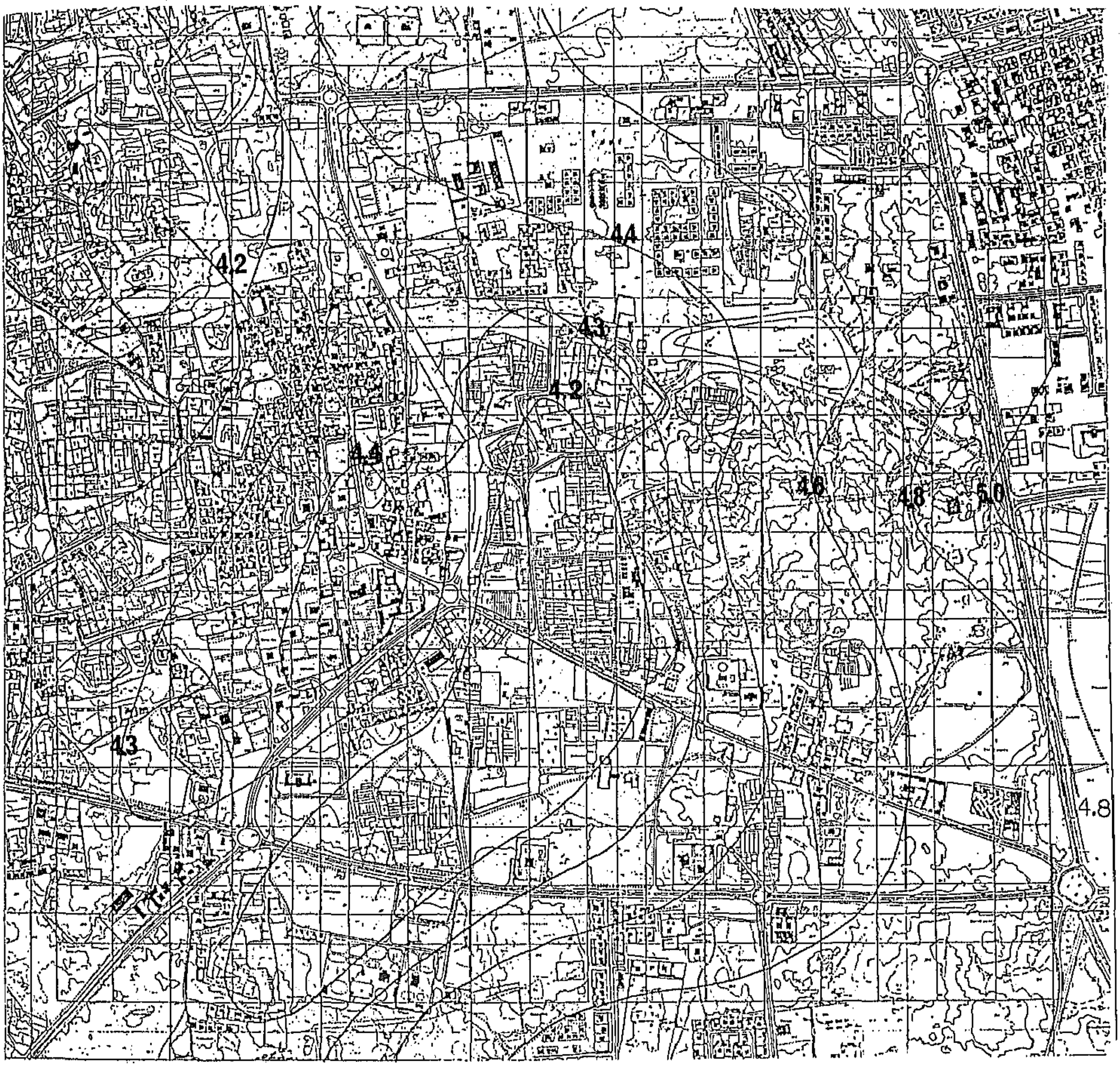


Fig. 3.3.5 Groundwater Level Contour Map of Rayyan: 1983

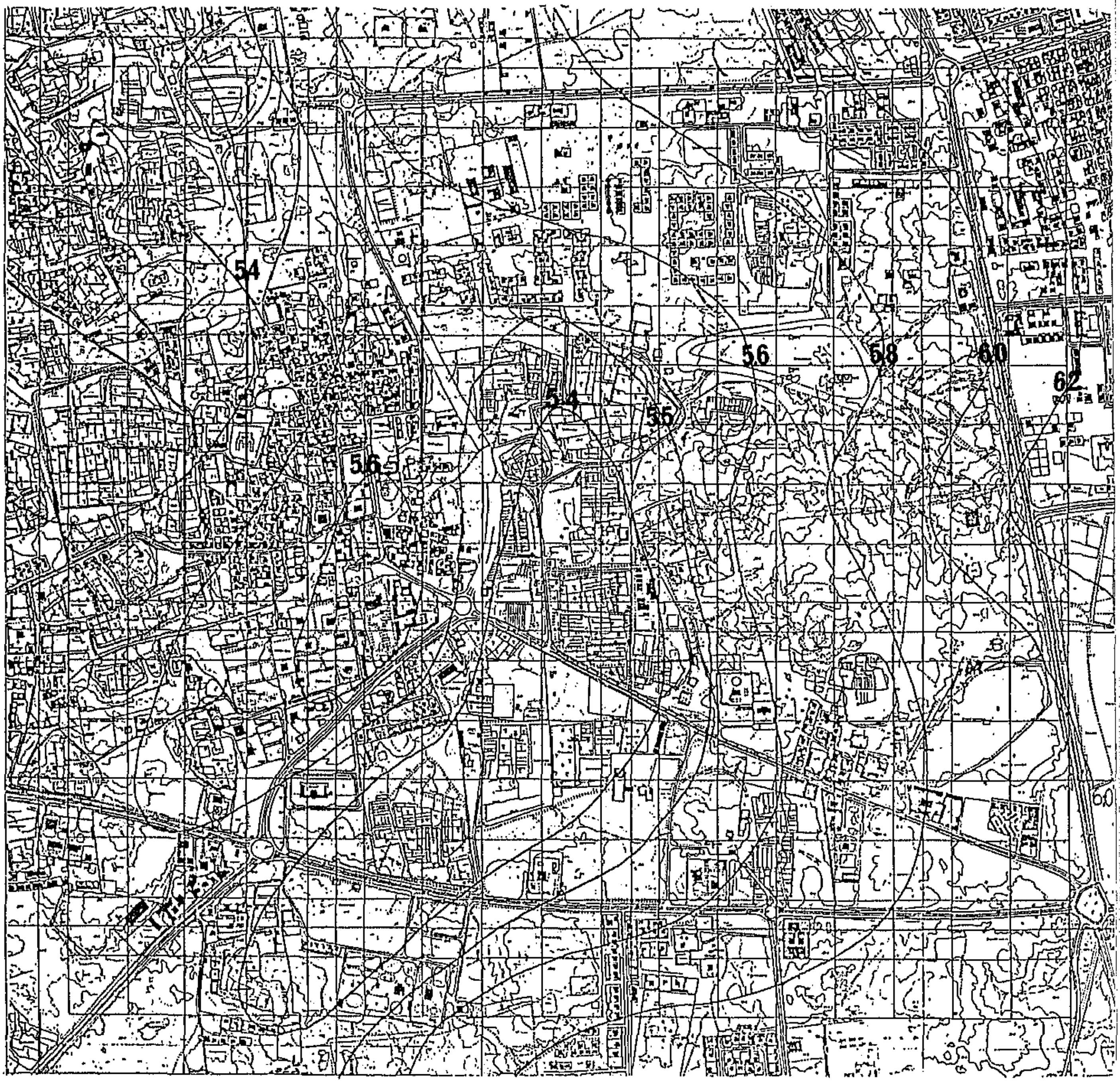
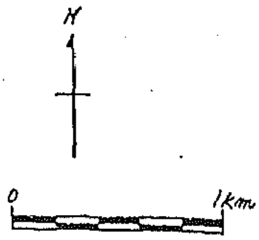
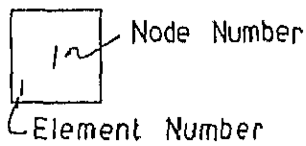


fig. 3.3.6 Groundwater Level Contour Map of Rayyan: 1986



Key Map

Legend



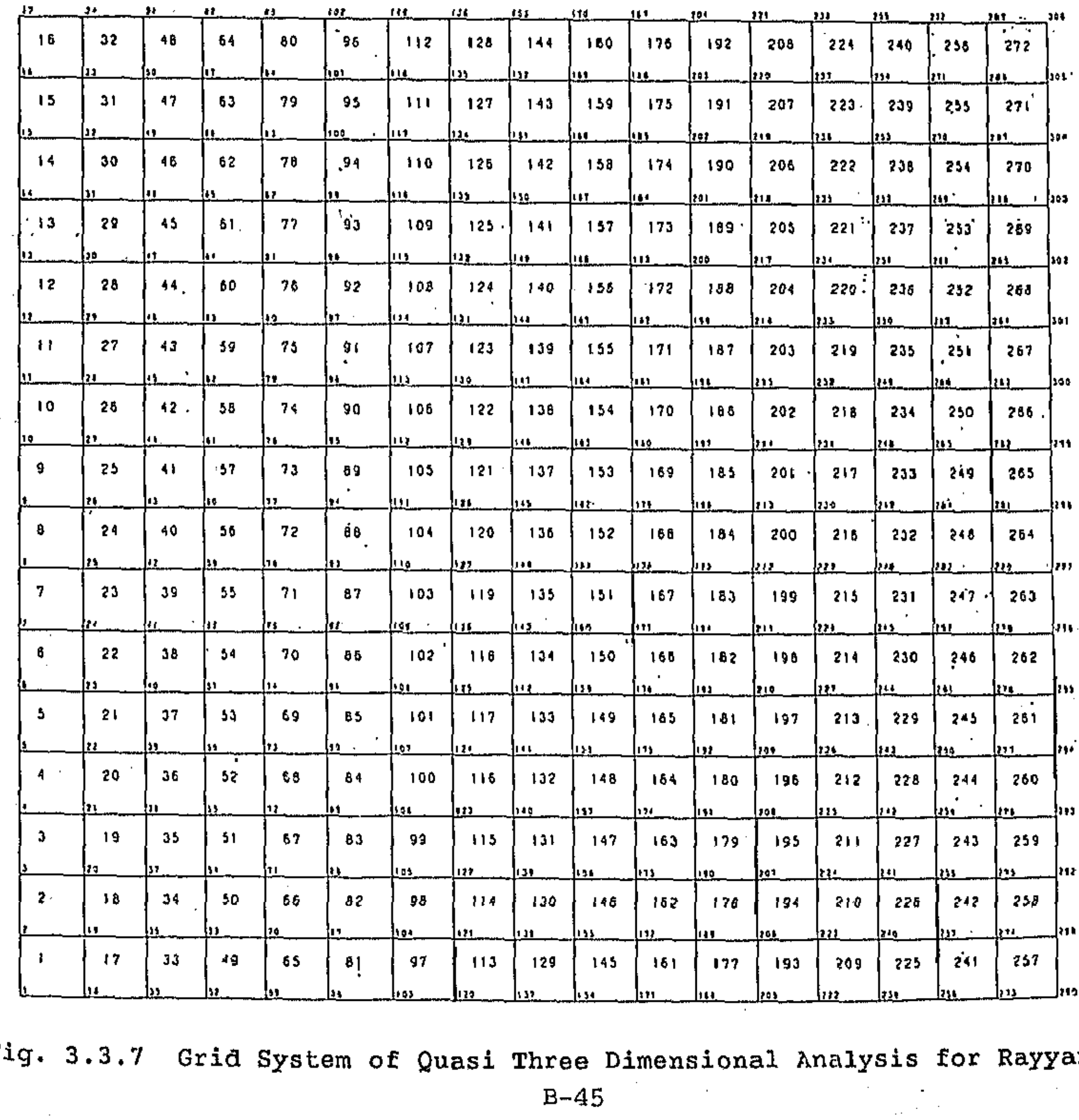


Fig. 3.3.7 Grid System of Quasi Three Dimensional Analysis for Rayyan

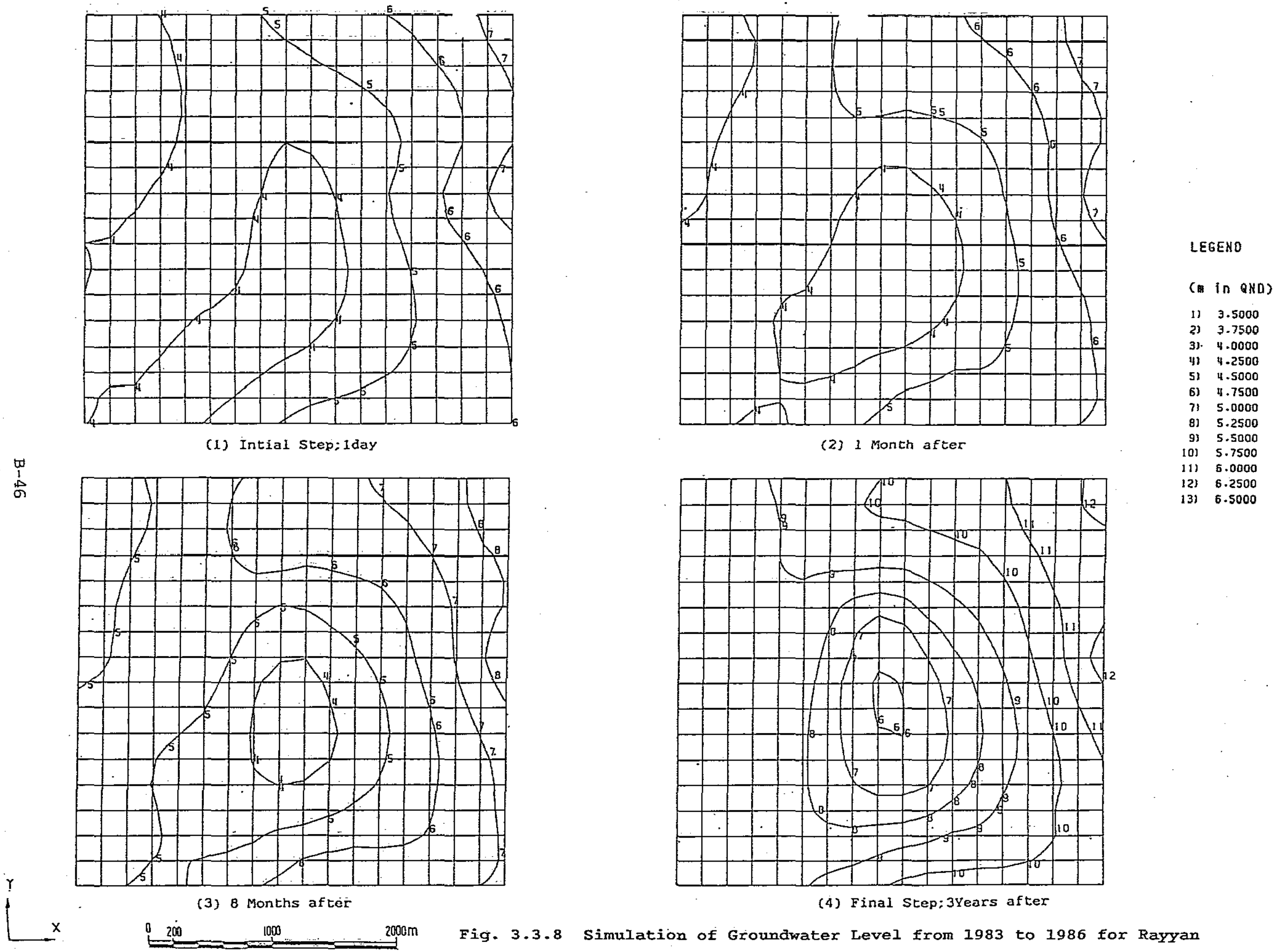


Fig. 3.3.8 Simulation of Groundwater Level from 1983 to 1986 for Rayyan

(2) Forecasting of Groundwater Inflow Amount

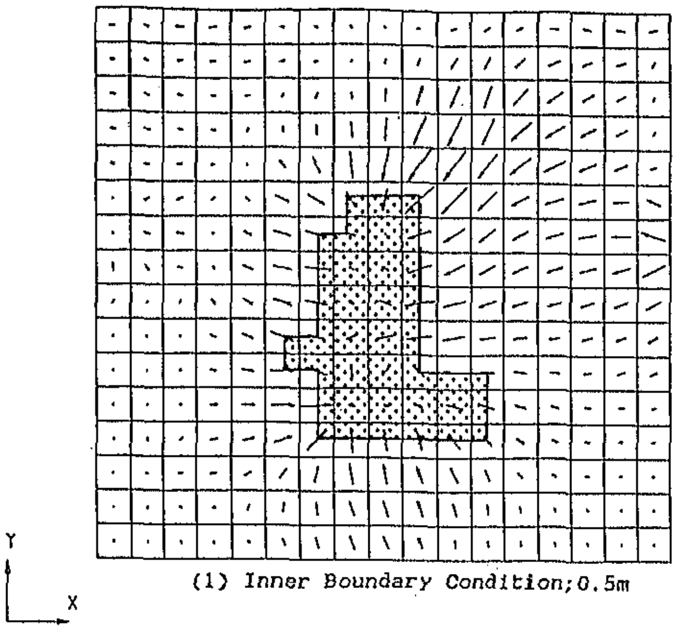
For the calculation of the groundwater inflow amount from outside the design collection area, the method used in the case of Wadi Musherib was also employed. The sensibility analysis was subsequently made on three cases of dummy groundwater level lowering amounts by trenches i.e. 0.5 m, 1.0 m and 2.0 m to evaluate the degrees of influence at the inner boundary conditions. Fig. 3.3.9 and Table 3.3.1 show the calculation results of the sensitivity analysis.

Table 3.3.1 - Groundwater Inflow Amount to Collection Facility : Rayyan

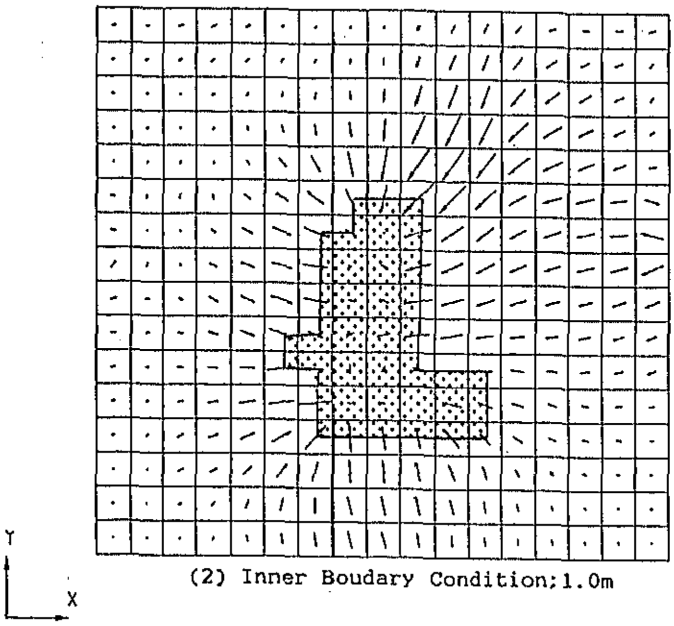
Case No.	Inner Boundary Condition	Estimated Groundwater Inflow Volume
1	0.5 m	0.870 million m^3/year
2	1.0 m	1.260 million m^3/year
3	2.0 m	1.990 million m^3/year

The simulation results to reproduce the current condition show that the inflow volume from outside the calculation area ranges from 4.0×10^5 m^3/year to 5.0×10^5 m^3/year and that the inflow to the collection facility is 7.6×10^5 m^3/year.

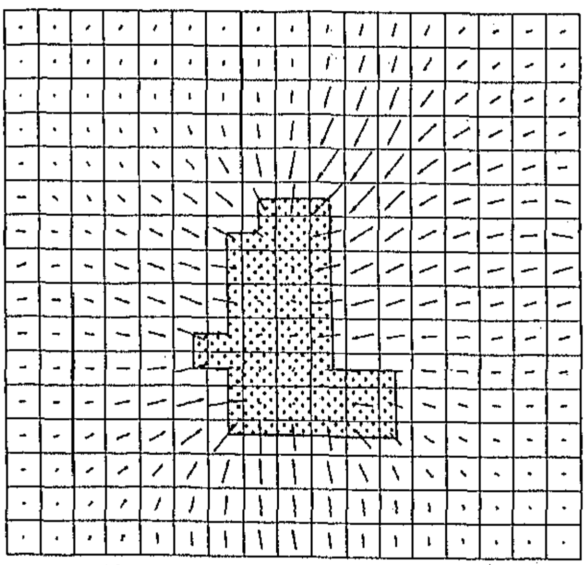
The inflow volume of Case 1 is insufficient as it is only 1.14 times higher than the current inflow volume. In comparison, the effect of Case 3 on the outer boundary condition appears to be too strong to be adopted. Therefore, it is judged that the inflow volume of Case 2 is appropriate in view of the assumed homogeneous and uniform porous media.



(1) Inner Boundary Condition;0.5m



(2) Inner Boudary Condition;1.0m



(3) Inner Boundary Condition;2.0m

Fig. 3.3.9 Groundwater Flow Vector Map of Sensibility Analysis for Rayyan

P A R T : C

Water Quality / Reuse / Water Treatment

CONTENTS

List of Figures

List of Tables

1. OBJECTIVES OF THE WATER QUALITY SURVEY

The water quality was conducted for the following objectives.

(1) To grasp the characteristics of groundwater quality in terms of regional extent of pollution area in the three study areas of Doha City, Rayyan District and New District.

(2) To grasp the trend in characteristics of change in water quality in the direction of vertical depth of mechanically drilled, artesian and other wells, if possible with due consideration to geological structure.

(3) To grasp from the water quality test results of groundwater continuously pumped from test trenches at the test work sites in Wadi Musherib and Rayyan the salinet features and changes in the water quality of relevant observation wells surrounding said test drainage trenches.

(4) To examine the possibility of reusing the pumped groundwater.

(5) To study the treatment method of groundwater, if necessary.

(6) To examine the possibility of discharge of the pumped groundwater into the sea.

2. METHOD OF WATER QUALITY SURVEY

2.1 Items to be Measured by Means of Simplified Analysis

The following three items were selected for preliminary analyses of the samples collected to roughly grasp the characteristics of water quality in accordance with the aforesaid final objectives of the water quality survey.

pH, Electric Conductivity (EC) and COD

2.2 Items Selected for Detailed Analyses

Partial and supplementary analyses of the following items (especially on those marked) were requested to the Water Quality Laboratory of the Doha South Sewage Treatment Works in order to examine the characteristics, similarities and differences of groundwater quality to the extent possible. Some of the analyses and tests were conducted and confirmed by the JICA Study Team.

Principal cations :	Ca, Mg (hardness component), Na , K
Principal anions :	Cl, SO_4
Items relevant to pollution:	BOD , COD, sulphide , ammoniacal nitrogen , orthophosphoric acid, sulphuric nitrogen, and coliform group bacteria test

Items relevant to pollution will be explained in section 5 herein.

The water quality tests during the continuous pumping test period at the test work sites were entirely dependent on the laboratory.

2.3 Analytical Apparatus

The following testing apparatus were brought in by the JICA Study Team and used for its own water quality tests in the laboratory space kindly provided by Wellfields Section of MEW. The testing apparatus (1) and (2) were donated to Qatar upon completion of the survey.

(1) Portable photoelectric photometer, Model DREL/5 and mounted rapid analytical kit (made by HACH Corporation, U.S.A. and Central Scientific Equipment Co., Japan)

(2) Portable/rapid COD meter (Model HC-307) (Central Scientific Equipment Co., Japan)

(3) Portable pH meter (accessory of HACH apparatus)

(4) Tabletop type electrical conductivity analyzer Model 30ET (Toa Radio Wave Industries Co., Japan)

(5) Coliform group detecting test paper (Colitep), simplified type for field use

2.3.1 Analytical Methods

As a rule, measurement was made in accordance with the improved and automated COD (Alkali) methods conforming to JICK-0102, 1981. Analyses at Doha South Sewage Treatment Works were basically based on the internationally accepted Standard Method for Water Quality Analysis by the American Water Works Association.

Basically, the rapid analytical kit for field test (HACH) conforming to the aforesaid standard methods should have been used, but because of the restriction of portable use, higher concentration reagents and simplified, smaller apparatus were used. The tests, therefore, may have been somewhat low in analytical accuracy but certainly not as large as to cause any significant error in the judgement and interpretation of water quality.

2.4 Sampling Method

2.4.1 Water Sampler

Besides a tube-shaped water sampler, a bucket was used to collect water from the deep wells and reservoirs. Samples were brought back to the laboratory for analysis in plastic bottles.

2.4.2 Sampling Depth

In spite of the fact that the depth and length of the well casing of the project wells drilled had been reported at the time of ASCO's Study, many of them could not be reached to the reported depth due to subsequent damages or choking with stones. etc. Also, most of the hard drilled wells in plantations were of the type whose upper part constituted a cistern so that there was no way of knowing the depth of the well itself. Samples with no description of sampling depth were taken from depths of 1 to 3 m below water surface.

2.4.3 Handling and Treatment of Samples

The sampled water were not specially treated such as by filtration. The sampled water which was filled to capacity in PVC container was brought back to the laboratory and kept still to allow sedimentation, whereupon the clear supernatant water was subjected to analysis. Some of the samples were tested on the sampling points for coliform group, pH and electrical conductivity.

About half of the samples collected on the filed were brought to the laboratory for confirmation test on common items (ph, EC, COD, Cl, TH, etc.) and for analysis of certain items (SO_4, Na, K, BOD, etc.) which were difficult to measure on the spot.

2.5 Water Sampling Points and Number of Samples

In the water quality survey carried out at various places the water samples were mainly collected from dug wells and mechanically artesian wells. They were also collected from drainage sumps on building construction sites, water storage tanks, dug testpits and bore holes, etc. Fig. 2.5.1 is a map which shows the location of the water sampling points within Doha City, Rayyan District and New District. The conditions of the water sampling points are summarized in Appendix 1 and Appendix 2.

The number of samples collected in each area is as follows.

a. Within Doha City

i) Northwestern area, South Khalifa area (Water sampling points)
4 samples

ii) Area along the 'C' Ring Road (outside the 'B' Ring Road)
11 samples

iii) Near the centre of city (besides Wadi Musherib, in the vicinity of the City's East Library, seaside drainage pump station, Toyota Roundabout, etc.)
21 samples

Hardly any suitable water sampling point, however, could be found in the central area of the old city (Al Jasrah District, Murgab District, and Souk District).

iv) Project wells near Rumaillah Hospital and Old Salwa Road
6 samples

v) Treated sewage effluent sample 1 sample

Total 43 samples

b. Rayyan District

i) In the surroundings of the test work sites (standing water on the ground surface), dug wells, wells with pump and wells from which water is taken and transported by tanker, etc.
9 samples

ii) Wells in rural villages west of the south-north road that runs on the west side of the test work site and within 2 to 3 km northwest of the said road (as far as north of Gharrafah Water works Reservoir).
9 samples

iii) Area along the Rayyan Road (3.5 km west of Jaidah Roundabout) and along the north and south sides of the road
5 samples

iv) Plantations and city gardens, etc. east of the test work site and west of the northern part of 'D' Ring Road

3 samples

Total 26 samples

c. New District

Two from old dug water pools in a vacant lot east of Al Markhiya, and one each from shallow well of the West Bay Stadium and the rainwater drainage underground infiltration gutter (soakaway).

Total 4 samples

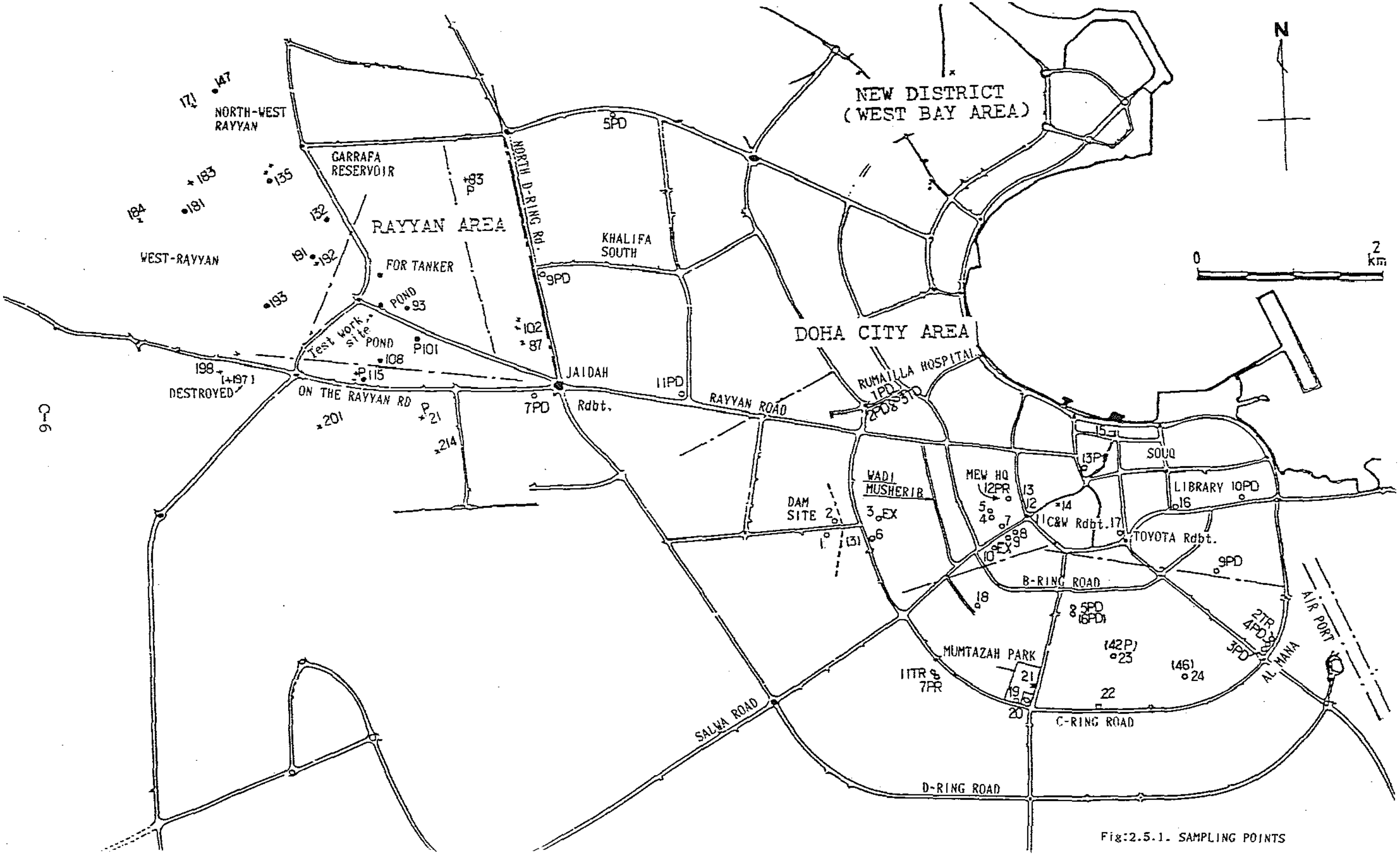


Fig:2.5.1. SAMPLING POINTS

2.6 Periodical Water Sampling from Pumping Test Trenches and Observation Wells

An L-shaped test trench (4 to 5 m in depth) was excavated in July 1986 at two test work sites in Musherib and Rayyan where continuous pumping tests to pump up groundwater which had seeped in and filled these trenches were carried out until the end of October in 1986. The water pumped from these test trenches and also water from the four wells selected to represent the observation wells in the vicinity were weekly sampled and tested for water quality in the laboratory.

3. WATER QUALITY SURVEY

Groundwater in various states - for example, groundwater of wells and of artesian wells, groundwater which had been pumped up and stored, groundwater which was abstracted from excavated pits at construction sites - throughout the three study areas of this study was sampled and analyzed for water quality. The results are summarized both from the viewpoints of (1) regional extent and (2) depth, as follows.

3.1 Regional Water Quality Survey Results

3.1.1 Water Quality in Doha City

Groundwater samples were collected from 32 points in Doha City by broadly dividing it into Wadi Musherib area and the area along the 'C' Ring Road which is a part of the City's environs. Analyses of the groundwater samples show the water quality to be different at every point and does not give definite regional tendency.

(1) pH values

With a few exceptions, the pH values of every sample collected in Doha City were on the level of 6 to 7 (mostly on the level of 7).

Note: (Samples with pH values of other than 6 to 7 level)

2339 12 PR	: 8.6
2339 11 TR	: 8.8
2339 Test Work Site	: 8.4
2339 Well, Old Salwa Road Reservoir	: 8.48
2339 Leaking Water (Swimming Pool in Montazah Park)	: 8.3

(2) EC values

It is said that to know the tendency of groundwater in Qatar a check of EC values would tell with relative ease the characteristics of the water quality and distinguish it from others. Fig. 3.1.1 is a map that plots the EC values of all points sampled during the current survey. Fig. 3.1.2 shows the changes in the values of EC of two sections, namely, the section from upstream to downstream (toward the sea) along Wadi Musherib and the other from north to southeast along the 'C' Ring Road.

The range of EC values of samples that were collected in Doha City during this study are as follows.

EC < 3,000 micro mhos/cm	(low)	5	samples
EC < 6,000 "		16	"
EC < 9,000 "	(slightly high)	7	"
EC > 9,000 "		5	"
	(Total	33	samples)

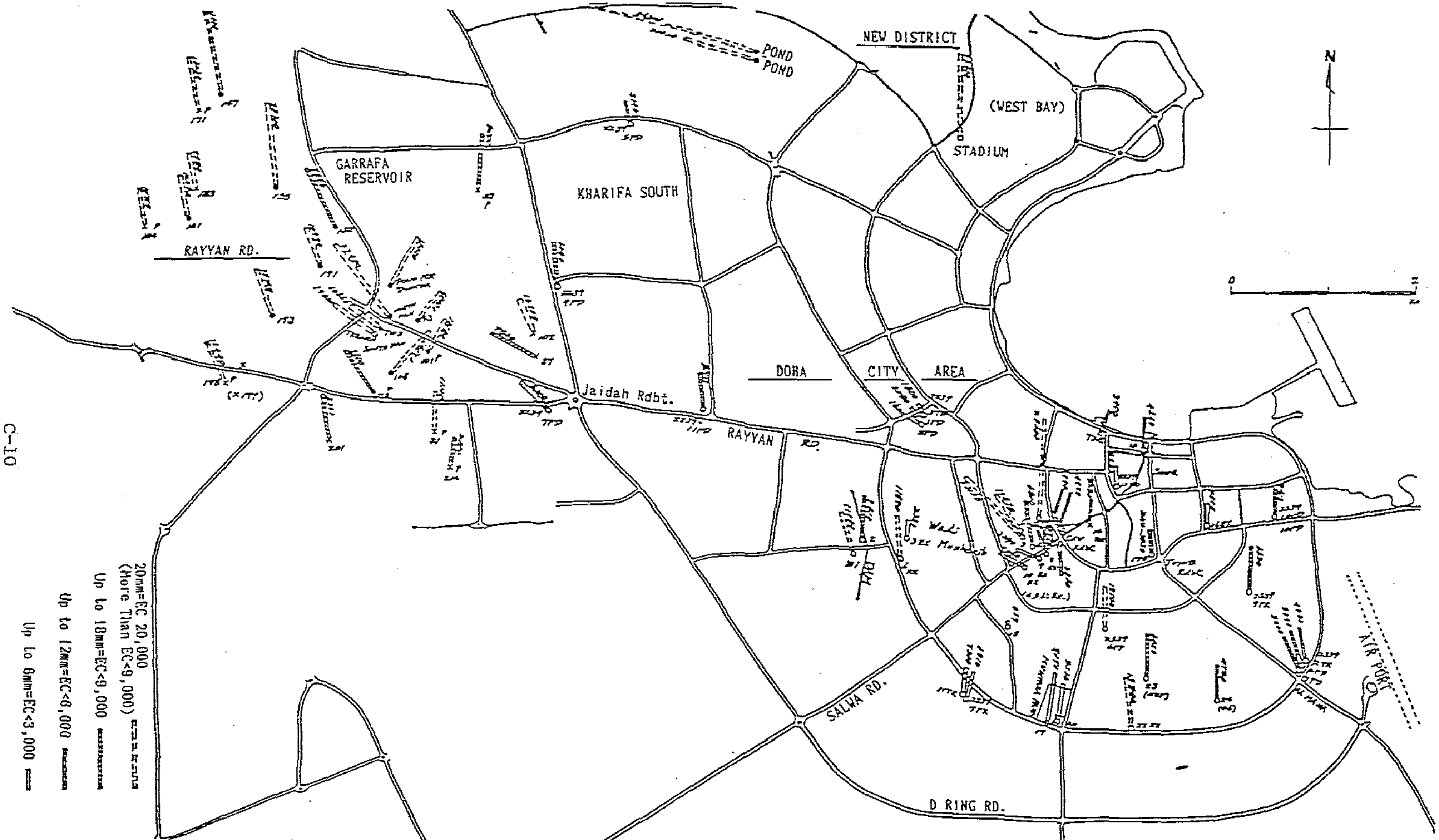
Reference: Potable water EC < 500
Treated sewage effluent (TSE) EC = 3,00 to 4,000

In other words, about two-thirds of the groundwater samples showed relatively low EC levels (below 6,000 micro mhos/cm) which might be interpreted to mean that groundwater in Doha City is already diluted by plain water due to human activities. For example, the water of the wells (2239 1PD, 2239 2PD, 2239 3TD) behind the Rumaillah Hospital have indicated EC values of 2,000 to 3,000 in previous investigations and this is considered attributable to the commingling of cooling water (plain water) from compressors.

However, there are cases where considerably high salinity is detected among the samples collected near the ground surface, such as in the water collected from pits excavated at construction sites. Water with high EC values is occasionally seen among the deep project wells, too.

1.	Building west of Dam Site	EC 11,980	
5.	JICA Hole (2)	EC 23,100	
6.	JICA Hole (3)	EC 11,870	
7.	Test Work Site	EC 15,050	
	2239 3PD 20 m	EC 54,000	
	2239 6PD 13 m	EC 12,000	(2 m below ground level)
	2239 12PD 28 m	EC 29,960	(6 m and 20 m below ground level)

Leaving these localized data aside, the EC values of groundwater in the shallower layers inside 'C' Ring Road in Doha City area may reasonably be considered to be below 6,000 on average and partly between 3,000 and 4,000 micro mhos/cm, or equivalent to the values of treated sewage effluent (TSE). Although the ASCO Report states that the reason the groundwater has such a low EC level is because of dilution by plain water related to human activities, such as potable water and treated sewage, it is difficult to ascertain how and where the plain water and groundwater become mixed.



LEGEND
B:BUILDING CONSTERUCTION SITE
Ex:EXCAVATED HOLE/POND
PWELL/TANK/ POND WITH POMP
PD. PR(TD.TR) : PROJECT TEST WELLS

Fig.3.1.1.
F C Values investigated in Feb.to April.1986.

20mm=EC 20,000
(More Than EC<9,000)
Up to 18mm=EC<9,000
Up to 12mm=EC<6,000
Up to 6mm=EC<3,000

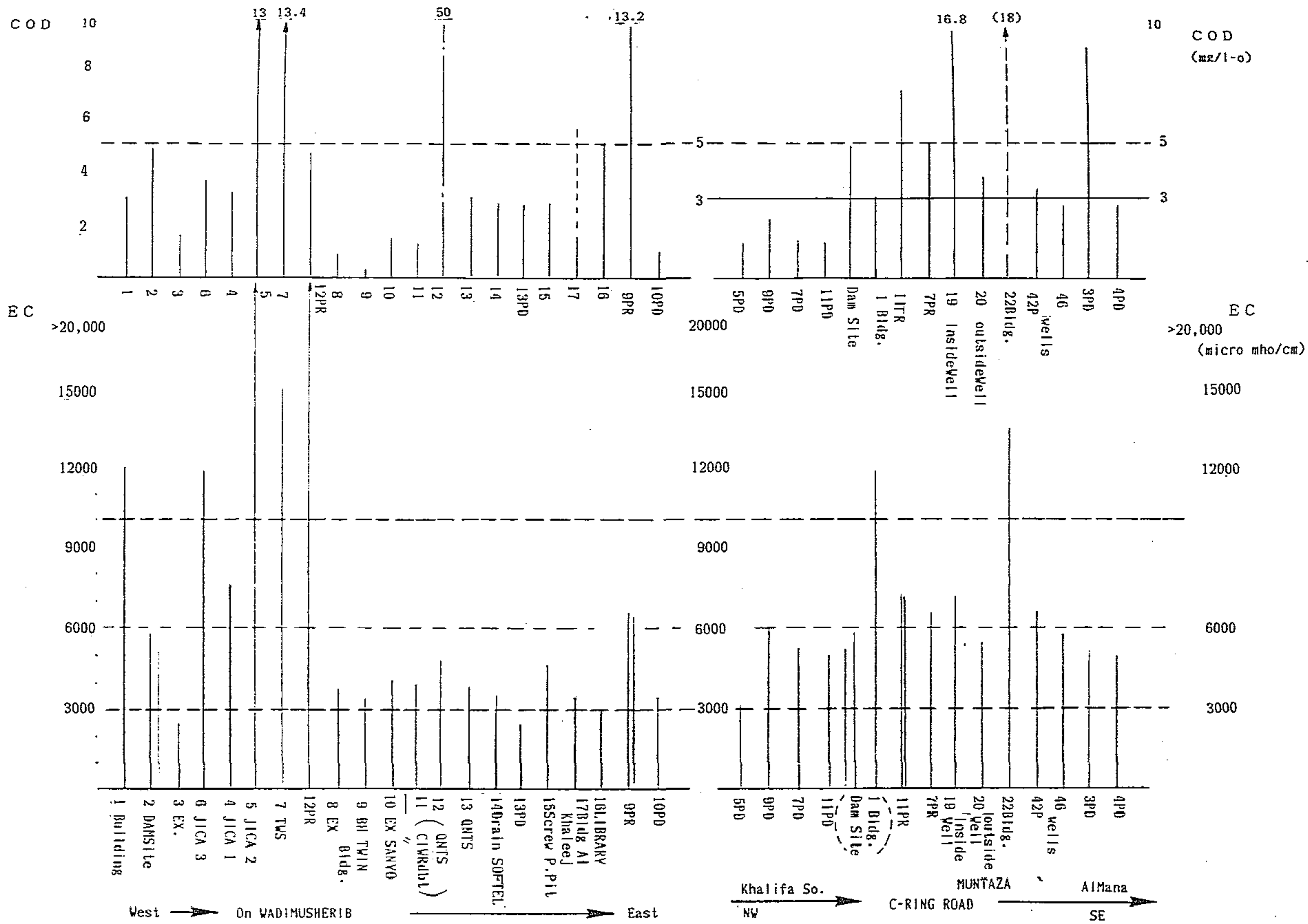


Fig.3.1.2.EC and COD of Groundwater on the line of West to EAST Througn Wadi Musherib

(3) COD

Fig. 3.1.3 shows the distribution of measured values of COD plotted on a map. Fig. 3.1.4. shows the measured values of COD plotted on the sections along Wadi Musherib and along 'C' Ring Road.

Classification of all 39 samples on which COD was measured show them to be distributed as follows.

COD < 3 ppm	17 samples	(9 from Project Wells)
COD < 5 "	10 samples	(2 ")
COD < 10 "	6 samples	(4 ")
COD > 10 "	6 samples	(1 ")

Twelve of the sampling points were above 5 ppm in COD which means that they must be polluted in some way or another, but it was impossible to identify how they became polluted.

When reviewing the degree and progress of pollution; however, the fact that half of the project wells show COD values of below 3 and those sampled from construction sites, excavated pits and holes, and stormwater trunk line laying site in Musherib are also low, leads to the judgement that the groundwater is not seriously polluted except in the following special cases.

Project well 2239 9PR (choked at a depth of about 7 m) and the well in Montazah Park (3 m water depth) which have a strong odour (sulphide smell) and have higher phosphoric contents and COD compared to normal groundwater are apparently polluted by sewage. The only severe pollution was observed in a telephone line manhole at Cable and Wireless Roundabout where a large amount of sewage had flown into groundwater, causing the manhole to be filled with terribly offensive odour and the water to generate black precipitates from which COD of about 50 ppm was detected. Also, when the construction site on the vacant lot adjacent to the Arab Library was excavated to a depth of about 1 m below ground, the drain pipe of the septic tank was found destroyed, and 5.1 ppm of COD and 1.3 ppm of orthophosphoric acid were detected from the groundwater which had seeped out. At the construction site of Al Khaleej Insurance Company Building near Toyota Roundabout, the earth was excavated to a depth of about 5 m below ground level for foundation work from where groundwater was continuously drained by three pumps (estimated to be 2 m^3/min) for 3 to 4 months. Water samples were collected here once a week for altogether six (6) times and analyzed for water quality. The results showed that COD values were less than 2 ppm two times but 4.1 ppm and 5.6 ppm respectively on two other occasions, from which it was inferred that probably some sort of pollution was occasionally flowing into the construction site. (Values of orthophosphoric acid did not rise).

The value of EC was stable in the range of 3,000 to 3,500 micro mhos/cm throughout the whole period.

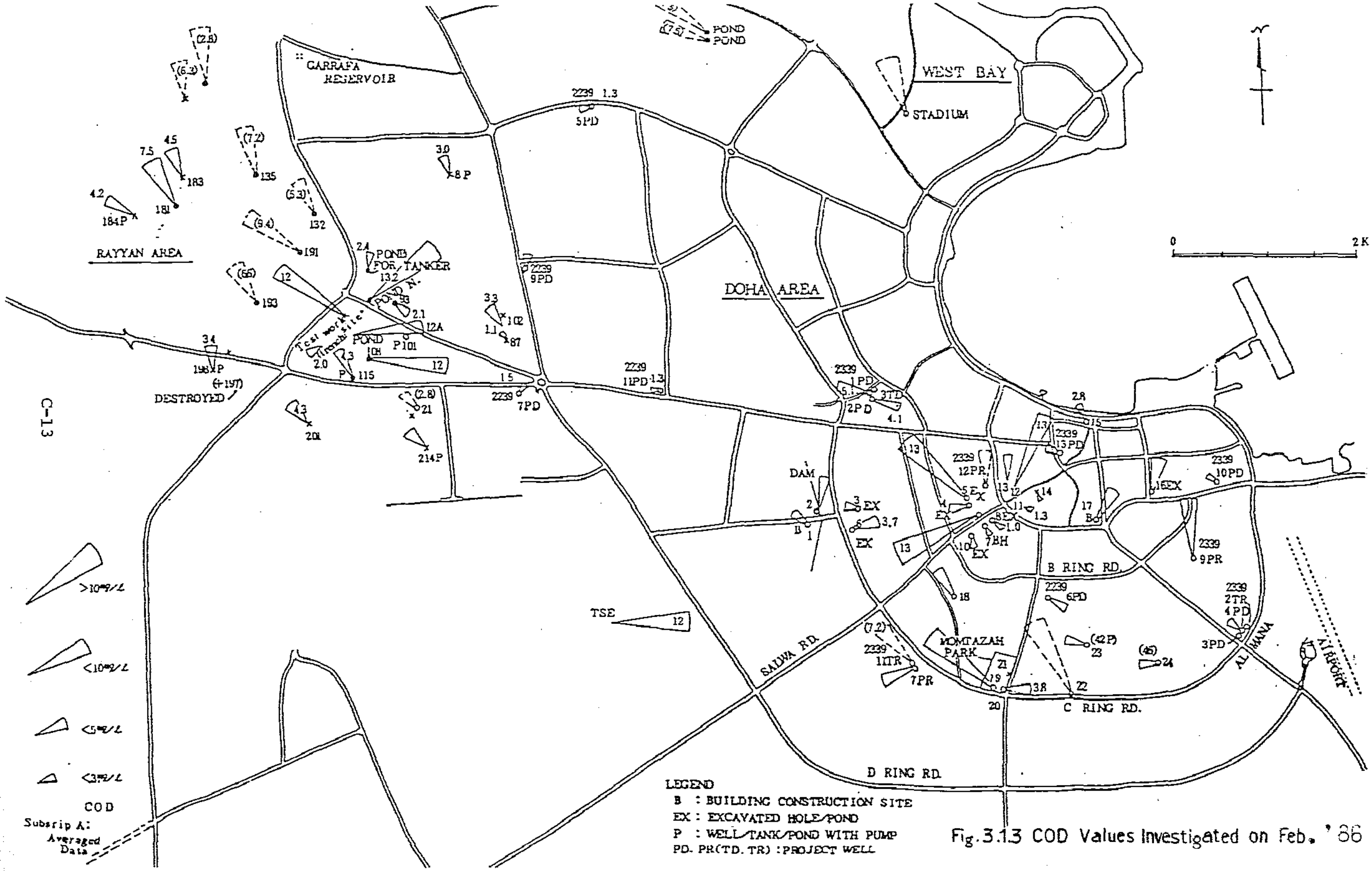


Fig. 3.1.3 COD Values Investigated on Feb. '86

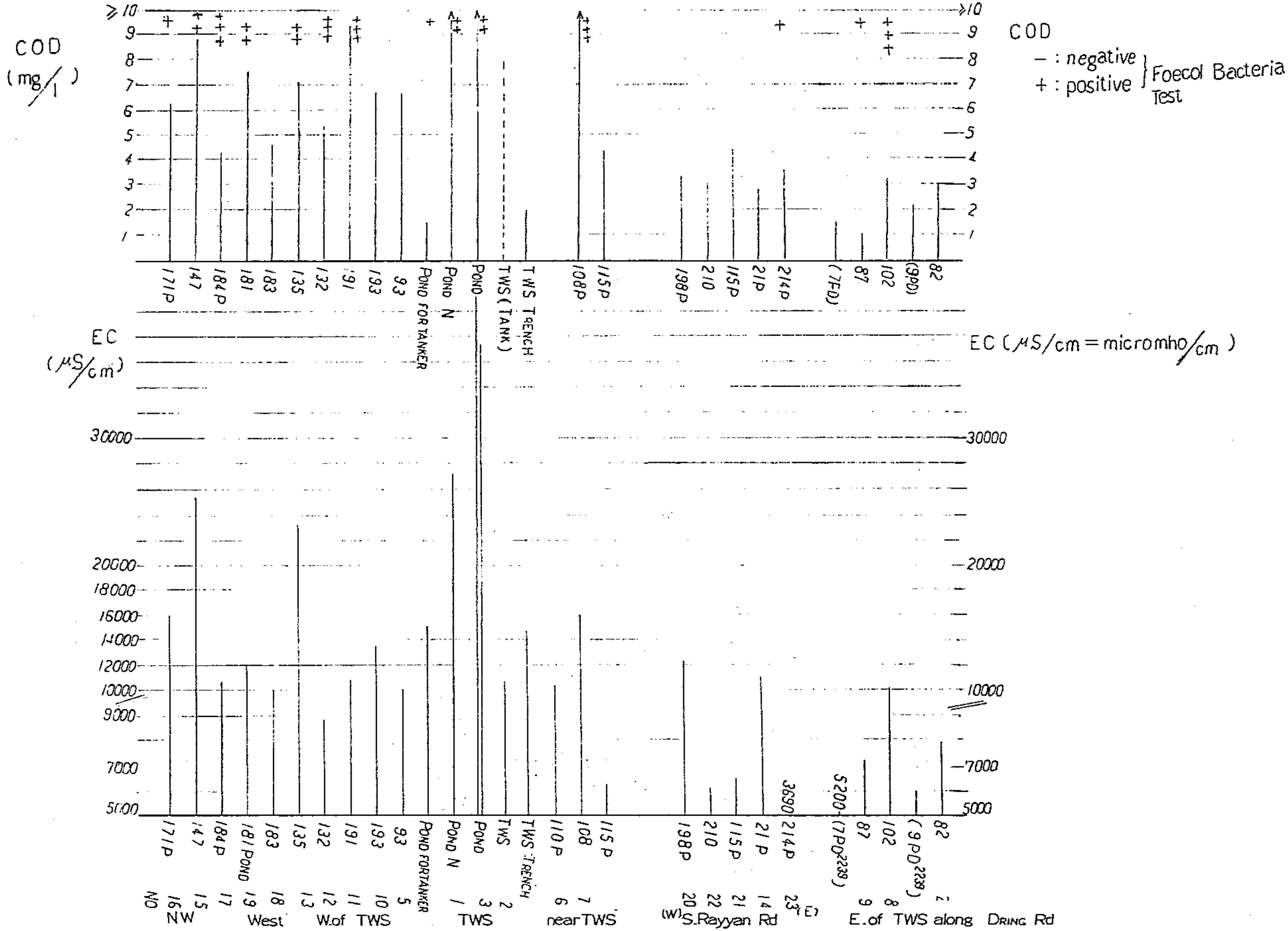


Fig 3.1.4 EC and COD of Groundwater on the line of C-Ring Road

(4) Principal cations and anions (Hardness constituents Ca, Mg, Cl and SO_4)

The tendency of ratio of principal ions could not be readily explained in any of the groundwater samples collected in the municipal area of Doha. This is because the water quality reflects various complex influences, for instance, the difference in water quality of the aquifer in Dammam Formation and that of Rus Formation underneath it, the kind and quantity of plain water which permeates, and outflow of various other kinds of water with various salt compositions including irrigation water which dissolves the salts which had deposited and accumulated on the ground surface by evaporation of water and permeates the underground.

3.1.2 Water Quality in Rayyan District

A phenomenon of increased standing water and swamp areas is developing over several hectares in the depressed basin-like lowlands of Rayyan due to the rising groundwater. There are many plantations in the test work site surroundings, particularly in the west to northwest, and at some of these plantations the plants have withered and farms have been abandoned.

The source of water supply for these plantations are artesian wells, wells with pump and dug reservoirs or concrete water tanks. Water samples were collected from these wells, reservoirs and tanks. The quality of groundwater in Rayyan District is different from that of Doha City were urbanization has advanced. It is higher in EC on average, suggesting the distribution of high salinity groundwater in the district.

(1) pH values

As in Doha City, the groundwater of Rayyan District shows pH values of the levels of 6 to 7, but mostly in the order of 7. Some of the samples taken from standing water on the ground surface and from reservoirs of plantations were in the order of pH 8, but otherwise, there was nothing particularly abnormal or different.

(2) EC values

Twenty-four samples collected from different points including standing water in the lowland surrounding the Rayyan test work site showed the EC values to be in the following range.

EC < 5,000	micro mhos/cm		1 samples
EC < 8,000	"		4 "
EC <10,000	"		2 "
EC <20,000	"		13 "
EC >20,000	"		4 "
		Total	24 samples

Standing water in places which had turned into swamps in the lowland indicated EC values of between 20,000 to 40,000 micro mhos/cm which is considerably higher compared to normal groundwater. This is because of evaporation and also redissolving of salts deposited and solidified on the ground surface. Almost all groundwater samples collected at plantations in the west, northwest and north of the test work site (in the range of 2 to 3 km) showed relatively high EC values ranging between 10,000 to 20,000 micro mhos/cm.

(3) COD values

The following shows the distribution of COD values of 24 samples collected in Rayyan District. The majority of the samples show COD values of below 5 ppm.

COD < 3 ppm	6 points
COD < 5 "	7 "
COD <10 "	8 "
COD >10 "	3 "

Some of these samples were tested for coliform group at the sampling points using a simple test paper. The result was that almost all samples proved positive to the coliform group test.

COD < 3 ppm	out of 2 samples	2 were positive	(Samples collected from water lifting pump	1)
COD < 5 "	" 4 "	3 "	("	3)
COD <10 "	" 5 "	5 "	("	1)
COD <10 "	" 3 "	3 "	("	0)

Almost all of the water sampling points in Rayyan District were the upper part of dug well water and storage tanks of pumped up groundwater on plantations, and because wastes and scum were afloat on the water surface their COD values were accordingly high. Out of 8 samples directly collected from pumped up water 5 showed positive results to the coliform group test.

3.1.3 New District (West Bay) Area

As there was hardly any well which was appropriate for sampling in the New District which lies on the west side of reclaimed land, the samples were collected only from a shallow well in the stadium and another two from old dug water pools (5 m square, depth about 5 m to water surface) in a vacant lot east of Al Markhiya District.

The water depth of the well in the stadium fell short of 1 m, and the water was clouded with lime-like substance and indicated an abnormally high pH value of 10.35. The water samples from the dug water pools had pH values of the level of 7 but their EC value were considerably high, one of them being almost close to the value of seawater (their respective values were EC 21,000 and 56,000 micro mhos/cm). The intrusion of seawater under the reclaimed land is therefore possible.

At a later date, it was discovered that stagnant water exists in one of the rainwater drainage underground filtration gutter in a residential area of the New District, from which a sample was collected and analysed.

3.2 Change in Groundwater Quality in the Direction of Depth of Well

The project test wells, which are classified by the symbols of PD (Dammam Formation) and PR (Rus Formation), hardly appear to have been used since the time of ASCO's Study (1982-1983). Some of them could not be reached to the bore depth recorded at the time, probably due to throwing in of stones or to subsequent destruction.

During this survey, water samples were collected from the seven project testpits tabulated below. The respective depths at which they were collected are also shown.

Well No.		Elevation	Casing Length	Total Length	Sampling Depth
2239	7PD	19.25	11.55	18.55	10, 13, 16, 17.5
"	3PD	7.60	(12.0 - 10.90)	23.7	7.5, 20
"	10PD	9.00	1.50	17.6	6, 9, 10.5
"	5PD	8.14	4.00	16.6	2, 13
"	13PD	6.10	2.00	18.0	5, 7, 13
"	12PR	4.17	19.00	49.0	6.5, 20, 28, 40

The following table shows the EC values of the seven project testpits in the direction of their depth.

Item	EC	pH	TH	Ca	Mg	Na+K	SO_4	Cl	NO_3
1) Analytical Results in 1960									
Mixed Water with Bh No. 1, 4, 7	4200	7.3	1725	475	131	507	1437	800	14
Bh. No. 12 (Surface water)	2300	-	-	-	-	-	493	510	-
" (at a depth of 5 m)	5000	7.1	1960	485	166	436	-	-	
" (Near bottom)	5200	-	-	-	-	-	1329	1035	8
2) JICA samples (No. 20 point)									
At a depth of 5 m									
At a depth of 13 m	5260	7.41	1550	400	120	700	1337	1035	8

PD and PR bore holes apparently show different changes in EC values by depth. In the case of PR bore holes, the deeper the water depth, the higher the EC value. In the deeper PD bore holes like 3PD, also the EC value at the bottom section is apparently higher than at the upper section. Not only the changes in EC values but changes in salt composition of three examples were reviewed by the ratios, the results of which are shown on the above table.

Since the analysis report on the water quality of the 16 wells which were drilled in the vicinity of the relatively old well in the parking lot of Montazah Park (in the neighborhood of JICA's survey point No. 20) in 1960 in order to supply water to Doha City was available, the findings of this report were compared with the sample collected at No. 20.

Other than the fact that the EC value of the surface water of bore hole No. 12 is low at 2,300, there is no significant difference from the analytical results of 1960. Nor is there any change in the direction of depth.

4. WATER QUALITY SURVEY AT TEST WORK SITES

In the JICA Study, an L-shaped test drainage trench was excavated at each of the two test work sites, one at Wadi Musherib in Doha City and the other at the lowland in Rayyan and the groundwater which had seeped into the trenches was continuously pumped for about four months during which time the drawdown and recovery conditions of groundwater table in the surrounding observation wells were observed. Also, the water in the trenches was periodically analyzed for quality. Samples were taken every day during the first week of the continuous draining period and approximately once a week thereafter and subjected to analysis for quality. Also, from among the surrounding observation wells four were selected from which water was collected and analyzed for quality simultaneously with the water from the test trenches. Duration of surveys were as follows.

Wadi Musherib	July 2 - October 27, 1986 (118 days)
Rayyan	July 11 - October 30, 1986 (111 days)

4.1 Analytical Results at Wadi Musherib Test Work Site

Water (T) continuously pumped up from the test trench at Wadi Musherib and the water of four wells, each in one of the four directions, namely, that of TB-1 and TB-4 wells (at the east and west ends north of the trench) and TB-14 and TB-17 wells (southwest and southeast of the trench, respectively) which were selected from among the surrounding 17 observation wells were subjected to quality analysis. The results of all water quality analyses are presented in Table WQ1 (Refer to Appendix 4) and their time series changes by item of water quality in figures (Refer to Appendix 4).

Items measured by water quality analysis were EC, pH, COD and as principal cations, Ca, Mg, Na+K, and as principal anions, Cl and SO_4.

4.1.1 EC

EC values of water continuously pumped from the test trench were stable throughout the period, ranging between 4,000 to 5,000 micro mhos/cm which are lower than values of water of any surrounding observation wells.

The EC values of observation well TB-1 which is quite close to the test trench were stable throughout the period, rising from 6,000 to 7,000 then dropping to 6,500. EC vales of TB-4 during the first week were slightly at 8,000 then later dropped to 6000, and during the last half of the period (from the end of July throughout the remainder of the period) reached between 4,500 and 5,000 which showed it to be stable in quality next to that of T (trench water). EC values of TB-14 were initially high in the range of 12,000 to 13,000 but suddenly dropped to the order of 8,000 during the middle of July and remained stable in the range of 7,000 to 8,000 since September.

EC values of TB-17 (located at the southeastern tip of the test work site, and because of being closest to the building on the south was influenced by the sewage from the said building during the survey period) were high from the beginning, ranging between 16,000 and 18,000, but jumped to a highest value of 49,000 during the middle of July and the middle of August by the effect of pollution while other items also rose abnormally; for instance, 72.7 of COD, 10,000 or more cations of Na+K and a particularly abnormal 17,000 of Cl among anions. Since the middle of August, however, the water quality improved greatly, with every item having a lowest quite close to that of the water sampled from the test trench.

On the whole, both the water collected from the test trench and the water from the respective observation wells began to show levels of EC equivalent to that of stable water quality after about three months since starting the tests.

When the EC values of the 13 observation wells, other than the four representative ones selected, were measured at the beginning and at the end of the period to test their water quality, they did not manifest any remarkable change on the whole. However, the EC value of TB-10 after termination of pumping from the test drainage trench was 23,000 and that of TB-16, 10,600, and the EC values of TB-10 which were the highest of all did not change even after a lapse of four (4) months. (Refer to Fig. 4.1.1 EC Contour Map)

4.1.2 pH

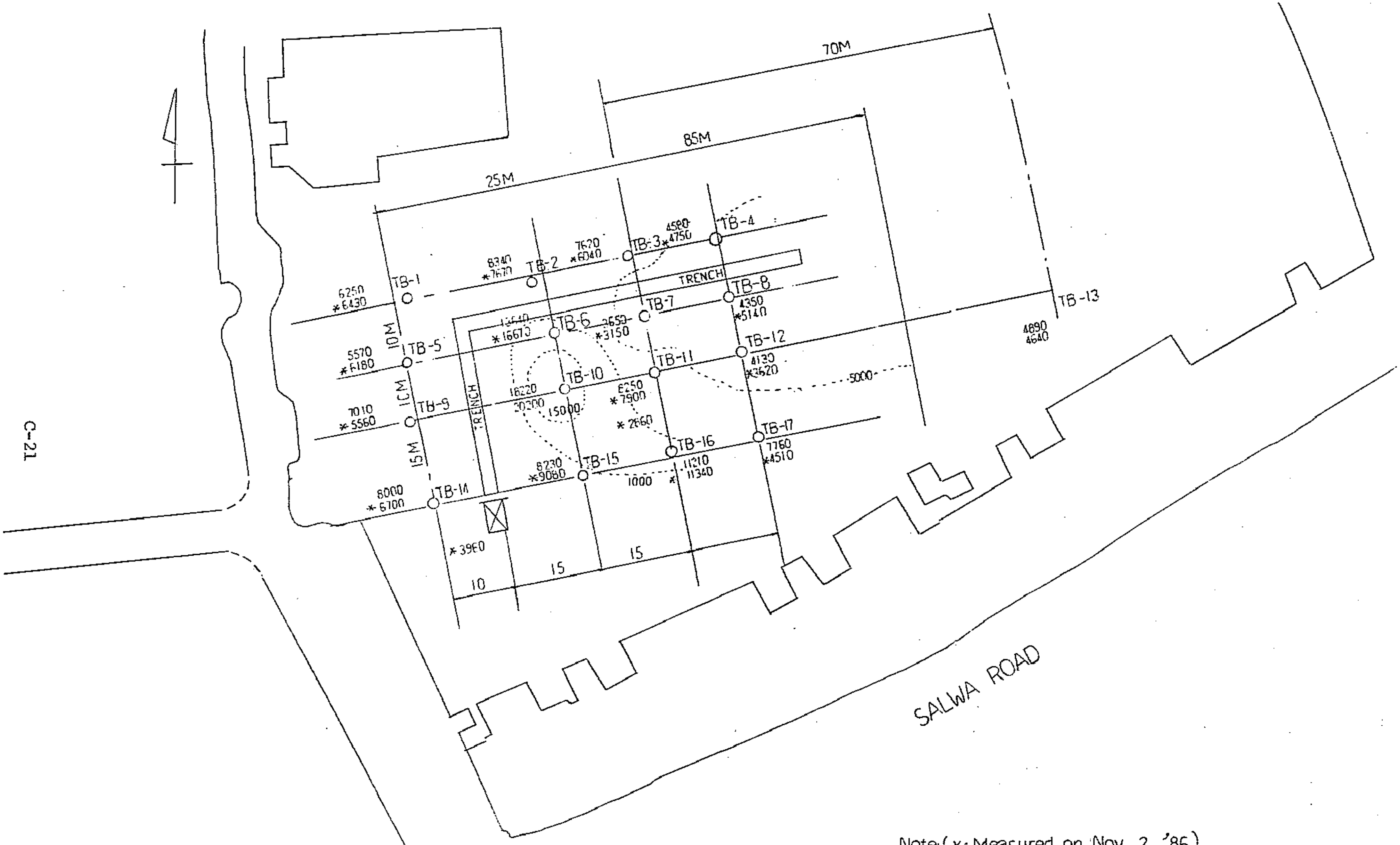
When pumping was started, the pH values were dispersed widely because of the influence of respective conditions surrounding the trench and the observation wells, but after about two (2) days the values, though different, became somewhat closer and began to show similar movements. Particularly about one (1) month after commencing operation, both the water from the trench and the water from the observation wells not only became relatively closer in pH value but alo began to show similar change in pH.

4.1.3 COD

Initially, the water from TB-1 indicated a COD value closest to that of water from the test trench while TB-4 and TB-17 indicated slightly higher values (COD 6 to 9 mg/l in TB-4 and above 11 in TB-14) from the beginning. TB-17, in particular, which was affected by the inflow of sewage from outside source indicated COD values of above 20, the highest of all being 72.7, but as in the case of its EC values, the anomaly subsided at last by the end of August with the COD values of water from the other observation wells (excluding TB-14 and TB-17) and TB-1 and TB-4 almost always indicated COD values of below 5.

4.1.4 Principal Cations (Ca, Mg, Na+K) and Anions (Cl, SO_4)

Changes in EC originally reflect the overall changes in principal cations and anions. Particularly in TB-14 and TB-17, the changes in cations appeared almost in parallel with the changes in EC, and it was the same in the case of anions. Particularly both cations and anions of water samples collected from the test trench and TB-1 and TB-4 seemed to have been stable. The largest change in TB-14 was seen in the combination of Na-SO_4, (a particularly large change at the end of July) while in TB-17 it was seen in Na-Cl. In the observation wells other than TB-17, the changes in both cations and anions were pronounced compared to the small changes in water quality. Particularly in the test at Musherib Test Work Site the concentration of SO_4 ions was high (the highest was above 6,000 but normally in the range of 1,500 to 4,000 mg/l) and that of Cl ions was low (the highest was 2,000, but normally in the range of 500 to 1,000 mg/l). In Rayyan this relationship was reversed.



Note (x: Measured on Nov. 2. '86)

Fig 4.1.1 Electric Conductivity Distribution in Musherib Test Work Site

4.2 Analytical Results at the Rayyan Test Work Site

The water (T) from the test trench in Rayyan and the water of four wells surrounding the trench, namely, TB-21 and TB-25 (at the western tip and eastern tip on the north side) and TB-42 and TB-45 (at the southeastern tip and southwestern tip) which were selected from among the 22 observation wells in the vicinity of the test trench were collected almost simultaneously and analyzed for water quality. The results of the water quality analyses are presented in Table WQ1 (Refer to Appendix 4) and the time series changes in water quality are illustrated in the figures (Refer to Appendix 4).

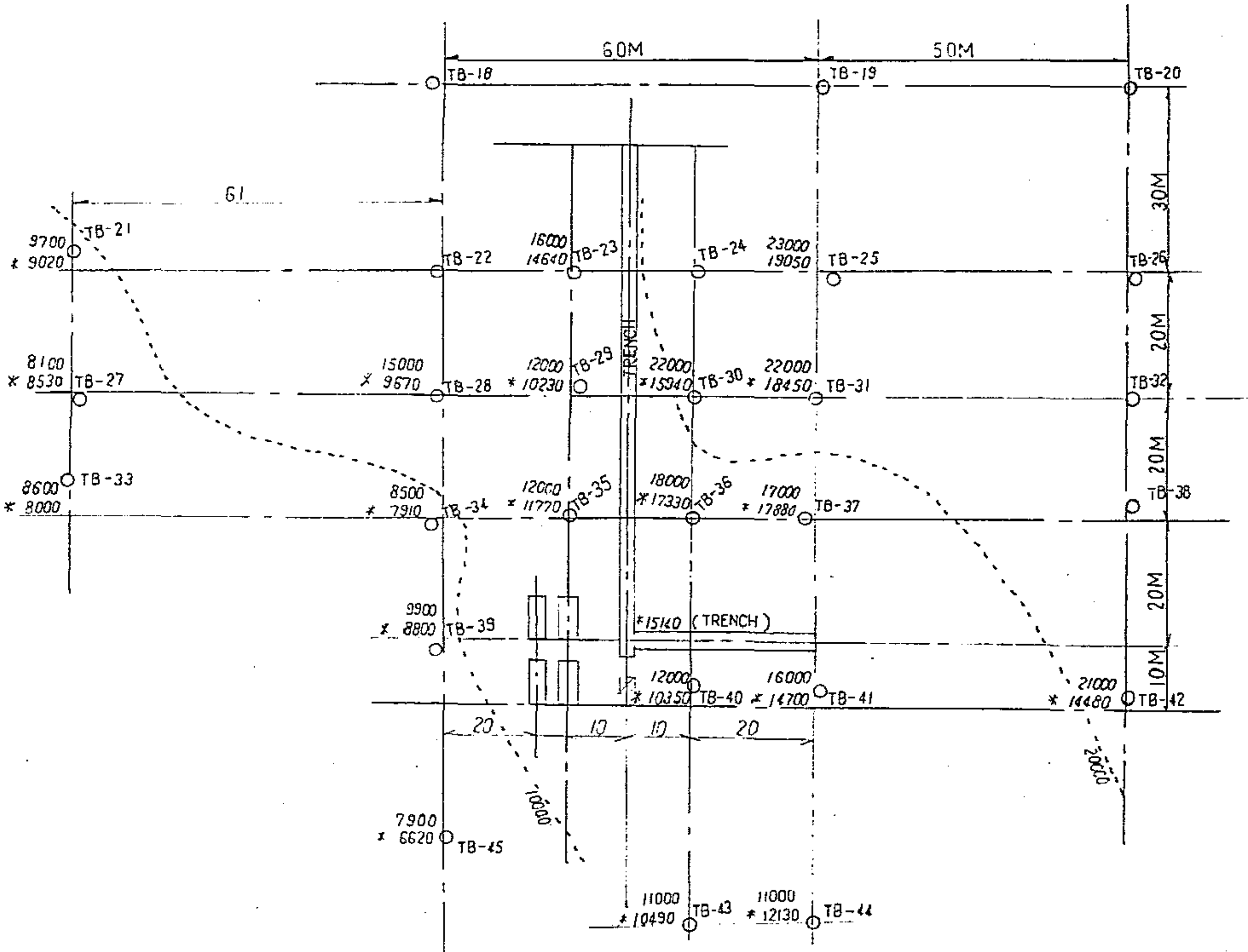
Continuous pumping of groundwater at the Rayyan Test Work Site was suspended once as the water pool in the nearby lowland into which the water had to be discharged initially became flooded. As for the surrounding observation wells, the well TB-23 (immediately west of the test trench) and TB-39 (immediately southwest and slightly closer to the pump well) were used during the first half of the test period, while in the latter half the four wells of No.21 on the west, TB-25 east, TB-42 southeast and TB-45 southwest, were used.

4.2.1 EC

EC values of water (T) from the test trench changed widely on the first day only and became slightly stable thereafter, dropping from 17,000 to 16,000 and further down to 14,000 after August until it hit the lowest level of 13,000 micro mhos/cm. During the final stage in October, however, it fluctuated slightly within the range of 14,000 ± 1,000.

EC values of TB-23 and TB-39 (during the first half) were generally stable at around 17,000 and 10,000 respectively throughout July. The last half, since the beginning of August, TB-21, 25, 42 and 45 were selected as the representative observation wells. TB-25 and TB-42 on the east side always exhibited higher EC values and larger variability compared to TB-21 and TB-45 on the west side. Specifically, the EC values in TB-25 was initially 20,000 ± 1,000 but rose above 20,000 (the highest was 24,800) since the end of August. In TB-42, the EC value was 16,000 initially but fell below 15,000 since the latter half of September until it dropped to the lowest of 13,200 and has remained more or less stable thereafter (during October). Compared to these, TB-21 and TB-45 (on the west and southwest) always tended to show lower EC values. EC values in TB-21 initially ranged between 9,000 and 10,500 and remained stable between 9,500 and 10,000 during August through October. EC value in TB-45 was generally stable between 7,000 and 7,700 during August and September but fell below 7,000 since the beginning of October.

At the Rayyan test Work Site, the coefficient of permeability in the underground is slightly large. The water (T) from the test trench was thought to be roughly of a quality that was an average of the water of all observation wells mixed together but like Musherib, the EC values of the observation wells surrounding the Rayyan test trench were uneven, some being high and others low, the highest being around TB-24, TB-25, TB-30 and TB-31 as the values on Fig. 4.2.1 show and difference in EC values of this extent continued to be maintained.



Note x: Measured at the end of October'86

Fig. 4.2.1. Electric Conductivity Distribution in Rayyan Test Work Site

4.2.2 pH

On the first day of the start of the test period, water from the test drainage trench and from each of the observation wells showed different pH values reflecting the conditions of each respective sampling point (within a wide range of between 7.5 and 8.3), but before long the pH values of five (5) samples began to settle within a narrow and relatively close range. Then from September through October the variations in pH value became larger on the whole (fluctuated between 8.2 and 7.3) for about one month, the reason for which remains unknown.

4.2.3 COD

The COD values of both the groundwater from the test trench and from the observation wells at the Rayyan Test Work Site occasionally fluctuated, the highest of which was around 12 mg/l. The COD value of water continuously pumped up from the trench in July fell from the highest level of 12 mg/l to the lowest of 4 mg/l, but since the beginning of August until the end of September it fluctuated at around 6 mg/l ± 2 mg/l. Since the end of September it began to rise again until it almost reached an all-time highest of 15 mg/l at one time.

Among the water samples collected from the other observation wells, COD value of TB-45 was the lowest of all since August and for the remainder of the period thereafter (2 to 5 mg/l.)

COD values of TB-21 showed little variation. They were high at close to 12 mg/l initially but fell below 10 mg/l since the end of August to the lowest of 6 to 8 mg/l. COD values of TB-42 ranged between 9 to 5 mg/l until the middle of September but after that rose to approximately the same level as those of water collected from the test trench. Water of TB-25 was around 6.5 mg/l in COD initially during August but rose gradually after that until it reached the highest level of 30 mg/l in October. By the end of October it fell back to 15 mg/l.

On the whole, the water (T) of the test trench and the water of each observation well respectively fluctuated considerably in COD value which reached rather high levels. Only TB-45 on the south side had rather stable and low COD values (below 5 mg/l.)

Note: Adhesion of algae on the internal wall of the trench began to be seen in the later stage of continuous pumping (around October) at the Rayyan test trench. Also, fine soil began to float on the water surface like scum. Although neither transparency of the accumulated groundwater declined nor was there any colouration into green, however the scums on the water surface were broken occasionally during sampling and became commingled in the water samples. The fact that COD values of samples (T) collected since October were high at 11.9, 14.8, 6.1 and 9.4 mg/l may have been due to the effect of those suspended solids. The generation of algae is judged to be attributable not only to the water surface being open but also to the groundwater which contains some nutrients.

4.2.4 Trend of Principal and Anions (CaH, MgH, Ca hardness, Mg Hardness)

CaH of water from the test trench was in the range of 2,200 to 2,500 mg/l (values above 2,500 were recorded only twice), MgH in the range of 1,000 to 2,000 mg/l (around 1,500 on average) and the highest Na+K at 2,500 and the lowest 1,000 mg/l. Every one of these values is considered to range in the middle of the respective value of all other observation wells.

Both cations and anions exhibited extremely large variations at the Rayyan Test Work Site, and their increase and decrease were also violent. The relatively simple and clear-cut tendencies among them are as follows.

a. Ca-SO_4 is soluble to some extent but not only easily solved because its saturation solubility is around 2,000 to 3,000mg/l. Therefore, it does not exhibit any remarkable fluctuation, in other words, its range of variability is narrow.

b. Water from TB-45 exhibited the lowest values (on average) compared to others. In relative terms, water samples from TB-25 and TB-42 generally indicated high values.

c. Water from the test trenches, when compared to water from each observation well, roughly indicated intermediate or average values overall.

d. Na+K showed a wide range of variability in every water sample because of its high solubility.

e. Test samples from Rayyan generally indicated high Cl values and relatively low SO_4 values. It is a tendency quite the opposite of that in Musherib.

f. It was found that the EC-Cl linear relationship in Rayyan and the EC-Cl relationship in Musherib are differently inclined. It is difficult to analyze the reasons for this, but on the whole, it is considered attributable to the difference in salt composition at each location (Fig. 4.2.2)

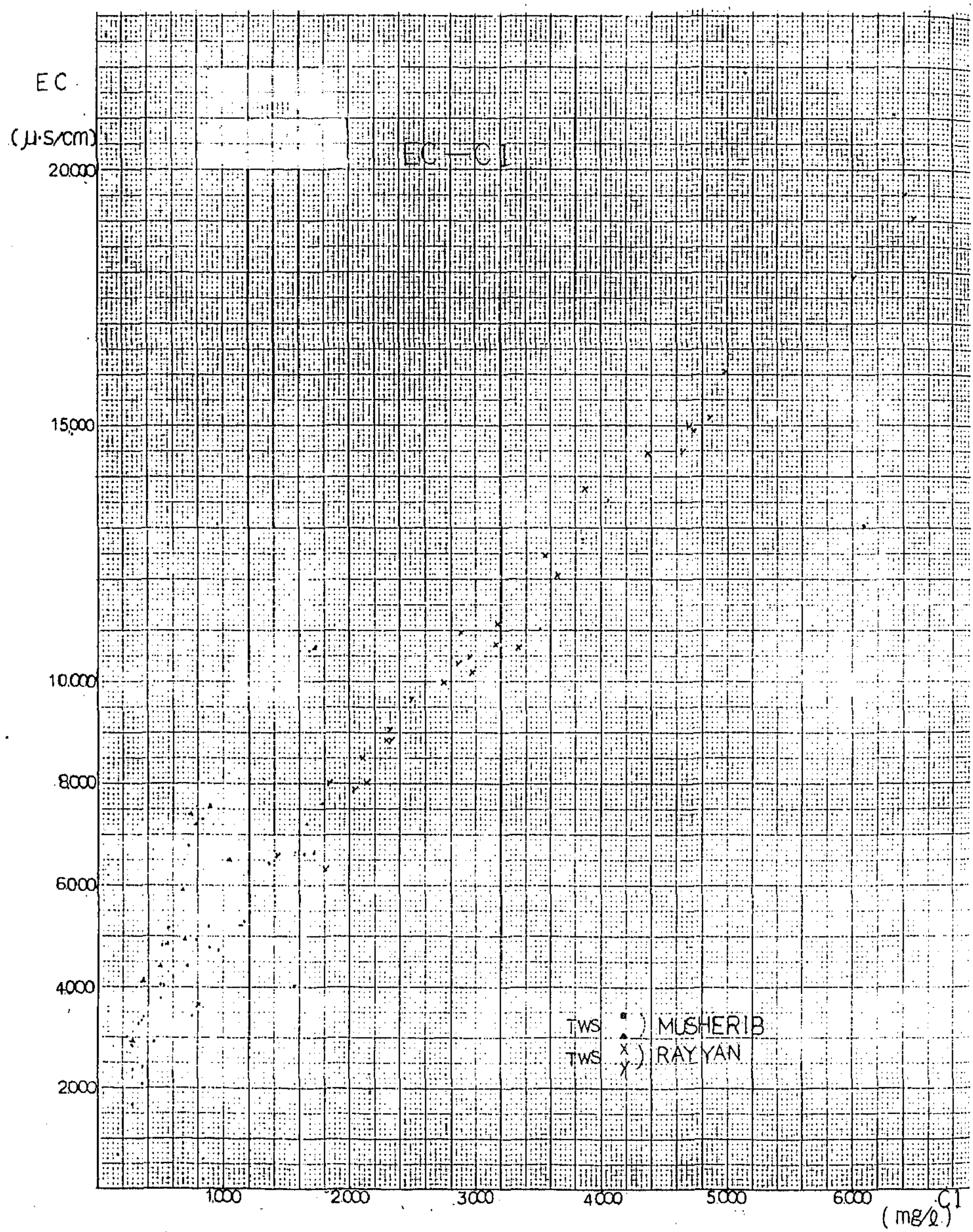


Fig. 4.2.2. Linearity of EC vs. C1

Comparing between those data of Musherib and Rayyan

5. OTHER INFORMATION DATA ON WATER QUALITY

5.1 Quality of Blending (Well) Water for Desalination of Seawater

Qatar has multistage flushing type seawater desalination facilities at two locations, one at Ras Abu Aboud and another on its eastern seashore Ras Fontas (about 10 km southeast of the Doha International Airport Building, on the way to Umm Said) with a combined total processing capacity of 27,000 m^3/day and which jointly supply 189,000 m^3/day of desalinated plain water to the citizens as of 1984.

Desalinated plain water is almost equivalent to distilled water and has corrosive properties. After adding lime, soda ash (sodium carbonate dehydrate) and methaphosphoric acid (Calgon) at the desalination plant the water is directly conveyed to the reservoirs at five locations within Doha (Airport, New Salwa Road, Old Salwa, West Bay and Gharrafa in the north of Rayyan District) and stored. At each reservoir, relatively high salinity groundwater pumped up from the surrounding wells is added in the ratio of about 1.5% (2,870 m^3/day as of 1984) of the quantity of desalinated plain water in order to give it the proper salinity as potable water (EC<500) and supplied to the citizens.

As a reference, the analytical results of the quality of blending (well) water at each of the reservoirs located on New Salwa Road, West Bay, Gharrafa and Wakra are shown in Table 5.1.1. (Examples analyzed at the laboratory of MEW's Water Department.)

Table 5.1.1 Examples of Quality of Blending Well Water at Reservoirs

Date	Reservoirs	Turb.	EC	pH	Alk	TH	TDS	Ca	Mg	Na	Cl	SO_4
Mar.11,'82	New Salwa Road	3.5	6460	7.53	104	2000	5000	568	141	810	500	2795
	(Distillate Water)	0	139	7.48	8	20	83	3.2	2.9	22	36	5.8
	(Blend Water)	1.5	450	7.62	20	100	272	24	9.7	52	100	39.5
Feb.19,'81	West Bay 1	-	13300	7.38	118	3050	9540	780	267	2200	4000	1854
Jul.20,'81	" New 3	3.75	14300	7.25	116	3300	10030	780	328	2200	4050	2280
Mar. 5,'81	Gharrafa	-	9358	6.98	84	2240	6858	584	190	1540	2900	1398
Mar.14,'81	" Rdbt.	4.5	8300	7.37	166	2560	6358	768	155	1010	2020	1722
Oct. 1,'81	" Farm W.	3.5	16300	7.75	148	3820	11990	936	360	2560	4900	2440
Feb. 9,'81	Wakra (32 m)	-	78600	7.36	62	11600	61020	1880	1774	17375	32750	4313
Dec.16,'82	" pumped	4.5	10830	7.68	108	2660	7520	752	190	1520	2760	1978
Mar.29,'84	" TB-4	-	11130	7.00	101	2700	7720	772	187	1620	2800	2140

5.2 Treated Sewage of Doha South Sewage Treatment Works (for reuse)

Doha City has a sewage treatment plant which can treat 54,000 m^3/day of sewage (or serve a population of 200,000 with discharge of 270 l/capita/day (design value) in Naijah in the southern part of the city, which performs primary treatment by sedimentation and clarification, secondary treatment by trickling filter or activated sludge and tertiary treatment by sand filtration. Treated water is disinfected by chlorine and reused as TSE (abbreviation of treated sewage effluent) for greening of parks, road sides and public facilities of Doha City. The quantity of TSE fluctuates according to season but is said to be 14,000 to 16,000 m^3/day. The rest of the treated sewage is discharged into Rayyan Sewage Disposal Sites (consisting of five sites) about 40 km southwest of Doha City in the desert and allowed to evaporate and infiltrate. For reference, some examples of the water quality of raw sewage (influx) and treated sewage effluent (TSE), and the records of the quantity of sewage which were treated at the time are introduced in Table 5.2.1.

Table 5.2.1 Water Quality of Influx Sewage, Treated Sewage and Dipped Up Night Soil

Item	pH	EC	TDS	COD	BOD	Alk	TSS	(Other items)
Influent raw sewage (Dec.25,'98)	7.25	2520	1764	435	186	189		(NH_3-N 23.7)
Final treated sewage (TSE)	7.74	3550	2485	51	-	-	7.8	(Residual Cl 6.2)
TSE, Mar.8,'86 (JICA)	7.55	3350	2345	11				(Alk 140, TH 1985, NO_3-N 0.6, PO_4 7.6)
TSE, Rakhya discharge outlet	7.44	3800	2660	37				(Alk 154, NH_3-N 37, No_3-N 0.3, PO_4 724)
Influent raw sewage (Oct.27,'86)	7.39	3610	2527	290	108	-		(NH_3-N 25.7)
Final treated sewage (TSE)	7.67	3980	2786	45	-			(Residual Cl 3.5, SO_4 710)
Dipped up night soil (tanker), Av.	7.23	(2120)	1482	-	692	425	442	(NH_3-N 133, Cl 227, T-S 6.8)
Dipped up night soil (Oct.28,'86)	7.58	1280	896	-	330	337	320	(NH_3N 107, T-S 26.6)

Quantity of sewage treated examples

December 1985	21(Sat.)	22(Sun.)	23(Mon.)	24(Tue.)	25(Wed.)	26(Thu.)	27(Fri.)
Influent sewage (m^3/day)	51000	53800	56200	55400	55200	56400	57000
TSE Supplied through pipe	3096	7005	8621	8184	8442	8645	6595

October 1986	25(Sat.)	26(Sun.)	27(Mon.)	28(Tue.)	29(Wed.)	30(Thu.)	31(Fri.)
Influent sewage (m^3/day)	67800	53000	66200	64200	54500	64200	66700
TSE Supplied through pipe	12240	11758	10783	10835	10685	9884	9691

5.3 Seawater Quality around the Doha Gulf

Three million m^3/day of seawater is said to be turned into plain water by desalination in the Arab Gulf lately as sources of supplying drinking water to the coastal countries.

As desalination plants intake twice as much as raw material seawater as the quantity of desalinated plain water, half of that content becomes doubly enriched. Accordingly, it means that the saline seawater of the Gulf is not only concentrated naturally by evaporation but also artificially as well.

During the period of this survey , seawater in the Doha Bay was sampled and analyzed. Also, in order to find out the pollution condition of seawater, seawater samples were collected from points along the coastline starting with West Bay (seashore on the east of the University) on the north, then toward south at the Sports Club in Doha Gulf, on the quay and on the seashore nearby the Gulf Hotel, and their COD values were measured. Samples were also taken from within Doha Bay.

The latter samples from within Doha Bay have 3.9 to 4.5 mg/l in COD, which are less than those values for samples along the coastal line. As far as the COD value of the seawater seems to be slightly less than that of the Rayyan groundwater (Rayyan groundwater COD is relatively higher than Musherib groundwater) it seems permissible that the groundwater be discharged into the sea (Doha Bay).

5.4 Heavy Metals in Water

Whether utilizing the pumped up groundwater or disposing of it somewhere, the important question is whether that water is polluted or not in view of the damaging effect that polluted water has on the environment. In this context, the presence or absence of heavy metals in water becomes at issue.

The presence or absence of heavy metals (ions) in water depends on the following causes, namely.

1) As a natural cause, when ores containing heavy metals as geological constituents are in contact with groundwater in the water course of underground aquifer.

2) Particularly prominent examples of 1) above are, when wastewater from mines, or mine water originating in or related to mines is flowing into the natural water area (river, lake, groundwater source); and

3) The influence of human activities, such as the outflow of wastewater from metal-related industries (metal smelting, metal products manufacturing, treatment, metal plating, etc.); and when metal products which are thrown away as wastes by corrosion or otherwise come into contact with rainwater and groundwater and eventually become mixed in the water area (environmental problems).