5.4.1 Heavy Metals in Groundwater Pumped from Two Test Trenches

In the course of the groundwater study this time, the scope of study was contained to analyzing the quality of groundwater pumped up from the test trenches at the two test work sites.

Table 5.4.1 Analyses Results for Heavy Metals of Groundwater
(Analyzed by the Bureau of Food Pollution Surveillance, Regional Centre, Ministry of Public Health, Government of the State of Qatar)

Item	Unit	a) Musherib trench groundwater	b) Rayyan trench groundwater	Japanese Water Quality Standards for Water Supply
Fe	(mg/l)	<0.0010	<0.0010	<0.30
Mn	"	<0.0010	<0.0010	<0.30
Cu	"	0.0230	0.0450	<1.00
Zn	"	0.0290	0.0450	<1.00
Pb	"	0.0026	0.0166	<0.10
Cd	"	0.0006	0.0033	<0.01
Hexad Cr	"	0.0027	0.0091	<0.05

5.4.2 Heavy Metals in Sewage Sludge of Doha City

Today, heavy metals are used for many purposes useful to human life, but when they enter into water (including cleaning water and wastewater) in the process of manufacturing, during use or when abandoned in some way or another, and that water is emitted as sewage with the heavy metals contained thus polluting the environment.

Most of the heavy metals seldom dissolve except in acidic water, and precipitate almost completely if the water is alkaline except in special cases. In sewage, therefore, heavy metals are concentrated in sludge, and if that sludge is incinerated they become concentrated in the ash as heavy metal salts.

At Doha South Sewage Treatment Works, sewage sludges (sludge from primary sedimentation tanks and final sedimentation tanks are gathered and digested) are treated with chemicals (lime, ferric salts) and dewatered. For reference, the analytical results of dewatered sludge cake are presented in Table 5.4.2.

Table 5.4.2 Analytical Results of Heavy Metals Contained in Dewatered Sewage Sludge Cake

Item	August 1984 (mg of metal/g of cake)	December 1984
Na	3.18	2.34
K	0.52	0.89
Cd	0.006	0.007
Cr	0.044	-
Cu	0.536	0.463
Pb	0.348	0.342
Ni	0.050	0.078
Zn	3.26	2.7
Ca	82.64 (about 8.3%)	82.031
Mg	14.95	8.95
Fe	17.6	52.631
Mn	0.119	0.25

The presence of Na, K, Ca and Mg in the sludge is considered to be due to their having entered through groundwater of which they are constituents, Fe and Ca from sludge treatment chemicals that were added, Cu and Zn from water piping and others from articles of daily use (Pb is suspected to have originated from tetraethyl lead in gasoline).

5.4.3 Heavy Metals Indicated in the ASCO's Report

The ASCO's report presents as reference the analytical values of As, Ba, Cd, Co, Cr, Cu, Fe, Li, Mn, Ni, Se, Sn, Sr and Zn as trace components of altogether 12 samples collected from wells, (9 samples from 2239 6PD, 4PD, 1PD, 2239 5PD, etc.) pits and trenches which were presumably excavated on the ground surface. According to this Report, the metal that indicated the highest content was Sr (strontium) with 6.6 to 36 mg/l, which is extremely high compared to other heavy metals. Other analytical values are as follows.

Fe	Range <0.01 to 1.1	mg/l
Li	0.74 to 0.05	"
Ba	0.14 to 0.026	"
Mn	0.1 to 0.012	"

Almost all other metals seem to be below the measurable limit.

It may be presumed that the groundwater in Doha City and its environs do not contain, at least in any significant amount, heavy metal ions based on the collected data in hand.

5.5 Water Quality of Sewage Collected at Each Pump Station

The Doha South Sewage Treatment Works not only checks the water quality related to sewage in the treatment process but also the water quality (EC, Cl ion, sulphide, BOD) of sewage collected at each pump station (abbreviated as PS) in the sewage collection (and transfer) network of Doha City Region, and prepares weekly reports. Table 5.5.1 presents the records for December 1985, April 1986 and October 1986.

Considering that the EC values of the water works and TSE are respectively maintained between 200 to 500 and 3,500 to 4,000 micro mhos/cm for normal supply and that BOD of influx sewage is on the level of 150 to 200 ppm unless diluted especially, it is conjectured that there is some inflow of groundwater into the sewage collected.

For instance, when the sewer piping at PS 26 in the coastal area of West Bay decayed and allowed groundwater mixed with seawater to infiltrate the values of EC and Cl ion increased, but when the pipes were repaired (in April 1986) the values returned to their normal levels. Also, at PS 2 near the municipality building, the inflow of groundwater is conceivable judging from the EC values (April 1986) and BOD values (April and October, 1986) there.

Table 5.5.1 Water Quality of Crude Sewage at Each Sewage Pump Station

Pump Station (Location)	End of Dec., 1985 EC	Cl	S	BOD	April 5, 1986 EC	Cl	S	BOD	End of Oct., 1986 EC	Cl	S	BOD
PS 2 near Municipal Bldg.	2190	515	3.5	100	5730	1495	1.4	47	2480	589	5.5	71
PS 8 North Air Port	1700	364	4.9	161	2710	611	7.6	258	2290	324	6.1	196
PS 7 East Al Ghanim	1710	374	5.6	254	1770	354	7.6	277	2000	451	5.5	315
PS 1 Near Police Station	3130	546	4.2	168	3690	788	6.2	179	3830	843	2.7	116
PS 6 New Doha	2700	444	6.3	154	4880	1323	6.2	182	3140	667	6.8	215
PS18 West Air Port Bldg.	1400	232	8.4	324	2620	414	4.8	198	1020	177	5.5	303
PS 3 North Naijah	1430	253	7.0	154	3330	682	9.0	209	1430	285	8.9	357
PS 4 Al Bida South Corniche Plaza	1320	253	5.6	445	1070	126	5.5	427	1150	172	5.5	558
PS 5 Musherib	2510	354	7.7	277	2310	303	6.9	233	2210	525	6.1	244
PS10 South of PS6	2860	444	4.9	202	2620	429	5.5	228	2180	333	4.1	254
PS11 Montazah	2810	394	7.0	190	2700	424	5.5	201	2540	412	8.9	513
PS30 NW of PS 3 Naijah	2690	364	4.2	130	3280	667	9.0	205	2520	451	6.1	269
PS27 West Bay North	3950	1020	4.9	183	3830	1040	20.3	4248	2740	716	8.9	609
PS25 "	3990	980	5.6	205	6410	1788	6.2	223	4220	1147	3.4	149
PS26/2 " Seaside	12490	4546	4.2	134	14500	4773	5.5	294	2750	775	4.8	206
PS26/1 " "	12550	3939	4.9	128	13910	4722	5.5	275	2770	784	3.4	199
PS26 South West Bay	10430	3182	8.4	260	8820	1891	2.8	154	3620	1029	7.5	193
PS15 Sadd Road West Dam Site	6350	1616	5.6	135	7030	1052	2.1	77.6	4460	1098	3.4	116
PS14 Rayyan	10430	3182	8.4	260	5240	1212	2.5	78.8	5120	1226	3.4	107
PS13 DRR. between Sadd & Jabar	6190	1818	5.6	124	6750	1799	8.6	131.2	4750	1137	2.7	101
PS31 West of PS5 Musherib	5730	1330	2.1	92	2550	389	27.7	156	2600	392	5.5	170
PS20 SW of Rawdat Al Khayl	1000	147	3.5	163	1060	146.5	4.2	212	1270	196	2.7	173

P A R T : D **Damage due to Rising Groundwater**

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D. 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. If the steady rise of the groundwater goes unchecked, future remedy will be very expensive.

In Rayyan, the rising rate at present is 0.3 to 0.5 meter annually. If present conditions continue, the standing water will widely spread, possibly forming a wide water body in the future.

In Wadi Musherib careful attention must be paid to limiting the extent of the Khayl groundwater mound in order to avoid the increase of damage in the future.

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.

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.

1.1 Standing Water

The first survey was conducted during 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. 1.1.1.

As the standing water caused by storm water depends on the rainfall amount and its distribution, Fig. 1.1.1 represents only one configuration of the storm water flooding area which varies with time.

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

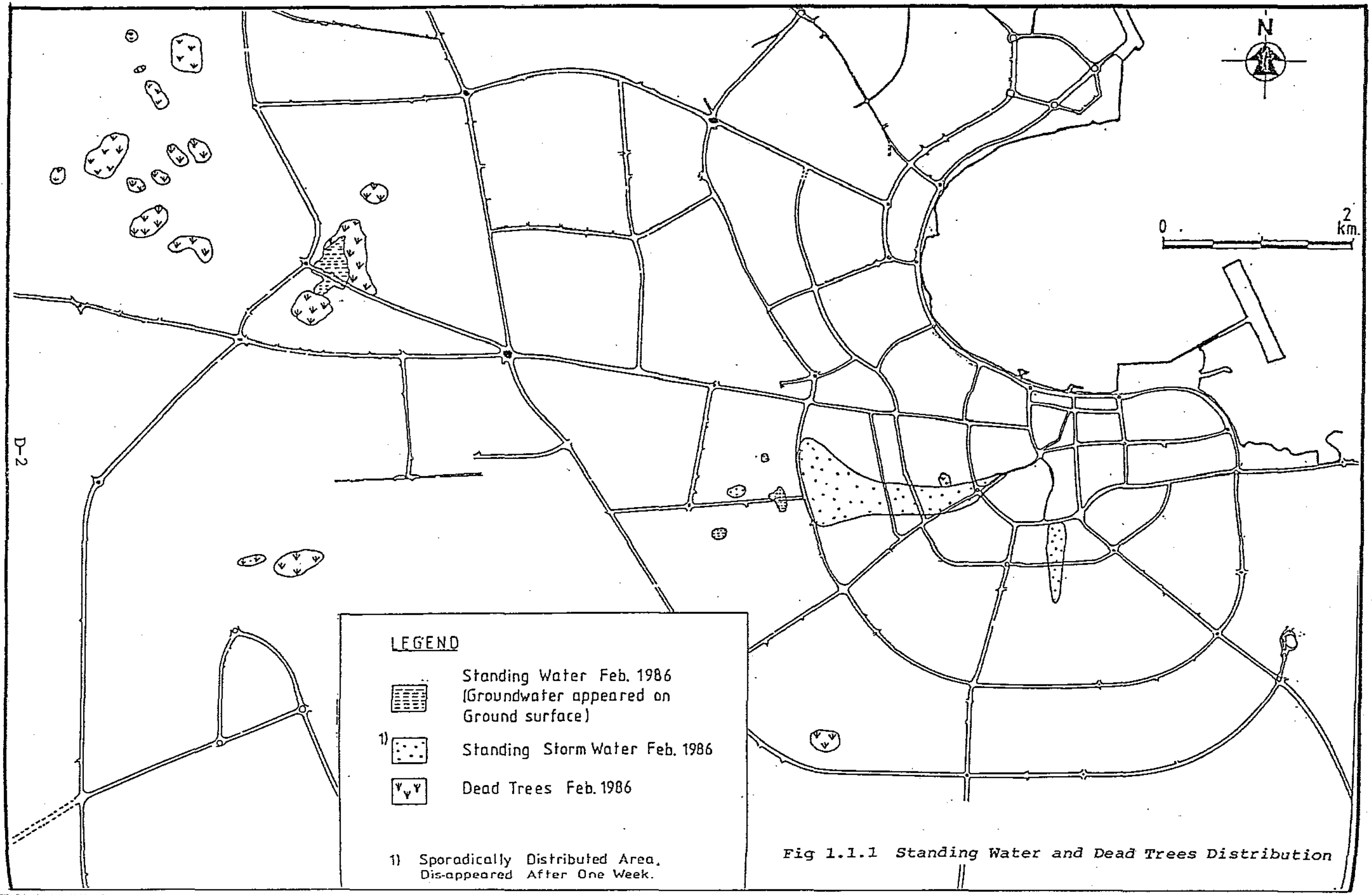


Fig 1.1.1 Standing Water and Dead Trees Distribution

1.1.1 Rayyan

Rayyan is the most affected area. Standing water first appeared in the early months of 1985 but soon decreased due to the strong evaporation during the dry season. The standing water observed in this study is new, reappearing under the weak evaporation conditions of the wet season.

1.1.2 Wadi Musherib

In the Abu Sadirah area where there are many embassies, complaints due to existence of a high groundwater table have arisen. In the field reconnaissance, many low areas, expected to be inundated by the standing water, were found to have been remedied by filling and the actual standing water areas are smaller than before, but the essential problems remain.

The standing water found in the right bank of Wadi Musherib Dam has high salinity in the order of 130,000 micro mhos/cm. This standing water seems to have recently appeared.

1.1.3 New District

Small scale standing water was found in Wadi Sail during the preliminary reconnaissance in Dec. 1985 but has disappeared at present.

1.1.4 Others

Abandoned farm near Al Ahli Sports Club and some areas of Abu Hamour have nearly the same groundwater properties; wetting area by capillary effect is widespread but the areas of standing water are small.

1.2 Dead Trees

A reconnaissance of dead trees was carried out from Feb. 1st to 25th, 1986 and their distribution is shown in Fig. 1.1.1.

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 2.7.

1.3 Building Basements, Roads and Underground Service Facilities

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

- i) Doha Municipality
- ii) QNTS
- iii) C.E.D Sewerage Division
- iv) C.E.D Road Division
- v) Water Department
- vi) Electricity Department
- vii) Materials Testing Laboratory, M.P.W.

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

In the case of structures where there was no groundwater at the time of construction and groundwater level has risen up later, water proofing is not sufficient and leakage is inevitable. In the case of building basements, the construction of containing wall or the operation of dewatering is necessary. Salt particles are deposited on the 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. 1.3.1 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 occuring 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.

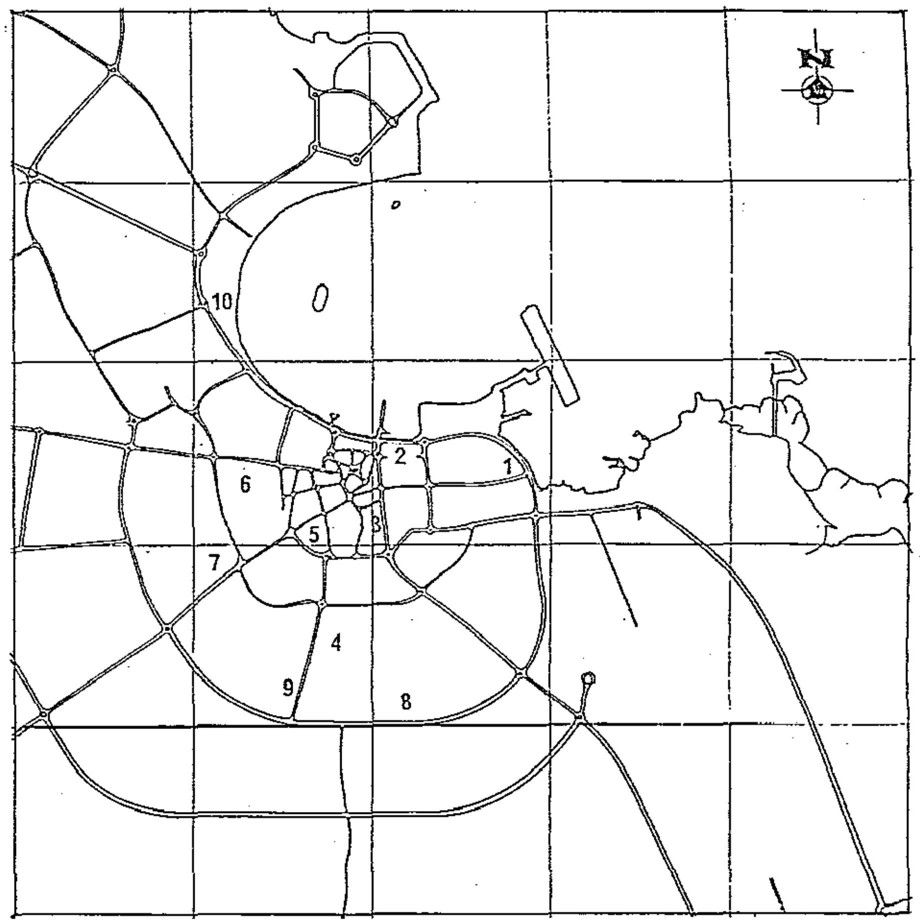


Fig. 1.3.1 Location of Some Structures Effected by Rising Groundwater

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 the 24th February and lasted for one month, ending on the 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 damages and opinions described below were expressed by these parties. In some cases damage was confirmed by site inspection.

2.1 Electric Power Distribution Network

2.1.1 General

The basic power distribution system of the Electricity Dept. uses underground cables. Only Wadi Sail and el Nagem areas have some overhead cables and these will gradually be replaced.

At present underground distribution cables have adequate waterproofing by the use of standard international specifications. Cables are in a lead sheath, surrounded by armour wire and enclosed in PVC ducts. Joints in ducts are well sealed against water entrance.

There are two construction specifications when the cables are laid within the trench. In the case of the cable going in at the same time as a new road is being constructed, SRC concrete is used as fill. When cables are being laid in existing roads and there is not enough time for the concrete curing, then cables are embedded in a 50 cm thick dune sand layer.

2.1.2 Effects of rising groundwater

(1) The trenches where dune sand is used sometimes act as a groundwater flow passage and groundwater flow may wash out the sand, causing subsidence and endangering the cables. To remedy this the Electricity Dept. has added a new specification that in areas where there is a high groundwater table, dune sand must be placed within a lining of "Non Woven Filter Membrane". This membrane allows the water to pass through while keeping the dune sand within. This membrane adds an extra cost of approximately 20 QR/m.

(2) Excessive dewatering operations during maintenance in wet areas must be carefully planned and is time consuming. A number of pumps are needed and the possibility of discharge into sewerage system must be considered. The Electricity Dept. has only one tanker so if tankers are needed, the number and provision of tankers must be decided upon.

While figures on extra costs which are encountered during such dewatering efforts could not be obtained, Electricity Dept. confirmed that such efforts are time consuming and costly.

(3) Installation prices quoted for wet areas are higher than those in dry places.

In the case of contracts in wet areas two additional clauses have been added, one obliging the contractor to make all necessary arrangements at his cost to remove the water from the trench, and the second is to use the Non Woven Filter Membrane.

(4) Joints of PVC ducts are enclosed in cast iron boxes and sealed by waterproof compounds so there is little danger of water intrusion. However in older type of joints, or where there is bad workmanship, water enters the ducts and corrodes the armour wire. There is such damage in the network but it is not widely spread.

(5) In some old substations in the Wadi Musherib area, the thickness of the concrete base is not sufficient or the groundwater becomes too high, and settlement occurs when the heavy transformers are placed.

In Rayyan cracks have appeared in foundations and walls of some substations, and officials believe this may be due to bad workmanship and/or settlement.

(6) In some places of the city where the old cables are still in service, there has been damage by groundwater. Old cables were wrapped with hessian instead of being enclosed in PVC ducts, and in some places the hessian is worn out.

2.2 Qatar National Telephone Service (QNTS):

2.2.1 General

The basic policy of the QNTS is underground cabling, although at the subscribers end the cabling is overhead.

The telephone cables are waterproof and run in PVC ducts. Joints between ducts are spigot type and are not waterproofed. Exchange cables have pressurized air inside such that in case of damage, air is released sounding off an alarm, as well as preventing water from coming into cables. On the distribution side, cables are jelly (grease) filled, which is also a waterproofing measure but with less effectiveness than the pressurized air.

Manholes in the system vary in size according to location, whether on the exchange side or the distribution side. All manholes are made from concrete, some are reinforced and others are plain concrete.

2.2.2 Effects of Rising Groundwater

(1) The groundwater is running through the PVC ducts and enters the manholes at the entry point of the ducts into manholes. To minimize the entrance of water into manholes a rubber material wrapping filled with resin is applied as a sealant between the cables and ducts at entry points, but this is costly and not so effective.

(2) In case of jointing operations (installing new lines), manholes must be kept dry for 2 to 3 days while the work is proceeding. Jointing is carried out about 4 times annually. Efforts exerted in dewatering when working in manholes full of water can double the time required, and it is thus costly and time consuming.

(3) Maintenance and repair works in manholes full of water can in some cases increase the time that would be needed in dry conditions, from 5 to 7 times. In the manhole facing the QNTS headquarters, 24 hours of continuous pumping is necessary before any work can proceed in it. QNTS manholes in the city center, within the 'B' Ring Road are mostly filled with water.

For dewatering operations QNTS has two tankers, but sometimes it is necessary to hire more tankers, thus increasing costs. QNTS also uses 17 units of 2-inch pump, and 1 unit of 4-inch pump.

(4) The exchange chamber where all the telephone lines of Qatar terminate is located underground, in front of the Cable and Wireless Headquarters. There is leakage of groundwater into the chamber from the points where the cables are entering the chamber, and from the corners. Salt contamination can be observed at the cables entry points and on parts of the walls. Three years ago this chamber was filled with water. The steel racks carrying the cables are coated with paint at the legs in order to prevent corrosion. Parts of the vertical walls have been rendered, but the rendering is peeling. QNTS has had concrete cores from the walls sampled and the strength of concrete was reported satisfactory. A pump is located at the corner of the chamber, in a sump pit and is activated automatically should the water rise above a certain level.

QNTS fear that if water level was to rise in this chamber some cables would be damaged inspite of the waterproofing measures taken.

(5) A severe health hazard facing QNTS work crews is the strong presence of hydrogen sulphide in some of its manholes which are filled with water.

2.3 Sewerage Network

2.3.1 General

Pressure lines are made of ductile iron pipes, and recent gravity lines are vitrified clay pipes. Formerly gravity lines were made of asbestos cement pipes.

In recently constructed manholes, tanking is done and the walls are thicker. Manholes are made of plain concrete, using sulphate resisting cement.

Up to 1978-79 the sewerage system was designed to carry 180 lit/cap./day. Due to increase in consumption, factories draining on main supply and other changes, the design figure was revised to 270 lit/cap./day.

Ninety percent of installation works are done by local contractors. Before a project is put out to tender, a site investigation is performed and project documents clearly state site conditions and groundwater table levels.

2.3.2 Effects of Rising Groundwater

(1) Intrusion of groundwater into the sewerage network is about 30% of the total flow. Intrusion occurs through cracks in damaged asbestos cement pipes, which are mainly located in shallow groundwater table areas. Roughly 40% percent of the groundwater intrudes in this way. Other means of intrusion include old manholes, and some parts of vitrified clay pipe system laid in the West Bay, which have been damaged due to settlement.

(2) Consideration is being made to repair the old manholes by lining them from inside with glass reinforced plastic (GRP), mainly to protect concrete against hydrogen sulphide attack.

(3) For all new manholes, tanking is done and for main lines GRP lining is also provided. Lining of GRP increases the costs by about 20%. Tanking of manholes also increases expenses. This may be considered as an extra expense necessitated by the rising groundwater.

(4) Sometimes tenders for house connections are put out on a fixed rate basis. In such cases, for house connections in high groundwater areas, the rate is 50% higher than for connections in dry locations.

(5) In most cases maintenance work is done by the Sewerage Section. When working in wet areas more time and effort in dewatering is required, thus increasing cost.

Extra water being pumped by the sewerage pumps tends to reduce the pumps life, making it necessary to pay for repair and replacement.

(6) In case of installation works, installation in dry areas as opposed to wet areas can be 20 to 30% cheaper depending on project value.

(7) Groundwater of high salinity in the New District attacks the pump impellers, corroding them, and again more expense is necessary for repairs and replacement.

Rising mains may be attacked by corrosion from the high saline groundwater and in the long run it is possible that this may have a bad effect.

(8) Retention time at the Doha South Treatment Works is designed for sewage water containing a certain amount of bacteria. When groundwater intrudes into the sewage water it dilutes it, and the same bacteria content has to cope with a larger amount of water. Theoretically in order to solve this problem, it is necessary to increase retention time, but that in turn would effect the works' other operations. So actual retention time is maintained as it is, and subsequently officials at the treatment works feel that quality of treated sewage is less than the standard the works can produce.

(9) Presence of hydrogen sulphide creates bad odour in pumping stations and causes corrosion problems.

2.4 Potable Water Distribution Network

2.4.1 General

The main pipelines are made up of a mixture of ductile iron and asbestos cement pipes. Only small sections of the network are cast iron pipes and these are being replaced. At present replacement of asbestos cement pipes is proceeding and within 2 - 3 years all the system will be made of ductile iron pipes. Pipelines located within the 'B' Ring Road are mainly made of galvanized steel, polythene or asbestos cement. Eighty percent of the system is gravity fed by water towers and pumping stations.

Pipes are protected against corrosion by the use of polythene sleeving and waterproofing. In future there are plans to apply zinc coating. New service connections are copper with plastic coating, however 60% of service connections are the old plastic type.

An average of 10 to 12 leaking underground pipes are repaired daily. Damage is usually caused by heavy traffic, ground movement or excavations by other parties. Daily maintenance works are done by Water Department labour groups. Due to the nature of the work, maintenance and installation works are usually carried out in wet conditions due to the water in the pipeline.

2.4.2 Effects of Rising Groundwater

(1) Due to the economic situation of the country the prices of installation have gone down, although dewatering efforts may have increased in parts of the city. For installation costs of pipelines at West Bay, which has a high groundwater table a contractor adds an extra 10 QR per meter to his tender.

(2) Officials believe that a properly laid ductile iron main should last 60 - 70 years, yet they have found that many ductile iron mains laid 10 to 15 years ago, especially in the secondary distribution system, have been damaged by corrosion. They believe that the main cause for this damage is excessive irrigation practice, but they do not rule out bad workmanship or groundwater as contributing factors. The Study Team were shown samples of corroded ductile iron pipes and copper service connections.

(3) One problem about the rising groundwater is that the Water Department's Distribution Section receives many complaints and requests to investigate areas where there is fear of burst or leaking pipes, but many times after running tests and wasting time it turns out to be groundwater instead. Such false alarms have increased in the past few years and are a nuisance to the section and costly in both time and money.

(4) Some areas of the city are under partial supply of potable water, in the range of 14 to 18 hours daily. Therefore pipes are not constantly under pressure so the officials fear possible groundwater intrusion in the system through cracks and faulty joints, although to date they are satisfied that such intrusion has not occurred.

2.5 Roads Network

2.5.1 General

Previously on the design of roads no consideration was given to the presence of high groundwater table. Waterproofing precautions, such as placing polythene sheets or concrete lining were considered too costly.

Roads Division officials consider it is generally difficult to construct storm water drainage system for the roads in Doha, since it is usually not possible to find a place to drain the water. Only Musherib road is at present having a drainage system installed in it. In some roads surface sewers have been provided such as Grand Hamad Ave., Jasser Road and under Ras Abou Aboud flyover.

Groundwater is not considered a major problem for the roads and is effecting only 2 to 3% of all roads in Qatar. The Roads Div. considers that the major problems for roads in Qatar are overloading and poor quality of construction materials.

2.5.2 Effects of Rising Groundwater

(1) Quite a few old roads have been damaged in the city and Rayyan area where the subbase has been weakened by the groundwater. However there are no figures describing the extent of the damage.

(2) At present in Wadi Musherib in some places groundwater level is directly below the tarmac, and at other places the level is up to the subgrade.

(3) In infill areas of West Bay it was necessary to alter the design of roads, by increasing subbase thickness (adding an extra layer) to protect the road from the rising groundwater. This extra thickness can in turn increase the costs by 10 to 15%.

2.6 Standing Water

Talking with residents, shopkeepers, and pedestrians revealed that in some places streets usually remain wet for around one week after heavy rains. In some streets tankers come and remove the surface water but that is not always done.

The Health Affairs Section, of the Doha Municipality receives few complaints regarding standing water in the streets, and as often as possible the municipality tankers are dispatched to remove such water. As for fighting mosquitoes breeding in the standing water, the Health Affairs Section uses spray and powder insecticides. But the section does not apply insecticides to private lands, such as farms, unless requested by the owner.

In Rayyan, where the standing water covers wide areas in some of the farms, the Study Team members talked to residents living in that area, who complained of the mosquitoes and odour. Mosquitoes could be seen in the standing water. Residents explained that in one farm water started appearing above ground surface around 6 months ago (i.e. September 1985). The owner of that farm lives elsewhere and has not cultivated his farm for over 10 years.

2.7 Cultivation

2.7.1 General

Since the beginning of the damage survey, a keen interest developed to look into any possible connection between the dead and dying palm trees and abandoned farms on the one hand, and the groundwater used for irrigation and standing water on the other hand.

The investigation relied on hearings with officials involved in agriculture & irrigation and also farmers. Many opinions exist and unfortunately to date there has been no study on this matter specifically.

Due to the importance of this subject all the factors that may have contributed to this phenomenon are outlined hereunder based solely on the hearings. It is hoped that in the near future a more detailed study will be conducted regarding this matter.

2.7.2 Notes on dead trees

(1) In Rayyan there has been a steady trend of farm owners abandoning agriculture in favour of urban development. Reasons mentioned were the small profits gained from farming, and also the attraction of constructing housing and other development projects on the farmland.

One explanation of the dead trees is that owners intentionally abandon their farms till the cultivation dies and the soil becomes poor, so as to overcome any existing zoning laws that may be in force against development in favour of agriculture.

(2) Talking with Rayyan farm owners where some farms have water above the surface and the trees are dying, they commented that around 4 years ago salt contamination signs began to appear on the top soil, and about 6 to 12 months ago (i.e first half of 1985) the palm trees began to die as water started to rise above the surface. In these farms, farmers believe the death of palm trees is due to presence of too much water.

Some officials stated that main reason for this phenomenon was intrusion of seawater into groundwater due to overpumping for irrigation and subsequent high increase in salinity of groundwater.

(3) One opinion was that poor farming due to decrease in quality and number of manpower (farmhands) was the reason. Perhaps the multinational composition of the farm work force is another factor since irrigation practices and soil characteristics differ from one country to another.

(4) One factor remains which it was not possible to definitely confirm, was the presence of insect attack or disease that is attacking palm trees. This beetle is said to have originated in Saudi Arabia and has in the past 3 to 5 years spread among the Gulf countries. Sometimes palm trees are imported from Saudi Arabia and Iraq for planting in Qatar.

2.8 Safety of Structures

2.8.1 General

There was an interest in finding the effects that rising groundwater has on the construction industry at present and will exert in the future. Construction projects were visited, interviews with officials, consultants, and contractors held and follow up on information regarding known cases of leakages.

The Doha Municipality, Project Section and Technical Affairs Section play the leading roles in regulation of projects, and the checking of documentation and drawings, while the structural safety of projects is the responsibility of three parties, namely consultant, contractor, and owner.

Concerning waterproofing precautions projects must adhere to the Qatari building codes which specify use of SRC concrete up to ground level, bituminuous coating, and 40 mm cover for reinforcement on the exposed side. Yet there are doubts among all concerned as to the extent the private sector projects follow these specifications. Choice of site investigations remains with the designer, although there have been cases in governmental projects where Doha Municipality requested additional tests.

Project drawings are all submitted to Doha Municipality and after being checked internally and approved by different utilities construction may proceed. Design calculations are not submitted unless specifically requested. In case of private projects there is hardly any site construction follow up from the Municipality's side. 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 problem in some ares of the city deems this necessary.

Use and type of waterproof membrane is left to the consultant and contractor and the Study Team members have visited two sites located alongside each other, of the same height and both having raft foundations. One site was using waterproofing membrane in addition to the bitumen coating, while the second was only applying bitumen coating.

The Study Team was informed of two sites where owners could not receive completion certificates, due to leakage problems in basements.
But site visits and hearings could not confirm whether leakage was due to poor workmanship or no waterproofing for one of the sites, while clearly poor workmanship was the reason on the second site.

The most dangerous situation that was brought to the Study Team's attention is when the owner is himself the material supplier and contractor. There have also been many complaints from consultants about owners who refuse to do tests considering them expensive or unnecessary, or do not follow consultants site supervision instructions. Usually in private projects consultants have little power, and thus mostly prefer to work on governmental projects, where the client is very powerful, and the contractor very obedient.

This state of the construction industry can be summarized in very rapid development, strong control of governmental projects, with weak control over private projects.

2.8.2 Findings

(1) Basically there is unified agreement among consultants that failures in old buildings are anticipated in the not to distant future. Failure may be due to a number of factors such as use of seawater and beach sand over 10 years ago as construction materials, poor workmanship and rising groundwater with inadequate insulation measures. Arrangement of these factors in the order of the most influential differed from one source to the'other.

The hearings did not lead to any case where it was believed that building or structure failed due to groundwater.

(2) The study team visited 4 completed projects where leakage has actually occurred. For two of them remedial measures have been taken to waterproof from inside. However the walls of basement from outside are badly waterproofed and it is expected that there is a danger of reinforcement corrosion.

(3) Contractors interviewed generally know the areas of the city having high groundwater table and their bids adequately cover dewatering operations. Estimation of increase in construction costs due to dewatering operations varied from 20 to 30% of costs of foundations construction.

The complaints of owners were concentrated in the increased construction costs due to the rising groundwater. Due to this increase some owners could not start construction, and in other cases owners who were originally planning to build 4 or 5 story buildings had to settle for 2 to 3 stories to keep down prices of foundations.

(4) Consultants fear future problems in the West Bay area. Some firms consider that extra attention is necessary when designing the suitable foundation.

(5) In the Materials Testing Laboratory of the Ministry of Public Works, waterproofing materials may be tested. However the opinion is that not all waterproof membranes now being used are satisfactory, and the often poor quality of foremen and labour in construction sites is aggravating the problem.

(6) It is safe to say that in this young industry the pace of development has been very rapid in the past two decades. Any effects of poor workmanship, poor materials, inadequate professional supervision, bad designs, high temperature, etc are only recently beginning to emerge and are causing concern. Rising groundwater can only worsen the problem, in many cases accelerating the damage.

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

3.1 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

3.2 Evaluation

Table 3.1.1 describes in detail the damage effecting each sector, and its evaluation in terms of its influence. At times repetition was unavoidable since one damage item may exert various influences.

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
- Strucutres : Dewatering site

iv) Increase of running costs

- QNTS : Continuous dewatering of Exchange Chamber
- Sewerage : 30% groundwater intrusion into network

v) Health hazard

- QNTS : Groundwater mixed with sewage in some manholes, having a very high rate of hydrogen sulphide
- Standing water: Breeding of mosquitoes and odour emission

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 damages 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

Table 3.1.1 Technical Evaluation of Damage

I - DIRECT DAMAGES

1) QATAR NATIONAL TELEPHONE SYSTEM

Evaluation Criteria	Damage Item	Technical Description/Observation	Actual Countermeasures
A) Lowering Service Level	Exchange chamber located underground infront of Cable & Wireless head-quarters, houses all the cables of Qatar. 3 years ago constant leakage into the chamber flooded it and disrupted services.	Salt was observed appearing on the chamber concrete walls. Water was leaking in at entrance points of cables into the chamber. Steel racks carrying the cables had some rust.	Sump pit constructed in chamber corner with an automatically activated pump placed in it. Concrete cores taken from chamber walls to test strength, were satisfactory. Steel racks were painted to protect against rusting.
B) Increase Maintenance and Repair Costs	QNTS manholes located in the city center, within the B ring road are mostly filled with water. Dewatering operations during repair works increase time and costs.	Groundwater runs through the QNTS duct, which do not have waterproof joints, and enters the manholes at entry points of ducts.	QNTS are now inserting some resin filled rubber membrane as sealant at entry points but these are not so effective, and are costly.
C) Increase Construction Costs	In case of jointing operations (new lines installation), manholes where work is proceeding must be dry, involving costly and time consuming dewatering operations.	Jointing operations are usually carried out 4 times annually, and manholes must be kept dry for 2 to 3 days continuously while work is in progress.	Continuous dewatering operations using various equipment as pumps, tankers, electric generators, air pumps, etc.
D) Increase Running Costs	Continuous dewatering operations to maintain Exchange Chamber dry.	Stoppage of the pump located in the chamber may lead to its filling with water, as happened 3 years back.	Use of sump pit as described above.
E) Health Hazard	Groundwater contaminated with sewage and found in some manholes, has in the case of the QNTS caused death to 2 maintenance crew members a couple of years back.	Contamination is very marked in QNTS manholes located between Cable & Wireless roundabout and Jaidah Flyover. This condition where only hydrogen sulphide exists, with little or no oxygen is deadly.	QNTS has taken stiff measures to prevent reoccurance of tragedy such as usage of gas detection equipment, clearly visible warning signs within the manholes, and forbidding use of manholes that are heavily contaminated.

(cont.)

2) ELECTRIC POWER DISTRIBUTION NETWORK

Evaluation Criteria	Damage Item	Technical Description/Observation	ActualCountermeasures
A) Lowering Service Level	Damage by other parties of cables located in shallow groundwater areas.	If such damage is not immediately reported, groundwater will intrude into damaged cables and create power failures.	Electricity Dept. is increasing the awareness of other services that prompt reporting, can in turn allow the dept. sufficient time for repairs without power failures.
B) Increase Maintenance and Repair Costs	Maintenance work in shallow groundwater areas.	Work requires more time and efforts for dewatering operations, then similar works in dry areas.	Electricity Dept. must plan and procure needed equipment for dewatering, and department has only one tanker available so equipment hiring or borrowing is always necessary.
C) Increase Construction Costs	Laying of cables in shallow groundwater areas.	Installation prices are higher than for those in dry areas.	Two additional clauses have been added for contracts in shallow groundwater areas. The first obliges contractor to maintain the trench dry, and the second is to surround fill material in trench by non woven filter membrane (when not using concrete as fill). Membrane adds an extra cost of approximately 20 QR/m.
D) Shorten Facilities Life	In old network ducts groundwater enters through cracks in ducts enclosing cables, or through worn hessian used instead of ducts.	Such intrusion corrodes the armour wire entwining the cables, used as protection.	Old portions of the network are being replaced and such damage is not wide spread.
	Washing out of trench fill material.	This results in subsidence of cables and consequent damage.	To counter this "non woven filter membrane" is being installed in trenches to prevent washing out of the dune sand used as trench fill. Also in some cases cables are embedded in SRC concrete.
	Settlement of some old substations in the Wadi Musherib area.	In some places substation concrete base thickness is insufficient and together with rising groundwater table, causes settlement to occur when heavy transformers are placed.	Care is taken in constructing base of sufficient thickness for new manholes to be constructed in the shallow groundwater areas.
	Cracks in foundations and walls of some substations in Rayyan.	It is considered that such cracks are caused by bad workmanship or settlement.	More control is being exerted during construction and groundwater conditions are considered during design.

(cont.)

3) SEWERAGE NETWORK

Evaluation Criteria	Damage Item	Technical Description/Observation	Actual Countermeasures
A) Lowering Service Level	Intrusion of groundwater in the network is estimated to be approx. 30%.	This intrusion creates extra work to pumping stations and network and decreases quality of treated effluent.	Design figures for capacity in 1978 - '79 was 180 lit/cap/day, which had to be revised recently to 270 lit/cap/day to accommodate intruding groundwater and other factors.
B) Increase Maintenance and Repair Costs	Maintenance work in shallow groundwater areas.	More time and effort needed for dewatering operations.	
	Increase in corrosion of pump impellers requiring additional maintenance.	High salinity of groundwater.	
	Increase wear due to high pumping rates requiring additional maintenance.	Rates increased due to 30% increased capacity from groundwater intrusion.	
C) Increase Construction Costs	Dewatering operations during installation of new pipelines.	Installation in shallow groundwater areas as opposed to dry areas can be 20 to 30% more expensive, depending on project value.	Before project is put out to tender, the Sewerage Division undertakes site investigation and project documents clearly describe site conditions and groundwater levels, so contractors can bid according to site conditions.
	Dewatering during installation of house connections.	Installation costs of house connections in shallow groundwater areas can be 50% higher than for dry areas.	
	Tanking of all new manholes, and glass reinforced plastic lining from inside for manholes on main lines increases costs.	Some measures are required for water-proofing manholes from outside, as well as preventing sewage within to escape. GRP lining increases costs by about 20%.	
D) Increase Running Costs	Intrusion of groundwater in the network at the rate of @ 30%, increases running costs. Also intrusion results in diminution of natural gravity flow in sewerage system necessitating use of tankers to transport sewage from septic tanks, thus increasing costs.	40% of intrusion occurs through cracks in damaged asbestos cement pipes, mainly located in shallow groundwater areas. Intrusion also occurs through old manholes, and some sections of vitrified clay pipes laid in West Bay, which have been damaged due to settlement.	Asbestos cement pipes are being replaced by vitrified clay pipes.

(cont.)

3) SEWERAGE NETWORK

Evaluation Criteria	Damage Item	Technical Description/Observation	Actual Countermeasures
E) Shorten Facilities & Equipment Life	Shortening of pump life due to groundwater intrusion and salinity.	Saline groundwater attack causes corrosion of pump impellors. Extra amount of sewage effluent due to groundwater intrusion also reduces pumps life.	
	Ducts are usually embedded in dune sand which is washed out of the trench by the groundwater flow.	Pipes laid in the West Bay area have been subject to such damages and subsequent subsidence of pipes has caused cracks.	Some measures have been taken to prevent washing out of fill material by use of non woven filter membrane. Various options as countermeasures are being tested at the Materials Testing Laboratory, of the Ministry of Public Works.

4) POTABLE WATER SUPPLY NETWORK

Evaluation Criteria	Damage Item	Technical Description/Observation	Actual Countermeasures
A) Increase Construction Costs	Increase of installation costs of pipelines at West Bay, where the groundwater is shallow.	At West Bay, prices for laying new pipelines increase by 10 QR/m.	
B) Shorten Facilities & Equipment Life	Corrosion of relatively new ductile iron mains in secondary distribution system and copper service connections. Officials consider this is mainly due to excessive irrigation, but they do not rule out bad workmanship and groundwater as contributing factors.	Corrosion appears on bottom side of relating newly-laid ductile iron pipes and is from the outside inwards. Copper pipes have holes caused by corrosion and their plastic sleeve has cracks and cuts.	More care is being taken in quality of waterproof wrapping and ensuring it is placed. Zinc coating will be specified in the future pipe laying. As for copper pipes at present only replacement of damaged sections is being done.
C) Lowering of Quality	Possible intrusion of groundwater into network.	Although this damage has not yet been reported, presence of corroded pipes in areas having partial water supply is creating concern to officials.	Repair of corroded pipes, either by replacement or using "stainless steel collar" around damaged sections.

(cont.)

5) ROADS NETWORK

Evaluation Criteria	Damage Item	Technical Description/Observation	Actual Countermeasures
A) Increase Maintenance and Repair Costs	Repair of damaged roads in city area and Rayyan.	Damage occurs in old roads where subbase has been weakened by the groundwater.	Previously in design of roads, no consideration was given to groundwater. Precautions such as concrete lining or polythene were considered too costly.
	Removal of standing water on streets after heavy rains.	In some streets water may remain for 1 week to 10 days causing some disturbance to traffic and pedestrians.	Water is removed by tankers sent by the Doha Municipality Health Affairs Section or belonging to Roads Div. upon receiving requests or complaints.
B) Increase Construction Costs	Extra layer of subbase thickness was added to the new roads in fill areas at West Bay as protection against rising groundwater table.	Extra layer has increased costs by 10 to 15%. Dewatering efforts are also costly.	Roads Division carries out site investigation before project execution and contractors are informed of site conditions prior to bidding.

6) STRUCTURES

Evaluation Criteria	Damage Item	Technical Description/Observation	Actual Countermeasures
A) Increase Maintenance and Repair Costs	Dewatering and repair where leakage occurs in building basements and underground structures (storage tanks for petrol stations, parking facilities, etc.).	Leakage has been observed in old and recently built structures as well as some under-construction projects. Groundwater leakage may be due to inadequate waterproofing, bad workmanship, poor quality materials or a combination of these factors.	Remedial efforts such as increasing waterproofing from within, grout injection or others.
B) Increase Construction Costs	Construction costs for building in shallow groundwater areas have increased.	Increased costs have delayed commencement of some construction projects, and scaling down in height or size of others in order to reduce expences. Waterproofing measures has increased foundations construction costs by 20 to 30%.	In shallow groundwater areas dewatering operations and waterproofing measures are employed.

(cont.)

6) STRUCTURES

Evaluation Criteria	Damage Item	Technical Description/Observation	Actual Countermeasures
C) Decrease in Quality and Safety of Structure	Fear among consultants, contractors and some officials that rising groundwater table, in association with other factors as bad workmanship or poor materials may endanger structural safety of existing old buildings (not insulated) and even some relatively new projects.	Observations such as no insulation for footings in newly constructed building in shallow groundwater area, no insulation for foundations in many single storey houses in the city, insufficient site investigation tests performed in some private building sites and poor insulation in others, presence of some poor quality waterproofing materials in the market, leakages in old, new and presently under construction projects, were all reported indicating potential danger to structures throughout the city from the rising groundwater problem.	Qatari Building Codes have specified 3 specifications as waterproofing measures, namely use of sulphate resisting cement in concrete mixture up to ground level, coating of foundations with bitumen and a minimum reinforcement cover of 40 mm for exposed surfaces. While such measures and others are observed in government projects, control is weak regarding private projects. Furthermore facilities at Materials Testing Laboratory of MPW are used for testing waterproofing materials, etc. Tests are made free of charge.

7) DEWATERING EQUIPMENTS

Evaluation Criteria	Damage Item	Technical Description/Observation	Actual Countermeasures
A) Shortening of Equipment Life	Heavy usage of pumps and tankers for dewatering operations by all services.	Arranging means of discharge (sewage network, direct discharge into sea, others) and needed equipment is time consuming and costly.	Services try to plan ahead when working in shallow groundwater areas and when necessary sometimes hire or borrow tankers and pumps.

(cont.)

8) STANDING WATER

Evaluation Criteria	Damage Item	Technical Description/Observation	Actual Countermeasures
A) Health Hazards	In Rayyan, in some private farms groundwater has appeared above the surface. In March, in Wadi Musherib very small pools of standing water caused by groundwater were found.	In Rayyan, odor emitting from the standing water and mosquitoes breeding in it, form a health hazard to the surrounding residents, and are a source of constant complaint. In Wadi Musherib the existing standing water was too saline to allow for breeding of mosquitoes.	Authorities at the Health Affairs Section of Doha Municipality carry out insecticides spraying to kill mosquitoes but they do not spray in private farms unless requested by the owners, for fear of harming the farm. Some residents near one private farm complained that the farm owner lives far from the farm and has not been utilizing it since over 10 years, and is doing nothing about the standing water problem in his farm.

9) VEGETATION

Evaluation Criteria	Damage Item	Technical Description/Observation	Actual Countermeasures
A) Decrease in Quality	Some farmers in Rayyan area complain that since 4 years ago signs of salt contamination began to appear on the top soil.	Many farmers and officials are concerned that salt contamination of the soil is causing death to some vegetation species, and obstructing the growth of others.	Officials at the Dept. of Agriculture & Water Research complained that some farmers in trying to eliminate the contaminated upper soil layer, were over irrigating by well water. Over use of well water meant in turn over extraction and subsequently the groundwater became highly saline. Efforts are being made by the Dept. to stop this practice and teach the farmers better agricultural methods.
	Farmers complained about the increased salinity of the groundwater extracted from the wells.	The theory that some farms have been abandoned or the phenomenon of dead palm trees in the Rayyan area were due to the rising groundwater and its salinity, as suggested in some previous studies, could not be confirmed from hearings with concerned officials. Some farms have been abandoned in favour of using land for development projects.	No study regarding the phenomenon of dying trees in the Rayyan area is at present being executed and there are many ideas as to the cause, however none are substantiated by research or facts.

(cont.)

II - INDIRECT DAMAGE

1) LAND USE

Evaluation Criteria	Damage Item	Technical Description/Observation	Actual Countermeasures
A) Decrease of Land Use Possibility	In some shallow groundwater areas, owners of land who wanted to construct 4 - 5 storey buildings had to settle for only 2 or 3 storey structures to reduce construction costs. Sometimes projects were delayed altogether due to increased costs.	The Doha Municipality had the same problem when they wanted to construct underground parking facilities nearby the Hotel Sofitel, but had to change the project to above surface multi-storey garage, in order to avoid high costs of construction of subsurface structure since the groundwater is very shallow in that area.	

2) TRAFFIC

Evaluation Criteria	Damage Item	Technical Description/Observation	Actual Countermeasures
A) Traffic Disturbance during Maintenance or Installation Works	Installation of new lines or repairs at QNTS manholes located at Cable & Wireless roundabout causes temporary occupation of sections of surrounding street and sidewalks for dewatering equipments.	Manholes must be kept dry throughout the work and equipment used may include tankers, pumps, air pumps and generators. Similar traffic disturbances are created wherever manholes are filled with water. In one instance jointing of new lines in Cable & Wireless roundabout involved work in 3 manholes, use of 4 pumps, 2 air pumps, 2 tankers, discharge into sewerage network and into sea, and generators.	In general services try to plan their work in order to have all the necessary equipment available, obtain permission from CED of MPW when sewerage network manholes are suitably located for discharging, and coordinate with traffic police and other services.
	Installation of stormwater drain in the Musherib Street, where the groundwater level is shallow, takes much time and dewatering efforts, and consequently traffic on this main street is disturbed.		Coordination between traffic police and contractors working on the project and diversion of the traffic to other streets.

(cont.)

3) LAND PROPERTY VALUES

Evaluation Criteria	Damage Item	Technical Description/Observation	Actual Countermeasures
A) Decrease in Values	In the Rayyan farms, where the top layer of soil has become contaminated by salt, the value of the land with respect to agricultural usage has fallen.	Comments were heard from different sources that some owners of abandoned farms are more interested in making development projects on their lands, and that some may have deliberately left their farms to deteriorate in order to find a way around any existing zoning laws which may prohibit construction of development projects on farmlands.	

4) AMENITY BETWEEN HUMAN AND GROUNDWATER

Evaluation Criteria	Damage Item	Technical Description/Observation	Actual Countermeasures
A) Amenity Degradation	In areas like Rayyan, where farms and greenery can be a pleasing sight, presence of standing water with odor and mosquitoes can distort the entire picture.		
	In West Bay area, where many major projects and embassies are built, emergence of the rising groundwater problem can cause much disturbance to inhabitants.		
	Specific problems such as West Bay Stadium, Qatar National Museum, and Montazah Garden Swimming Pool sites which have been subject to various degrees of damage by groundwater are an excellent example. Such spots are meant for recreation and relaxation and people become disappointed if they cannot visit.		Consultants have been commissioned to solve the stadium problem and some remedial work has been done there. Pencol has been working at the museum where the main attraction, the aquarium is located underground. The pump room of the swimming pool still remains a problem although some consultants are looking into it.

4. Relationship between Groundwater Level and Damage

4.1 Groundwater Level and Types of Damage

Damage caused by the rising groundwater is classified into three groups, as shown in Fig. 4.1.1, depending on the 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.

4.1.1 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 roads 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.

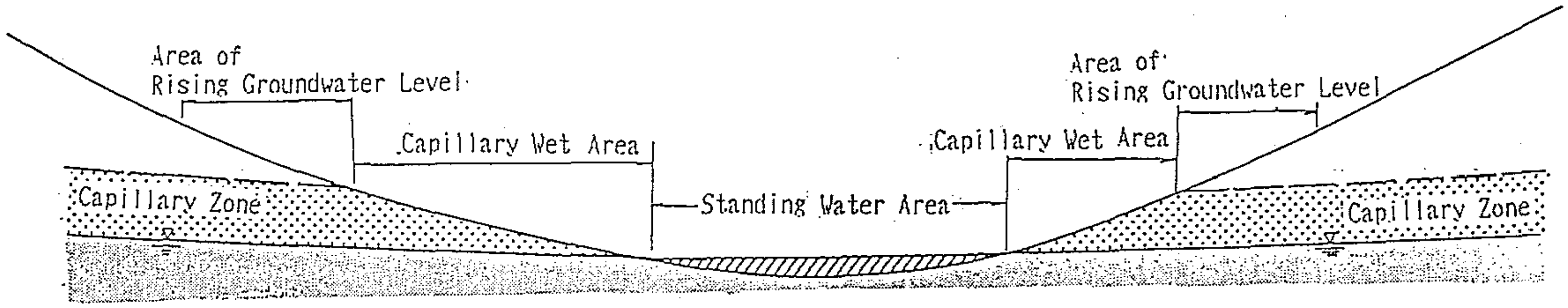
(3) Pollution of Groundwater Resources by High Salt Content of Standing Water

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.

4.1.2 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. 4.1.1 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.

4.1.3 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 be introduced 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 reinforced water proofing and by 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.

4.2 Measures to Reduce Groundwater Level

4.2.1 Necessity of Introducing Groundwater Level Lowering Measures

Table 4.2.1 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.

4.2.1 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 4.2.2.

Table 4.2.1 Damage Caused by Groundwater Rising and Countermeasures

Area	Phenomenon	Type of Damage	Selected Countermeasure
Standing Water	Occurance 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 4.2.2 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)	?

4.2.3 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 higher 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

P A R T : E Test Work

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TEST WORK

1. INTRODUCTION

1.1 Selection of Test Sites

From the very beginning of JICA's commitment to the rising groundwater problem, this test work was considered as an actual demonstration test for lowering groundwater level in critical areas. Therefore at the stage when the existing studies were reviewed and preliminary reconnaissance was done, Lower Wadi Musherib and Old Rayyan were selected as test work sites where groundwater levels are actually almost at ground surface or flooded at some of the lower points.

Although locations for potential test sites were very limited, especially in Lower Wadi Musherib because of its proximity to the city center, two sites were kindly arranged by Doha Municipality, as follows:

- an open area just north of the S.E.D building at Lower Wadi Musherib
- an old farm of H.E. Sheik Khalid at Old Rayyan

1.2 Purpose of the Test

By the use of test trenches, having approximate length of 100 metres, width of 1 metre and depth of 4-5 metres and abstraction by test pumping, the following results were expected:

- Actual drawdown of groundwater level around the site
- Hydraulic constants
- Discharge amount
- Water quality

1.3 Undertaking on Test Work Construction

For the execution of the Test Work, the following required preparation works were assumed by both JICA and Qatar Government:

(i) JICA

- Test Trench construction including observation house and ground tanks
- Testing equipment such as pumps, flowmeters
- Hydrological measurement equipment

(ii) Qatar Government

- Open hole drilling for observation holes
- Electricity supply facility
- Road tankers for transportation of abstracted groundwater at Rayyan and sewerage line arrangement at Lower Wadi Musherib
- Automatic recording equipment for groundwater levels

1.4 Program of the Test Work

The test work construction and test works were carried out according to the schedule in Tables 1.4.1 herein attached at both sites respectively. Key events are dated as follows:

- Site selection - January '86
- Design and Specification of test schemes - January '86
- Test equipment preparation - February-April '86
- Trench excavation - March-June '86
- Open hole drilling - April-May '86
- Equipment installation - May-June '86
- Electricity supply - May-July '86
- Disposal arrangement - June-August '86
- Test pumping - July-October '86
- Reinstatement - November '86

1.5 Handover of the Test Equipment

At the end of the test works, all the equipment and instruments listed below which were imported or procured by JICA for the test works were donated to the Ministry of Electricity and Water.

1) Submerged pumps with control panel and flowmeter

2) Engine pumps

3) Observation equipment
   - Temperature-humidity-barometer recorder
   - Wind recorder
   - Rain gauge
   - Evaporation pan

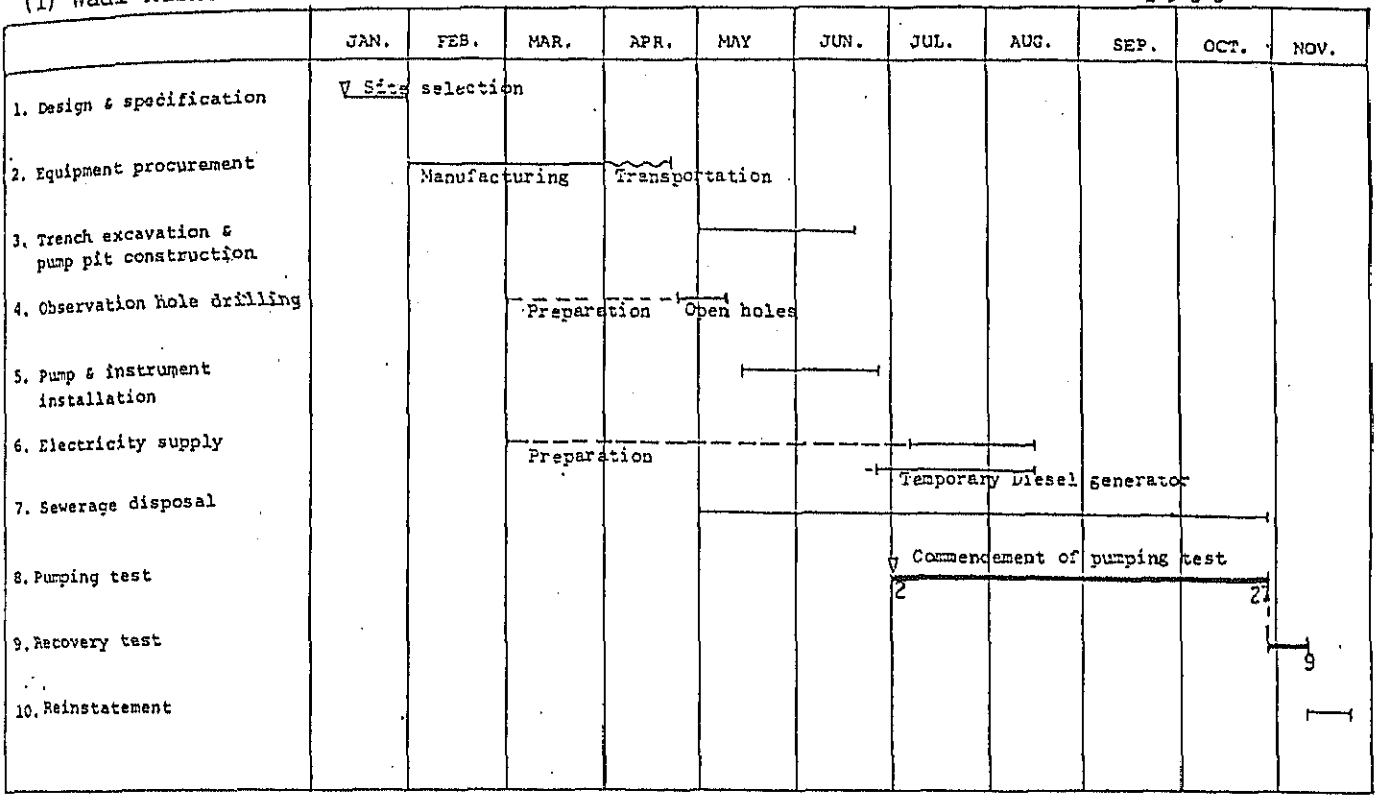
4) Chemical analyser
   - HACH
   - COD meter

5) 5,000 Imp. gallon fibreglass water tanks

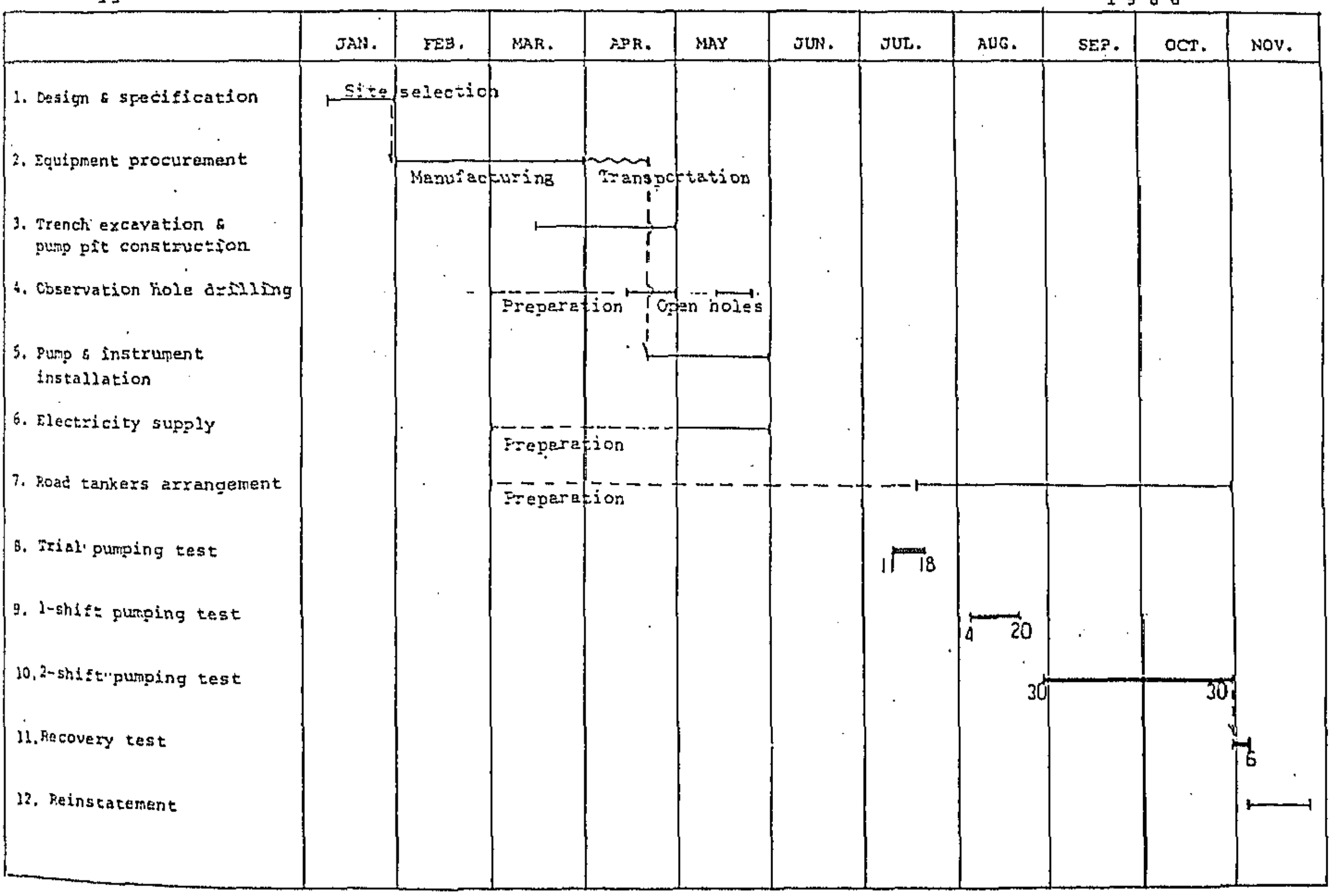
6) Room air conditioners

Table 1.4.1 Construction Schedule at Lower Wadi Musherib Site

(1) Wadi Musherib



(2) Rayyan



2. PREPARATION OF TEST WORKS

2.1 Test Work Construction at Lower Wadi Musherib

(1) Arrangement

General arrangement of Test Work is shown in Fig. 2.1.1 and 2.1.2.

(i) Test Trench

As shown in the figure, this test site is of limited area but the arrangement of the test Trench was planned considering the following factors:

- In the eastern part of the proposed site there are remains of buildings as confirmed by electrical sounding (Induced Polarization Method) employed to represent the natural geological condition for pumping test.
- Trench should be as far away as possible from any nearby buildings to avoid any claims of damage by excavation and abstraction water.
- Electrical sounding showed that the thickness of weathered layer becomes thin in the direction of the S.E.D building.
- L-shape Trench may permit a better understanding of underground conditions governing groundwater inflow occurring due to abstraction.

(ii) Observation holes

- Observation holes were mainly arranged inside the site and core boring for geological investigation was planned outside.

(iii) Disposal of abstracted water

The quantity and quality were confirmed by a preliminary test during test Trench construction, as 0.14 m^3/min. and 5,000 micro mhos/cm respectively. During test work it was permissible to discharge abstracted water into the public sewerage line for the S.E.D. building adjacent to the test site.

(2) Test Trench Construction

Construction for the Test Work consisted of the following:

1) Trench excavation
2) Pump pit and shed
3) Electric power supply
4) Pumping system procurement
5) Pumping system installation
6) Water level observation
7) Abstracted water disposal
8) Reinstatement

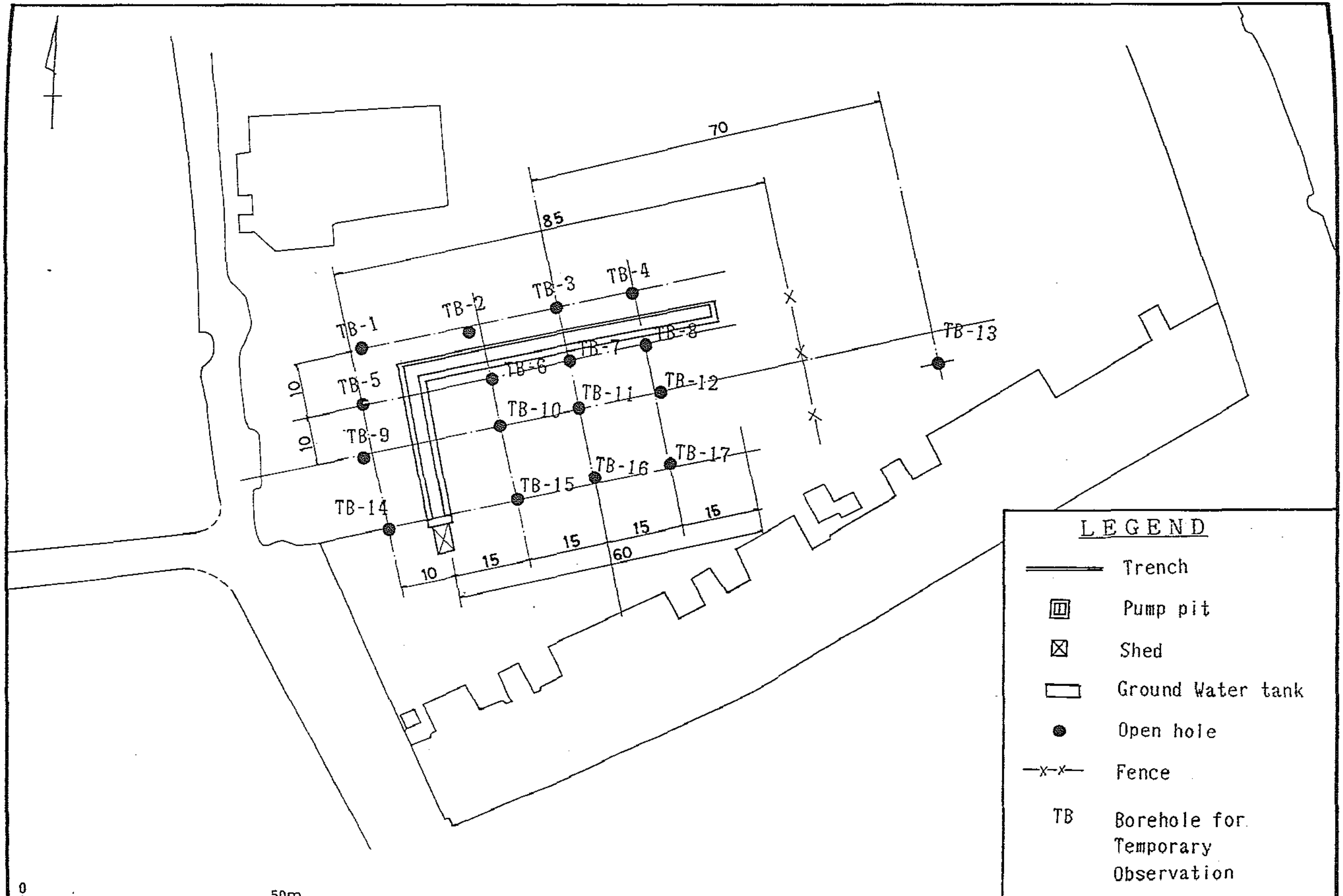


Fig. 2.1.1 Location of Musherib Test Works Site

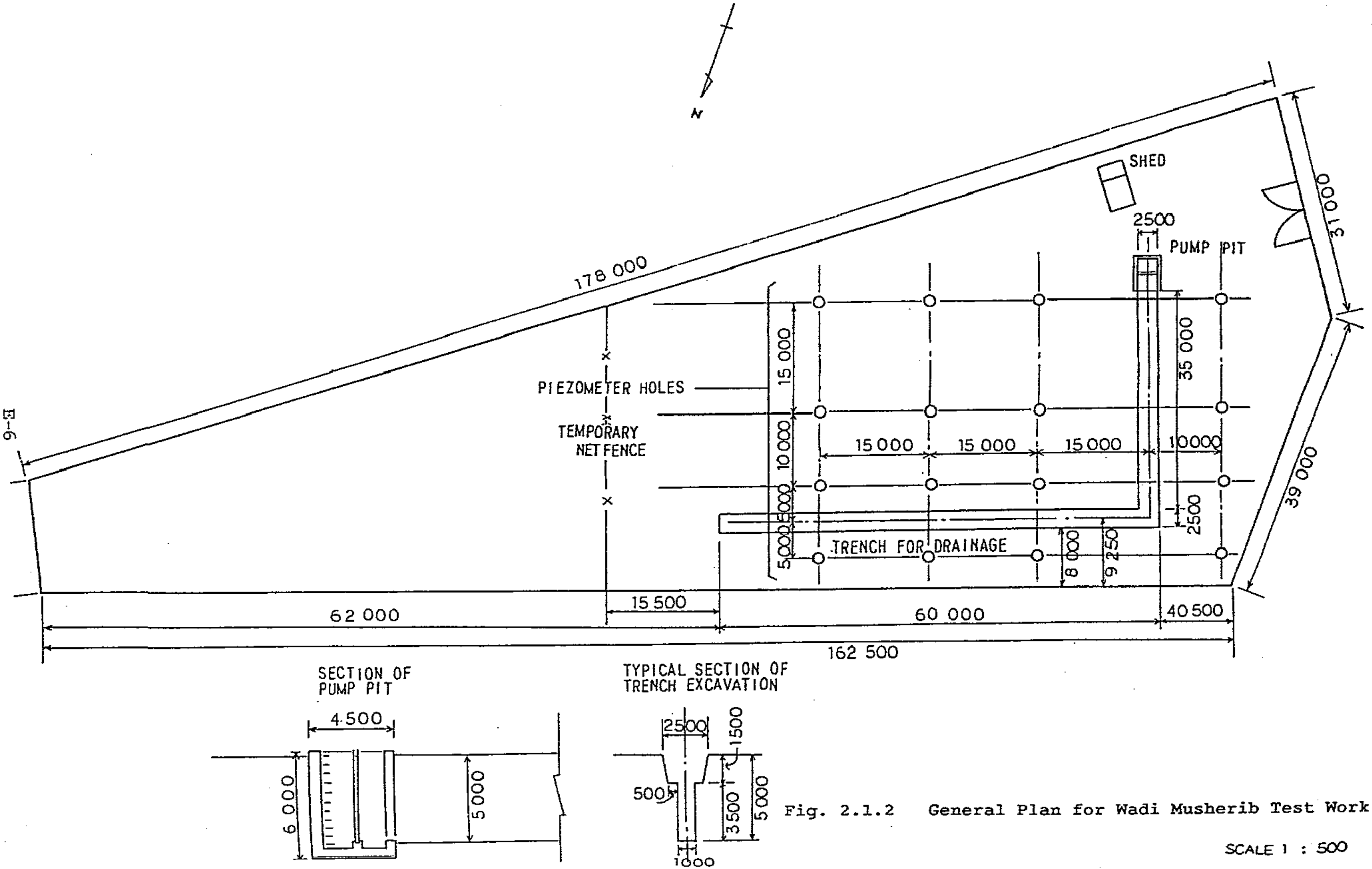


Fig. 2.1.2 General Plan for Wadi Musherib Test Work

SCALE 1 : 500

(i) Trench excavation

As shown in the Fig.-2.1.2, the L-shaped Trench is of depth 5 meter and length 90 meter and considering the surface weathered layer the upper part of the Trench was shaped with grades.

Approximately 760 m^3 of Trench excavation was made in 20 days using one hydraulic clam shell and one engine breaker on the Poclain. Dewatering was needed continuously but excavated wall was considered stable, therefore, excavation work proceeded without difficulty.

(ii) Pump pit and shed

For installation of submerged pumps and access to the Trench, a reinforced concrete pump pit was prepared at the end of the Trench. A temporary small shed was also prepared at the site for field test works.

(iii) Electricity supply

Temporary electricity power supply was arranged by S.E.D. from the city network for the test work at the Lower Wadi Musherib site. Because of delay of the arrangement, a diesel generator set was installed by the Drilling Section, M.E.W.

Required power was:

Capacity :	20 KVA
Voltage :	415 V
Equipment:	Submerged pump, air conditioning, lighting, etc.

(iv) Pumping system procurement

Pumps having capacities of 1.0 m^3/min and 0.5 m^3/min with control panels and flowmeters were provided from Japan and one 1.0 m^3/min pump with engine was prepared for emergency purpose.

(v) Pumping system installation

Considering the figures from the preliminary test during the Trench excavation, one submerged pump, capacity 1.0 m^3/min was installed with an integrated flowmeter which was connected to the sewerage line.

(vi) Water storage tanks

At the initial stage of the study, buffer tanks were considered to adjust the discharge rate to road tankers however direct discharge to the sewerage line accepted by C.E.D. made test pumping possible without such tanks.

(vii) Observation hole

Seventeen open holes for water level observation were drilled by the Drilling Section of the Water Division with diameters 100 mm and depths 5 m. Each open hole was protected from caving with PVC perforated casing of diameter 75 mm with cap and cemented at the top.

(viii) Abstracted water disposal

Disposal to the public sewerage line at the west end of the S.E.D. building was arranged.

(ix) Reinstatement of test work sites

From the very beginning, reinstatement of the site to the original situation was a precondition for use since this land is private property.

After the recovery rate observation, reinstatement work began by dewatering on November 13th and filling work in the Trench started on November 15th. At the same time, the temporary power supply was disconnected by the S.E.D. at JICA's request.

However, on November 16th, JICA was informed that Doha Municipality decided to continue the pumping test and was instructed to stop the reinstatement work.

Consequently JICA stopped the work and handed over the site to the Qatari side.

2.2 Test Work Construction at Rayyan

(1) Arrangement

General arrangement is shown in Fig.2.2.1 and 2.2.2.

(i) Test Trench

This test site is on the northern side, along the perimeter fence of an old farm, where there is already flooding showing groundwater level around the site being higher than the ground level of +5.4 m QND. For the arrangement of the Test Trench, the following points were considered:

- Excavation work for septic tank, which was being carried out at the test site, showed that the groundwater inflow to pit was mainly governed by fissure system. Therefore L-shape Trench was adopted for pilot drainage scheme to well understand the frequency and direction of fissures.

- From the shape of the site, the longer leg of the Trench was arranged in the north-south direction at right angle to the Old Rayyan Road.

- The shorter leg of the Trench was extended on the east side for easy arrangement of observation holes.

(ii) Observation holes

Observation holes for this site were arranged as follows:

- Arrangement of two directional Trench was considered.

- There are many existing wells around the test site.
  Therefore new observation wells were concentrated around the Test Trench.

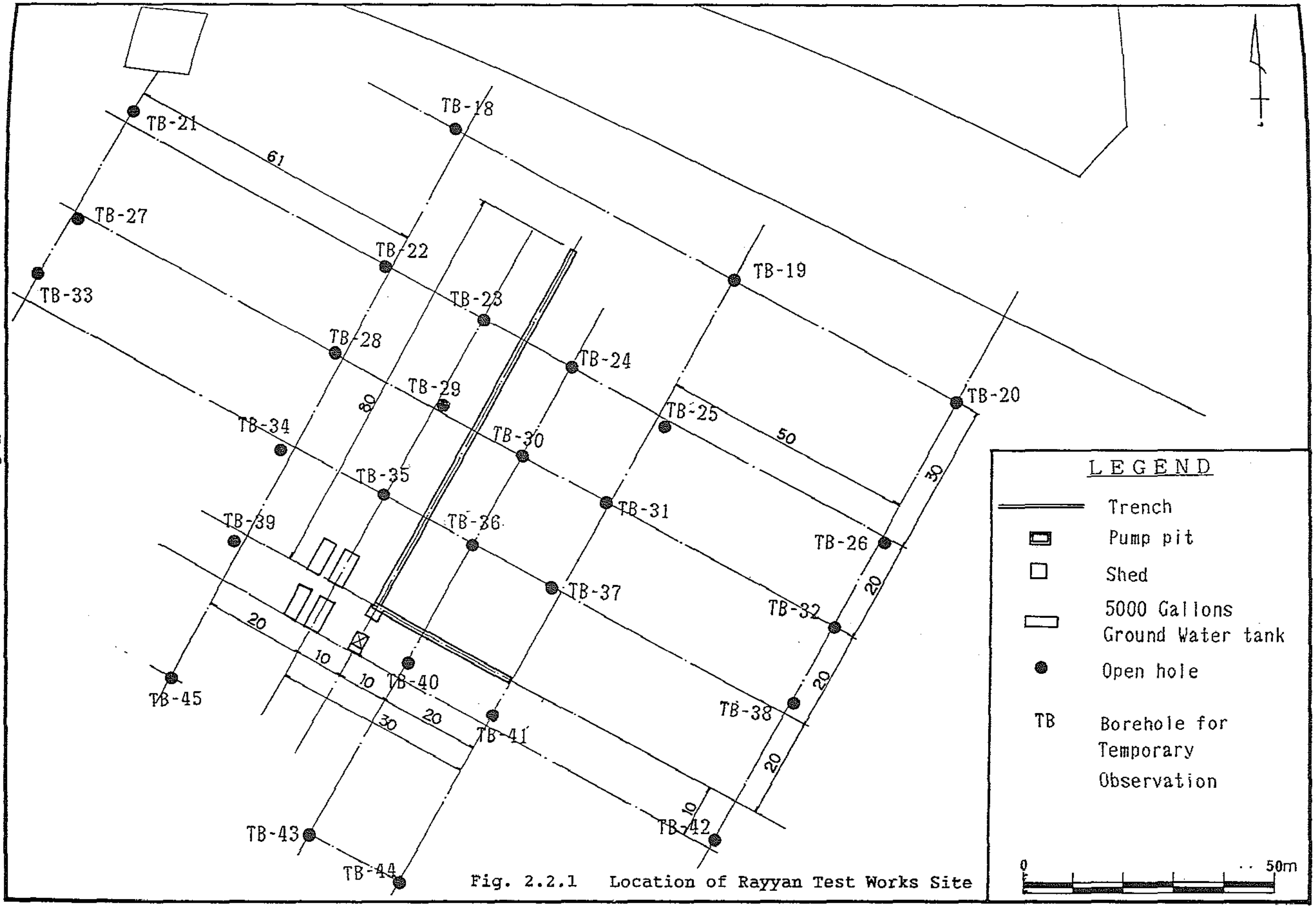


Fig. 2.2.1 Location of Rayyan Test Works Site

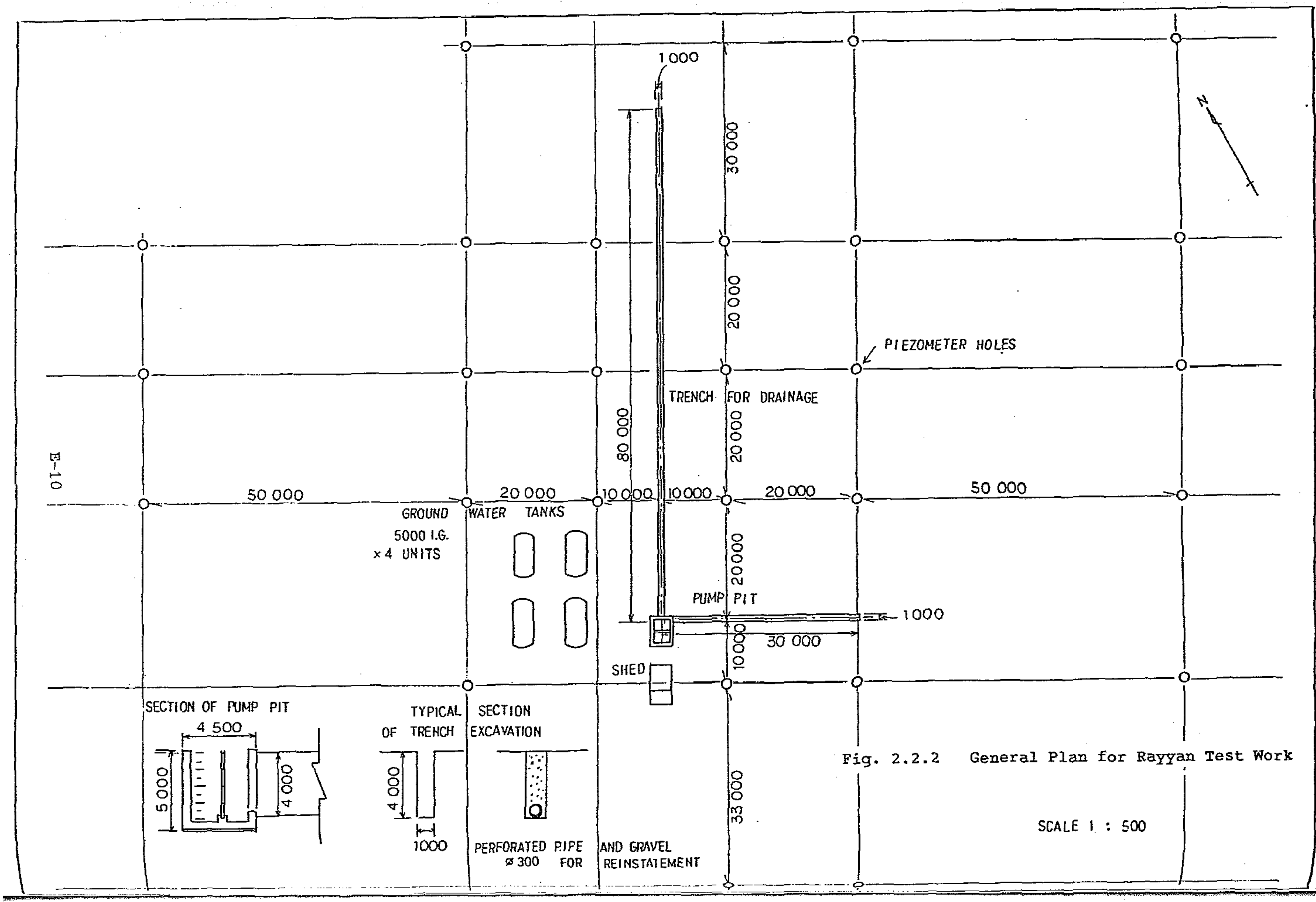


Fig. 2.2.2 General Plan for Rayyan Test Work

SCALE 1 : 500

(2) Test Trench Construction

Construction for the test work at Old Rayyan site consisted of the following:

1) Trench excavation
2) Pump pit and shed
3) Electric power supply
4) Pumping system procurement
5) Pumping system installation
6) Water storage tanks
7) Water level observation holes
8) Abstracted water disposal
9) Meteo. observation equipment
10) Reinstatement

(i) Trench excavation

As shown in the Fig. 2.2.2, the L-shaped Trench has a 4 meter depth and 110 meter length and because of the thin heavily weathered surface layer, Trench excavation was made vertically.

Approximately 1,000 m^3 of Trench excavation was done in 20 days using one hydraulic clam shell and one engine breaker on the Poclain. Dewatering was required continuously but excavated wall was considerably stable, therefore excavation work proceeded without difficulty.

(ii) Pump pit and shed

For installation of submerged pumps and access to the Trench, a reinforced concrete pump pit was prepared at the corner of the L-shaped Trench and a temporary small shed, 3.0 m x 6.0 m was prepared for the field test work.

(iii) Electricity supply

Temporary electricity supply was arranged by S.E.D. from the city network for the test work.

Required power was:

Capacity :	20 KVA
Voltage :	415 V
Equipment:	Submerged pumps, unloading pumps, flood lighting, air conditioner and lighting for shed, etc.

(iv) Pumping system procurement

Pumps having capacities of 1.0 m^3/min and 0.5 m^3/min with control panels and flowmeters were provided from Japan and two 1.0 m^3/min pumps with engine were prepared for emergency purposes.

(v) Pumping system installation

Taking into consideration the figures from the preliminary test during the Trench excavation, two submerged pumps, capacity 1.0 m^3/min and 0.5 m^3/min were installed in the pump pit with integrated flowmeters.

These pumps were connected to the water storage tanks and unloading nozzles for road tankers.

(vi) Water storage tanks

In order to buffer the road tankers' transportation, eight 5,500 Imp. gallon fibre glass tanks were provided and pump and piping unloading for road tankers were also installed at the tank yard.

(vii) Observation holes

Twenty-eight holes for water level observation were prepared for test pumping. Twenty-two out of 28 holes were drilled by the drilling rig of the Water Dept. with diameters 100 mm and depths 5 m and the other 6 holes were placed in the standing water area and made by shot hole drilling machine with diameters 50 mm and depths 5 m.

All observation holes were protected from caving with PVC perforated casings and caps which diameters were 75 mm for open holes and 25 mm for shut holes.

(viii) Abstracted water disposal

It was decided by C.E.D. that all the water abstracted from the test work should be disposed not through the sewerage line but by road tankers because of the estimated quality and quantity of water. Subsequently 4 road tankers with capacity of 6,000 Imp. gallons each were provided by M.P.W.

(ix) Meteorological observation equipment

Meteorological observation and recording equipment for the following subjects were provided from Japan and installed at the Old Rayyan site:

- Temperature
- Humidity
- Barometric pressure
- Rainfall
- Surface wind direction and velocity
- Evaporation

(x) Reinstatement of test work site

After confirming that the recovery rates had stabilized, reinstatement works began at the Old Rayyan site.

At the request of H.E. Sheik Khalid's Farm the test Trench was to remain for future drainage operation. But considering the safety aspect and convenience of land use, perforated pipe was laid at the bottom of the Trench and overlaid with gravel for the whole Trench section, as in Fig. 2.2.3.

Reinstatement work commenced with dewatering on November 13th and was completed on November 24th.

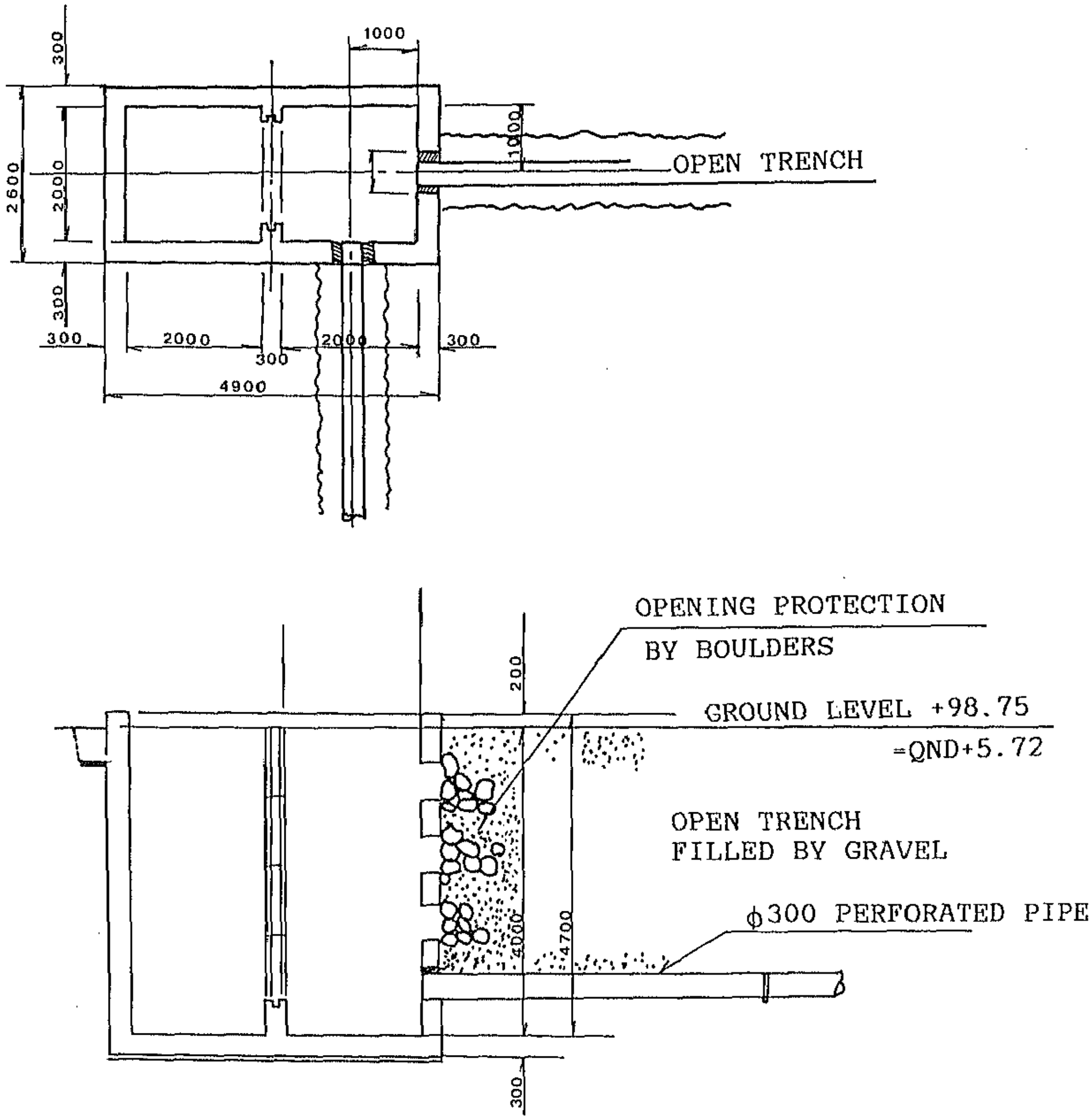


Fig. 2.2.3 Reinstatement at Old Rayyan

2.3 Observation Programe

2.3.1 Observation Items

Pumping test in Trench aimed at obtaining more detailed information related to the effect of groundwater level lowering by Trench type dewatering and the reuse of abstracted groundwater.

The effect of groundwater level lowering by pumping test in Trench was evaluated through the groundwater level and abstraction amount observation.

With regard to water quality, the shallow part of the aquifer has low salinity in general according to the stratified structure of salinity and the Test Trench aimed at collection of low saline groundwater. The possibility of groundwater reuse and the necessity of water treatment were examined from the chemical analysis data.

Observation items were as follows:

(i) Abstraction discharge from Test Trench

(ii) Groundwater level

- Water level in Test Trench
- Groundwater level at open holes
- Groundwater level at existing wells

(iii) Water Quality

- Electric conductivity (EC)
- COD, BOD, pH
- Major Ions

2.3.2 Observation Network

Observation network consisted of Test Trench, open holes and existing wells. The general plans of Test Trench and open holes at Rayyan and Lower Wadi Musherib are respectively shown in Fig. 2.1.1 and Fig. 2.2.1. Their datum elevation was surveyed and tabulated in Table 2.3.1 and Table 2.3.2.

The network of existing wells was located within an area of 1 Km radius from the Test Trench, in order to monitor the lowering extension due to the dewatering at the Test Trench.

Rayyan area has many existing wells, but the Lower Wadi Musherib, has a very limited number and few in distribution density. Therefore, in the case of Rayyan the points mentioned below were considered when selecting observation well points, however no observation wells were used in Lower Wadi Musherib.

Selection conditions for observation network establishment were as follows:

(i) Uniform density of distribution in the observation network.

(ii) Easy access to measurement.

(iii) Less influences to groundwater caused by pumping and irrigation activities.

(iv) Water level at well point seemed to be representative in the surrounding area.

(v) Avoid wells having suspended wastes and/or strange water colour.

Observation network of existing wells in Rayyan as shown in Fig. 2.3.1 and Table 2.3.3 was established after well point survey applying the selection conditions.

Table 2.3.1 Datum Elevation at Lower Wadi Musherib

Hole No.	Measurement Point (m in QND)	Ground Level (m in QND)	Hole No.	Measurement Point (m in QND)	Ground Level (m in QND)
TB-1	5.83	5.21	TB-10	6.06	5.38
TB-2	5.86	5.41	TB-11	5.92	5.33
TB-3	5.97	5.51	TB-12	5.71	5.23
TB-4	5.77	5.19	TB-13	5.95	5.52
TB-5	5.97	5.38	TB-14	6.20	5.53
TB-6	5.88	5.53	TB-15	5.91	5.35
TB-7	5.94	5.31	TB-16	5.99	5.32
TB-8	5.72	5.19	TB-17	5.92	5.14
TB-9	6.09	5.42	Trench	6.43	-

Table 2.3.2 Datum Elevation at Rayyan

Hole No.	Measurement Point (m in QND)	Ground Level (m in QND)	Hole No.	Measurement Point (m in QND)	Ground Level (m in QND)
TB-18	6.15	5.62	TB-33	6.40	6.08
TB-19	6.43	5.79	TB-34	6.37	5.88
TB-20	6.29	5.58	TB-35	6.47	6.03
TB-21	6.45	5.99	TB-36	6.37	5.79
TB-22	6.67	5.91	TB-37	6.53	5.75
TB-23	6.30	5.68	TB-38	6.38	5.60
TB-24	6.48	5.82	TB-39	6.46	5.82
TB-25	6.23	5.70	TB-40	6.32	5.62
TB-26	6.51	5.73	TB-41	6.36	5.53
TB-27	6.20	5.74	TB-42	6.21	5.52
TB-28	6.27	5.79	TB-43	6.71	5.78
TB-29	6.24	5.69	TB-44	6.26	5.74
TB-30	6.44	5.78	TB-45	6.54	5.90
TB-31	6.39	5.69	Trench	6.07	-
TB-32	6.35	5.62			

Table 2.3.3 List of Observation Wells in Rayyan Area

Well No.	Elevation (Q.N.D)	Well Type	Well No.	Elevation (Q.N.D)	Well Type
36	7.97 m	B.W	112	7.98 m	B.W
90	6.62 m	D.W	113	7.01 m	D.W
91	6.66 m	B.W	116	7.47 m	D.W
93	5.78 m	D.W	117	8.10 m	B.W
94	6.80 m	B.W	118	7.26 m	D.W
96	6.41 m	D.W	25-2-(1)	10.95 m	B.W
98	6.65 m	D.W	17-5-(1)	5.80 m	D.W
99	5.92 m	B.W	17-5-(2)	5.90 m	D.W
100	5.67 m	D.W	15-5-(3)	5.80 m	D.W
101	5.81 m	D.W	17-5-(4)	5.65 m	D.W
103	5.64 m	D.W	17-5-(5)	5.90 m	D.W
104	5.79 m	D.W	17-5-(6)	5.80 m	D.W
105	5.60 m	D.W	17-5-(7)	5.50 m	D.W
108	5.42 m	D.W	17-5-(8)	5.10 m	D.W

Note: B.W = Boring Well, D.W = Dug Well

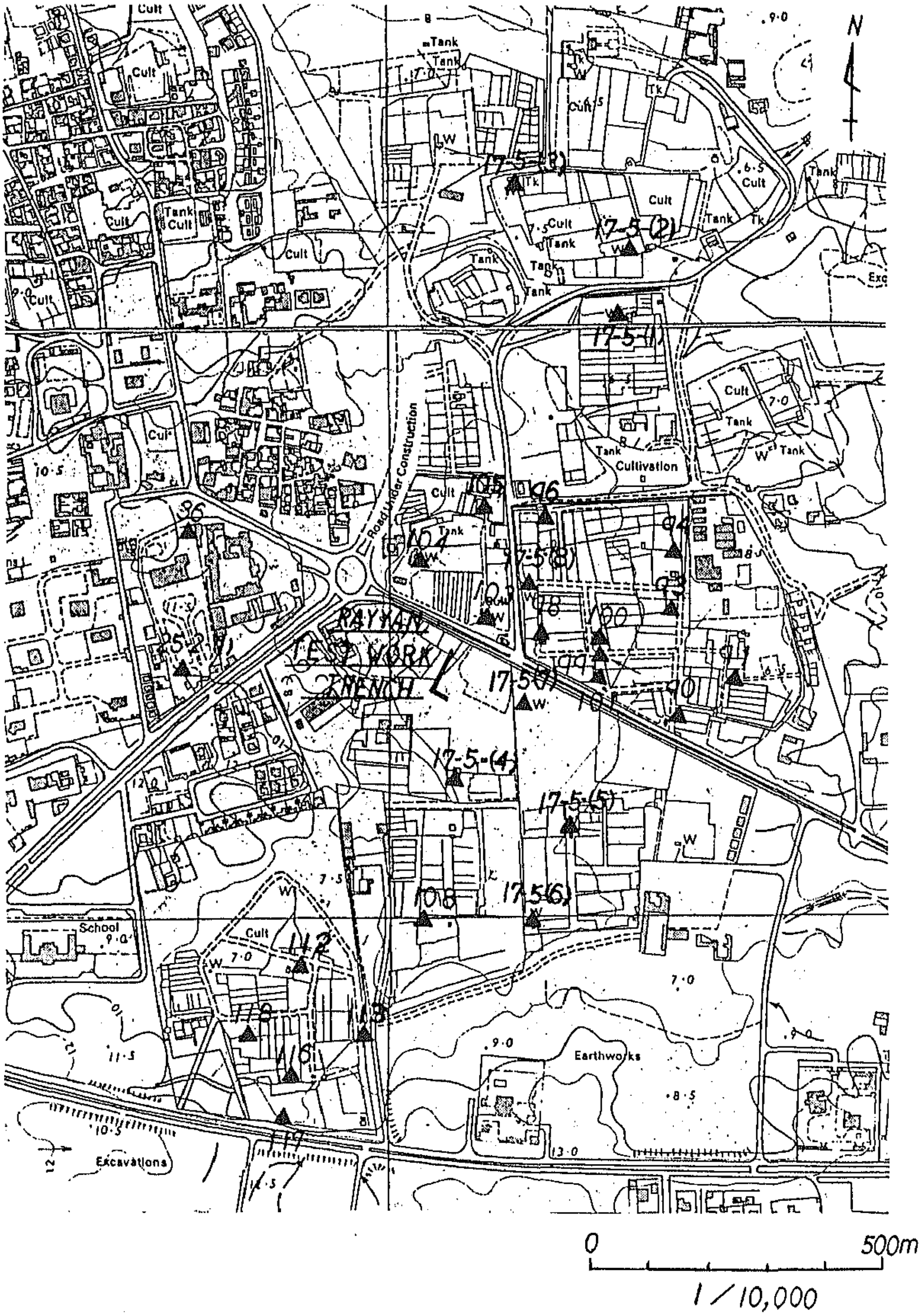


Fig. 2.3.1 Location Map of Observation Wells during Testing Work in Rayyan

2.3.3 Observation System

Observation system for each test work site consisted of the following three observation stages:

(i) Observation before pumping test

(ii) Intensive observation for pumping test

(iii) Regular observation

(1) Observation before Pumping Test

The purpose for observation before Pumping Test was to identify the actual groundwater level and water quality in EC value; at the open holes and existing wells.

(2) Intensive Observation

As the lowering effect by Test Pumping has the tendency to extend from Test Trench to further points, this intensive observation was carried out especially at Test Trench and open holes. Its period was one week and observation frequency was high in the first three days.

Taking into consideration the high temperature in the daytime, test pumping was started in the evening, 19:00 for Rayyan and 17:00 for Lower Wadi Musherib. Planned schedule of observation is shown in Fig. 2.3.2.

(3) Regular Observation

After the completion of one week intensive observation, regular observation was applied. As the lowering effect of Test Pumping extended to the further points, observation was done not only at Test Work Site but also in the observation network of existing well.

Observation frequency was two times a week for Lower Wadi Musherib, and daily for Rayyan.

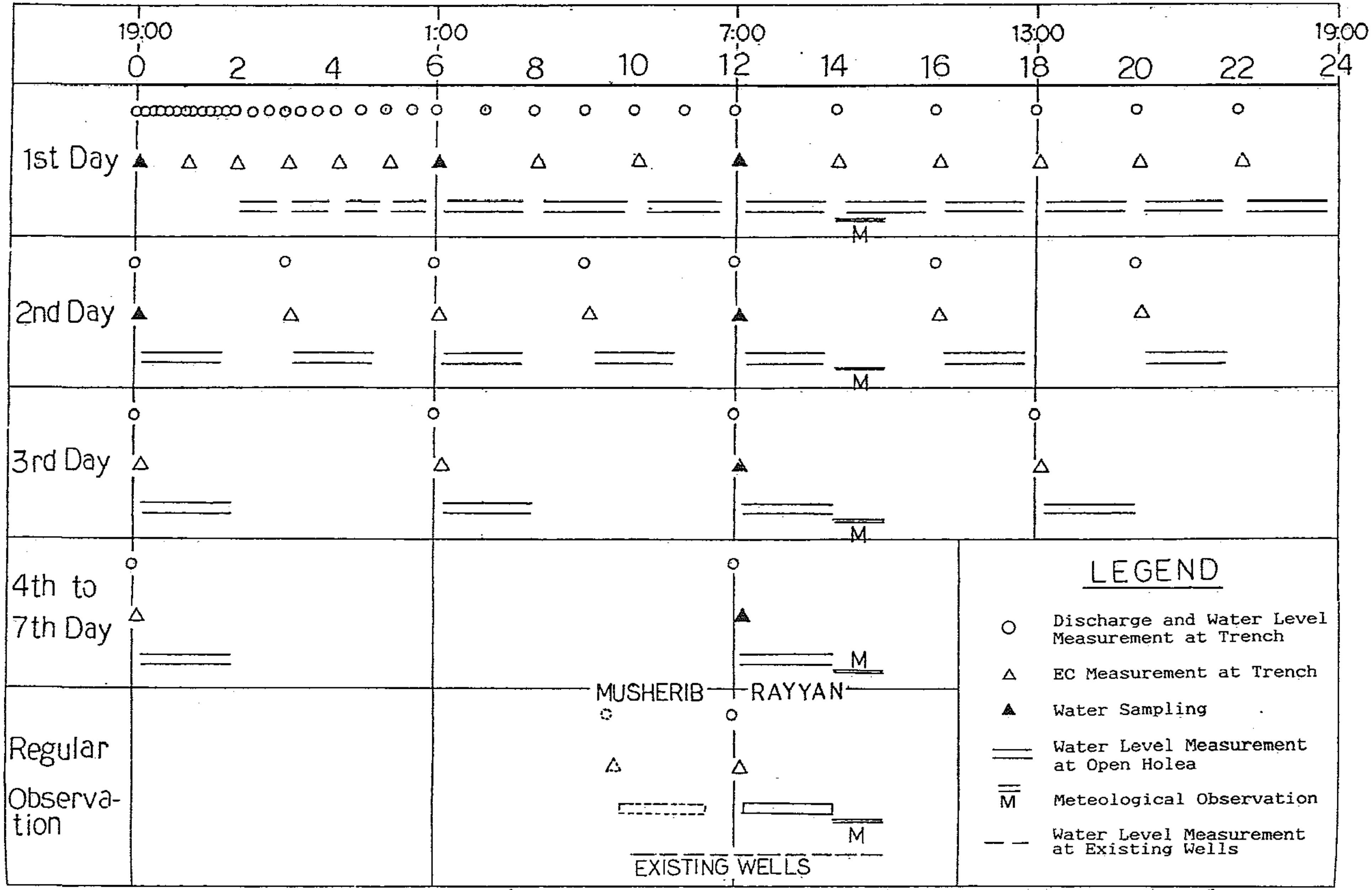


Fig. 2.3.2 Planned Schedule of Observation

3. LOWER WADI MUSHERIB

3.1 Pumping Test

3.1.1 Continuous Pumping Test

(1) Activity

Pumping test commenced on the 2nd of July 1986 at Lower Wadi Musherib and continued until the 27th of October 1986 without any major stoppage. On the 16th of July, an abrupt partial blockage occured at the sewage outlet and since then the discharge amount was controlled to avoid any overflow from the sewage manhole. This blockage was cleared in mid-October and the discharge amount recorded thereafter was as the beginning of test.

(2) Groundwater Inflow to the Trench

At the end of the longer leg of the Trench, groundwater freely flowed out but in other parts of the Trench, distinctive flowing water channels were not found. However, small amounts of groundwater did seep out along bedding planes and irregular clay veins.

(3) Discharge Amount

The relationship between the water level at Trench and discharge amount can be summarized as follows:

(i) When the water level at the Trench was maintained nearly at the bottom, i.e., (1.05 - 1.20 m in QND), the discharge amount varied in the range of 300 - 400 m^3/day (0.21 - 0.28 m^3/min), as shown in Fig. 3.1.1.

(ii) During the discharge limitation period from the 16th of July to mid October, most of the time the water level was in the range of 2.30 - 2.60 m in QND and the corresponding discharge amount was 230 - 260 m^3/day (0.16 - 0.18 m^3/min).

(4) Drawdown Depth

The outline of pumping test condition was as follow:

a. After 95 hours from the start of the pump test, the water level in the Trench reached the bottom i.e. 3.3 m draw-down.

b. From 95 to 320 hours elapsed time, a steady state was maintained with the water level at the bottom of the Trench.

c. At 320 hours, a blockage caused an abrupt decrease in the capacity of the sewage outlet. This resulted in a rapid increase in the Trench water level by 1.5 meters.

The groundwater level lowering observed at the open holes and the Trench is shown in Fig. 3.1.2. The drawdown depth distribution around the Trench and its profile are respectively shown in the Fig. 3.1.3 and Fig. 3.1.4. The propagation characteristics of drawdown due to the abstraction from Trench are shown in Fig. 3.1.5.

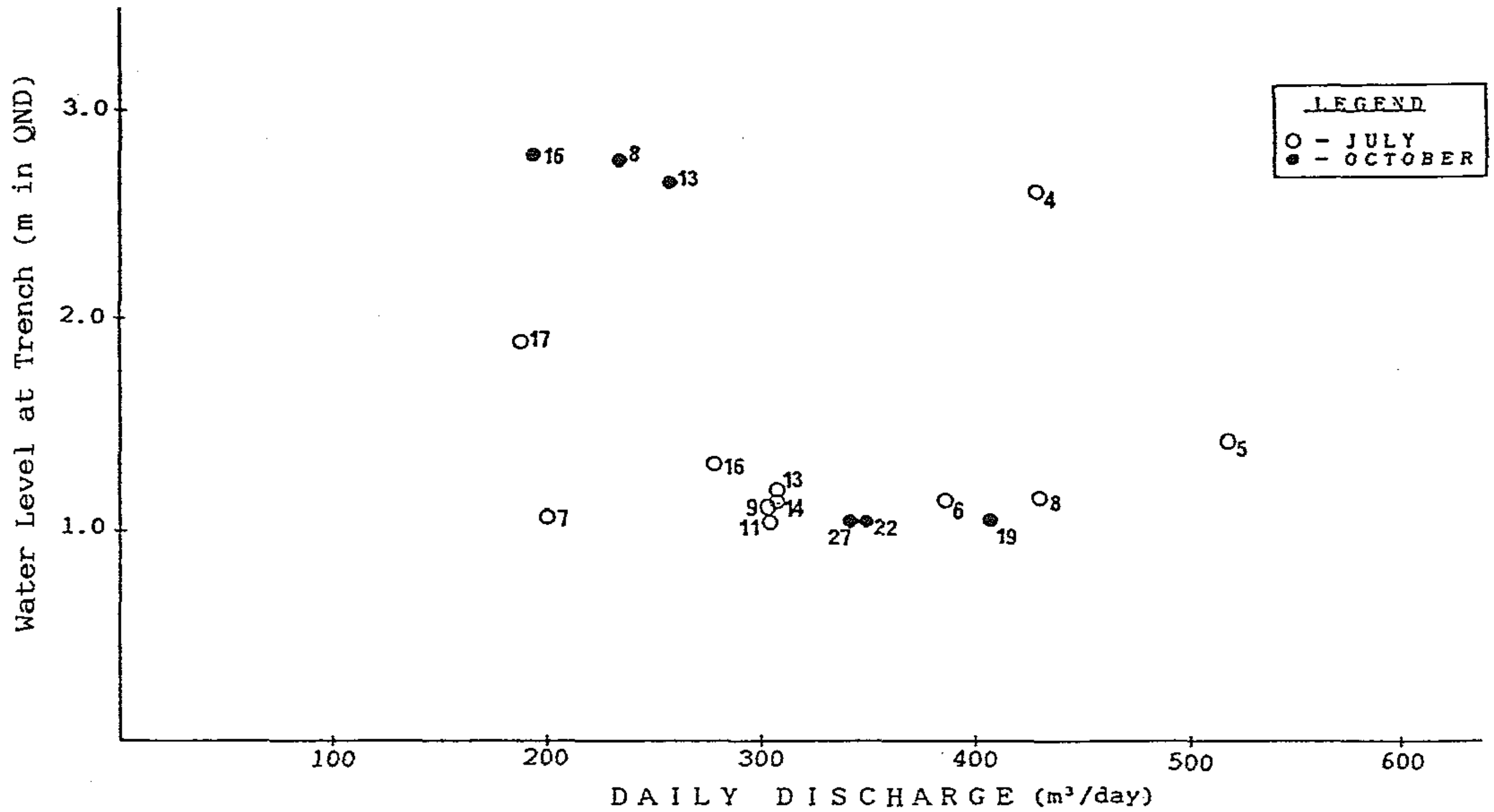


Fig. 3.1.1 Variation of Discharge Amount at Wadi Musherib

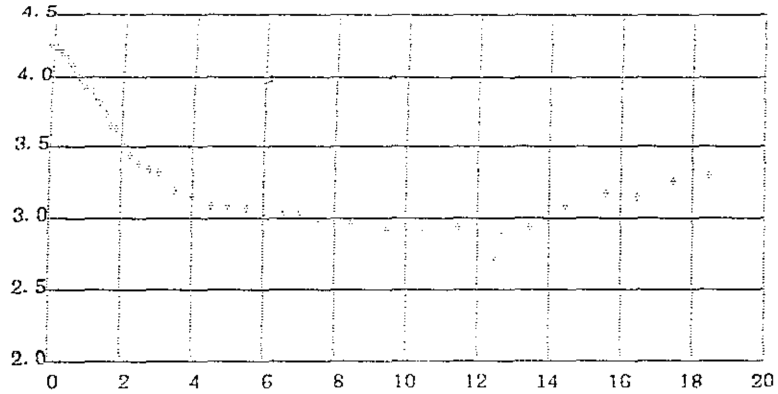


Fig. Pumping Test Results at Wadi Musherib
Continuous Pumping : 2/7 - 21/7 : TB- 1

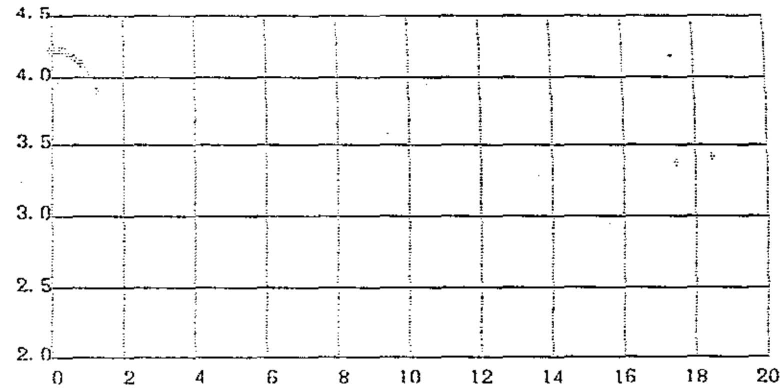


Fig. Pumping Test Results at Wadi Musherib
Continuous Pumping : 2/7 - 21/7 : TB- 3

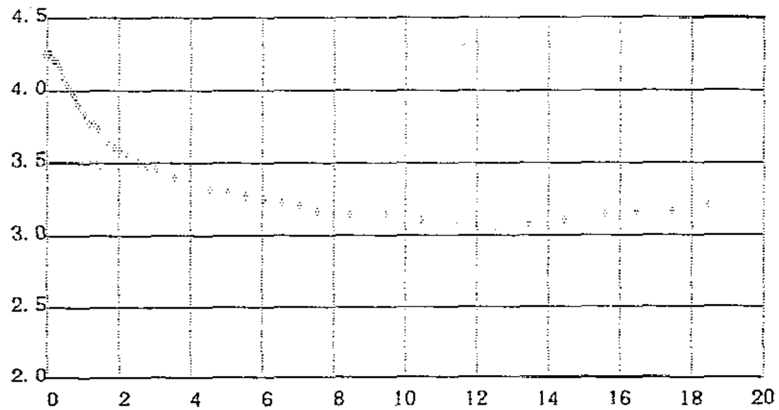


Fig. Pumping Test Results at Wadi Musherib
Continuous Pumping : 2/7 - 21/7 : TB- 2

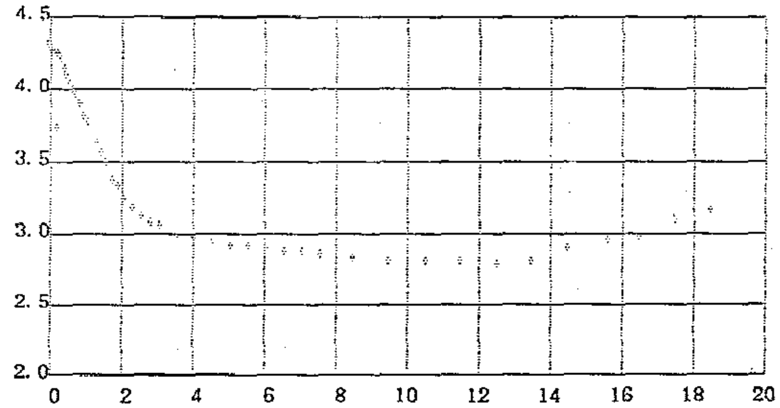


Fig. Pumping Test Results at Wadi Musherib
Continuous Pumping : 2/7 - 21/7 : TB- 4

Fig. 3.1.2 (1) Continuous Pumping Test Results at Wadi Musherib: 2/7-7/21

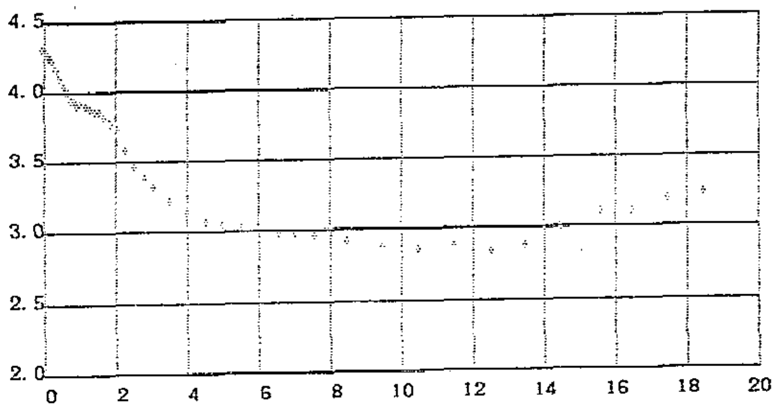


Fig. Pumping Test Results at Wadi Musherib
Continuous Pumping : 2/7 - 21/7 : TB- 5

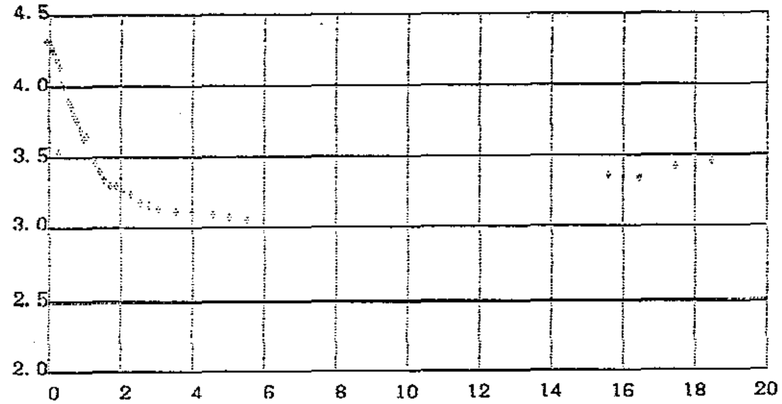


Fig. Pumping Test Results at Wadi Musherib
Continuous Pumping : 2/7 - 21/7 : TB- 7

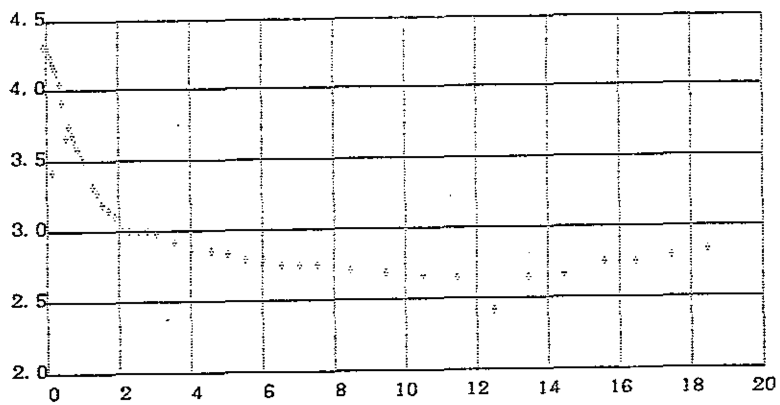


Fig. Pumping Test Results at Wadi Musherib
Continuous Pumping : 2/7 - 21/7 : TB- 6

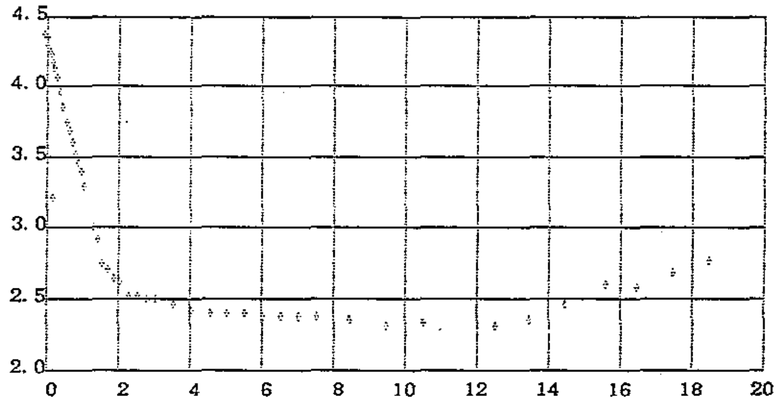


Fig. Pumping Test Results at Wadi Musherib
Continuous Pumping : 2/7 - 21/7 : TB- 8

Fig. 3.1.2 (2) Continuous Pumping Test Results at Wadi Musherib: 2/7-7/21

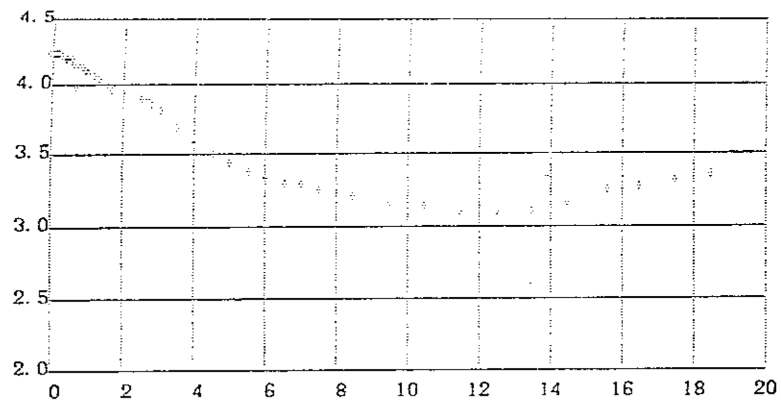


Fig. Pumping Test Results at Wadi Musherib
Continuous Pumping : 2/7 - 21/7 : TB- 9

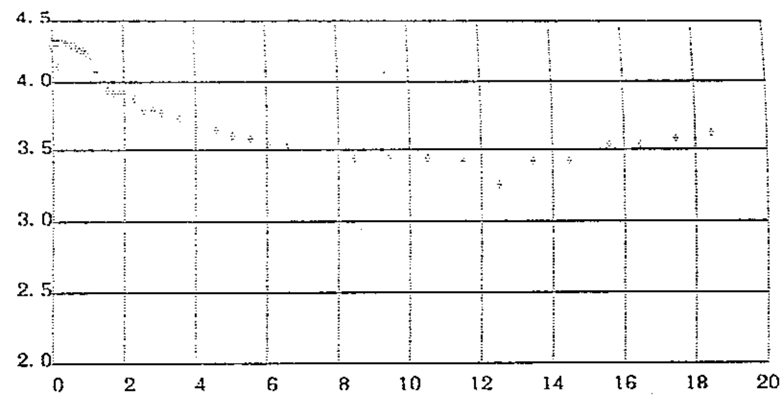


Fig. Pumping Test Results at Wadi Musherib
Continuous Pumping : 2/7 - 21/7 : TB-11

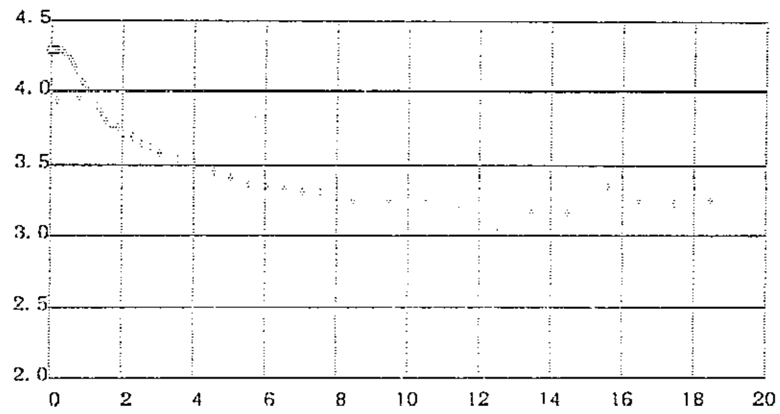


Fig. Pumping Test Results at Wadi Musherib
Continuous Pumping : 2/7 - 21/7 : TB-10

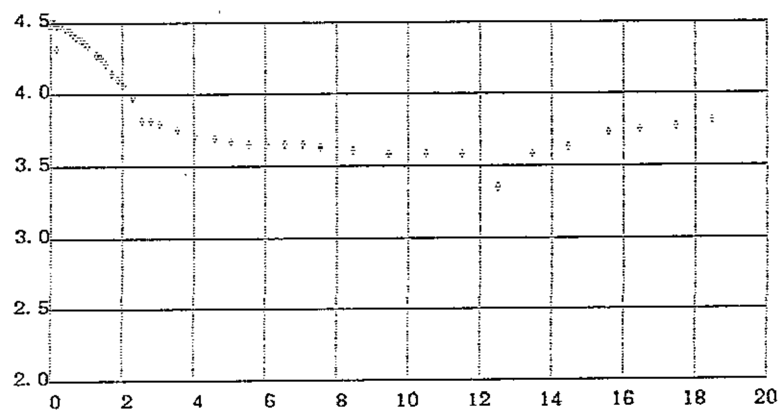


Fig. Pumping Test Results at Wadi Musherib
Continuous Pumping : 2/7 - 21/7 : TB-12

Fig. 3.1.2 (3) Continuous Pumping Test Results at Wadi Musherib: 2/7-7/21

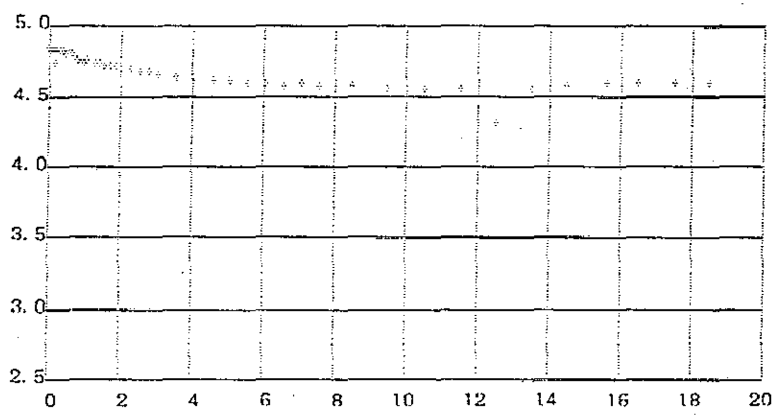


Fig. Pumping Test Results at Wadi Musherib
Continuous Pumping : 2/7 - 21/7 : TB-13

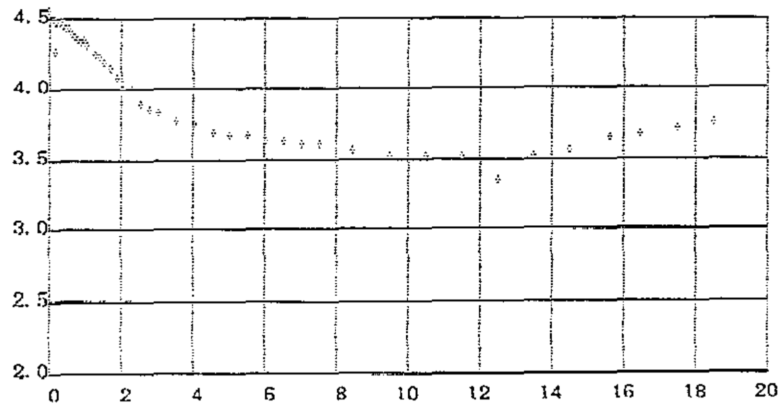


Fig. Pumping Test Results at Wadi Musherib
Continuous Pumping : 2/7 - 21/7 : TB-15

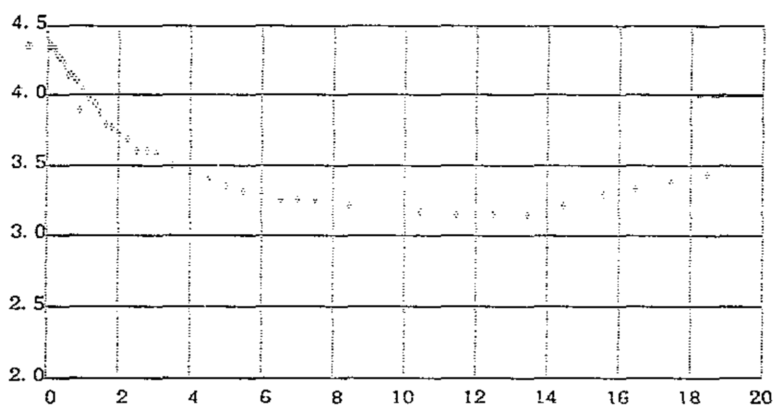


Fig. Pumping Test Results at Wadi Musherib
Continuous Pumping : 2/7 - 21/7 : TB-14

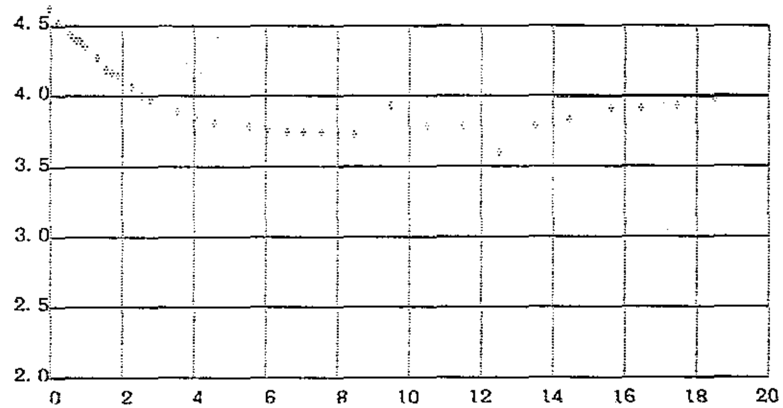


Fig. Pumping Test Results at Wadi Musherib
Continuous Pumping : 2/7 - 21/7 : TB-16

Fig. 3.1.2 (4) Continuous Pumping Test Results at Wadi Musherib: 2/7-7/21

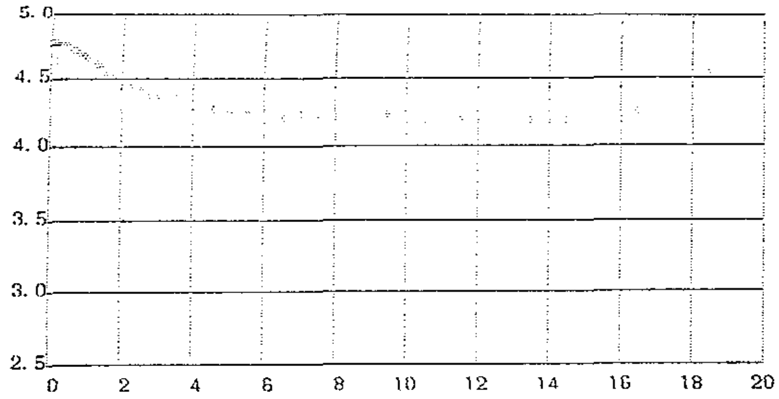


Fig. Pumping Test Results at Wadi Musherib
Continuous Pumping : 2/7 - 21/7 : TB-17

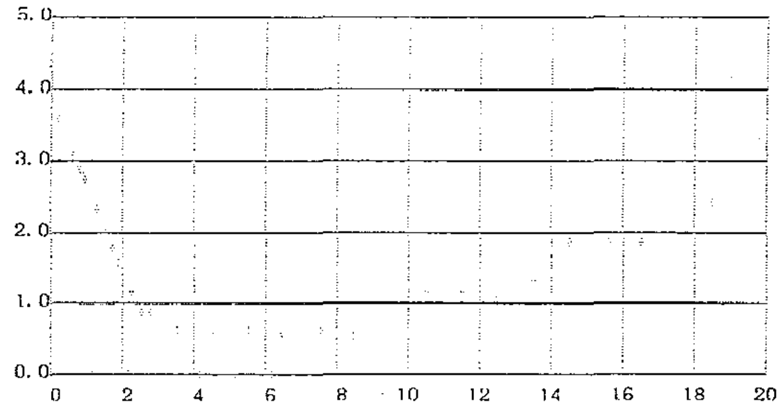


Fig. Pumping Test Results at Wadi Musherib
Continuous Pumping : 2/7 - 21/7 : TRENCH

Fig. 3.1.2 (5) Continuous Pumping Test Results at Wadi Musherib: 2/7-7/21

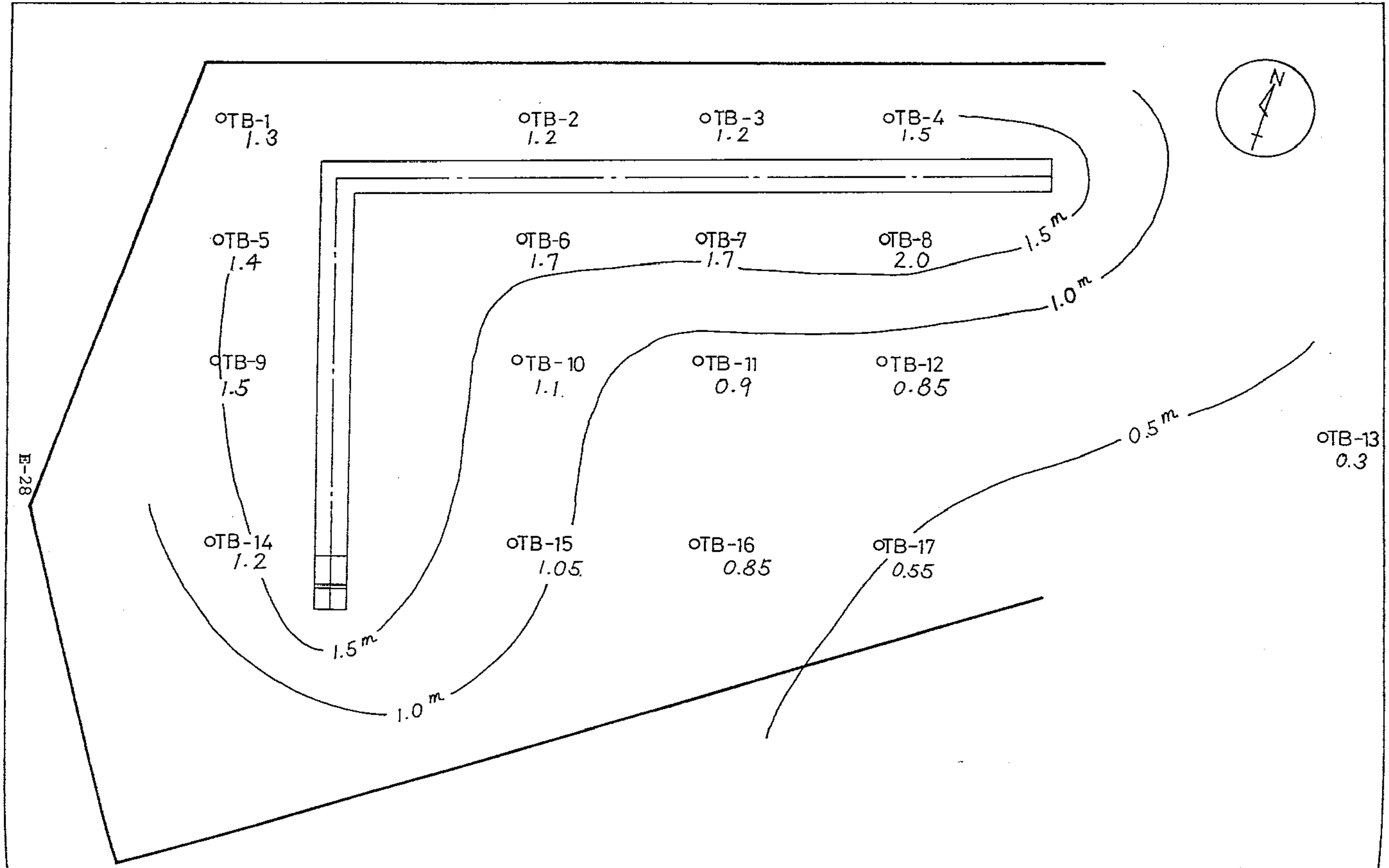


Fig. 3.1.3 Drawdown Depth Distribution at Wadi Musherib

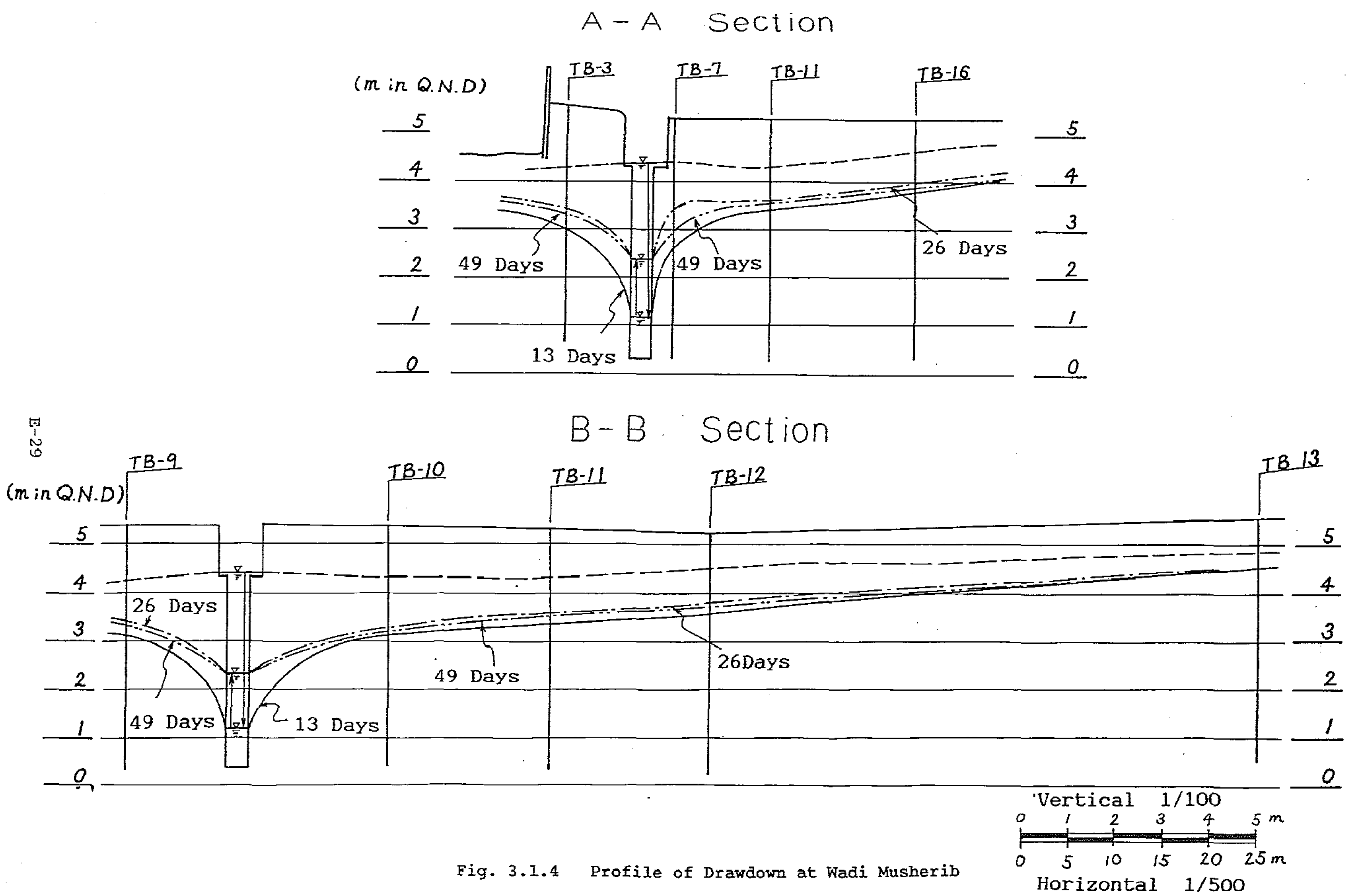


Fig. 3.1.4 Profile of Drawdown at Wadi Musherib

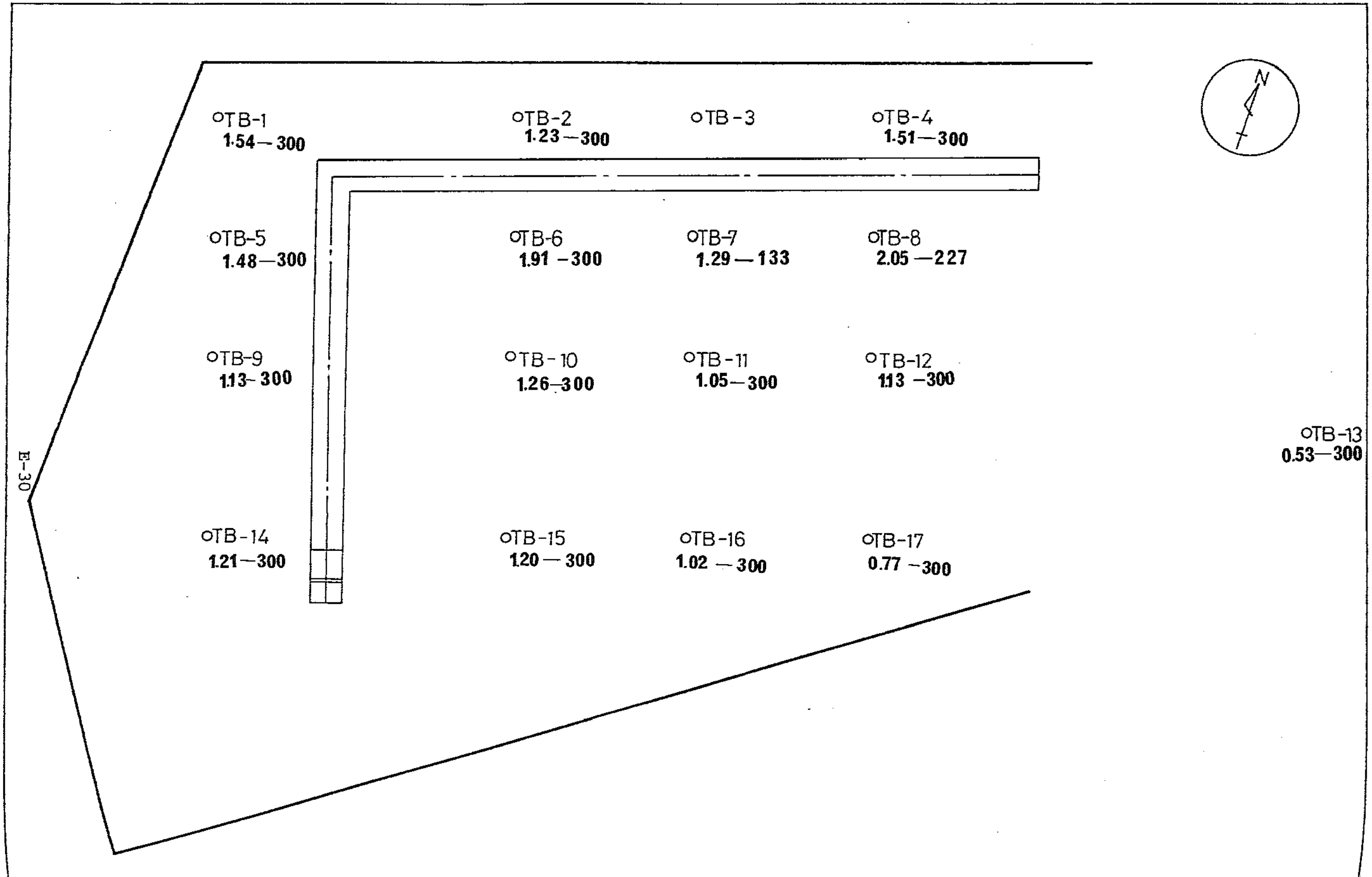


Fig. 3.1.5 Maximum Drawdown Rate and Its Occurring Time at Wadi Musherib

3.1.2 Recovery Test

(1) Test period

The recovery test was planned for 1 (one) week period, but recovery rates observed at Wadi Musherib were relatively slow, so the test was then extended until the recovery rates became less than 1 cm per day. Finally the test period was from October 27th to November 9th 1986.

(2) Observation

Observation results at open holes and the Trench are shown in Fig. 3.1.6.

(3) Total recovery height

Total recovery height at the Trench was 3.40 m and those of the open holes became smaller according to the distance from the Trench, as shown in Fig. 3.1.7.

Rough figures of the recovery heights according to distance from the Trench are:

Distance from Trench	Recovery Height
5 m	2.0 - 2.5 m
10 m	1.3 - 1.8 m
15 m	1.1 - 1.2 m
30 m	0.7 - 1.0 m

(4) Recovery percentage in Time

Recovery percentages at the Trench after 47 hrs (approx. 2 days) and 119 hrs. (approx. 5 days) were 67 and 87 percent respectively. Corresponding recovery percentages of the open holes were smaller than that of the Trench, as shown in Fig. 3.1.8.

Especially, recovery percentage after 47 hrs at TB-10 was too small and the surrounding area of TB-10 may have low permeability.

(5) Peak recovery rate

Ratio of peak recovery rate to mean recovery rate (R max./R mean) was introduced as reference index and the distribution of R max./R mean is shown in Fig. 3.1.9. The ratio of R max./R mean at the Trench was 2.6 and those of TB-6,7,8 and 18 were slightly higher values.

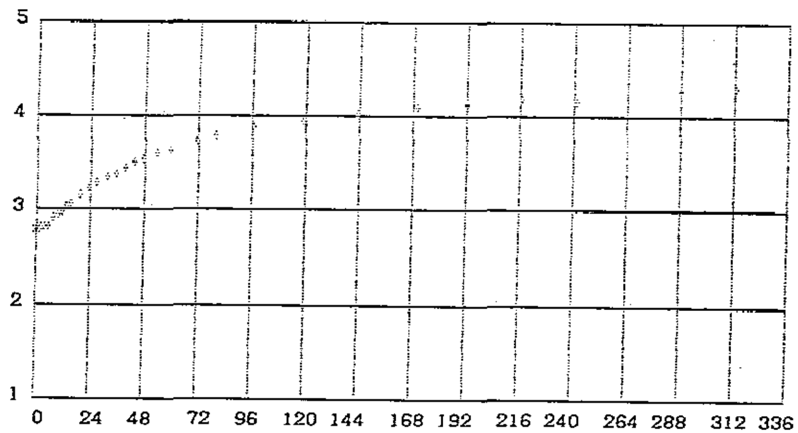


Fig. Recovery Test Results at Musherib:10/27 - 11/9: TB- 1

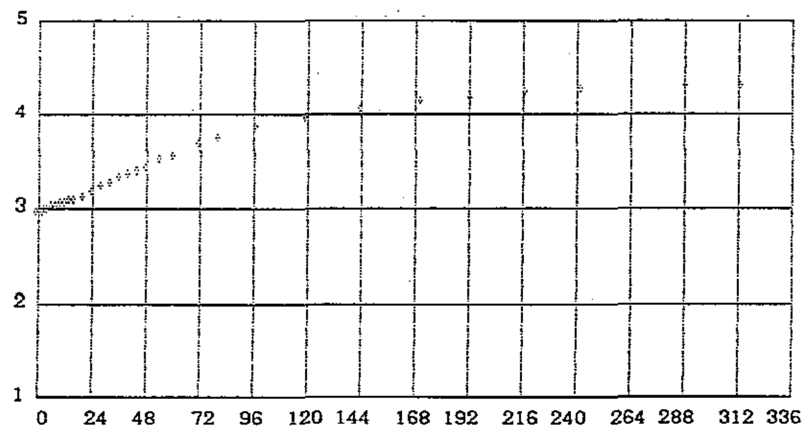


Fig. Recovery Test Results at Musherib:10/27 - 11/9: TB- 3

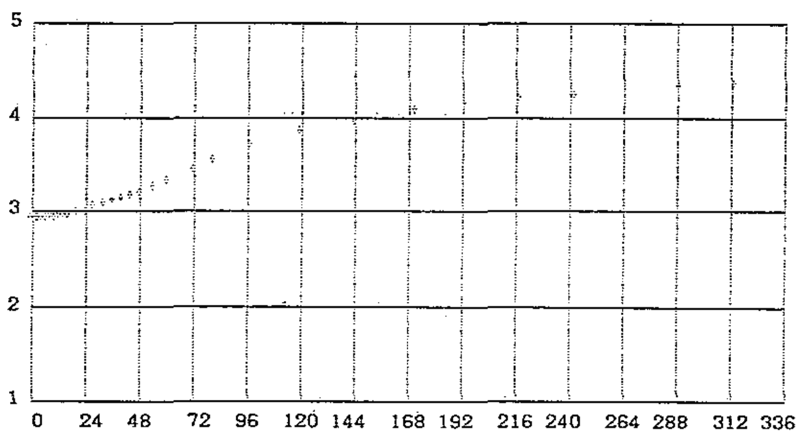


Fig. Recovery Test Results at Musherib:10/27 - 11/9: TB- 2

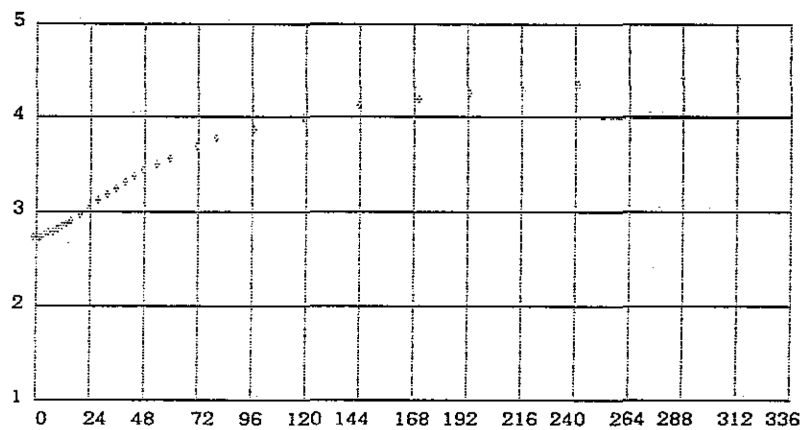


Fig. Recovery Test Results at Musherib:10/27 - 11/9: TB- 4

Fig. 3.1.6 (1) Recovery Test Results at Wadi Musherib

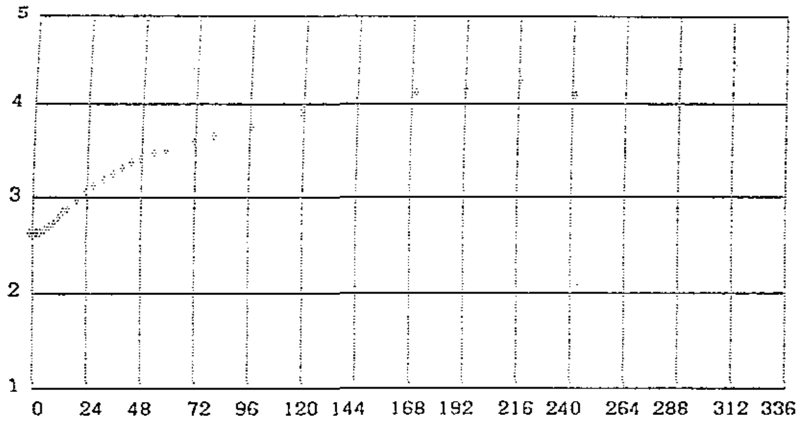


Fig. Recovery Test Results at Musherib:10/27 - 11/9: TB- 5

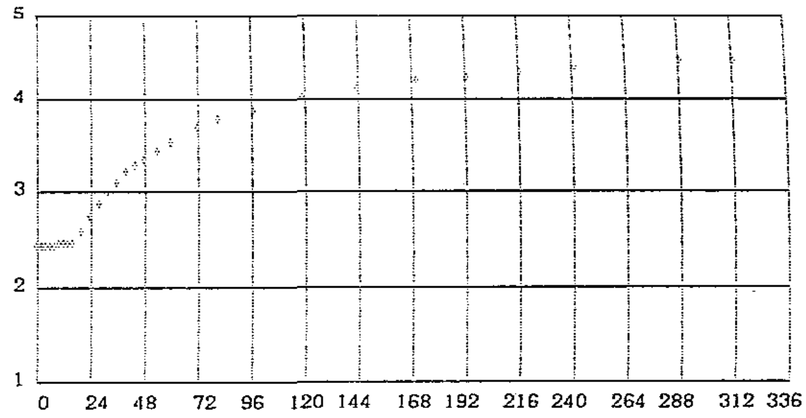


Fig. Recovery Test Results at Musherib:10/27 - 11/9: TB- 7

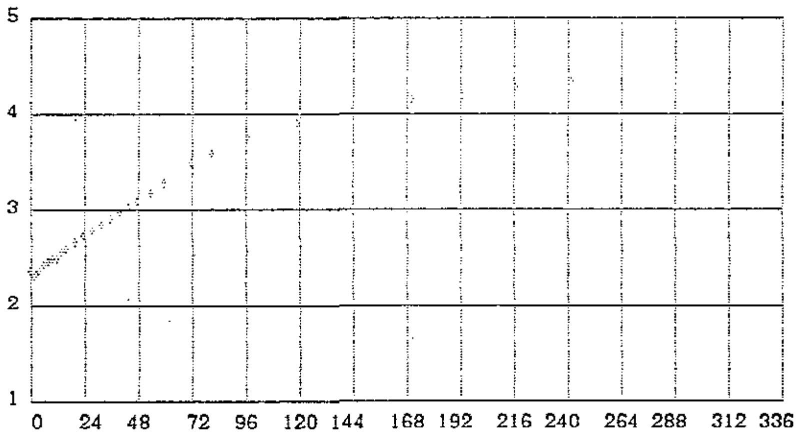


Fig. Recovery Test Results at Musherib:10/27 - 11/9: TB- 6

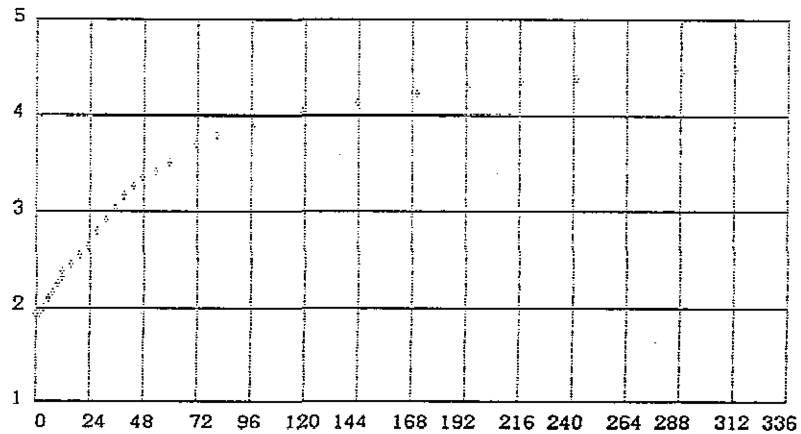


Fig. Recovery Test Results at Musherib:10/27 - 11/9: TB- 8

Fig. 3.1.6 (2) Recovery Test Results at Wadi Musherib

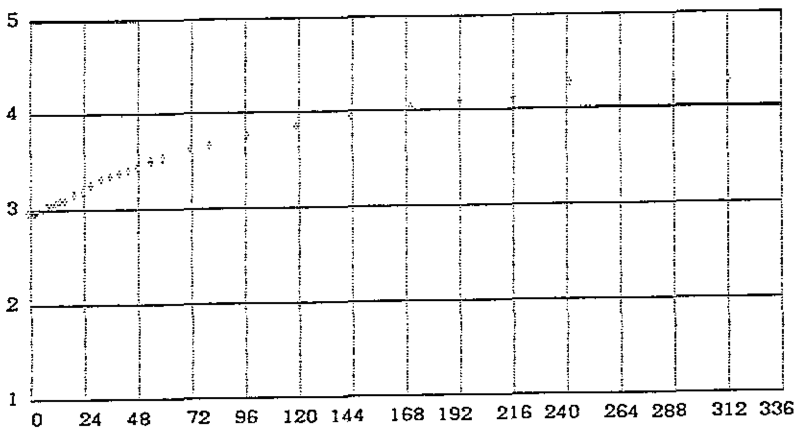


Fig. Recovery Test Results at Musherib:10/27 - 11/9: TB- 9

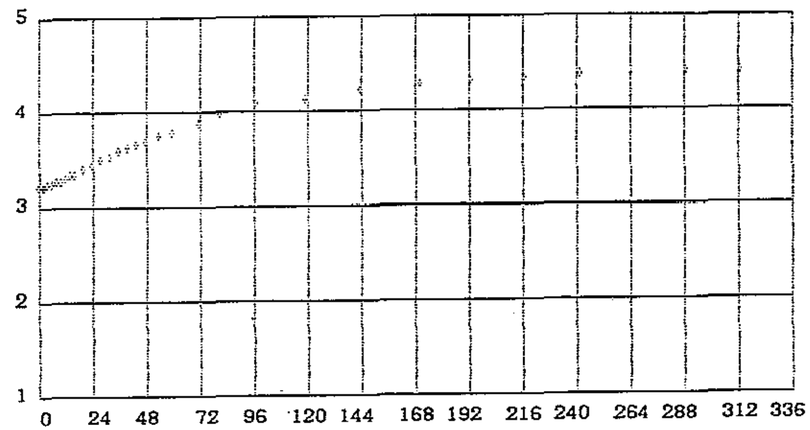


Fig. Recovery Test Results at Musherib:10/27 - 11/9: TB-11

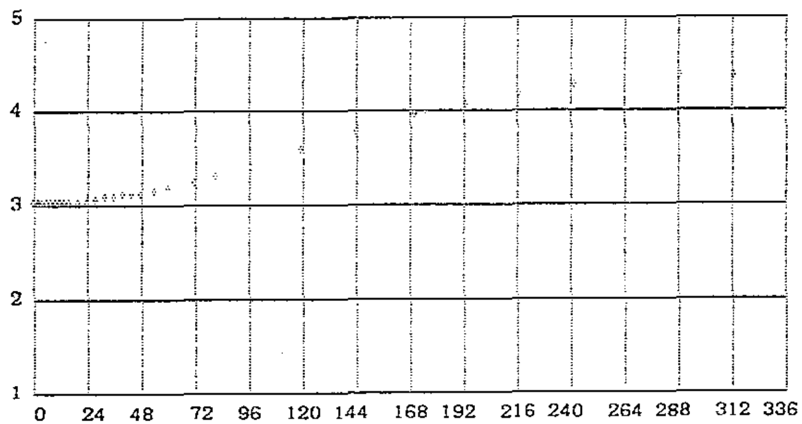


Fig. Recovery Test Results at Musherib:10/27 - 11/9: TB-10

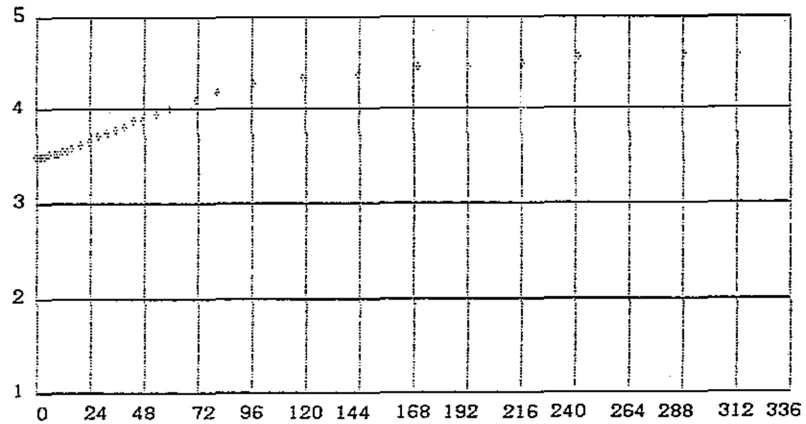


Fig. Recovery Test Results at Musherib:10/27 - 11/9: TB-12

Fig. 3.1.6 (3) Recovery Test Results at Wadi Musherib

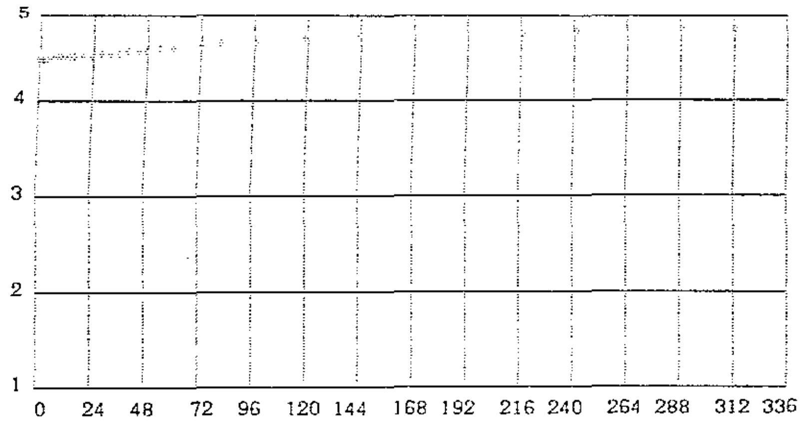


Fig. Recovery Test Results at Musherib:10/27 - 11/9: TB-13

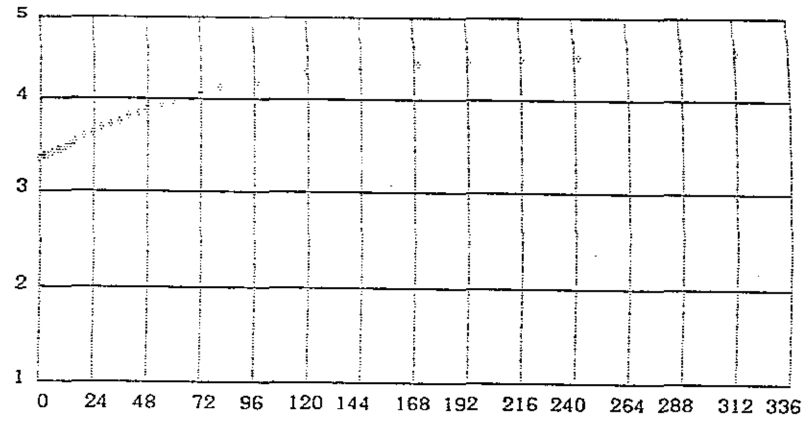


Fig. Recovery Test Results at Musherib:10/27 - 11/9: TB-15

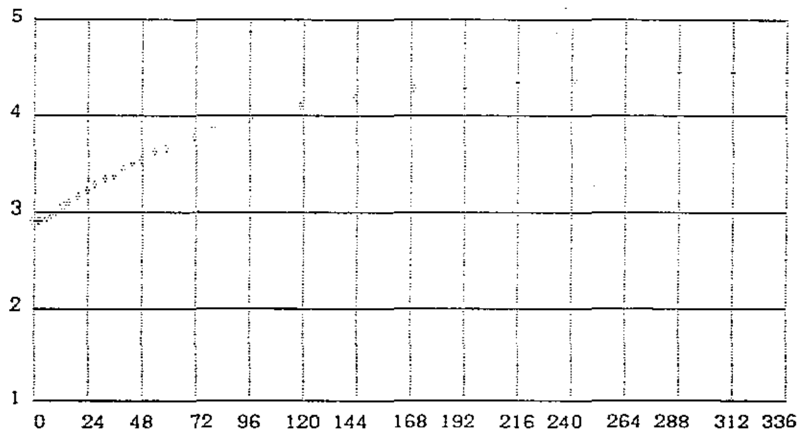


Fig. Recovery Test Results at Musherib:10/27 - 11/9: TB-14

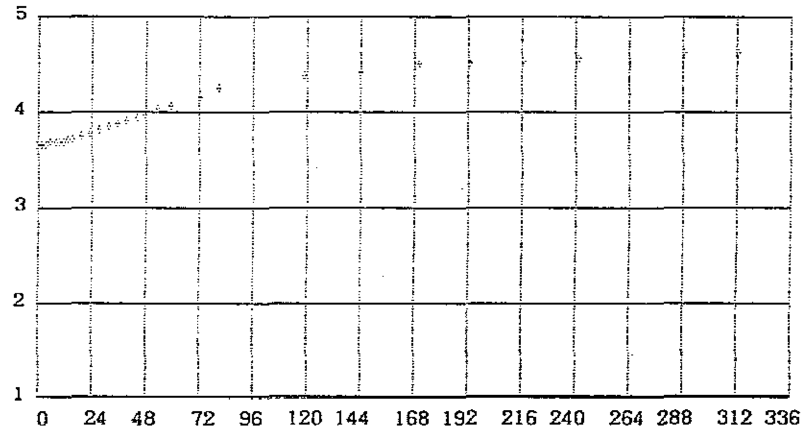


Fig. Recovery Test Results at Musherib:10/27 - 11/9: TB-16

Fig. 3.1.6 (4) Recovery Test Results at Wadi Musherib

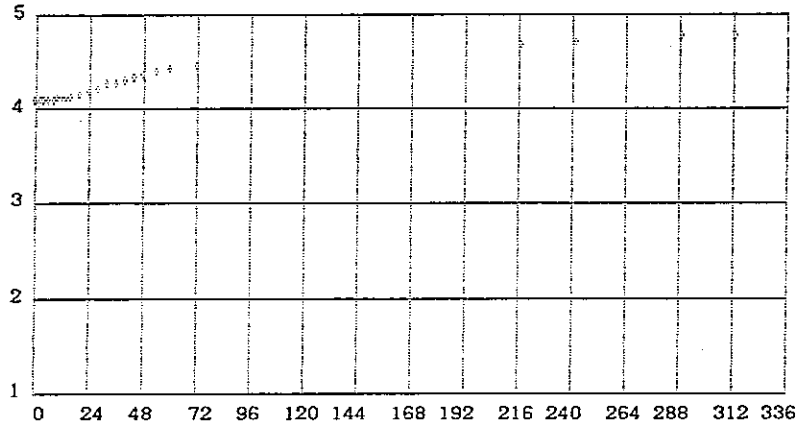


Fig. Recovery Test Results at Musherib:10/27 - 11/9: TB-17

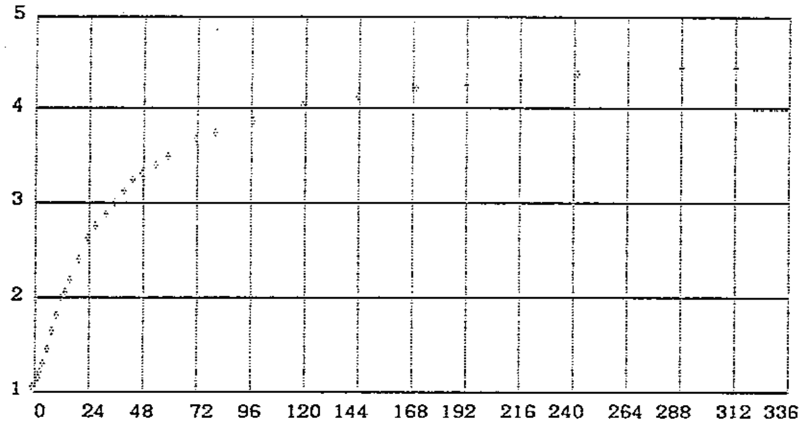


Fig. Recovery Test Results at Musherib:10/27 - 11/9: TRENCH

Fig. 3.1.6 (5) Recovery Test Results at Wadi Musherib

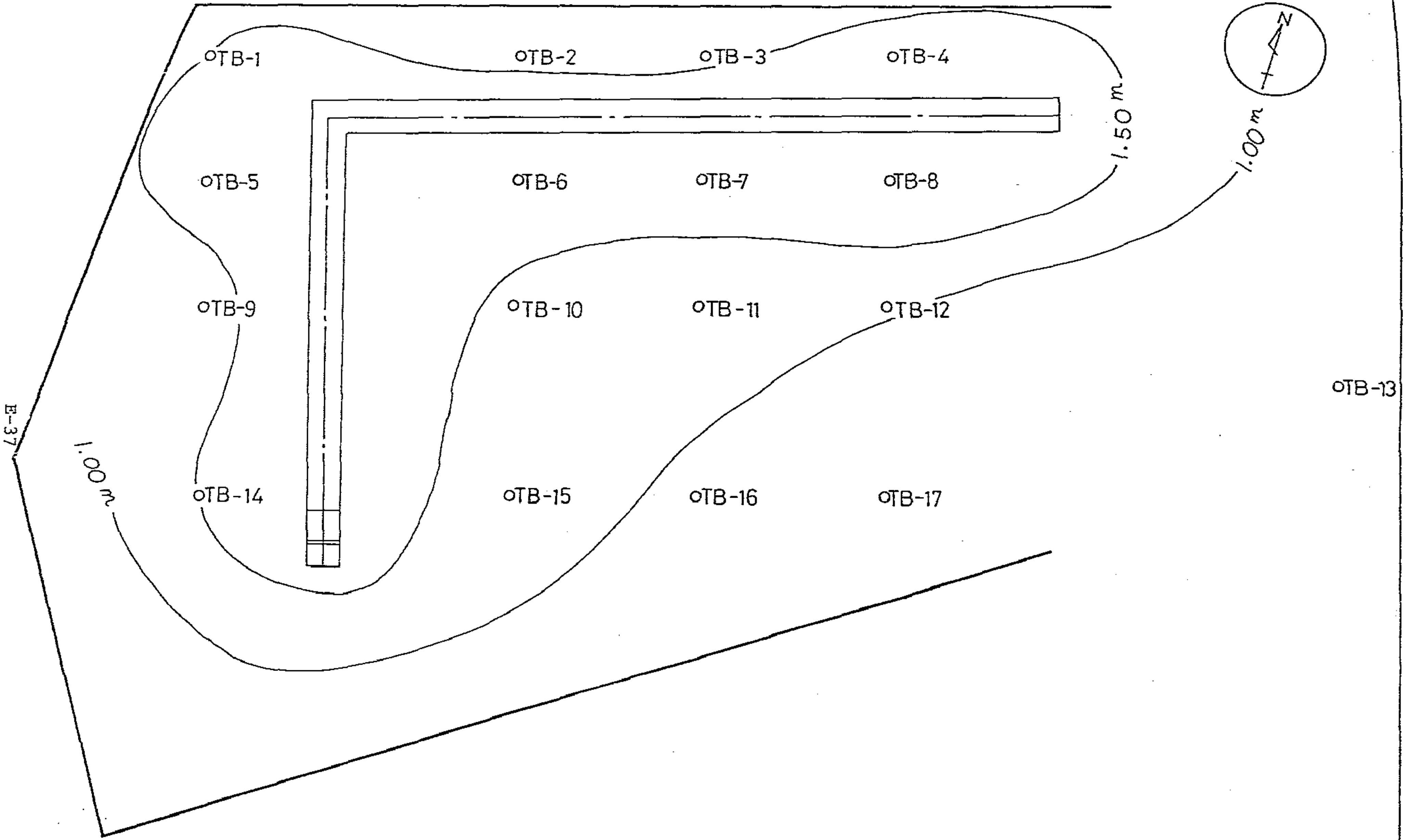


Fig. 3.1.7 ecovery Percentage after 47 and 119 hrs at Wadi Musherib.

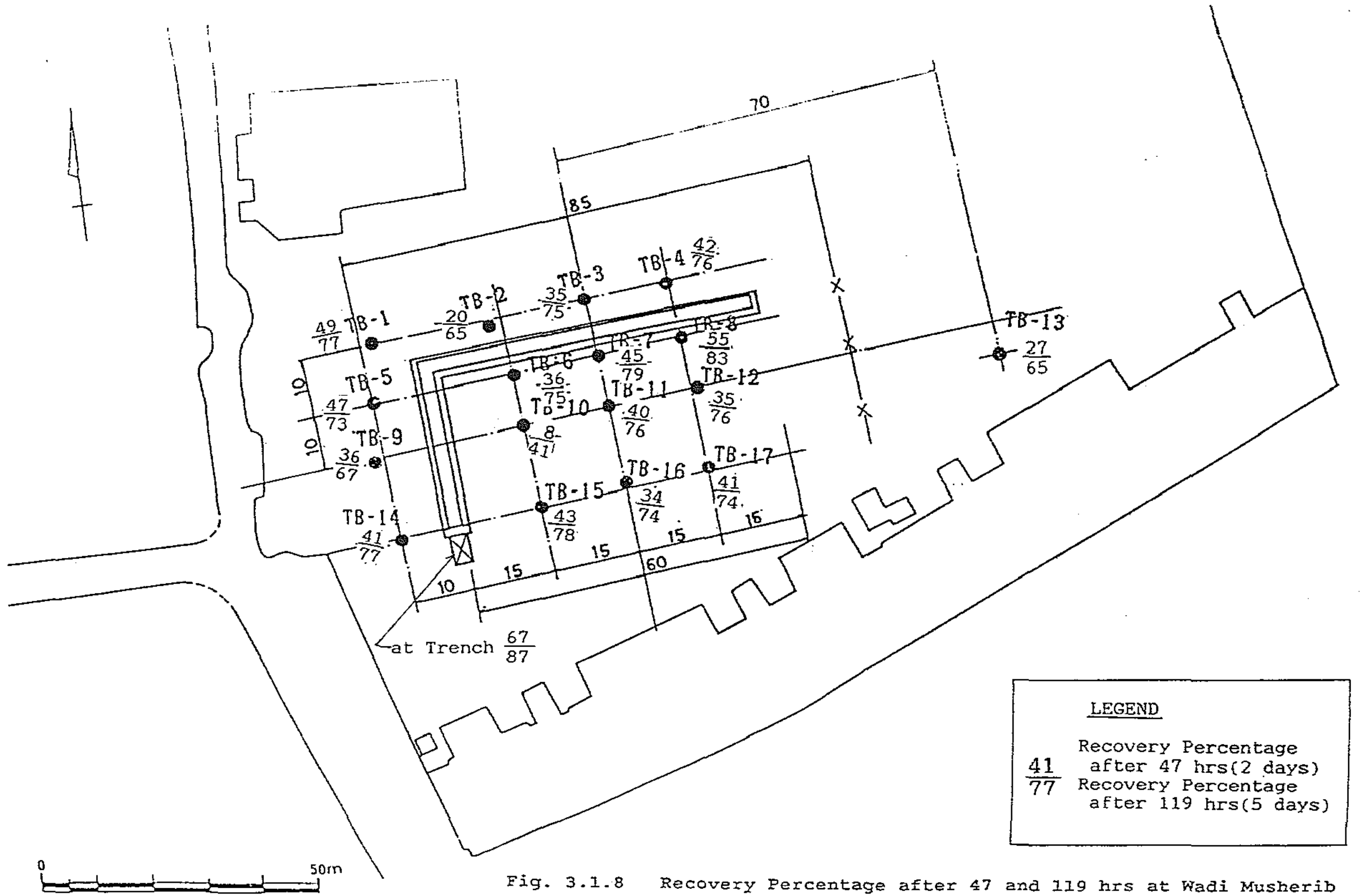


Fig. 3.1.8 Recovery Percentage after 47 and 119 hrs at Wadi Musherib

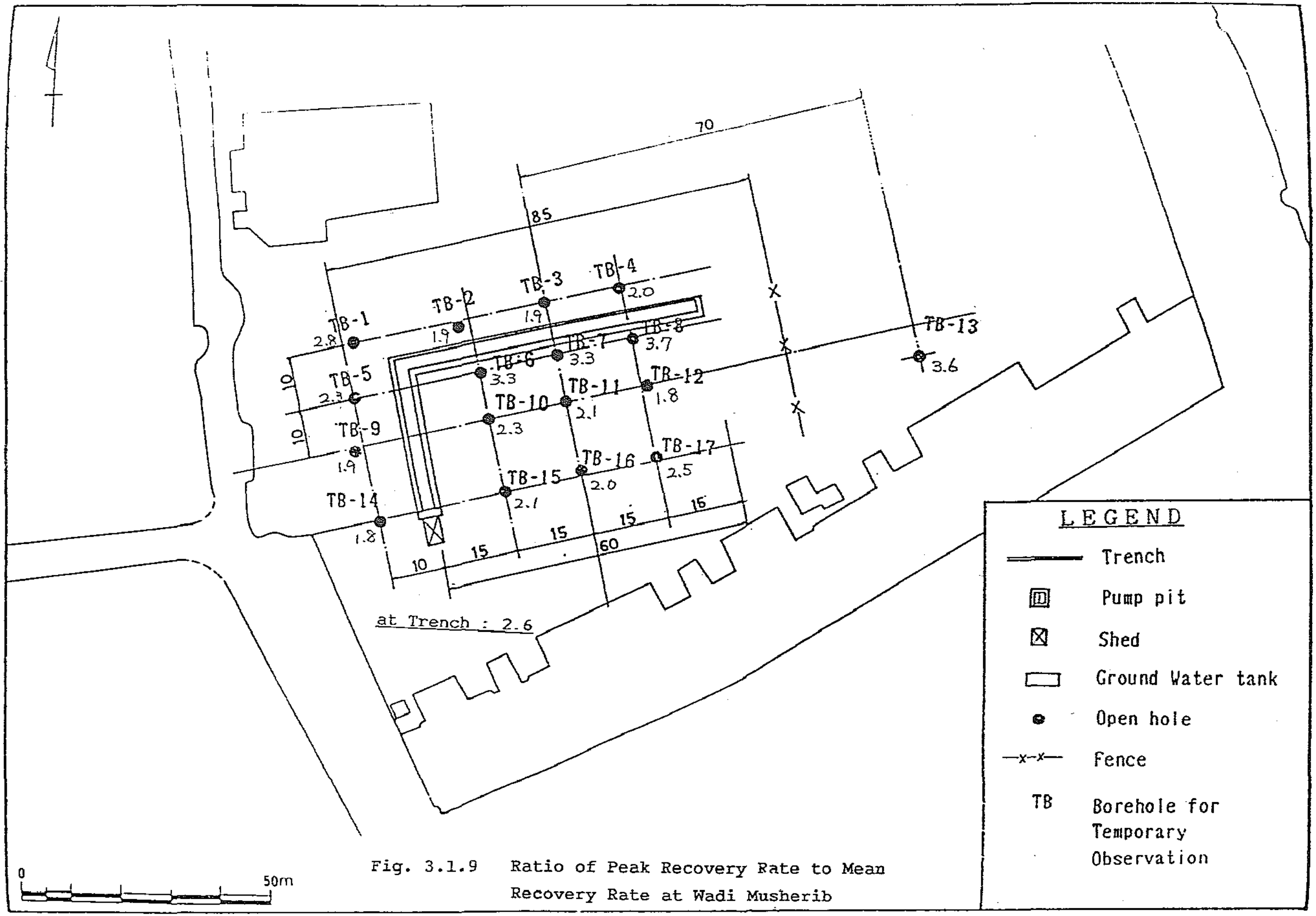


Fig. 3.1.9 Ratio of Peak Recovery Rate to Mean Recovery Rate at Wadi Musherib

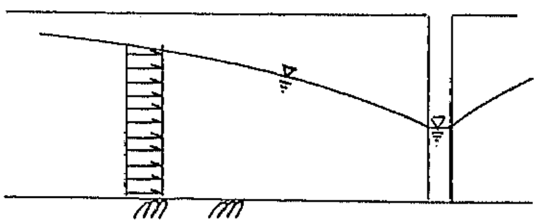
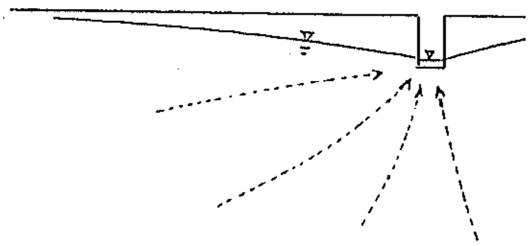
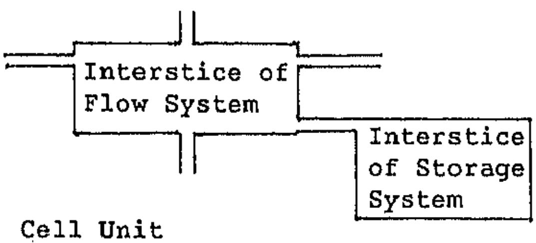
3.2 Numerical Analysis for Drawdown Simulation

3.2.1 Mathematical Model

The purpose of the drawdown simulation is to determine the hydraulic constants and to evaluate the drawdown effects of drainage system.

The principal simulation models are shown in Table 3.2.1. In the case where the trench length is much longer than its width, the two dimensional vertical plane which is at the right angle with the length direction is usually used as the calculation domain.

Table 3.2.1 Mathematical Methods for Drawdown Simulation

Model	Required Dimension(s) and Calculation Method
<u>Horizontal Model</u>  Base Rock	o One Dimensional Analysis o Finite Difference Method
Vertical Plane Model 	o Two Dimensional Analysis o Finite Element Method
Rock Infiltration Model  Cell Unit	o Two Dimensional Analysis o Finite Difference Method

The following facts should be considered in the selection of a mathematical model in view of the pumping test results.

a. As the trench partially penetrates into the aquifer, the vertical flow element is dominant near the trench bottom.

b. If fissures only exist in the shallow part of the aquifer, the discharge should quickly diminish. However, the actual discharge stabilised a few days after water level of the trench reached the bottom. This fact indicates that the fissures have developed not only in the horizontal direction but also in the vertical direction.

The horizontal model is not adequate due to its strong deviation from the assumed uniform horizontal flow. In comparison, the vertical plane model is widely used in the civil engineering field and can express vertical flow element. The rock infiltration model is occasionally referred to in the research papers but its application examples are very poor.

Generally speaking, the aquifer of limestone has strong heterogeneity as porous media and its permeability should be treated in the stochastic phenomena. This kind of approach demands much information and time for analysis.

The model selected here aims to seek the mean value of permeability corresponding to the stochastic distribution of permeability in the heterogenous field.

In the present study, the two dimensional vertical plane model is adopted. The governing equation is expressed as follows.

$$\frac{\partial \rho}{\partial t} = \text{div } (k \text{ grad } \psi)$$

Where, ρ : Mass Volume in Porous Media
t : Time
K : Permeability Coefficient
ψ : Hydraulic Head
div : Divergence
grad: Gradient

The finite element method is used for the present purpose of the study. The initial conditions and the boundary conditions are set in accordance with the purpose of the analysis.

3.2.2 Simulation of Drawdown

(1) Calculation Domain

The calculation domain includes the following three layers which are strictly related with the pumping test by trench abstraction method.

1 First Layer : Strong Weathered Zone of Upper Dammam Formation: 6 m in thickness

2 Second Layer: Weak Weathered Zone of Upper Dammam Formation: 5 m in thickness

3 Third Layer : Lower Dammam Formation: 20 m in thickness

The drawdown effect at a point of 100 m distance from trench is estimated to be negligible and this distance is sufficient to set up the boundary condition.

The calculation domain of two dimensional vertical plane model for drawdown simulation for Wadi Musherib is expressed by the grid system as shown in Fig. 3.2.1.

(2) Calculation Procedure

The tentative permeability coefficient of each layer was evaluated from the mean value of Lugeon value obtained from the Lugeon test.

The judgment condition is the concordance of drawdown depth curve in function of the distance from trench.

The final solution was sought by the trial and error method.

This calculation procedure is shown in Fig. 3.2.2.

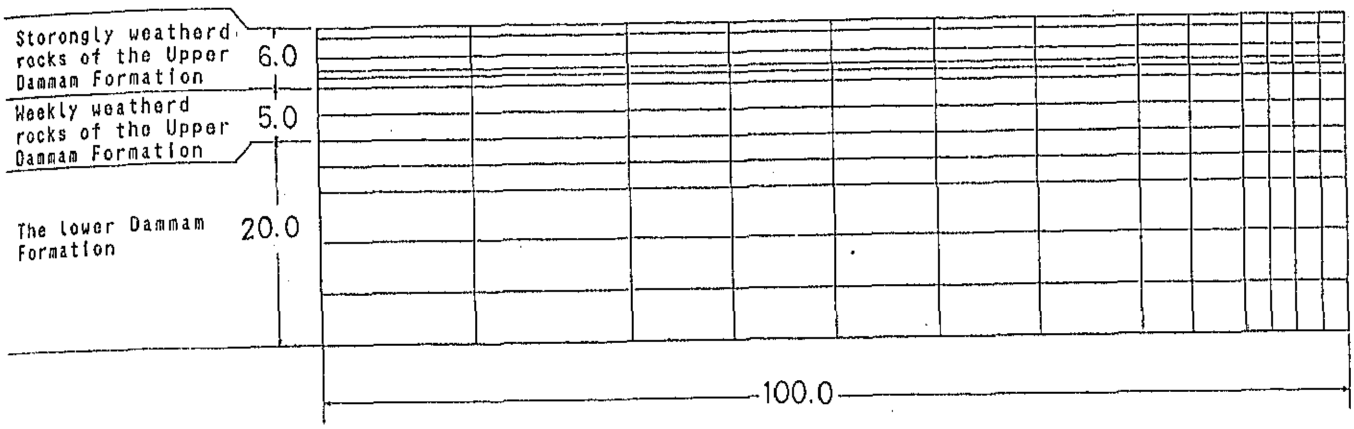


Fig. 3.2.1 Grid Network of Two Dimensional Vertical Plane Model: Wadi Musherib

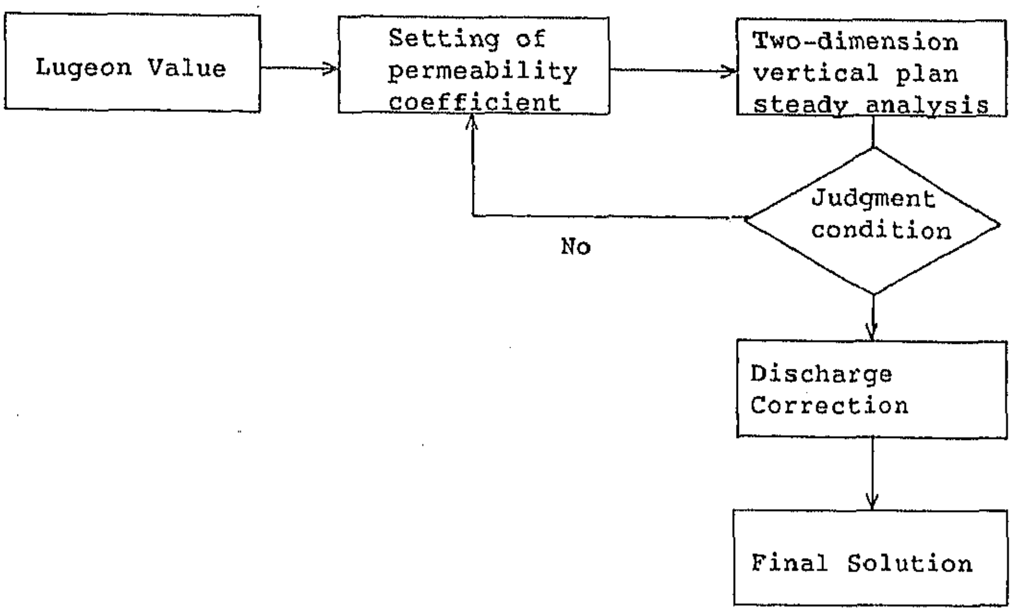


Fig. 3.2.2 Identification Procedure of Permeability Coefficient

(3) Initial and Boundary Condition

1 Initial conidition

$h\ (x,\ 0) = ho$

Where, ho : Initial Water Level

2 Boundary condition of Trench

$h\ (x,\ t) = ho - d$

Where, d : Drawdown at Trench

3 Boundary condition beneath the Trench

(Right boundary)

$$\frac{\partial h\ (x,\ t)}{\partial x} = 0$$

4 Bottom boundary

$h\ (x,\ t) = h_b$

Where, h_b: Piezometeric head of bottom
h_b= ho - 0.5 m

5 Boundary of Opposite Side (Left boundary)

$h\ (x,\ t) = f(x)$

Where, f(x) is linear interpolation between h_o and h_b according to the position.

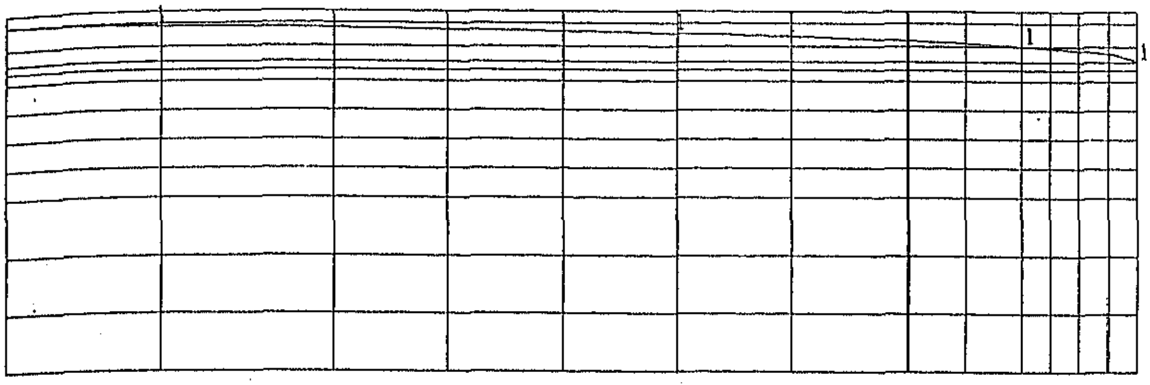
6 Upper boundary

No groundwater recharge.

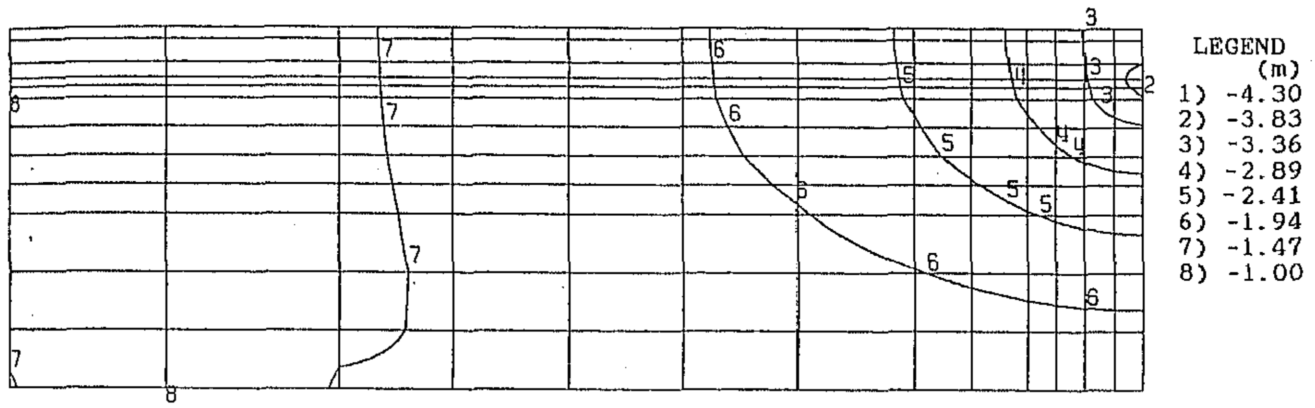
(4) Calculation Results

During the delay of the core boring, the fundamental nature of the vertical plane model with approximately 20 runs was studied; Different kinds of boundary condition, setting of calculation domain, etc.

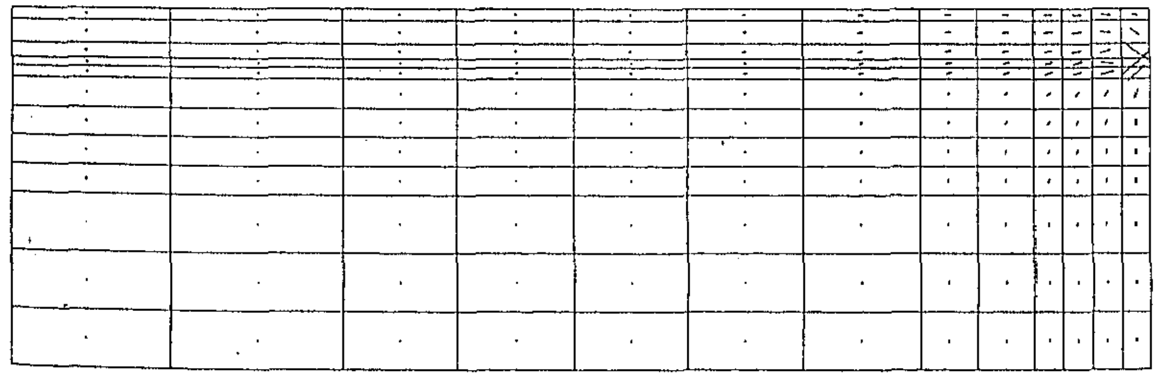
After having obtained the Lugeon values and core logs, eight runs were carried out, as shown in Table 3.2.2. Some examples of hydraulic head distribution are as shown in Fig. 3.2.3.



(1) Groundwater Table



(2) Hydaulic Head Distribution



(3) Flow Vector Distribution

Fig. 3.2.3 Simulation of Hydraulic Head Distribution by Two Dimensional Plane Model: Wadi Musherib

Table 3.2.2 List of Test Runs for Premeability Coefficient Identification: Wadi Musherib

	Permeability Coefficient (m/sec)		
	1st Layer	2nd Layer	3rd Layer
Case 1	4.52×10^{-4}	1.31×10^{-4}	5.99×10^{-5}
Case 2	4.04×10^{-4}	1.18×10^{-4}	5.36×10^{-4}
Case 3	2.25×10^{-4}	6.54×10^{-4}	2.98×10^{-4}
Case 4	4.17×10^{-5}	1.20×10^{-5}	5.51×10^{-5}
Case 5	4.17×10^{-5}	3.00×10^{-5}	1.90×10^{-6}
Case 6	4.17×10^{-5}	6.00×10^{-4}	3.10×10^{-6}
Case 7	4.17×10^{-5}	2.00×10^{-5}	1.50×10^{-5}
Case 8	2.71×10^{-5}	1.30×10^{-5}	9.74×10^{-5}

The permeability coefficient of each layer obtained from final solution is as follows,

- First layer (Strong weathered layer): 2.71×10^{-5}m/s
- Second layer (Weak weathered layer): 1.30×10^{-5}m/s
- Third layer (Lower dammam) : 9.74×10^{-5}m/s

The drawdown result of the final solution is as follows;

Distance from Trench	Drawdown Depth
5 m	2.34 m
10 m	1.98 m
30 m	1.12 m

3.2.3 Forecasting of Drawdown Effect

(1) Mathematical Model

Two dimension vertical plane steady analysis for which hydraulic parameter was indentified by the trial and error method, was also employed to obtain the numerical information on the determination of interval between neighbouring trenches in Collection System.

1 The shape of the groundwater table cross-section on the central line of the 2 parallel collection trenches is symmetrical. Either the right or the left half of the groundwater table cross-section is analysed.

2 The groundwater table is level on the central line.

3 The shape of the groundwater table cross-section, from the collection trench to the central line, is determined by the groundwater recharge amount.

4 The leakage amount from the bottom is included in the groundwater recharge amount and the bottom is regarded as an aquitard.

The following three types of grid system were used.

- 100 m Model
- 200 m Model
- 300 m Model

(2) Initial and Boundary Conditions

1 Initial condition

$$h\ (x,\ 0) = h_o$$

2 Boundary Condition of Trench

$$h\ (x,\ t) = h_o - d$$

3 Boundary Beneath the Trench (Right Boundary)

$$\frac{\partial h\ (x,\ t)}{\partial x} = 0$$

4 Bottom Boundary

$$\frac{\partial h\ (x,\ t)}{\partial x} = 0$$

5 Boundary of Opposite Side
(Left Boundary)

$$\frac{\partial h\ (x,\ t)}{\partial x} = 0$$

6 Upper Boundary

$$q = \frac{\varepsilon \cdot b \cdot t}{365 \times 24 \times 3{,}600}$$

Where, q : Groundwater recharge amount given at each node on the upper boundary

: Groundwater recharge rate

b : Length given at each node

t : Time step

(3) Calculation Results

The following runs as shown in Table 3.2.3 were carried out under the different conditions of groundwater recharge amount.

Table 3.2.3 List of Simulation Runs for Drawdown Forecasting: Wadi Musherib

Groundwater Recharge Amount	100 m Model	200 m Model	300 m Model
1000 mm/yr	Case 1	Case 2	Case 3
700 mm/yr	Case 4	Case 5	Case 6
400 mm/yr	Case 7	Case 8	Case 9

The relationship between the drawdown depth and the distance from collection trench is estimated as shown in Table 3.2.4 and the hydraulic head distributions of each run are shown in Fig. 3.2.4.

Table 3.2.4 Degree of Groundwater Level Lowering under the Constant Groundwater Recharge Amount: Wadi Musherib

(Unit: m)

Case	Recharge Volume (mm/yr)	Distance from Trench 5	10	30	100	200	300
1	1000	3.168	3.113	2.969	2.781	-	-
2	"	3.034	2.922	2.603	1.885	1.510	-
3	"	2.900	2.731	2.236	0.987	-0.141	-0.518
4	700	3.208	3.170	3.069	2.938	-	-
5	"	3.114	3.036	2.813	2.311	2.049	-
6	"	3.020	2.902	2.556	1.682	0.894	0.691
7	400	3.248	3.226	3.169	3.094	-	-
8	"	3.194	3.150	3.023	2.737	2.587	-
9	"	3.141	3.073	2.876	2.377	1.927	1.775

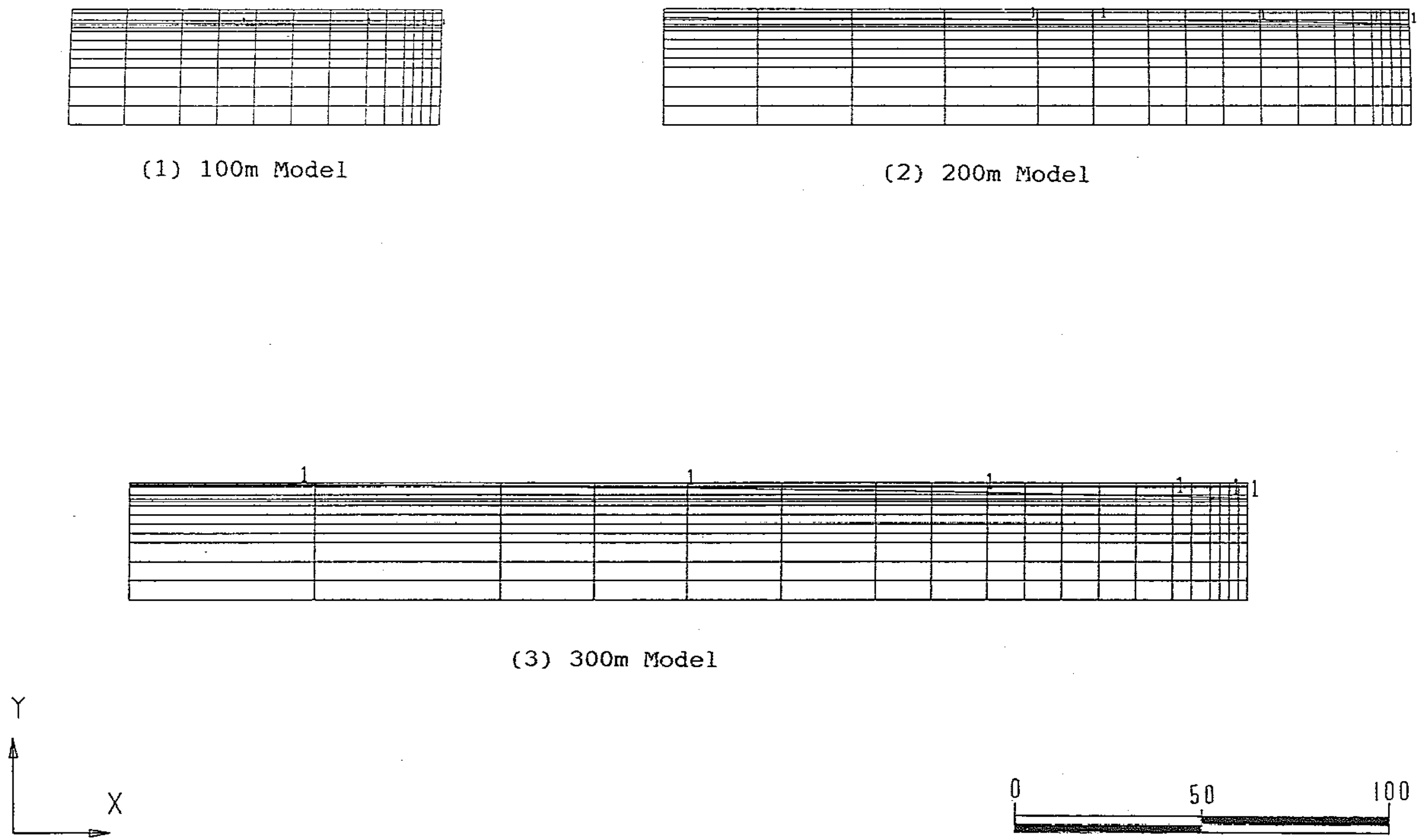
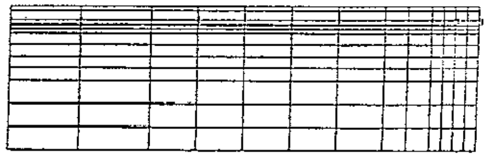
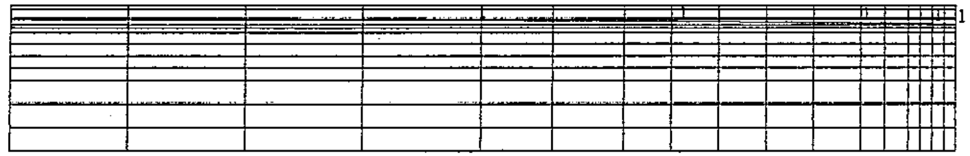


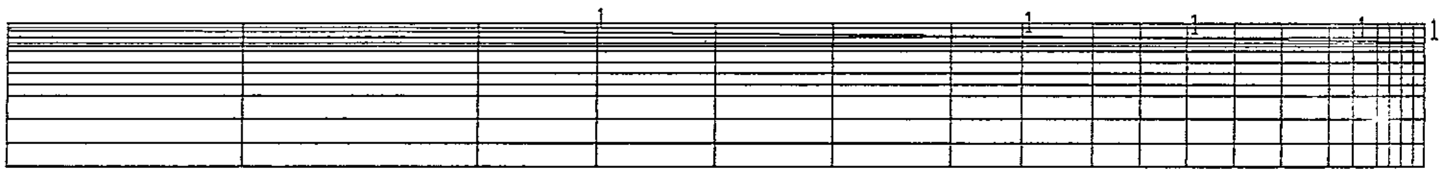
Fig. 3.2.4 Forecasting of Drawdown Depth by Two Dimensional Plane Model:
Wadi Musherib: Groundwater Recharge Amount 1000 mm/yr



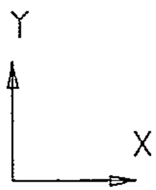
(1) 100m Model



(2) 200m Model



(3) 300m Model



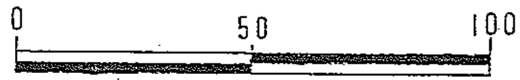


Fig. 3.2.4 Forecasting of Drawdown Depth by Two Dimensional Plane Model:
Wadi Musherib: Groundwater Recharge Amount 700 mm/yr

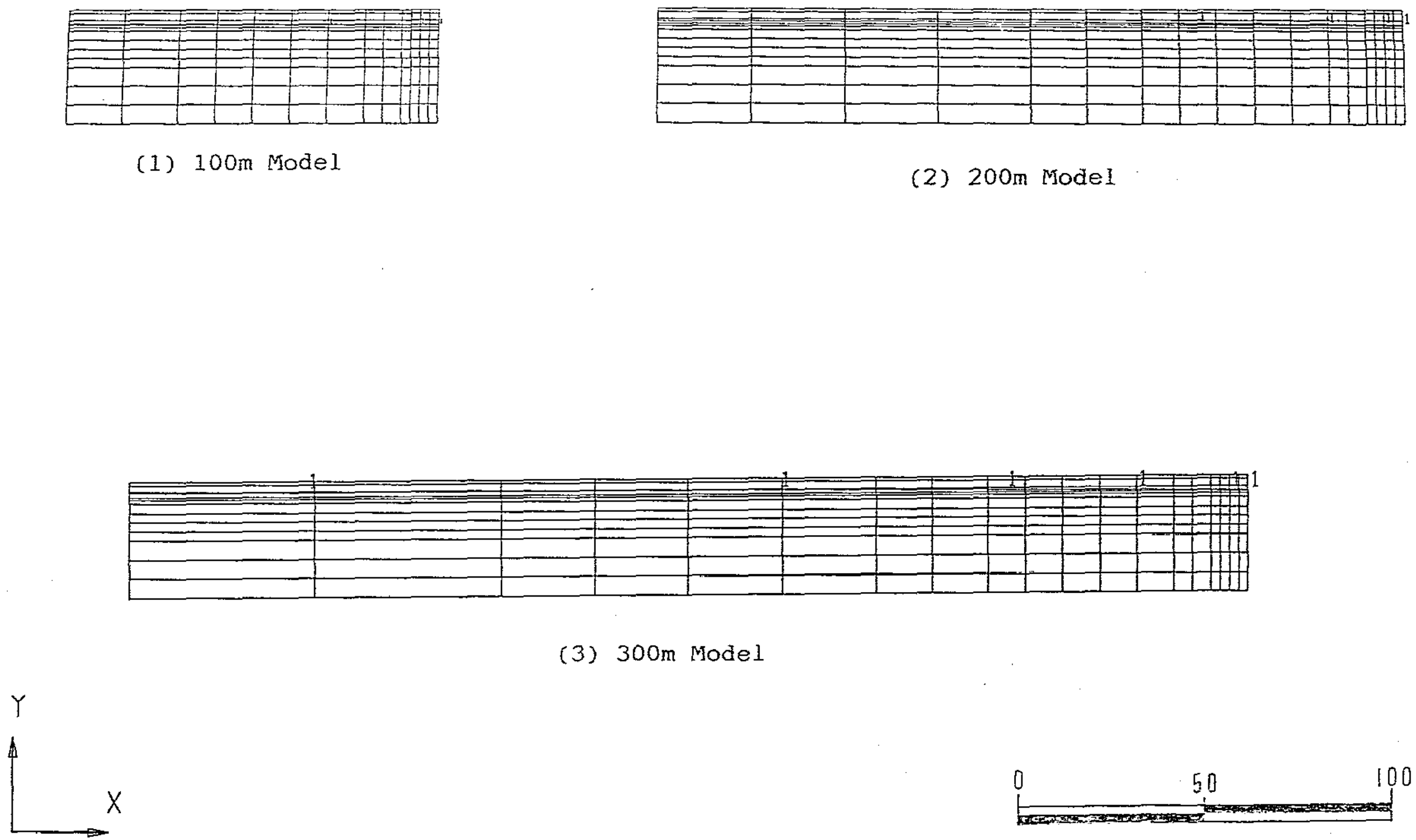


Fig. 3.2.4 Forecasting of Drawdown Depth by Two Dimensional Plane Model:
Wadi Musherib : Groundwater Recharge Amount 400 mm/yr

3.3 Water Quality

3.3.1 Sampling

The quality of the groundwater drained to the Trench is an important factor for determining the utilisation of groundwater, water treatment and dumping destination. Water sampling was, therefore, carried out regularly from the Trench and observation wells at the four corners. The water samples were then analysed with the cooperation of the Doha South Sewage Treatment Works Laboratory.

The items for analysis were as follows.

- o pH
- o Electric Conductivity (EC)
- o Chemical Oxygen Demand (COD)
- o Chlorine Ion
- o Sulphate Ion
- o Calcium Ion (As $CaCO_3$)
- o Magnesium Ion (as $CaCO_3$)
- o Sodium Ion
- o Potassium Ion

3.3.2 Analysis Results

The results of the analysis are shown in Table 3.3.1 and the characteristics of each water sample are summarised as follows.

1) Quality of Trench Water

The quality of the Trench water was both the best and the most stable. While there was some small fluctuation in the quality during the first few days following the commencement of the test pumping, the quality later stabilized.

Some values in both initial and final stages of the test were

o	EC	:	4000 - 5000 micro mhos/cm
o	COD	:	1 to 3 mg/l
o	Ca	:	900 to 1200 mg/l
o	Na	:	200 to 500 mg/l
o	SO_4	:	1200 to 1400 mg/l
o	Cl	:	600 to 750 mg/l

2) Quality of TB-1 Water (NW corner)

There was little fluctuation in the quality of the TB-1 water in regard to the pH and EC values but the COD value showed specific fluctuation. The COD value before July 16th was 0.7 - 2.7 mg/l, reaching 7.3 mg/l on July 23rd and then gradually dropping with a final reading of 3.1 mg/l on October 27th.

Table 3.3.1 Chemical Analysis Results at Wadi Musherib

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WATER CHEMICAL ANALYSIS DATA AT MUSHERIB TEST WORK SITE

DATE	7/2	7/3	7/3	7/3	7/4	7/5	7/6	7/7	7/8	7/9	7/16	7/23	7/30	8/3	8/10	8/19	8/24	8/31	9/7	9/14	9/21	9/28	10/5	10/13	10/19	10/27
P H	8.30	8.45	8.16	8.25	7.94	8.02	7.80	7.76	7.85	7.71	7.60	7.88	7.83	7.63	7.62	7.70	7.96	7.92	7.81	8.24	7.87	7.71	7.78	8.27	7.77	7.71
E C (ms/cm)	4820	4870	4930	4930	4720	4470	4490	4670	4180	4350	4140	4040	4030	3880	3830	3830	4100	4010	4120	4060	4050	3640	3930	3940	3920	4090
C O D (mg/l)	1.8	1.9	2.0	1.6	1.8	2.7	0.6	1.4	1.7	1.9	2.9	2.5	2.0	1.0	0.7	1.3	2.3	1.9	2.3	3.5	2.9	2.5	1.7	1.8	1.20	1.60
C l (mg/l)	630.0	580.0	585.9	565.7	545.5	545.5	606.1	545.5	520.0	630.0	686.9	480.0	500.0	510.0	472.4	462.3	510.0	494.9	464.6	563.4	679.3	566.0	518.9	509.4	469.5	495.0
S O 4 (mg/l)	2049.0	2087.0	1553.0	1647.0	2017.0	1989.0	1923.0	1690.0	1774.0	1807.0	1811.0	1618.0	1656.0	1634.0	1687.0	1743.0	1746.0	1321.0	1620.0	1774.0	2073.0	1796.0	1691.0	1999.0	1517.0	1737.0
C a (mg/l)	1270.0	1310.0	1320.0	1290.0	1230.0	1160.0	1150.0	1140.0	1080.0	1060.0	1120.0	1120.0	1120.0	1140.0	1180.0	1080.0	1120.0	1050.0	1050.0	1150.0	1075.0	875.0	1000.0	1000.0	1080.0	1120.0
M g (mg/l)	330.0	290.0	280.0	310.0	310.0	300.0	310.0	260.0	360.0	380.0	280.0	340.0	280.0	220.0	200.0	320.0	340.0	370.0	325.0	325.0	325.0	475.0	425.0	400.0	340.0	320.0
K (mg/l)	71.7	68.2	69.6	68.2	66.8	64.4	63.9	62.9	61.8	61.8	57.6	58.1	56.4	56.9	59.5	60.5	56.7	61.2	55.3	58.3	58.3	28.7	27.0	29.0	54.2	59.6
N a (mg/l)	505.3	498.7	505.3	498.7	492.0	474.5	489.8	500.0	438.8	469.4	389.4	379.8	373.4	392.8	396.7	380.0	263.3	256.9	250.0	286.0	269.7	193.5	173.3	187.7	383.1	464.3
Cl/35.45(em/l)	17.77	16.36	16.53	15.96	15.39	15.39	17.10	15.39	14.67	17.77	19.38	13.54	14.10	14.39	13.33	13.04	14.39	13.96	13.11	15.89	19.16	15.97	14.64	14.37	13.24	13.96
SO4/48.03(em/l)	42.66	43.45	32.33	34.29	41.99	41.41	40.04	35.19	36.94	37.62	37.71	33.69	34.48	34.02	35.12	36.29	36.35	27.50	33.73	36.94	43.16	37.39	35.21	41.62	31.58	36.16
Ca/50(em/l)	25.40	26.20	26.40	25.80	24.60	23.20	23.00	22.80	21.60	21.20	22.40	22.40	22.40	22.80	23.60	21.60	22.40	21.00	21.00	23.00	21.50	17.50	20.00	20.00	21.60	22.40
Mg/50(em/l)	6.60	5.80	5.60	6.20	6.20	6.00	6.20	5.20	7.20	7.60	5.60	6.80	5.60	4.40	4.00	6.40	6.80	7.40	6.50	6.50	6.50	9.50	8.50	8.00	6.80	6.40
Na+K(em/l)	23.80	23.43	23.75	23.43	23.10	22.28	22.93	23.35	20.66	21.99	18.40	18.00	17.68	18.53	18.77	18.07	12.90	12.73	12.28	13.93	13.22	9.15	8.23	8.90	18.04	21.71
Na/Cl	0.80	0.86	0.86	0.88	0.90	0.87	0.81	0.92	0.84	0.75	0.57	0.79	0.75	0.77	0.84	0.82	0.52	0.52	0.54	0.51	0.40	0.34	0.33	0.37	0.82	0.94
SO4/Cl	3.25	3.60	2.65	2.91	3.70	3.65	3.17	3.10	3.41	2.87	2.64	3.37	3.31	3.20	3.57	3.77	3.42	2.67	3.49	3.15	3.05	3.17	3.26	3.92	3.23	3.51
SAR	3.81	3.72	4.10	4.00	3.75	3.68	3.84	4.09	3.57	3.81	3.13	3.16	3.08	3.24	3.22	3.11	2.14	2.29	2.10	2.30	2.09	1.63	1.45	1.49	3.27	3.78

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WATER CHEMICAL ANALYSIS DATA AT MUSHERIB TEST WORK SITE

DATE	7/02	7/03	7/03	7/03	7/04	7/05	7/06	7/07	7/08	7/09	7/16	7/23	7/30	8/03	8/10	8/19	8/24	8/31	9/7	9/14	9/21	9/28	10/5	10/13	10/19	10/27
P H	7.8	7.8	7.7	7.7	7.6	8.1	7.8	7.7	7.8	7.7	7.8	7.7	7.8	7.5	7.5	7.7	7.8	8.0	7.8	8.3	8.0	7.7	7.7	8.3	7.7	7.8
E C (ms/cm)	6020	5940	6240	6230	6070	6270	6530	6870	6770	6980	7000	6320	6420	6590	6380	6390	6260	6520.0	6560.0	6420.0	6620.0	5940.0	6520.0	6520.0	6500.0	6520.0
C O D (mg/l)	1.6	0.9	1.7	1.2	1.4	2.6	0.6	2.9	3.1	3.0	3.0	7.3	5.4	2.8	1.9	2.1	3.0	3.3	3.6	2.4	3.4	4.1	4.6	4.1	2.6	3.1
C l (mg/l)	850.0	816.7	841.8	791.2	841.8	824.9	875.4	909.1	883.3	983.3	1212.1	900.0	940.0	1000.0	1005.0	1021.8	1216.7	925.9	909.1	1032.9	1066.4	1037.7	1014.2	1037.7	1032.9	1064.4
S O 4 (mg/l)	2773.0	2895.0	2413.0	2507.0	2390.0	2577.0	2665.0	2577.0	2469.0	2693.0	2763.0	2345.0	2091.0	2483.0	2633.0	2521.0	2773.0	2624.0	2540.0	2460.0	2913.0	2278.0	2745.0	2960.0	2400.0	2820.0
C a (mg/l)	1470.0	1480.0	1440.0	1470.0	1490.0	1460.0	1470.0	1480.0	1480.0	1420.0	1480.0	1540.0	1480.0	1460.0	1460.0	1500.0	1400.0	1675.0	1500.0	1525.0	1450.0	1450.0	1525.0	1425.0	1540.0	1460.0
M g (mg/l)	400.0	360.0	360.0	330.0	330.0	370.0	360.0	380.0	400.0	480.0	460.0	380.0	380.0	400.0	440.0	420.0	400.0	130.0	375.0	375.0	475.0	450.0	325.0	525.0	360.0	500.0
K (mg/l)	104.6	103.3	103.3	104.6	104.6	110.3	115.5	117.5	117.5	122.7	116.2	102.0	110.5	113.8	118.9	123.3	103.1	118.1	107.4	112.5	110.4	56.4	53.0	54.4	104.2	108.5
N a (mg/l)	731.4	731.4	731.4	731.4	704.8	738.1	809.5	869.0	886.9	934.5	833.3	688.9	712.7	942.8	860.0	873.3	773.3	555.5	569.4	613.0	611.8	426.0	414.8	421.2	838.7	884.1
Cl/35.45(em/l)	24.0	23.0	23.7	22.3	23.7	23.3	24.7	25.6	24.9	27.7	34.2	25.4	26.5	28.2	28.3	28.8	34.3	26.1	25.6	29.1	30.1	29.3	28.6	29.3	29.1	30.0
SO4/48.03(em/l)	57.7	60.3	50.2	52.2	49.8	53.7	55.5	53.7	51.4	56.1	57.5	48.8	43.5	51.7	54.8	52.5	57.7	54.6	52.9	51.2	60.6	47.4	57.2	61.6	50.0	58.7
Ca/50(em/l)	29.4	29.6	28.8	29.4	29.8	29.2	29.4	29.6	29.6	28.4	29.6	30.8	29.6	29.2	29.2	30.0	28.0	33.5	30.0	30.5	29.0	29.0	30.5	28.5	30.8	29.2
Mg/50(em/l)	8.0	7.2	7.2	6.6	6.6	7.4	7.2	7.6	8.0	9.6	9.2	7.6	7.6	8.0	8.8	8.4	8.0	2.6	7.5	7.5	9.5	9.0	6.5	10.5	7.2	10.0
Na+K(em/l)	34.5	34.4	34.4	34.5	33.3	34.9	38.1	40.8	41.6	43.8	39.2	32.6	33.8	43.9	40.4	41.1	36.3	27.2	27.5	29.5	29.4	20.0	19.4	19.7	39.1	41.2
Na/Cl	1.3	1.4	1.3	1.4	1.3	1.4	1.4	1.5	1.5	1.5	1.1	1.2	1.2	1.5	1.3	1.3	1.0	0.9	1.0	0.9	0.9	0.6	0.6	0.6	1.3	1.3
SO4/Cl	2.4	2.6	2.1	2.3	2.1	2.3	2.2	2.1	2.1	2.0	1.7	1.9	1.6	1.8	1.9	1.8	1.7	2.1	2.1	1.8	2.0	1.6	2.0	2.1	1.7	2.0
SAR	7.4	7.4	7.5	7.5	7.2	7.5	8.2	8.8	8.9	9.3	8.2	6.8	7.2	9.5	8.6	8.7	7.9	5.7	5.7	6.1	6.1	4.2	4.2	4.1	8.4	8.7

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WATER CHEMICAL ANALYSIS DATA AT MUSHERIB TEST WORK SITE

DATE	7/02	7/03	7/03	7/03	7/04	7/05	7/06	7/07	7/08	7/09	7/16	7/23	7/30	8/03	8/10	8/19	8/24	8/31	9/7	9/14	9/21	9/28	10/5	10/13	10/19	10/27
P H	7.5	7.5	7.3	7.3	7.6	7.8	7.6	7.4	7.5	7.4	7.5	7.8	7.8	7.6	7.6	7.6	7.8	7.8	7.8	8.3	8.1	7.9	7.7	8.3	7.7	7.7
E C (ms/cm)	7800	7850	8370	7720	7290	7760	7880	7550	6890	6580	6300	4970	4700	4690	4530	4400	4640	4790.0	4880.0	4790.0	4790.0	4320.0	4630.0	4600.0	4670.0	4840.0
C O D (mg/l)	5.6	5.2	5.4	5.8	7.1	6.8	7.4	8.8	7.8	7.3	6.7	2.9	1.8	1.4	1.1	1.2	1.2	2.4	2.5	2.0	3.0	2.6	3.3	2.6	6.7	2.4
C l (mg/l)	1283.3	1283.3	1313.1	1077.4	841.8	1144.8	1195.3	1077.4	900.0	783.3	993.3	550.0	560.0	640.0	562.8	542.7	566.7	585.9	484.8	657.3	600.3	597.5	597.5	723.3	586.9	631.2
S O 4 (mg/l)	3408.0	3520.0	3268.0	3193.0	3221.0	3371.0	3287.0	3100.0	3399.0	3007.0	2763.0	2180.0	1951.0	2063.0	1982.0	1967.0	2017.0	1830.0	1914.0	2245.0	2279.0	2029.0	2185.0	2540.0	1961.0	2124.0
C a (mg/l)	1530.0	1510.0	1480.0	1440.0	1440.0	1560.0	1500.0	1520.0	1480.0	1420.0	1440.0	1220.0	1180.0	1240.0	1140.0	1130.0	1220.0	1175.0	1150.0	1175.0	1125.0	1175.0	1175.0	1100.0	1300.0	1200.0
M g (mg/l)	660.0	700.0	720.0	740.0	730.0	730.0	830.0	700.0	720.0	780.0	680.0	380.0	420.0	340.0	440.0	400.0	360.0	400.0	425.0	550.0	425.0	200.0	375.0	600.0	360.0	480.0
K (mg/l)	146.3	143.5	144.9	113.5	104.6	121.6	124.7	123.7	116.5	111.3	98.9	81.9	80.7	85.1	87.9	36.8	80.4	80.8	78.8	83.3	81.2	41.0	39.0	39.0	72.9	80.8
N a (mg/l)	970.7	1010.6	1010.6	917.6	851.1	979.6	989.8	928.6	826.5	765.3	692.3	490.0	476.2	475.6	477.8	477.8	472.2	347.2	340.3	479.6	494.6	247.2	233.0	236.2	437.5	579.3
Cl/35.45(em/l)	37.25	37.25	38.12	31.27	24.44	33.23	34.70	31.27	26.12	22.74	28.83	15.97	16.26	18.58	16.34	15.75	16.45	17.01	14.07	19.08	17.43	17.34	17.34	21.00	17.04	18.32
SO4/48.03(em/l)	70.96	73.29	68.04	66.48	67.06	70.19	68.44	64.54	70.77	62.61	57.53	45.39	40.62	42.95	41.27	40.95	41.99	38.10	39.85	46.74	47.45	42.24	45.49	52.88	40.83	44.22
Ca/50(em/l)	30.60	30.20	29.60	28.80	28.80	31.20	30.00	30.40	29.60	28.40	28.80	24.40	23.60	24.80	22.80	22.60	24.40	23.50	23.00	23.50	22.50	23.50	23.50	22.00	26.00	24.00
Mg/50(em/l)	13.20	14.00	14.40	14.80	14.60	14.60	16.60	14.00	14.40	15.60	13.60	7.60	8.40	6.80	8.80	8.00	7.20	8.00	8.50	11.00	8.50	4.00	7.50	12.00	7.20	9.60
Na+K(em/l)	45.95	47.61	47.65	42.80	39.68	45.70	46.22	43.54	38.91	36.12	32.63	23.40	22.77	22.85	23.02	21.72	22.59	17.16	16.81	22.98	23.58	11.80	11.13	11.27	20.89	27.25
Na/Cl	1.13	1.18	1.15	1.28	1.51	1.28	1.24	1.29	1.38	1.46	1.04	1.33	1.27	1.11	1.27	1.32	1.25	0.89	1.05	1.09	1.23	0.62	0.58	0.49	1.12	1.37
SO4/Cl	1.90	1.97	1.79	2.13	2.74	2.11	1.97	2.06	2.71	2.75	2.00	2.84	2.50	2.31	2.53	2.60	2.55	2.24	2.83	2.45	2.72	2.44	2.62	2.52	2.40	2.41
SAR	9.02	9.35	9.37	8.54	7.94	8.90	8.92	8.57	7.66	7.09	6.54	5.33	5.18	5.20	5.23	5.31	5.16	3.80	3.73	5.02	5.46	2.90	2.57	2.49	4.67	6.14

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WATER CHEMICAL ANALYSIS DATA AT MUSHERIB TEST WORK SITE

DATE	7/02	7/03	7/03	7/03	7/04	7/05	7/06	7/07	7/08	7/09	7/16	7/23	7/30	8/03	8/10	8/19	8/24	8/31	9/7	9/14	9/21	9/28	10/5	10/13	10/19	10/27
P H	8.1	8.0	7.9	7.9	7.9	8.0	8.0	7.9	7.9	7.9	7.9	7.9	7.9	7.6	7.7	7.8	7.9	7.8	7.9	8.3	8.0	7.8	7.8	8.3	7.7	7.7
E C (ms/cm)	12410	12040	12760	12730	12700	12700	12630	13050	12620	12730	13030	7290	8260	8510	8040	7730	8250	8320.0	8350.0	7770.0	7720.0	6760.0	7440.0	7260.0	7210.0	6780.0
C O D (mg/l)	1.4	1.1	2.6	2.7	3.3	2.0	3.1	5.2	5.4	7.2	7.3	3.7	2.4	2.6	2.6	2.8	4.0	4.6	4.1	3.8	4.2	3.7	4.4	4.5	2.5	3.2
C l (mg/l)	1750.0	1750.0	1565.7	1565.7	1616.2	1641.4	1691.9	1717.2	1550.0	1700.0	2222.2	1800.0	1200.0	1066.7	1005.0	979.9	1050.0	2449.5	909.1	1126.8	947.9	849.1	872.6	817.6	798.1	742.6
S O 4 (mg/l)	5900.0	5461.0	5060.0	4827.0	5200.0	5293.0	5340.0	5433.0	5349.0	5480.0	5527.0	3380.0	3183.0	3828.0	4015.0	3735.0	3987.0	3985.0	3427.0	4033.0	3940.0	1503.0	3707.0	3959.0	3371.0	3333.0
C a (mg/l)	1250.0	1260.0	1250.0	1220.0	1260.0	1280.0	1250.0	1300.0	1280.0	1300.0	1240.0	1380.0	1280.0	1260.0	1280.0	1280.0	1320.0	1325.0	1300.0	1200.0	1300.0	1275.0	1250.0	1250.0	1320.0	1320.0
M g (mg/l)	670.0	630.0	610.0	650.0	610.0	980.0	710.0	650.0	640.0	540.0	700.0	440.0	540.0	520.0	560.0	540.0	520.0	525.0	550.0	700.0	2450.0	550.0	600.0	650.0	500.0	500.0
K (mg/l)	156.2	156.2	154.8	156.2	156.2	148.4	149.5	153.6	161.8	161.8	150.5	102.0	125.6	138.3	150.5	148.4	140.2	150.0	153.2	144.8	142.7	73.4	92.0	73.0	129.2	134.0
N a (mg/l)	2234.0	2207.4	2180.8	2260.6	2180.8	2309.5	2404.8	2428.6	2428.6	2452.4	2244.4	1000.0	1194.8	1285.7	1253.3	1186.7	1253.3	708.3	750.0	554.8	565.8	529.0	522.1	527.4	937.5	1024.4
Cl/35.45(em/l)	49.37	49.37	44.17	44.17	45.59	46.30	47.73	48.44	43.72	47.95	62.69	50.78	33.85	30.09	28.35	27.64	29.62	69.10	25.64	31.79	26.74	23.95	24.61	23.06	22.51	20.95
SO4/48.03(em/l)	122.84	113.70	105.35	100.50	108.27	110.20	111.18	113.12	111.37	114.10	115.07	70.37	66.27	79.70	83.59	77.76	83.01	82.97	71.35	83.97	82.03	31.29	77.18	82.43	70.19	69.39
Ca/50(em/l)	25.00	25.20	25.00	24.40	25.20	25.60	25.00	26.00	25.60	26.00	24.80	27.60	25.60	25.20	25.60	25.60	26.40	26.50	26.00	24.00	26.00	25.50	25.00	25.00	26.40	26.40
Mg/50(em/l)	13.40	12.60	12.20	13.00	12.20	19.60	14.20	13.00	12.80	10.80	14.00	8.80	10.80	10.40	11.20	10.80	10.40	10.50	11.00	14.00	49.00	11.00	12.00	13.00	10.00	10.00
Na+K(em/l)	101.13	99.97	98.78	102.28	98.81	104.21	108.38	109.52	109.73	110.76	101.43	46.09	55.16	59.44	58.34	55.39	58.08	34.63	36.53	27.83	28.25	24.88	25.05	24.80	44.07	47.97
Na/Cl	1.97	1.94	2.15	2.23	2.08	2.17	2.19	2.18	2.41	2.22	1.56	0.86	1.53	1.86	1.92	1.87	1.84	0.45	1.27	0.76	0.92	0.96	0.92	0.99	1.81	2.13
SO4/Cl	2.49	2.30	2.39	2.28	2.37	2.38	2.33	2.34	2.55	2.38	1.84	1.39	1.96	2.65	2.95	2.81	2.80	1.20	2.78	2.64	3.07	1.31	3.14	3.57	3.12	3.31
SAR	22.17	22.08	21.99	22.73	21.93	21.12	23.62	23.91	24.10	24.86	22.15	10.19	12.18	13.25	12.70	12.09	12.70	7.16	7.58	5.53	4.02	5.38	5.28	5.26	9.55	10.44

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WATER CHEMICAL ANALYSIS DATA AT MUSHERIB TEST WORK SITE

SAMPLING DATE	7/02	7/03	7/03	7/03	7/04	7/05	7/06	7/07	7/08	7/09	7/16	7/23	7/30	8/03	8/10	8/19	8/24	8/31	9/7	9/14	9/21	9/28	10/5	10/13	10/19	10/27
P H	8.0	8.0	7.8	7.9	7.9	8.1	8.0	8.0	7.8	7.8	7.8	7.8	8.0	7.8	7.4	7.9	8.0	7.9	8.0	8.3	8.1	8.0	7.9	8.3	7.9	7.9
E C (ms/cm)	16000	15730	16450	16380	16170	17370	16850	17840	17360	17230	41200	49040	36480	25440	13880	10310	8950	7480.0	7560.0	6590.0	6280.0	5270.0	5550.0	5350.0	5360.0	5040.0
C O D (mg/l)	10.5	11.7	13.0	13.6	13.5	10.8		21.6	22.7	24.0	72.7	68.6	44.9	23.2	13.9		8.7	5.1	5.1	3.2	4.0	2.9	3.6	3.2	0.9	1.8
C l (mg/l)	4050.0	4100.0	3686.9	3585.9	3434.3	3838.4	3762.6	5252.5	4500.0	4550.0	15959.6	17000.0	11300.0	7850.0	3718.6	2462.3	2000.0	984.8	1060.6	845.1	758.3	676.1	581.8	550.3	469.5	457.9
S O 4 (mg/l)	4875.0	5304.0	4547.0	3987.0	4332.0	4491.0	4481.0	4211.0	4313.0	4080.0	6200.0	5715.0	4827.0	4893.0	3931.0	3492.0	3660.0	3072.0	2867.0	2997.0	3007.0	2540.0	2997.0	2997.0	2475.0	2885.0
C a (mg/l)	1600.0	1620.0	1620.0	1600.0	1580.0	1700.0	1680.0	1660.0	1680.0	1700.0	2550.0	3250.0	2600.0	2350.0	1850.0	NODATE	1500.0	1325.0	1425.0	1375.0	1325.0	1300.0	1350.0	1250.0	1380.0	1360.0
M g (mg/l)	1020.0	940.0	960.0	940.0	920.0	1020.0	1060.0	1020.0	1000.0	920.0	1700.0	2200.0	1450.0	850.0	700.0	NODATE	750.0	600.0	475.0	600.0	525.0	375.0	450.0	600.0	460.0	460.0
K (mg/l)	227.0	219.4	219.4	219.4	216.8	219.1	225.5	225.5	235.8	237.1	631.3	616.2	460.2	335.1	265.8	220.0	178.9	309.9	289.1	278.3	264.7	63.8	60.0	60.0	103.3	110.6
N a (mg/l)	2978.7	2872.3	2872.3	2925.5	2872.3	3452.4	3422.6	3422.6	3541.7	3511.9	8461.5	3750.0	5909.1	4512.2	2722.2	1850.0	1333.3	1205.3	1012.0	380.0	803.0	389.0	323.5	306.8	524.2	585.4
Cl/35.45(em/l)	114.2	115.7	104.0	101.2	96.9	108.3	106.1	148.2	126.9	128.3	450.2	479.5	318.8	221.4	104.9	69.5	56.4	27.8	29.9	23.8	21.4	19.1	16.4	15.5	13.2	12.9
SO4/48.03(em/l)	101.5	110.4	94.7	83.0	90.2	93.5	93.3	87.7	89.8	84.9	129.1	119.0	100.5	101.9	81.8	72.7	76.2	64.0	59.7	62.4	62.6	52.9	62.4	62.4	51.5	60.1
Ca/50(em/l)	32.0	32.4	32.4	32.0	31.6	34.0	33.6	33.2	33.6	34.0	51.0	65.0	52.0	47.0	37.0		30.0	26.5	28.5	27.5	26.5	26.0	27.0	25.0	27.6	27.2
Mg/50(em/l)	20.4	18.8	19.2	18.8	18.4	20.4	21.2	20.4	20.0	18.4	34.0	44.0	29.0	17.0	14.0		15.0	12.0	9.5	12.0	10.5	7.5	9.0	12.0	9.2	9.2
Na+K(em/l)	135.3	130.5	130.5	132.8	130.4	155.7	154.6	154.6	160.0	158.8	384.0	178.8	268.7	204.8	125.2	86.1	62.5	60.3	51.4	23.6	41.7	18.5	15.6	14.9	25.4	28.3
Na/Cl	1.1	1.1	1.2	1.3	1.3	1.4	1.4	1.0	1.2	1.2	0.8	0.3	0.8	0.9	1.1	1.2	1.0	1.9	1.5	0.7	1.6	0.9	0.9	0.9	1.7	2.0
SO4/Cl	0.9	1.0	0.9	0.8	0.9	0.9	0.9	0.6	0.7	0.7	0.3	0.2	0.3	0.5	0.8	1.0	1.4	2.3	2.0	2.6	2.9	2.8	3.8	4.0	3.9	4.7
SAR	25.3	24.7	24.6	25.2	25.0	28.8	28.4	28.7	29.7	29.8	56.4	22.1	40.4	34.7	23.4		12.2	11.9	10.1	3.7	8.1	4.1	3.3	3.1	5.3	6.0

3) Quality of TB-4 Water (NE corner)

There was a big change in the quality of the TB-4 water before and after July 16th. Before July 16th, the EC and COD values were as high as 6,500 - 8,370 micro mhos/cm and 5.2 - 8.8 mg/l respectively. After that date, however, the EC value dropped to 4,300 - 4,970 micro mhos/cm and the COD value gradually dropped reaching 1.1 mg/l on August 10th, then began rising evenly to 6.7 mg/l on October 19th, finishing at 2.4 mg/l at the end of pumping test. Cl values up to July 16th ranged between 1300 to 900 mg/l while after that value was relatively steady at 590 mg/l, finishing at 630 mg/l at the end of test.

4) Quality of TB-14 Water (SW corner)

The EC value of the TB-14 water was 12,040 - 13,050 micro mhos/cm before July 16th but dropped to 6,760 - 8,510 micro mhos/cm after July 23rd. The COD value increased from 1.1 mg/l to 7.3 mg/l in the period from the commencement of the sampling test to July 16th, dropping to 2.4 - 4.6 mg/l after July 23rd. Cl value initially was 1750 mg/l on July 2nd, peaking to 2450 mg/l on August 31st, before falling to 743 mg/l on October 27th.

5) Quality of TB-17 Water (SE corner)

The quality of the TB-17 water was worse than that of the other water samples and showed much fluctuation. EC value had a rather steady average rate of 16,700 micro mhos/cm up to July 9th, rising sharply to 49,040 micro mhos/cm on July 16th, and falling rapidly to 5,040 micro mhos/cm on October 27th. COD value initially 10 mg/l on July 2nd peaked to 72.7 mg/l on July 16th, falling to 1.8 mg/l at the close of the test. Cl also showed fluctuating values of 4,050, 17,000 and 458 mg/l on July 2nd, July 23rd and October 27th respectively.

3.3.3 Water Quality Assessment

EC values for all observation wells were measured both in the initial and final stages, and the values of each well respectively changed slightly in both stages, however, the distribution of EC values in the area of Test Work Site (Fig. 3.3.1) showed the same tendency, TB-10 was the highest at both times (EC 18,220 and 20,200 micro mhos/cm), the next highest was TB-6 (EC 13,640 and 16,670 micro mhos/cm).
The Trench water showed the lowest values regarding all items throughout the test period.

After a period of showing some water quality fluctuation for both Trench and the four observation wells where water samples were taken for chemical analysis, almost all water quality data for Trench and observation wells water except TB-17 became stable and tended to show each characteristic level. In the case of TB-17 well, polluted water entered it from a building located on the Southern side. Showing very high values of EC, COD and Cl in mid July, these values sharply decreased by August 10th.

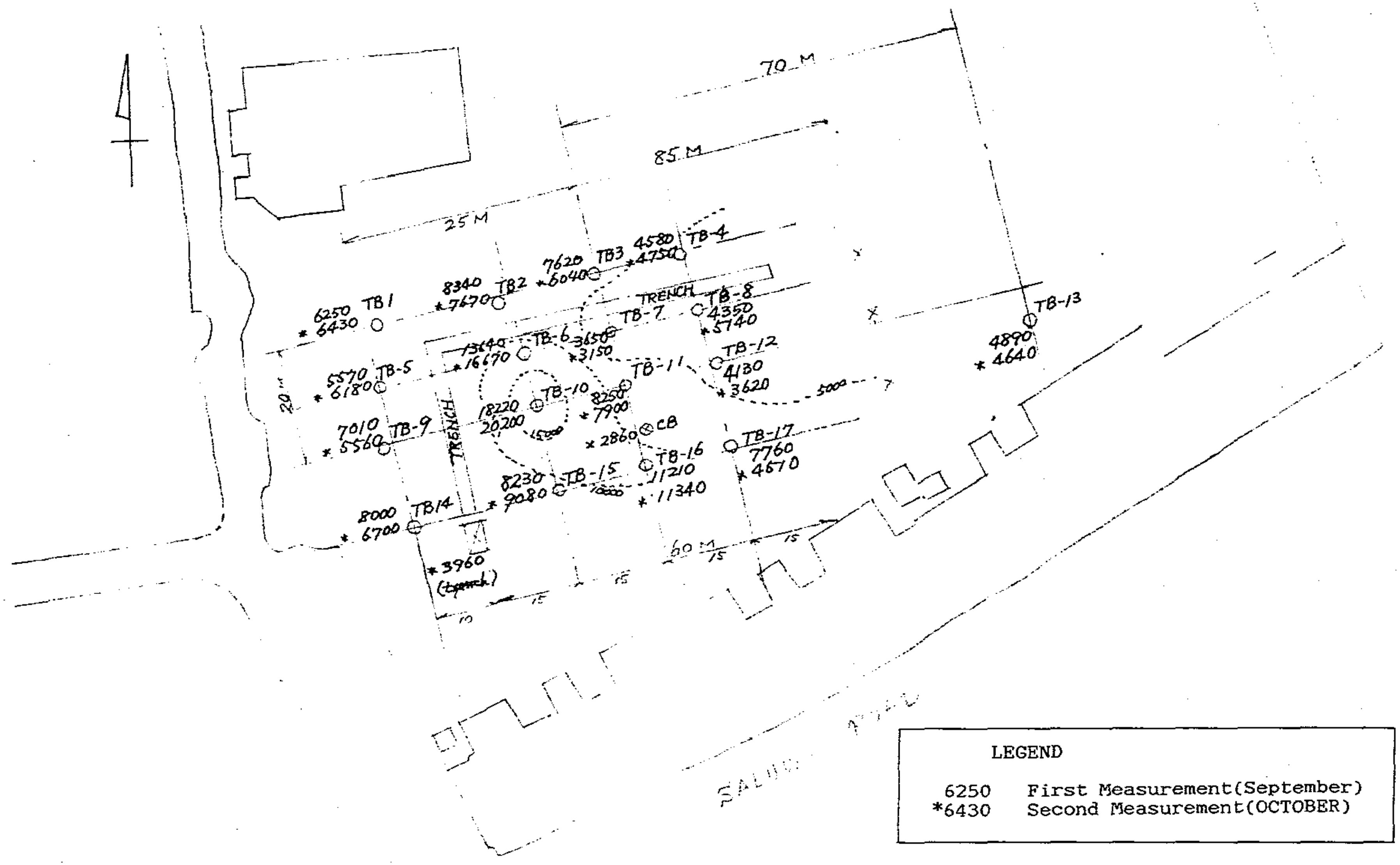


Fig. 3.3.1 Electric Conductivity Distribution Map at Wadi Musherib

4. OLD RAYYAN

4.1 Pumping Test

4.1.1 Continuous Pumping Test

(1) Activity

Due to the delay of transportation to remove the abstracted groundwater and of decision for its disposal, the test pumping had many difficulties to start at Rayyan Test Work Site and the following three plans were made.

1 Preliminary test

Prior to the main pumping test scheduled to start in August, a preliminary test was carried out in July. This allowed testing of the apparatus and pumps and enabled investigation of the hydrogeological conditions of the test site.

2 Trial run with 1 shift transportation

Test pumping began on August 5th, 1986 and was continued until August 20th. The test was carried out with only 4 hours discharging per day, between 7 am and 11 am. Since the volume of water abstracted was so small, the water level in the Trench dropped by only about 1.2 m per day and almost recovered to its original level within twelve hours. As only a small volume of water was abstracted and discharging intermittent, it has been assumed that the groundwater level did not reach a steady state.

3 Continuous run with 2 shifts transportation

Owing to the kind help provided by the Ministry of Public Works (MPW), a longer pump test began on August 30th, 1986 with 14 hours discharging per day, and consequently it became possible to obtain more reliable results. This test was continued until October 30th.

(2) Groundwater Inflow to the Trench

In the Trench many groundwater discharge points were observed. Two discharge mechanisms could be distinguished, one along the bedding planes and another along the fissures. Large amount of discharge was observed along the fissures, especially in the shorter leg on the Trench (30 m). In case of discharge along bedding plane it was obvious that the discharging rate increased toward the fissures.

(3) Discharge Amount

The relationship between the water level at the Trench and the discharge amount can be summarized as follows:

1 Pumping was 14 hours daily (Friday holiday) and relationship is examined between Trench water QND level at 06:00 hr on Thursday and weekly discharge as shown in Fig. 4.1.1. From second to fourth week there was a drop in Trench water level of around 50 cm with a corresponding fall in weekly discharge amount. From the fifth to eighth week the water level fluctuated within 10 cm, while discharge amount showed an increase from 5,900 to 6,300 m^3/week dropping to 6,200 m^3/week on the eighth week.

2. Fig. 4.1.2 shows relationship between hourly discharge and Trench water levels. During the period from 13 September up to the last few days in October hourly discharges ranged from 45 to 60 m^3/hr (0.75 and 1 m^3/min) with QND levels of water Trench measured at 20:00 hr ranging between 2.0 to 2.2 m.

(4) Drawdown Depth

The outline of pumping test condition was as follows;

In July a preliminary pumping test was executed with the following results.

(a) After 18 hours from the beginning of the pump test, the water level in the Trench reached the bottom i.e. 2.0 m drawdown.

(b) The groundwater levels at the boreholes reached a steady state at about 18 to 24 hours. The drawdown from initial groundwater level was approximately 1.0 metres in the vicinity of the Trench, (i.e. within 30 m of the Trench).

With two shifts operating daily for a total of 14 hours, the water inside the Trench, could be drained in 7 - 8 hours and drainage at the Trench bottom level could be carried on for a further 6 - 7 hours. At distances of 30 and 90 m from trench groundwater level was lowered by 0.5 - 0.7 m and 0.1 - 0.2 m respectively.

The groundwater levels lowering observed at Trench and the open holes during 2 shift transportation are shown in Fig. 4.1.3 and Fig. 4.1.4.

The drawdown depth distribution around the Trench and its profile are respectively shown in Fig. 4.1.5 and Fig. 4.1.6.

Propagation characteristic of drawdown due to the abstraction from Trench is shown in Fig. 4.1.7.

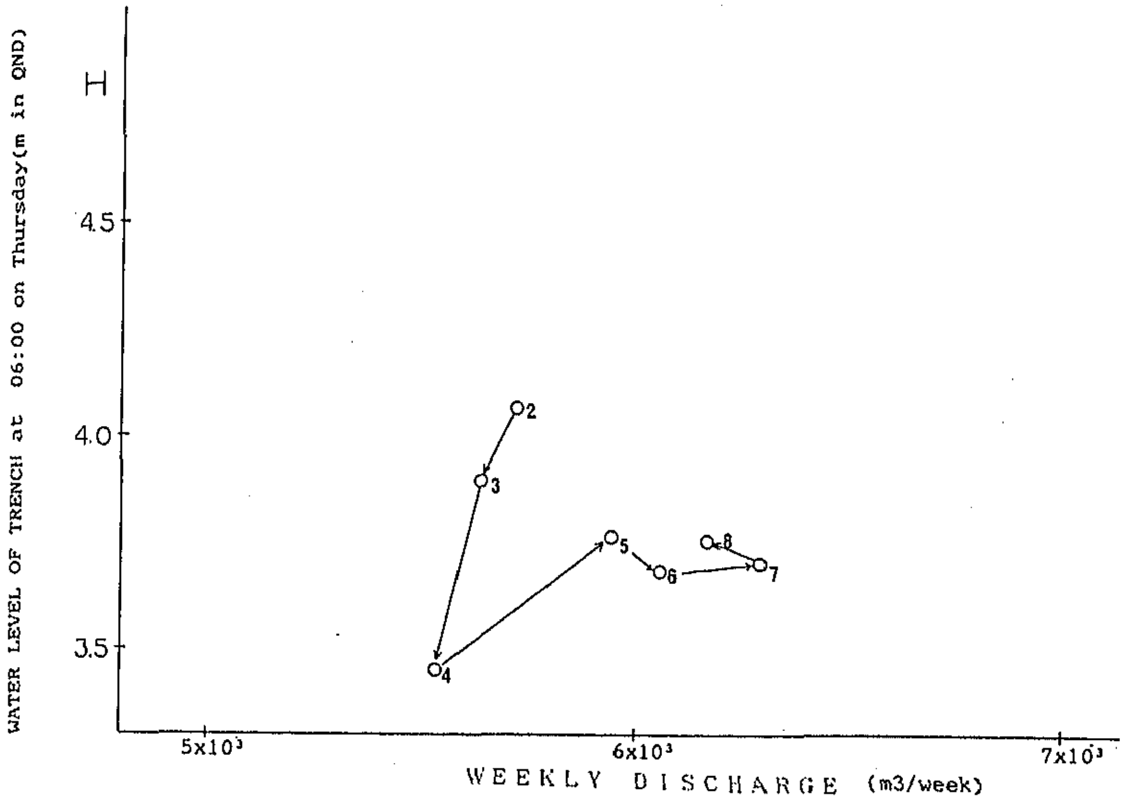


Fig. 4.1.1 Relationship between Weekly Discharge Amount and Water Level at Trench

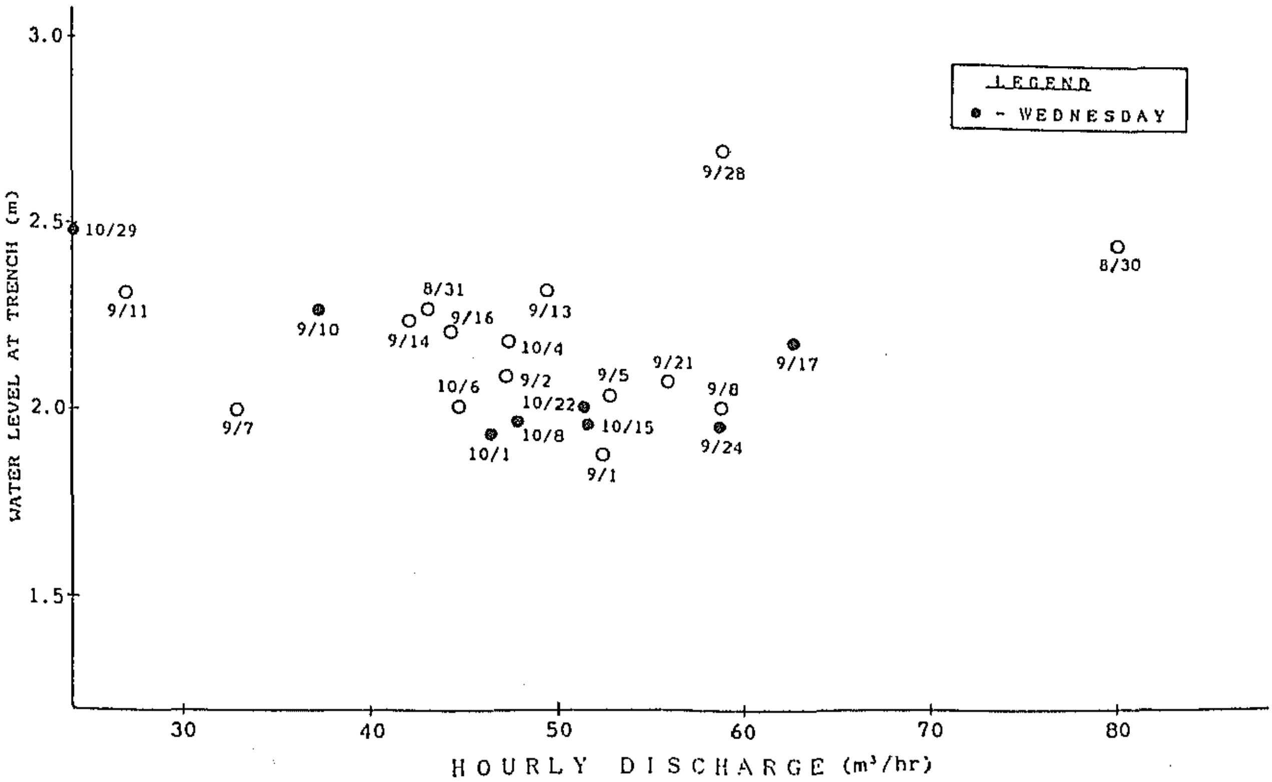


Fig. 4.1.2 Relationship between Hourly Discharge Amount and Water Level at Trench

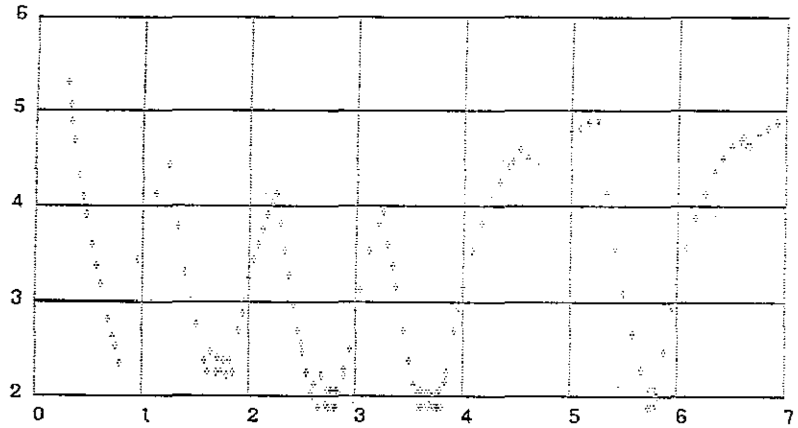


Fig. Water Level Fluctuation of Trench at Rayyan during 2 Shift Transportation : 30 Aug to 5 Sep

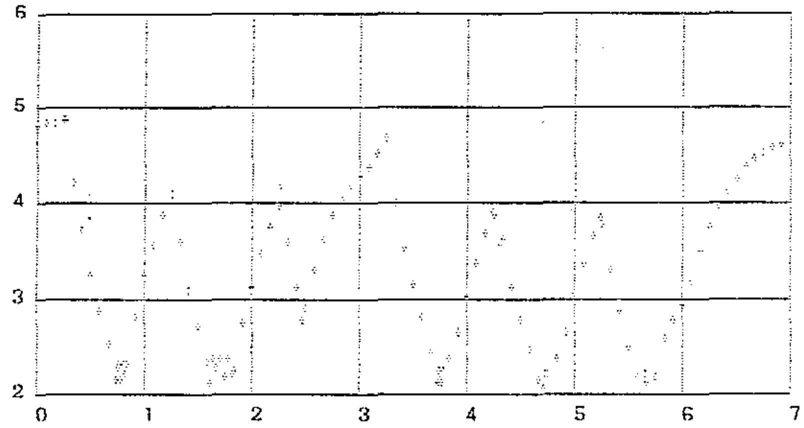


Fig. Water Level Fluctuation of Trench at Rayyan during 2 Shift Transportation : 13 Sep to 19 Sep

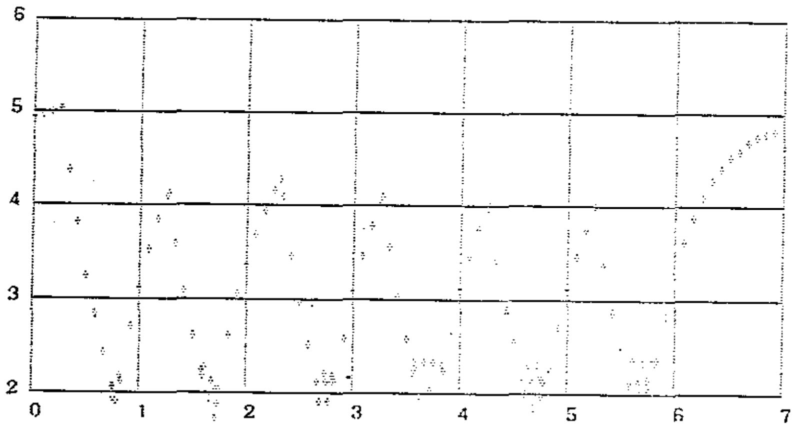


Fig. Water Level Fluctuation of Trench at Rayyan during 2 Shift Transportation : 6 Sep to 12 Sep

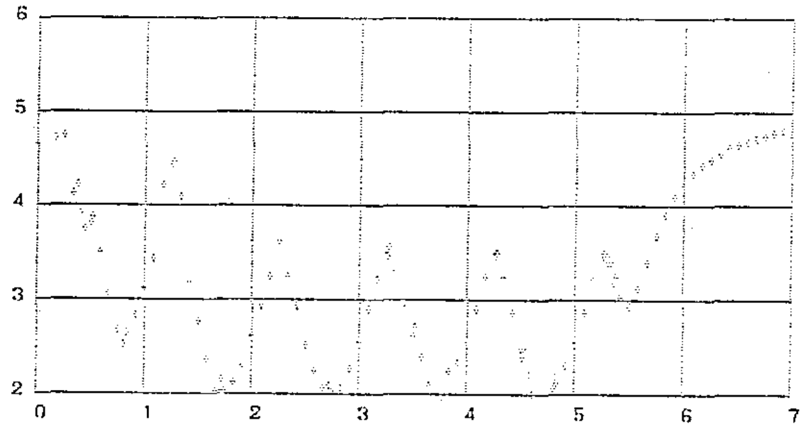


Fig. Water Level Fluctuation of Trench at Rayyan during 2 Shift Transportation : 20 Sep to 26 Sep

Fig.4.1.3(1) Water Level Fluctuation of Trench at Rayyan during 2 Shift Transportation

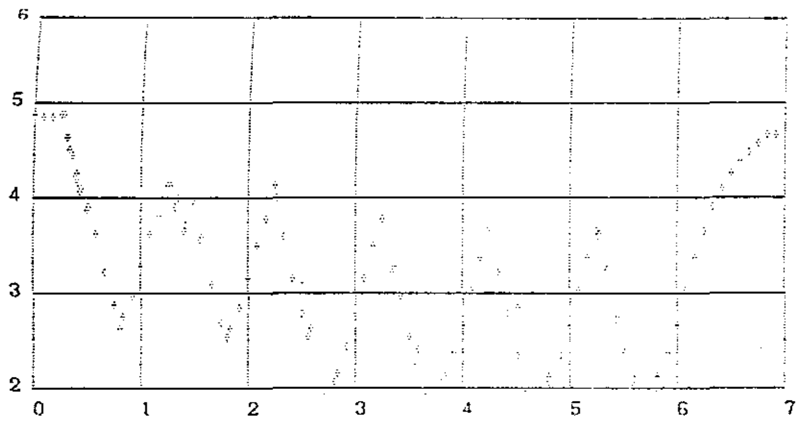


Fig. Water Level Fluctuation of Trench at Rayyan during 2 Shift Transportation : 27 Sep to 3 Oct

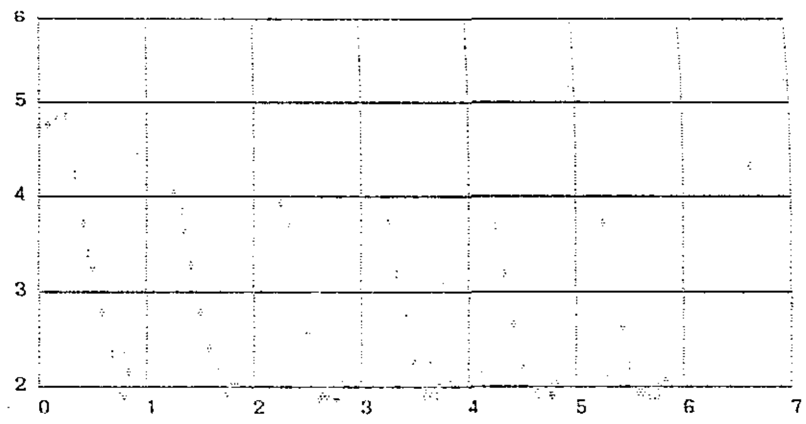


Fig. Water Level Fluctuation of Trench at Rayyan during 2 Shift Transportation : 11 Oct to 17 Oct

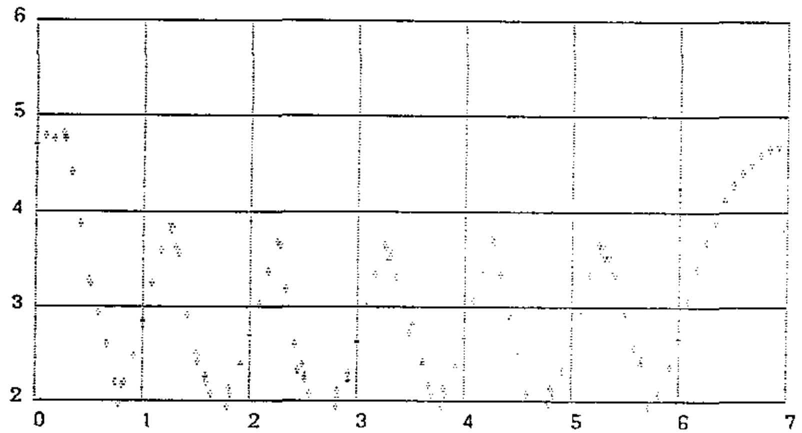


Fig. Water Level Fluctuation of Trench at Rayyan during 2 Shift Transportation : 4 Oct to 10 Oct

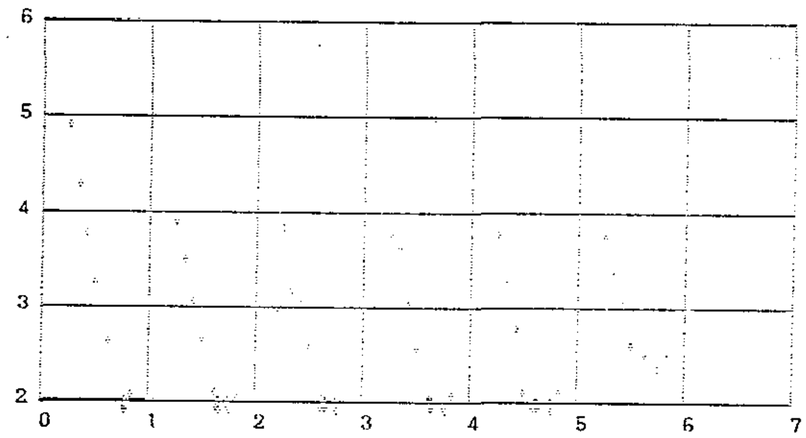


Fig. Water Level Fluctuation of Trench at Rayyan during 2 Shift Transportation : 18 Oct to 24 Oct

Fig.4.1.3(2) Water Level Fluctuation of Trench at Rayyan during 2 Shift Transportation

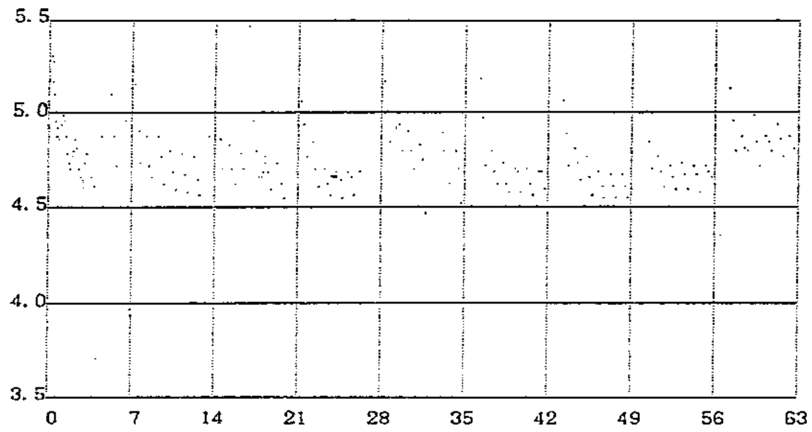


Fig. Continuous Pumping Test at Rayyan
2 Shift Transportation : 8/30-10/28 : TB-22

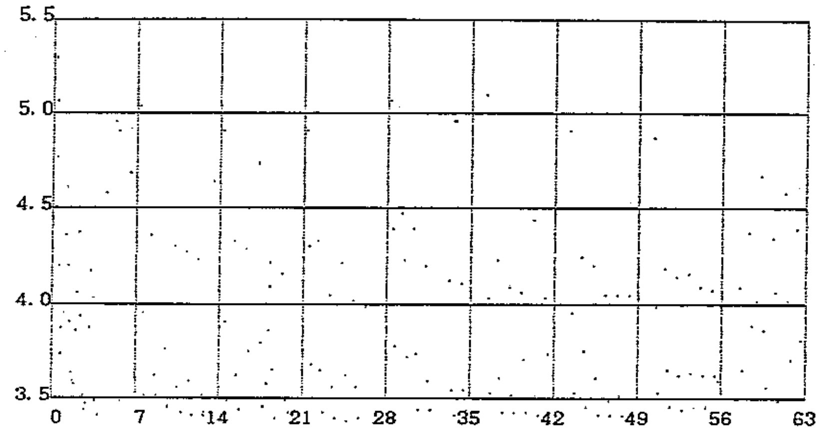


Fig. Continuous Pumping Test at Rayyan
2 Shift Transportation : 8/30-10/28 : TB-24

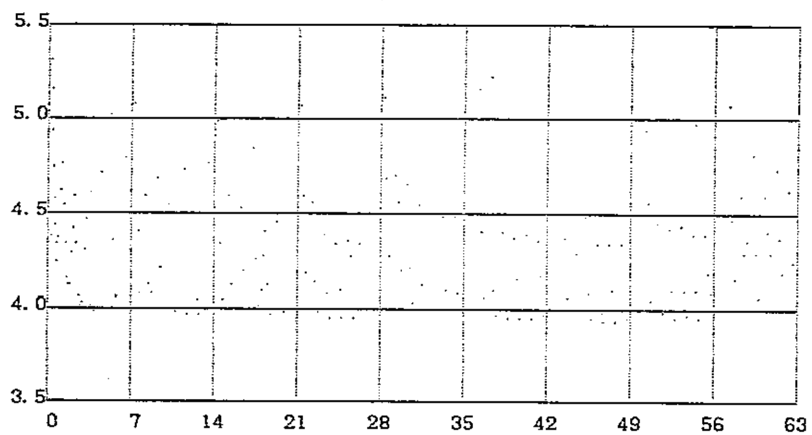


Fig. Continuous Pumping Test at Rayyan
2 Shift Transportation : 8/30-10/28 : TB-23

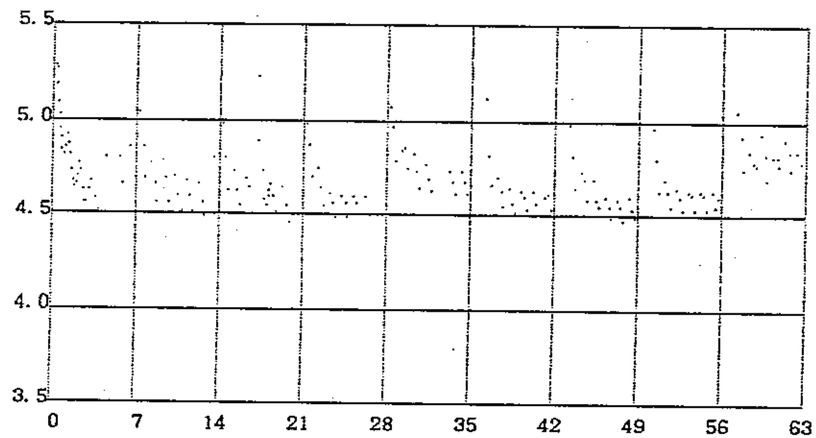


Fig. Continuous Pumping Test at Rayyan
2 Shift Transportation : 8/30-10/28 : TB-25

Fig. 4.1.4 (1) Continuous Pumping Test with 2 shifts Transportation at Rayyan: 8/30-10/28

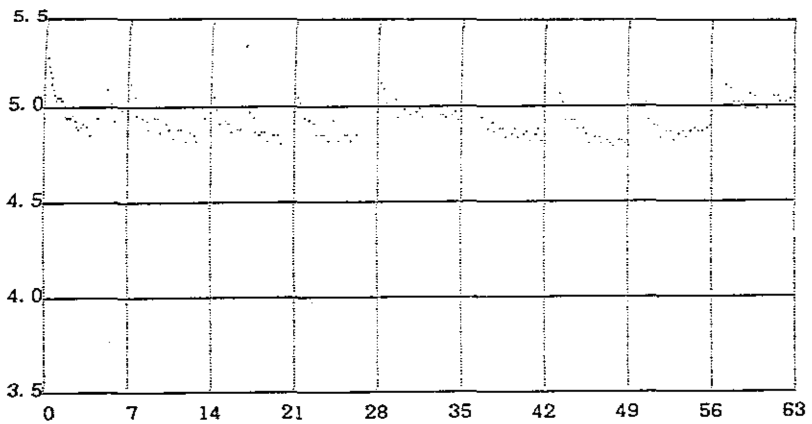


Fig. Continuous Pumping Test at Rayyan
2 Shift Transportation : 8/30-10/28 : TB-26

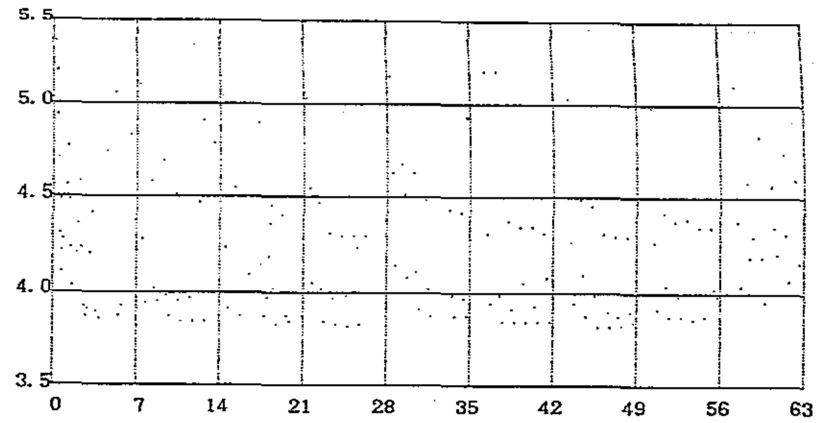


Fig. Continuous Pumping Test at Rayyan
2 Shift Transportation : 8/30-10/28 : TB-28

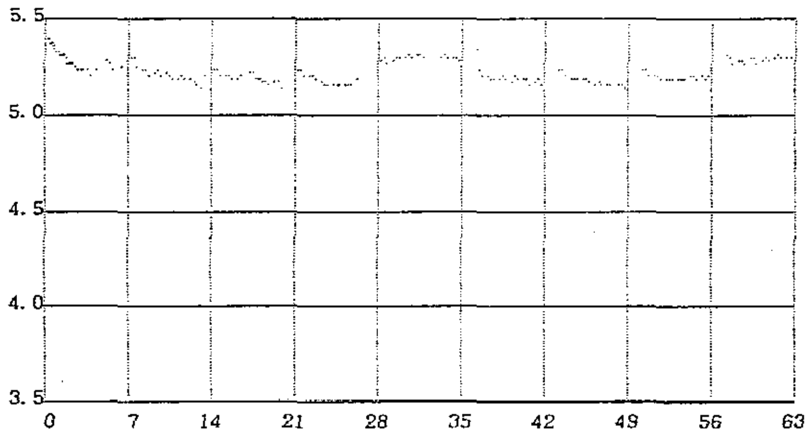


Fig. Continuous Pumping Test at Rayyan
2 Shift Transportation : 8/30-10/28 : TB-27

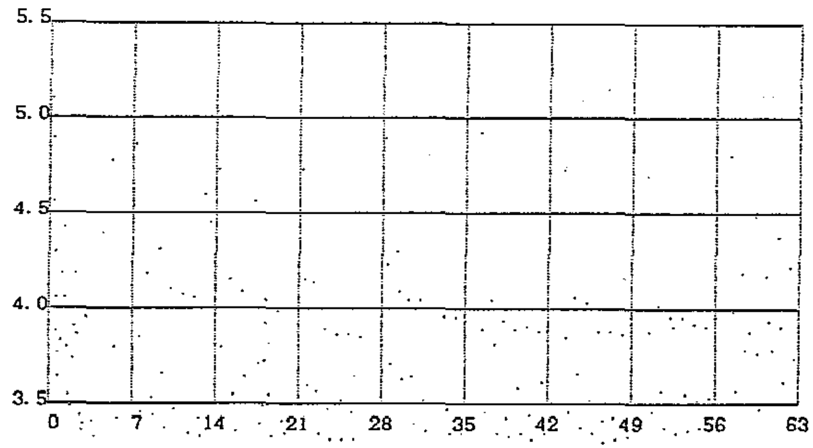


Fig. Continuous Pumping Test at Rayyan
2 Shift Transportation : 8/30-10/28 : TB-29

Fig. 4.1.4 (2) Continuous Pumping Test with 2 shifts Transportation at Rayyan: 8/30-10/28

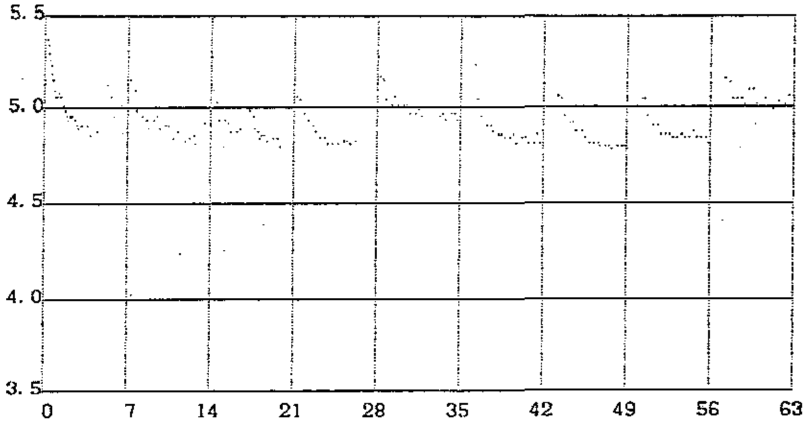


Fig. Continuous Pumping Test at Rayyan
2 Shift Transportation : 8/30-10/28 : TB-30

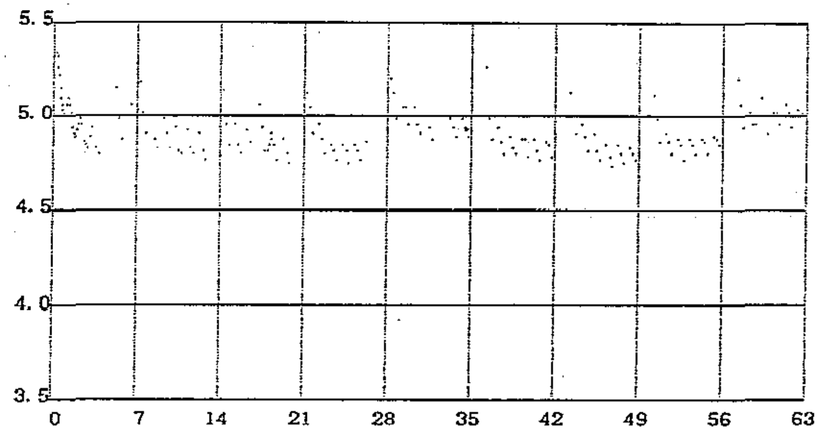


Fig. Continuous Pumping Test at Rayyan
2 Shift Transportation : 8/30-10/28 : TB-32

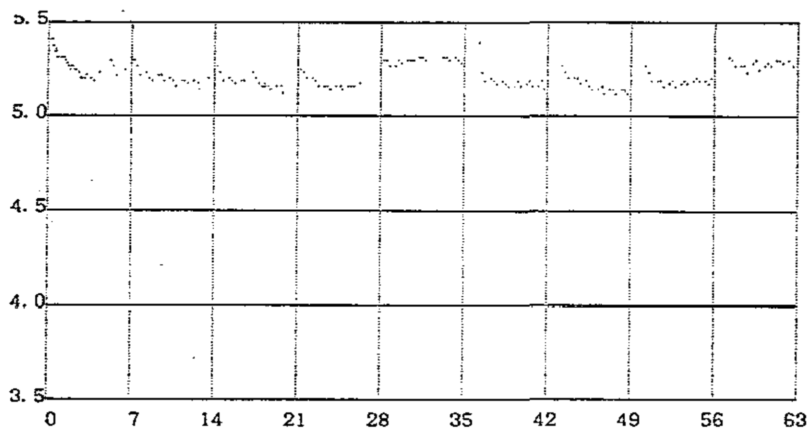


Fig. Continuous Pumping Test at Rayyan
2 Shift Transportation : 8/30-10/28 : TB-31

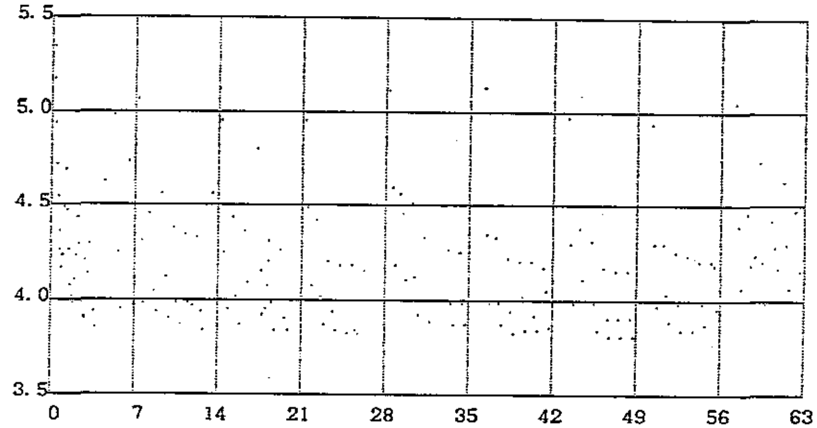


Fig. Continuous Pumping Test at Rayyan
2 Shift Transportation : 8/30-10/28 : TB-33

Fig. 4.1.4 (3) Continuous Pumping Test with 2 shifts Transportation at Rayyan: 8/30-10/28

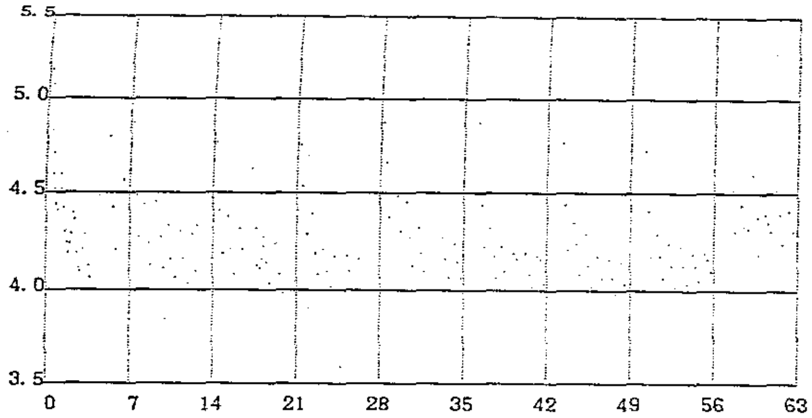


Fig. Continuous Pumping Test at Rayyan
2 Shift Transportation : 8/30-10/28 : TB-34

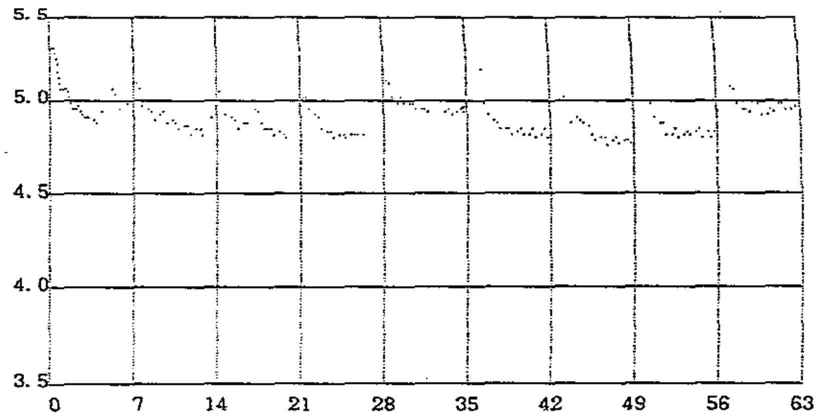


Fig. Continuous Pumping Test at Rayyan
2 Shift Transportation : 8/30-10/28 : TB-36

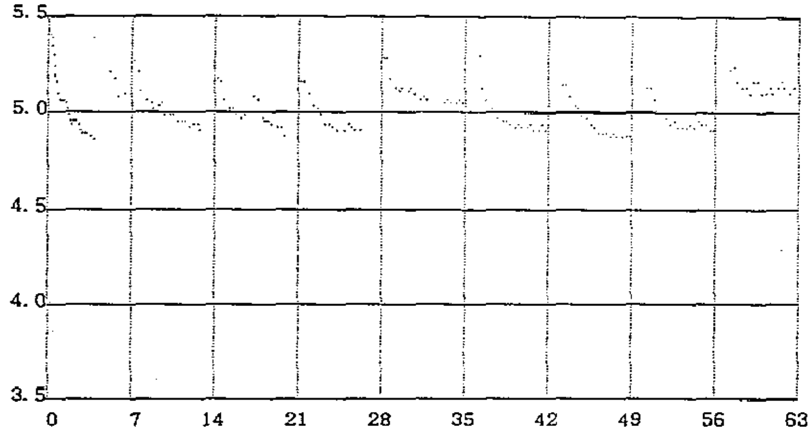


Fig. Continuous Pumping Test at Rayyan
2 Shift Transportation : 8/30-10/28 : TB-35

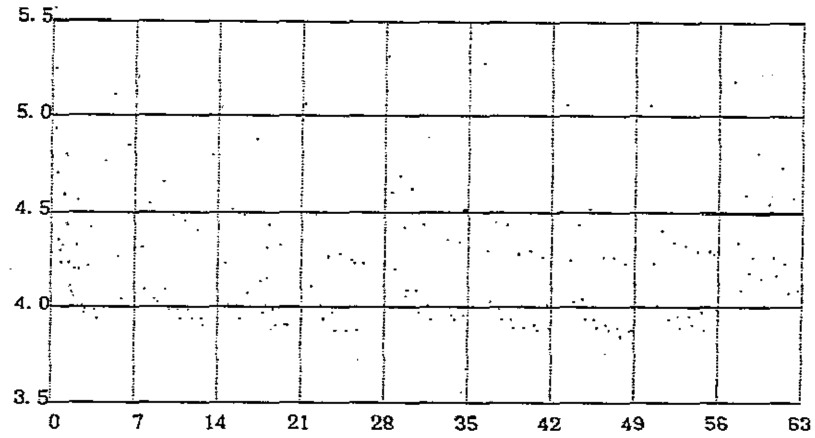


Fig. Continuous Pumping Test at Rayyan
2 Shift Transportation : 8/30-10/28 : TB-37

Fig. 4.1.4 (4) Continuous Pumping Test with 2 shifts Transportation at Rayyan: 8/30-10/28

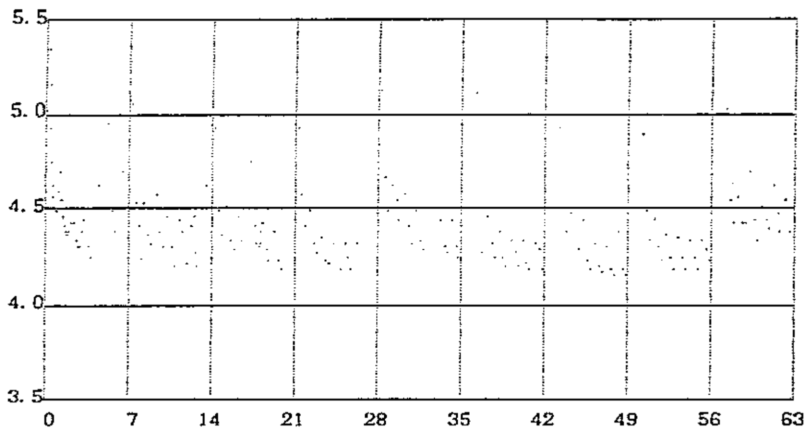


Fig. Continuous Pumping Test at Rayyan
2 Shift Transportation : 8/30-10/28 : TB-38

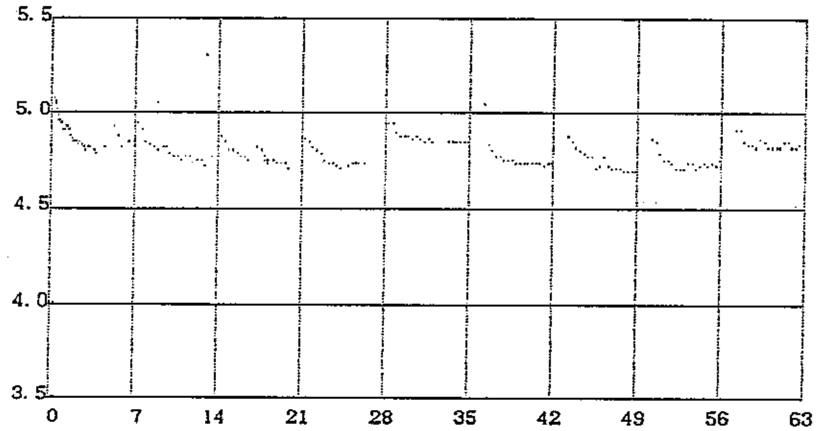


Fig. Continuous Pumping Test at Rayyan
2 Shift Transportation : 8/30-10/28 : TB-40

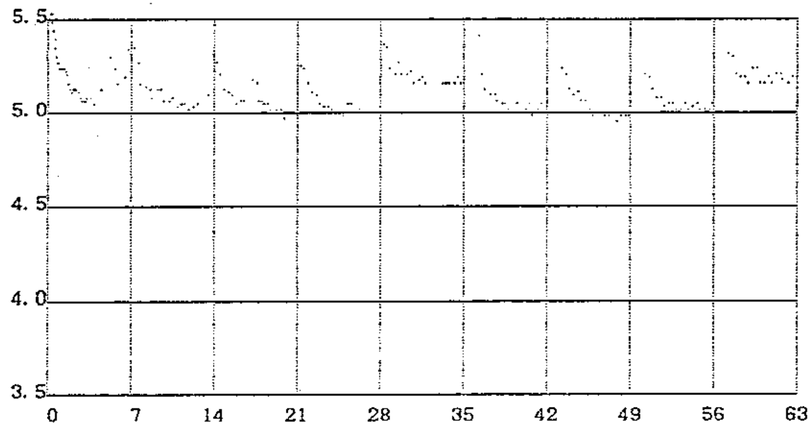


Fig. Continuous Pumping Test at Rayyan
2 Shift Transportation : 8/30-10/28 : TB-39

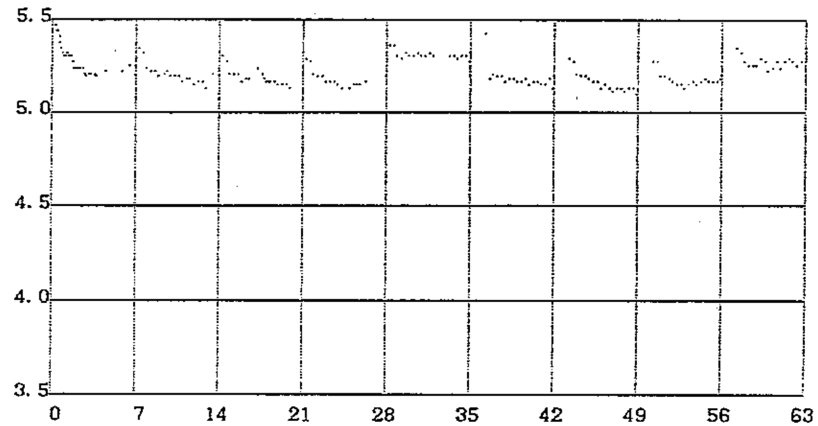


Fig. Continuous Pumping Test at Rayyan
2 Shift Transportation : 8/30-10/28 : TB-41

Fig. 4.1.4 (5) Continuous Pumping Test with 2 shifts Transportation at Rayyan: 8/30-10/28

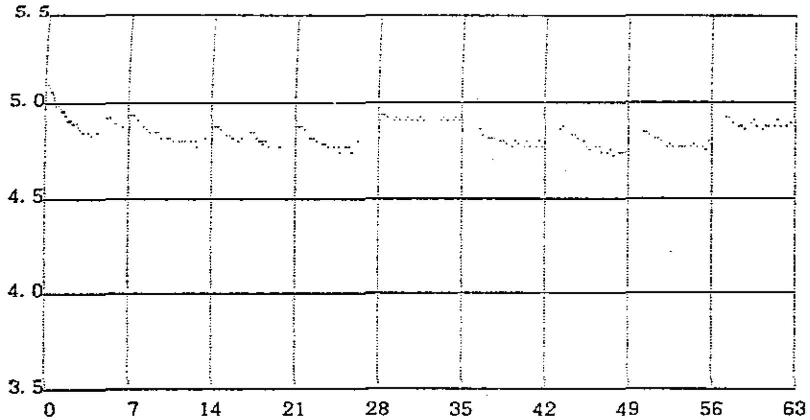


Fig. Continuous Pumping Test at Rayyan
2 Shift Transportation : 8/30-10/28 : TB-42

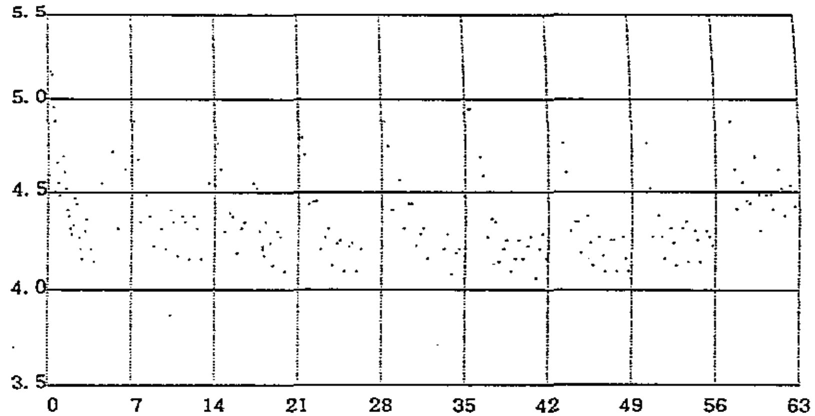


Fig. Continuous Pumping Test at Rayyan
2 Shift Transportation : 8/30-10/28 : TB-44

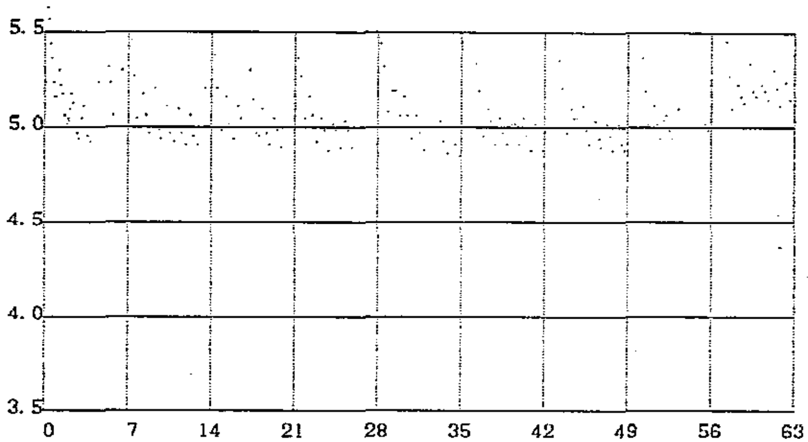


Fig. Continuous Pumping Test at Rayyan
2 Shift Transportation : 8/30-10/28 : TB-43

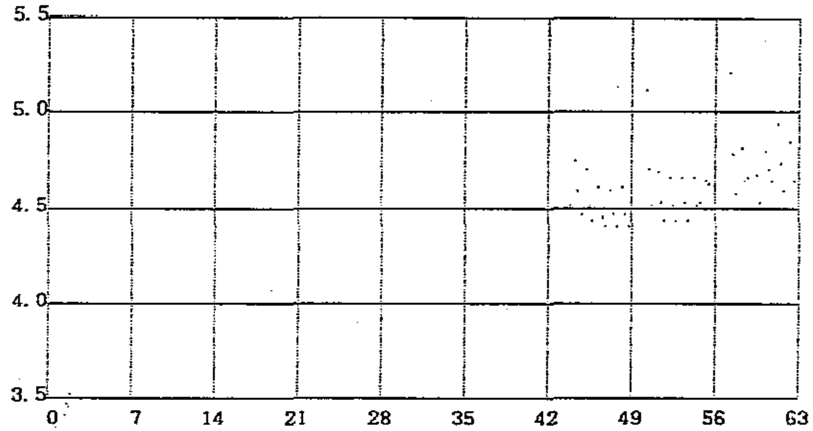


Fig. Continuous Pumping Test at Rayyan
2 Shift Transportation : 8/30-10/28 : TB-45

Fig. 4.1.4 (6) Continuous Pumping Test with 2 shifts Transportation at Rayyan: 8/30-10/28

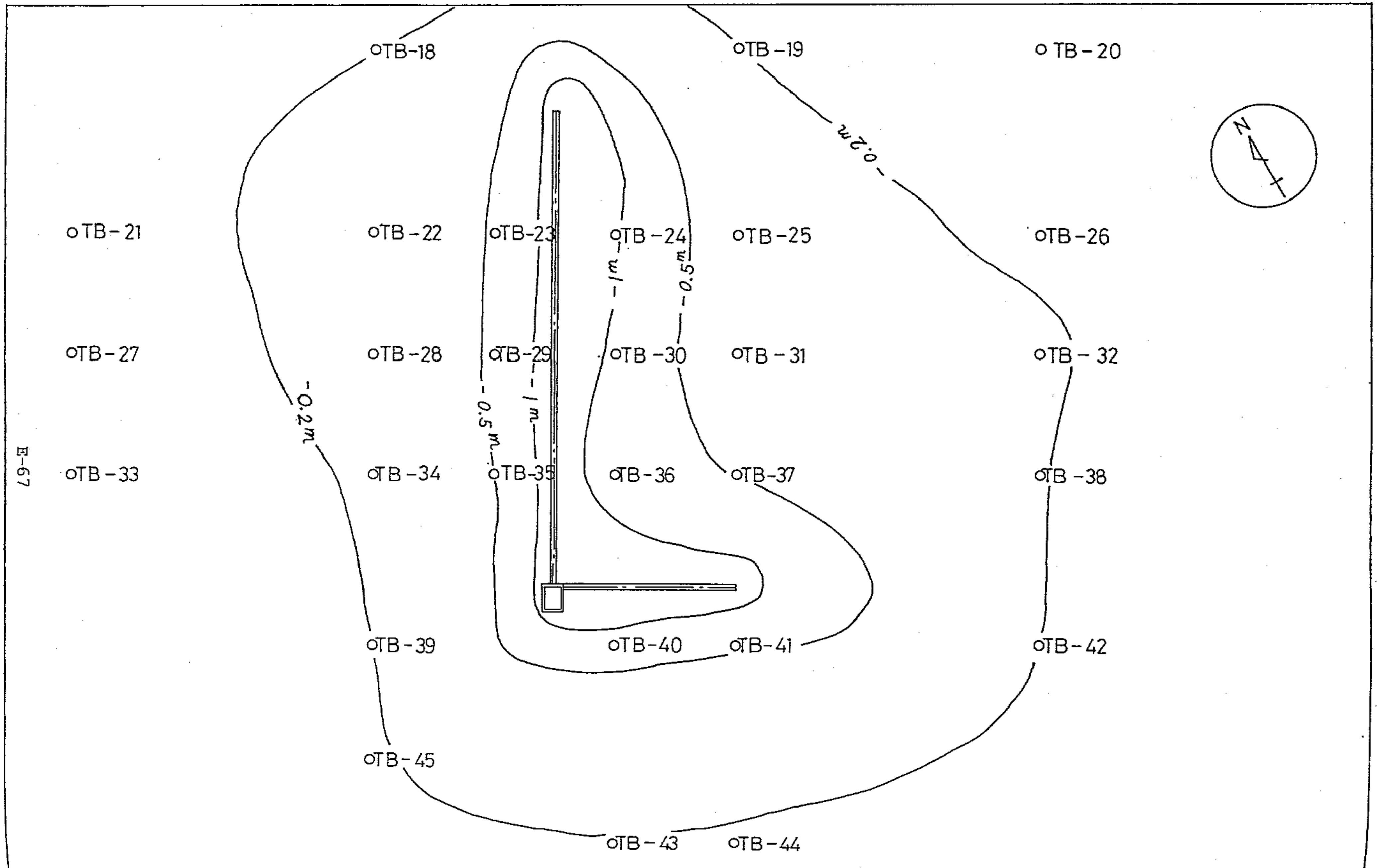


Fig. 4.1.5 Drawdown Depth Distribution of Rayyan (July 1986)

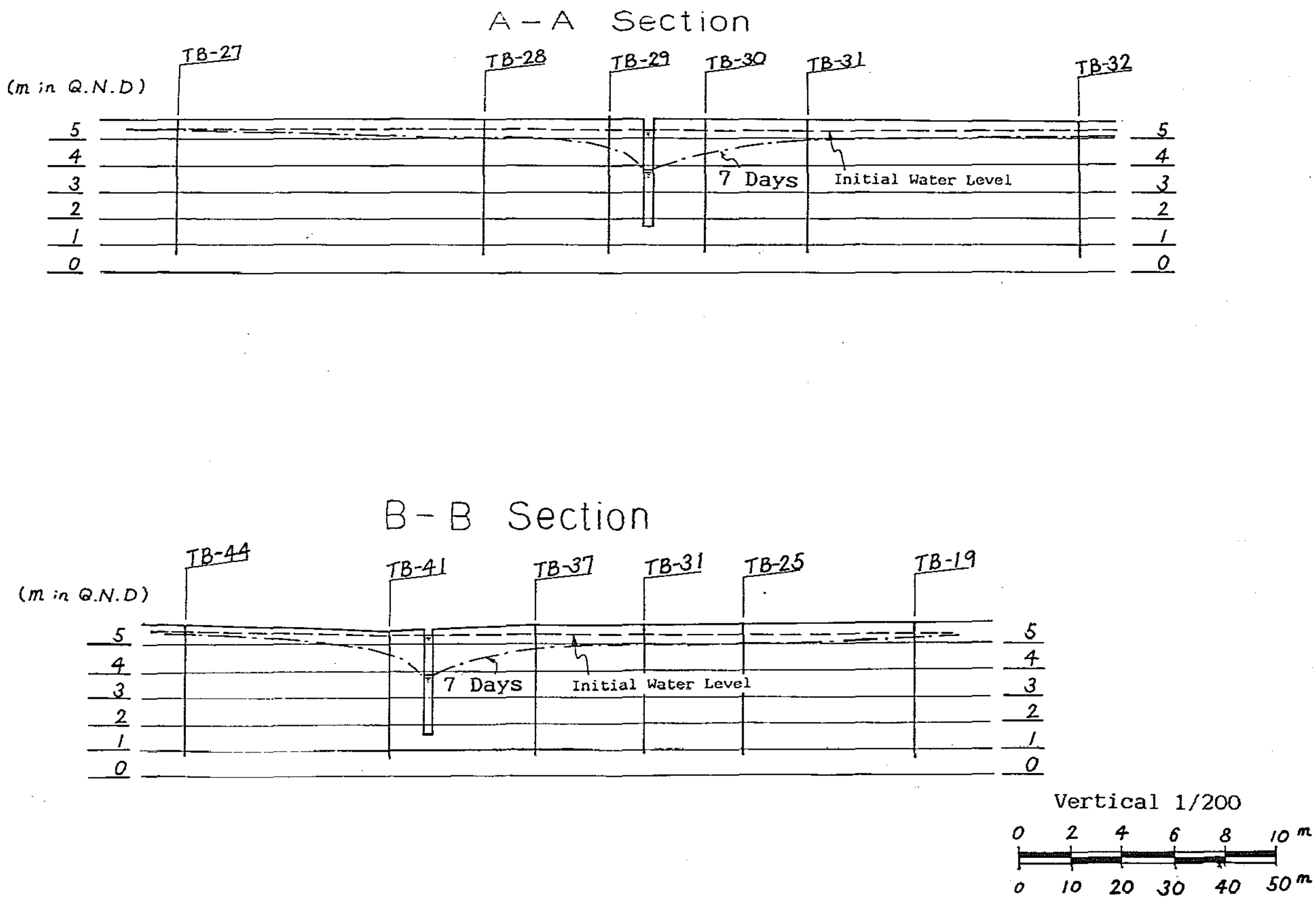
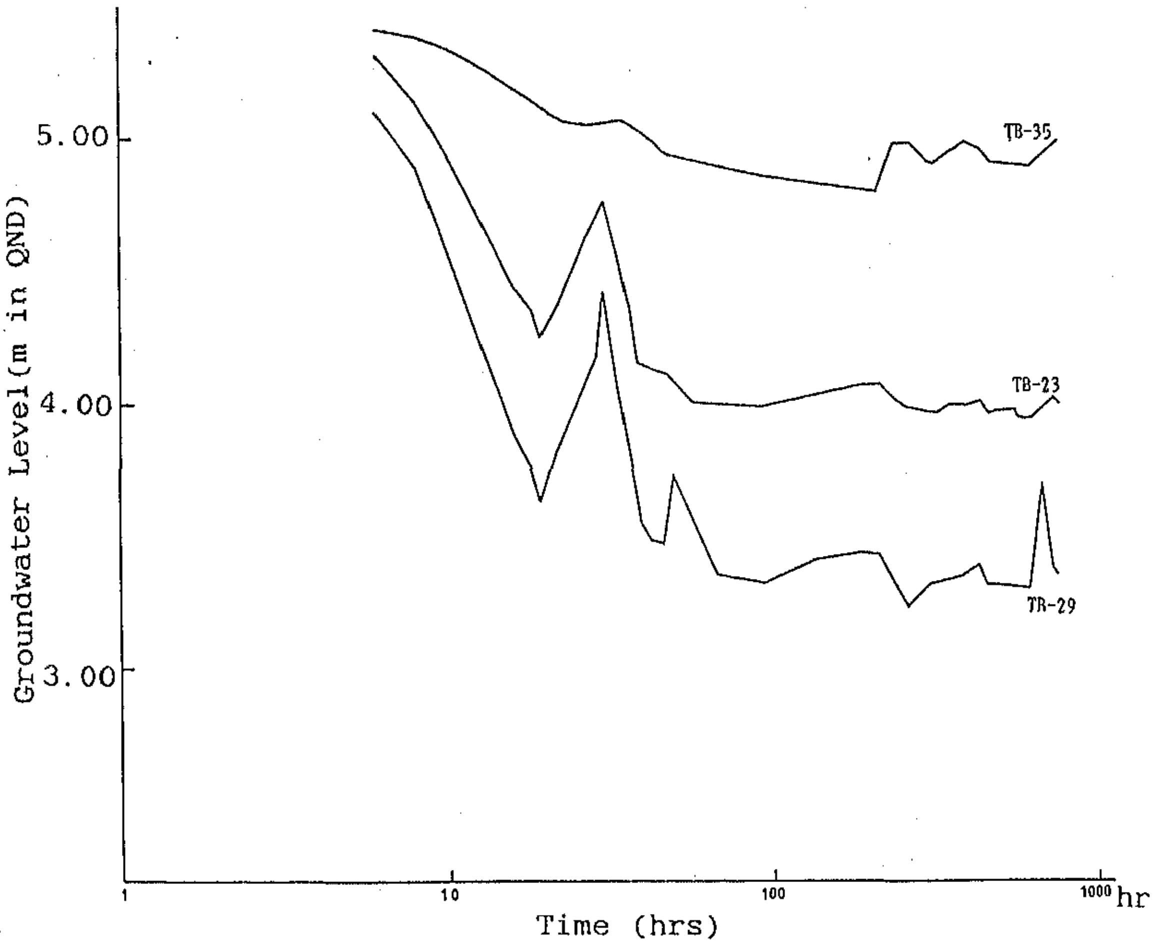


Fig. 4.1.6 Profile of Drawdown at Rayyan



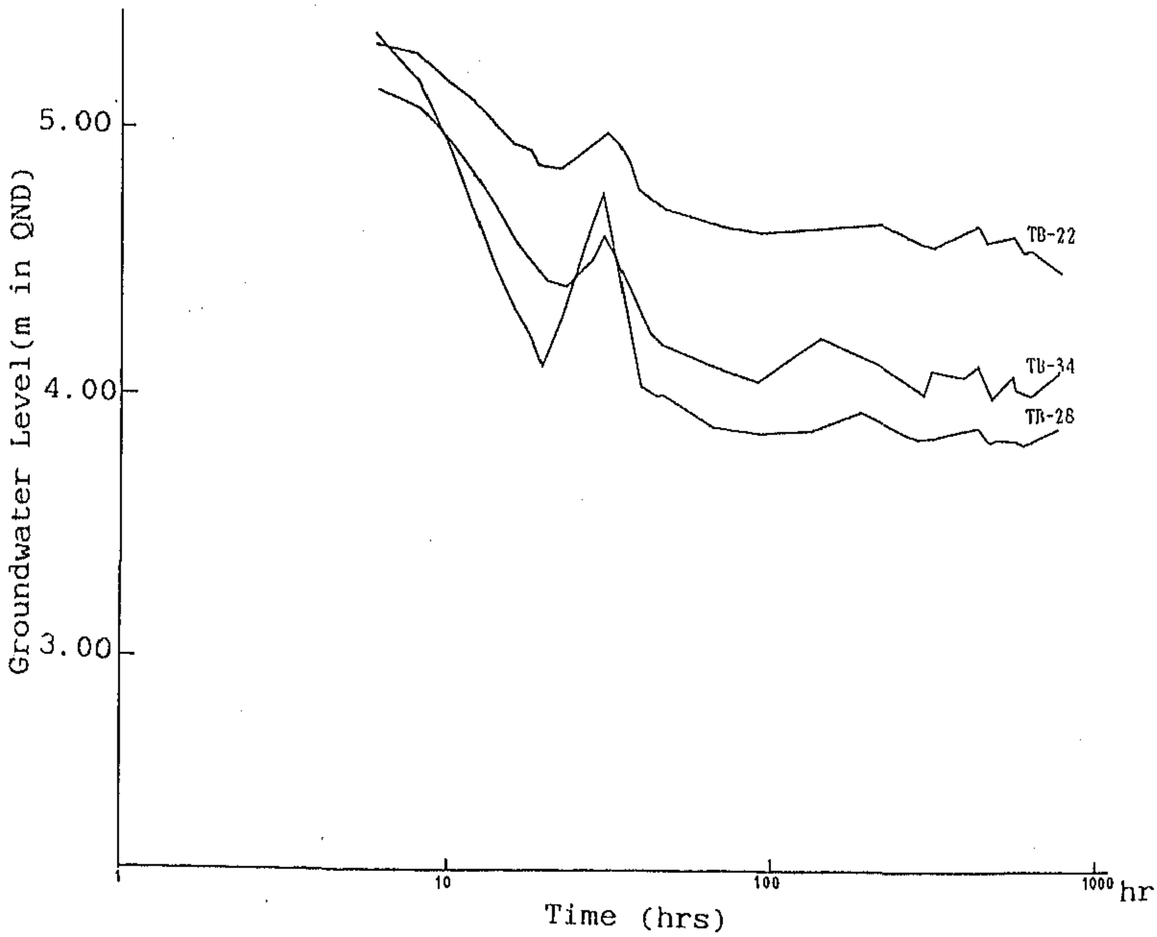


Fig. 4.1.7 Propagation Characteristics of Drawdown at Rayyan