6.2 Basic Framework of Drainage Plan

6.2.1 Basic Composition of Drainage Facilities

The composition of the drainage facilities depends on various conditions, such as the topography, geology, groundwater quality, design drainage volume, types of reutilisation and the constraints imposed by the disposal destinations. In general, however, these facilities consist of a groundwater collection facility, a water transfer facility and a disposal facility, as shown in Fig. 6.2.1.

(1) Groundwater Collection Facility

The open channel or the blind trench method is recommended as a suitable type of collection facility in view of reliability, past performance and the project areas being lowland, etc. (see Fig. 4.2.2).

(2) Water Transfer Facility

While a comparison of the types of water transfer facilities is given in Table 6.2.1, the gravity flow type is the most appropriate from economic viewpoint, but the pressurised type using a pump is required in view of the topography of the subject areas such as inland depression type having large discharge amount. Depending on the topographical conditions at the final disposal facility site, the combined application of the gravity flow type may be viable.

(3) Disposal Facility

The disposal facility should be planned based on the assumption that the abstracted groundwater will be reused. The decision to reuse the groundwater, however, should be made on the basis of the thorough consideration of such related aspects as the water quality and the balance between the supply and demand, etc. Table 6.2.2 gives an outline of the groundwater reutilisation methods.

With regard to the disposal destination, the Umm Er Radhuma formation is excluded due to the possible complications described in Item 4.1.4 which, therefore, leaves discharge to the sea and desert dumping. As desert dumping involves a long transportation distance, it is clearly unsuitable. In comparison, discharge to the sea appears advantageous since it will not cause much damage to the sea in terms of environmental conservation as already described in Item 3.5.5. In this case, two methods are viable, i.e. direct discharge and discharge via Wadi Musherib stormwater trunk line.

6.2.2 Determination of Conditions for Drainage Plan

For the preparation of the drainage plan, a. the design groundwater level, b. the design drainage volume and c. the design water quality must be determined in advance.

(1) Design Groundwater Level

The design groundwater level should be 1.0 - 1.5 m below the ground surface in order to prevent the appearance of standing water in the project areas and in order to eradicate the capillary wet areas causing salt accumulation due to the capillary phenomenon.

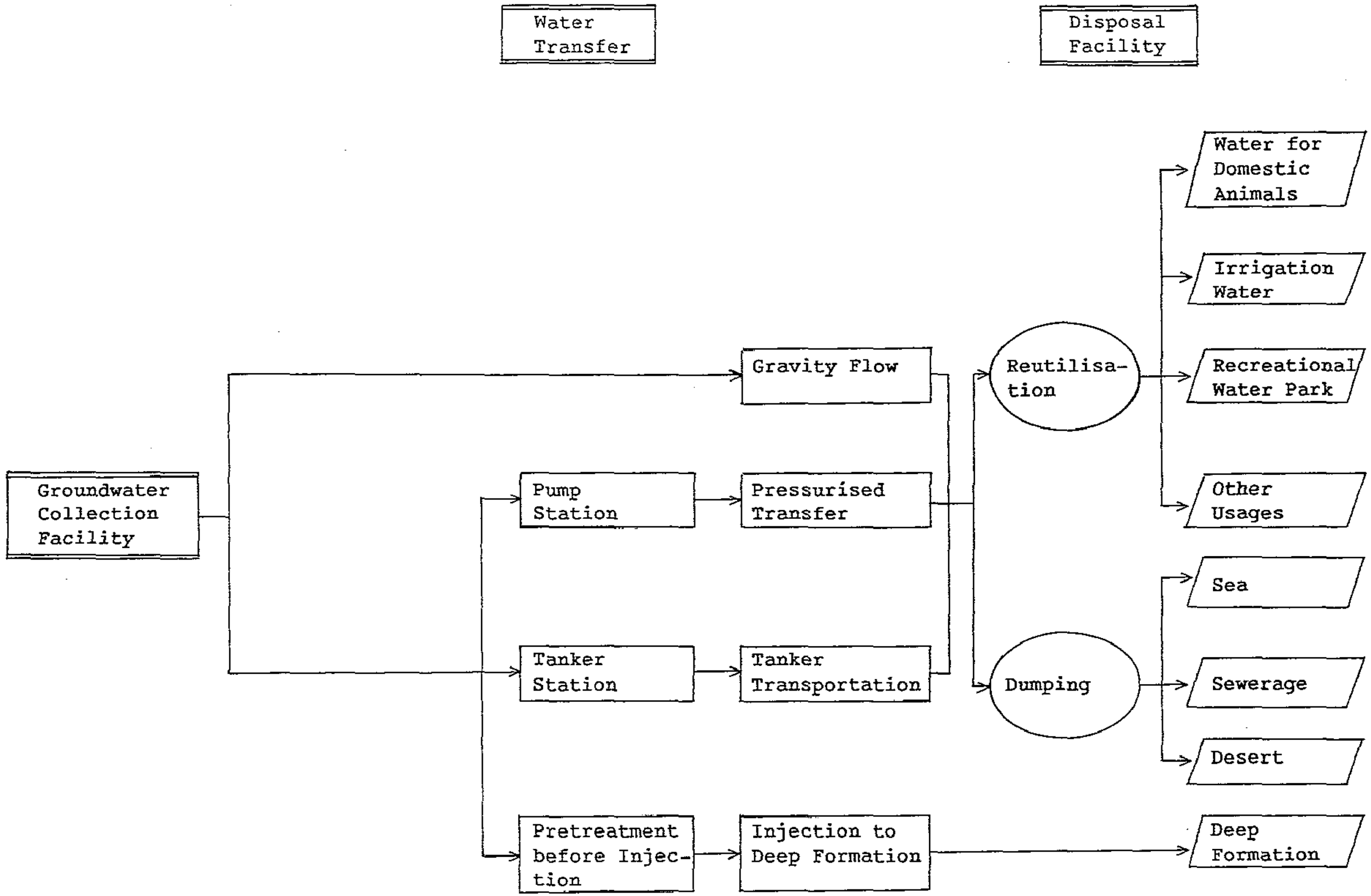


Fig. 6.2.1 Combination of Drainage Facilities

Table 6.2.1 Comparison of Transportation Types

	Gravity Flow	Pressurise Transfer	Tanker	Injection to Deep Formation
Applicable Areas	Route must be able to secure necessary gradient	Inland depression areas and flat coastal plane areas	Any	Those suitable for injection
Water Transfer Capacity	Large	Large	Small	Depends on injection pressure and permeability of injected formation
Cost	More economical than pressurised transfere methods	Pump operation is expensive	Transportation cost is high	Maintenance cost to prevent or repair clogging is relatively high
Post Applications	Many	Many	Generally a temporary emergency measure	Some examples relating to oil and industrial waste water
Problems	Required gradient depends on difference between groundwater and sea levels	None	Transportation of large volume is constrained by number of drivers and vehicles involved	Examination of technical feasibility absolutely necessary

Table 6.2.2 Types of Groundwater Reutilisation

	Water for Domestic Animals	Irrigation Water	Recreational Water Park	Others
Purpose	Drinking water for domestic animals	Afforestation of urban areas and agriculture	Expansion of recreation areas for citizens	o Compacting for road construction or land preparation work o Emergency drinking water supply o Water for flushing toilets o Water for fire-fighting
Required Facilities	Pipelines and reservoirs	Pipelines and irrigation facility or connection to TSE pipes	Preparation of a park with a pond and water channels, etc.	Tanker filling station and storage tanks with auxiliary facilities
Required Water Quality	Low salt density	Low salt density	Restrictions on COD and BOD values	Different conditions apply for different purposes
Demand Estimate	Demand limited to those areas far from planned urban development areas	Depends on local afforestation plan and agriculture improvement plan	Limitless demand as flowing water is preferred for parks	Demand not large and limited number of utilisation places

(2) Design Drainage Volume

In the present Project, the design drainage volume is determined based on the simulation analysis using the mathematical model, which in turn is established based on the test work data and the field survey results. The simulated calculation model to determine the design drainage volume is already described in the Progress Report (April, 1986). Fig. 6.2.2 shows the analytical flow for the preparation of this model.

The basic requirements for the simulation analysis are as follows.

- o The effects of the collection channels on the lowering of the groundwater level in the surrounding area of the channels (inner boundary conditions) are determined on the basis of the test work measurement results.

- o Hydraulic constants for a model showing the process of the groundwater level rise between 1983 and 1986 are identified taking the discharge amount of the test work into account.

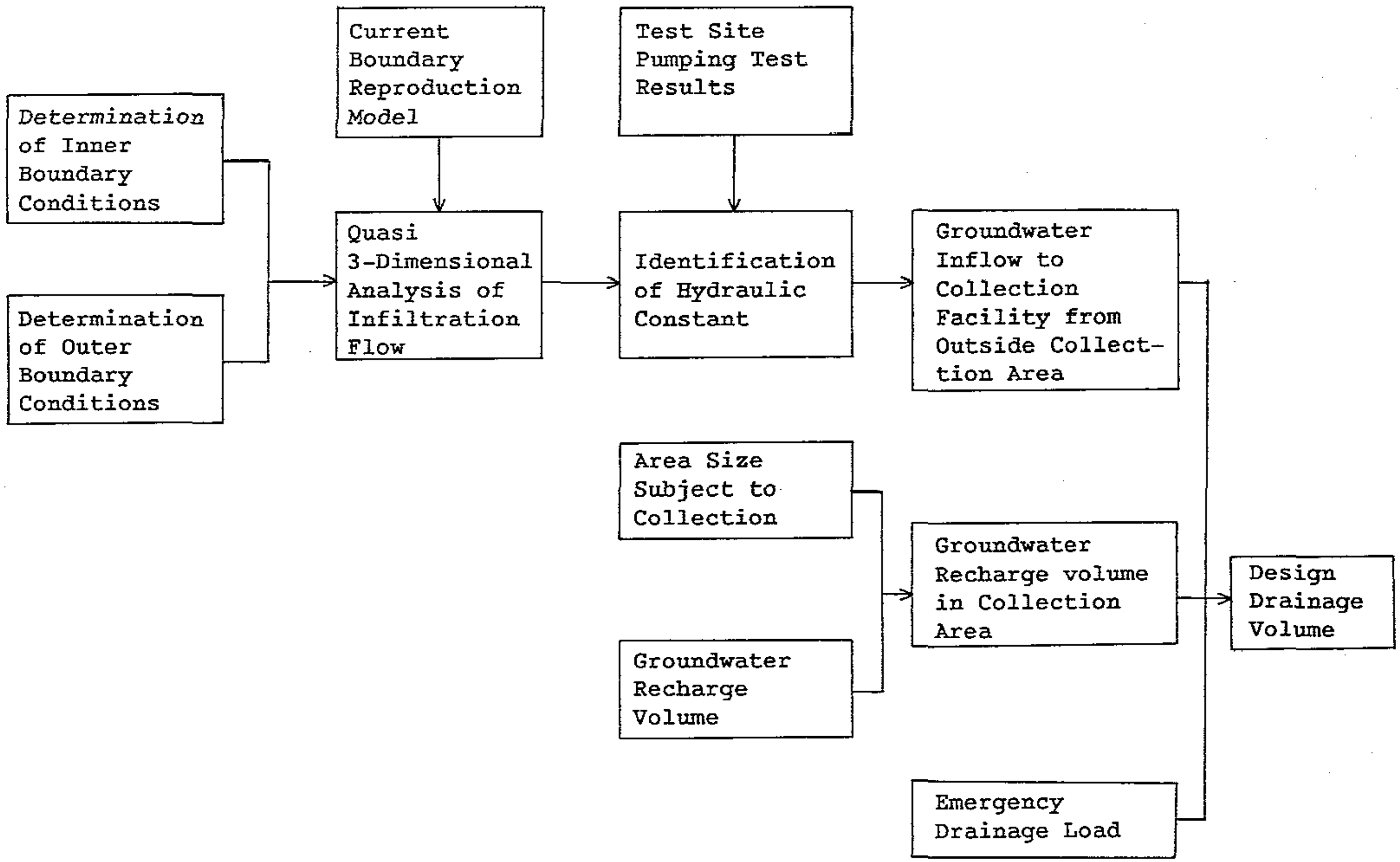


Fig. 6.2.2 Analytical Flow to Determine Design Drainage Volume

6.3 Basic Policy for Wadi Musherib Drainage Plan

6.3.1 Basic Framework of Drainage Facilities Plan

(1) Wadi Type Drainage Facilities

Wadi Musherib has a wadi structure produced by a depression, in turn caused by the dissolution of limestone, and this wadi structure gently inclines from west to east.

A wadi type drainage plan is characterised by the fact that the collection facility can also act as a transfer facility due to the natural gradient.

The Wadi Musherib stormwater trunk line, which is currently being constructed by the MPW, is considered to be the disposal destination.

The basic combination of wadi type drainage facilities is as follows.

a. Collection : Blind Trench
b. Transfer : Gravity Flow
c. Disposal : Wadi Musherib Stormwater Trunk Line

As the drained groundwater may be used for irrigation depending on the results of the water quality analysis during the pump test at test sites, a water reutilisation facility may also be required.

(2) Design Groundwater Level

Table 6.3.1 shows the distribution of the groundwater depth from the ground surface in the area. The Lower Wadi Musherib area, located downstream from the 'C' Ring Road, is mostly urbanised while the Upper Wadi Musherib area, located upstream from the 'C' Ring Road, has scattered farming fields but will be gradually urbanised in the future.

Table 6.3.1 Distribution of Groundwater Depth from Ground Surface

Ground Water Depth Form Ground Surface	LOWER WADI MUSHERIB (m)			UPPER WADI MUSHERIB (m)		
	0 - 1	1 - 2	2 - 3	0 - 1	1 - 2	2 - 3
Area (ha)	45.0	92.0	48.0	30.0	46.0	110.0
Built up Area	41.0	77.0	38.0	19.0	22.7	34.7
Cultivated Area				5.0	1.9	0.3
Standing Water Area		0			0.2	
Sewerage Network (km)	2.0	4.0	8.0	8.0	10.0	6.0
QNTS	6.0	12.4	4.8	4.0	4.2	8.2

Note: Upper Wadi Musherib is upstream from the 'C' Ring Road
Lower Wadi Musherib is downstream from the 'C' Ring Road

This area was chosen as a subject area for the urgent drainage project of the 1983 ASCO Study which proposed that the groundwater level at that time be adopted as the design groundwater level.

The damage in Wadi Musherib consists not only of that caused by the accumulation of salt through groundwater evaporation near the ground surface but also substantial damage to the underground structures and building foundations.

The damage to such underground facilities as power and telephone cables, which should not be exposed to water and are burried in a relatively shallow depth, can largely be reduced, if the design groundwater level is set at 1.5 m below the ground surface. Therefore, the design groundwater level of 1.5 m below the ground surface is adopted.

6.3.2 Examination of Collection Trenches

(1) Bottom Depth of Collection Trenches

The excavation depth of 5 m for the test trench is set as the standard bottom depth of the collection trenches in view of the following requirements.

a. The elevation of the downstream collection trenches should be above sea level to prevent the inflow of sea-water.

b. Based on the bottom depth of the downstream collection trenches, the depth of those trenches upstream should be determined by taking the necessary gradient for gravity flow into account.

(2) Placement Interval of Collection Trenches

The interval between neighbouring trenches should be determined so that the groundwater level at the halfway point between these two parallel trenches is lower than 1.5 m below the ground surface, as shown in Fig. 6.3.1. The appraisal of the degree of the groundwater level lowering should be made based on the steady solution for the two dimensional vertical plane analyses of which the analytical Domain is shown in Fig. 6.3.2. In this case, the following is assumed.

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

b. The groundwater table is level on the central line.

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

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

e. The results of the pump test during the test work are used to provide the permeability coefficient.

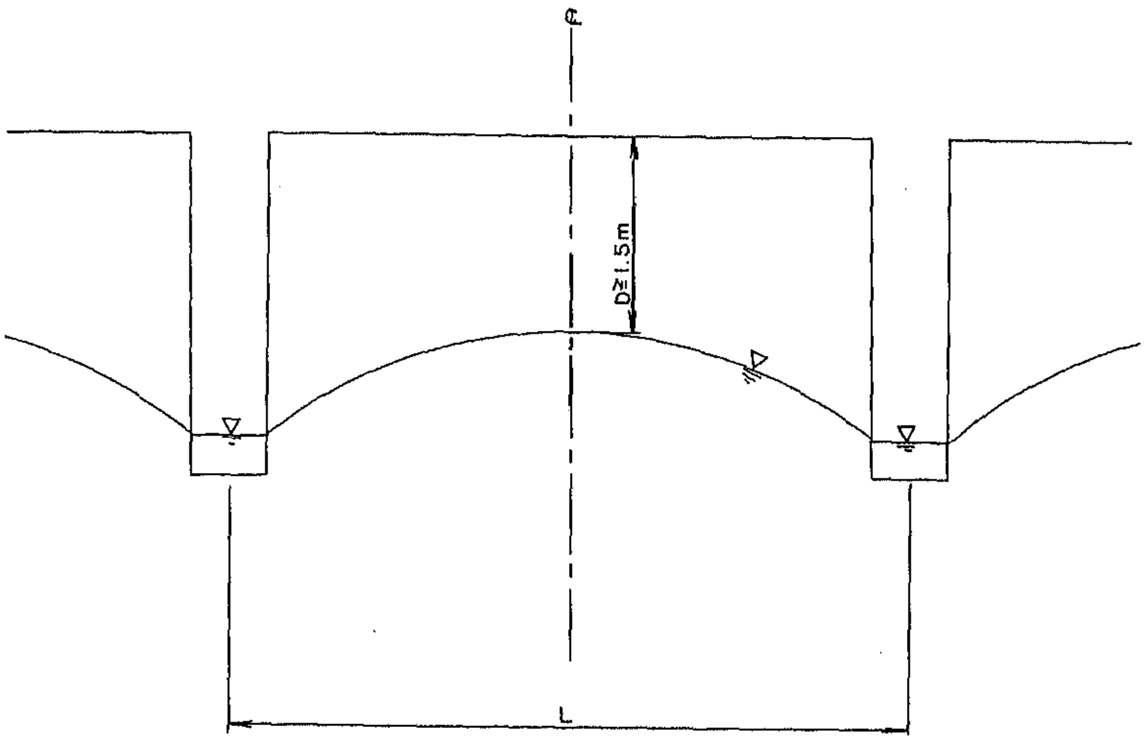


Fig. 6.3.1 Pitch of Collection Trench

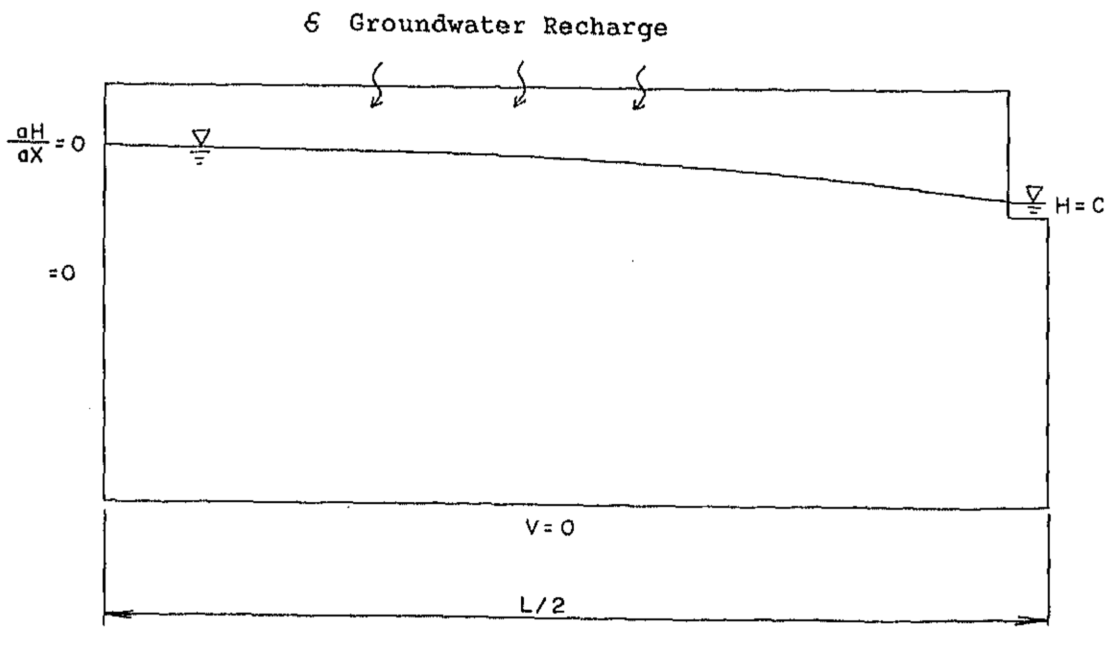


Fig. 6.3.2 Analytical Domain for Drowdown Effect Evaluation around the Collection Trench

As shown in Table 6.3.2, there are nine different combinations of the distance between the collection trench and the central line (L/2) and the groundwater recharge volume for calculation.

Table 6.3.2 Calculation Conditions

Groundwater Recharge Amount	Distance from Collection Trench to Central Line (L/2)		
	100 m	200 m	300 m
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

Table 6.3.3 Degree of Groundwater Level Lowering Given Constant Groundwater Recharge Volume

(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. 6.3.3 shows the calculation results of 100 m, 200 m and 300 m models under the condition for groundwater recharge amount of 700 mm/year. The relation between the degree of groundwater level lowering and the interval of the collection trenches is shown in Table 6.3.3.

Fig. 6.3.4 shows the relation between the degree of groundwater level lowering on the central line between 2 neighbouring trenches and the interval between these trenches. When the initial groundwater level is deep, the interval between the trenches is wide. Conversely, when the groundwater level is shallow, the interval is narrow. For planning purposes, the ground surface is assumed to be 0.5 m above the groundwater level. This is based on the fact that the groundwater level lowering by the collection trenches is fairly effective when the groundwater level is 0 - 1 m below the ground surface. In this case, the interval between the trenches is 460 m for a recharge volume of 1,000 mm/yr or 560 m for 700 mm/yr. Based on these calculations, the interval of some 500 m should prove satisfactory.

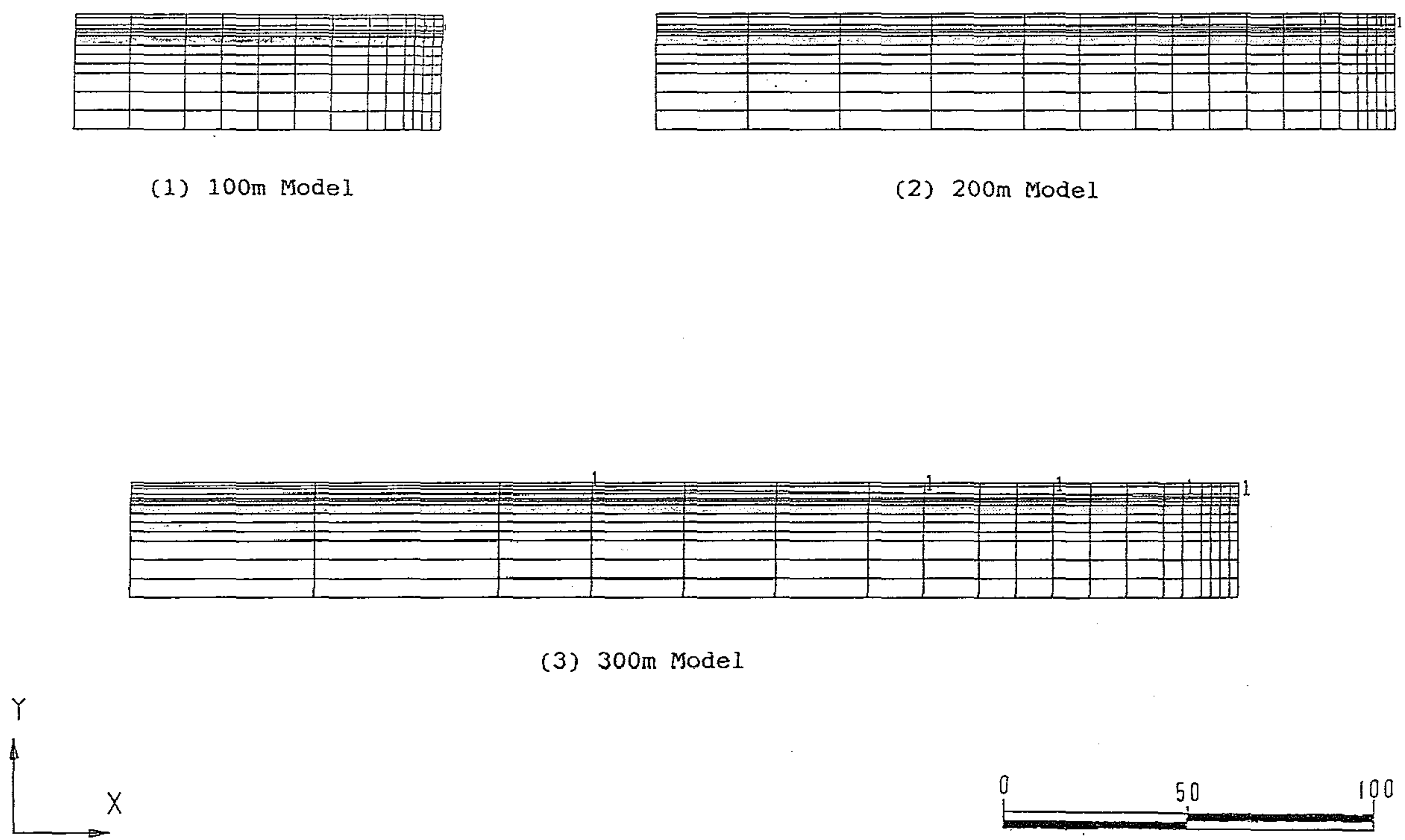


Fig. 6.3.3 Calculation Results on the Drawdown Effect around the Collection Trench using Two Dimension Profile Model: Wadi Musherib

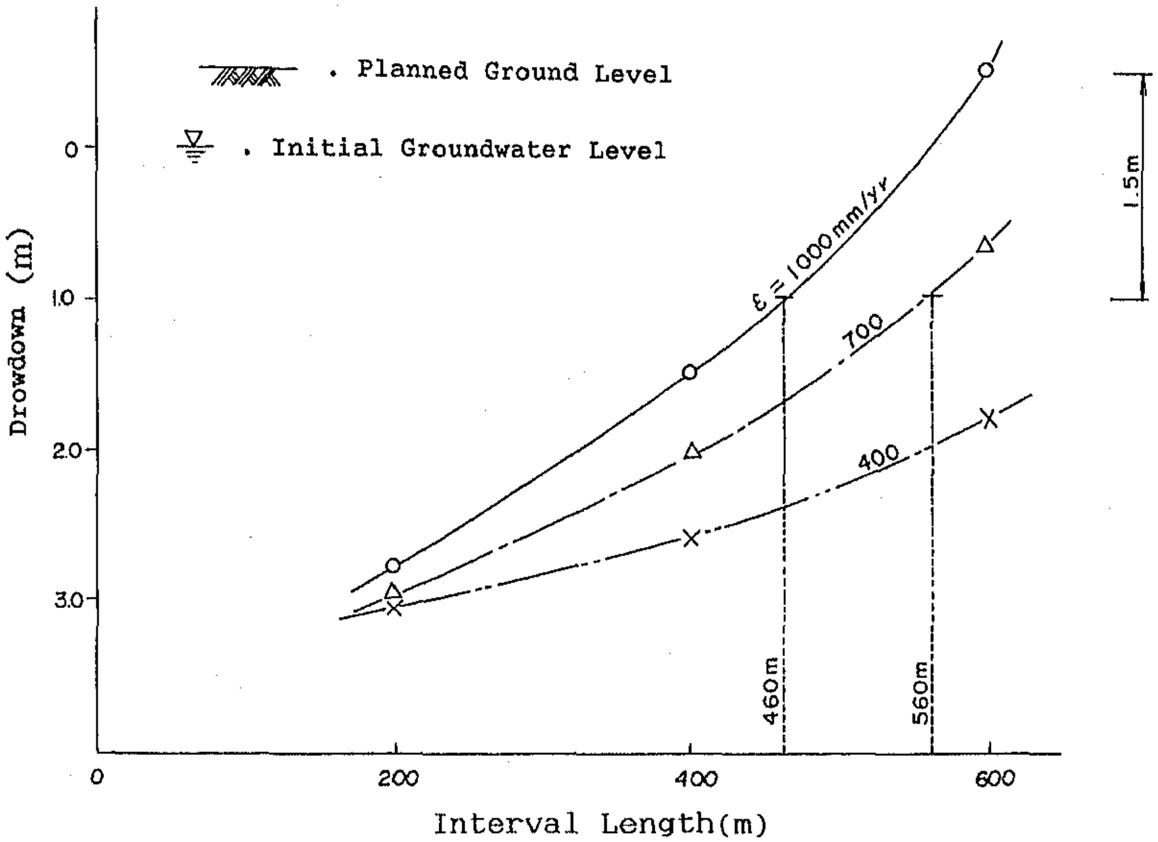
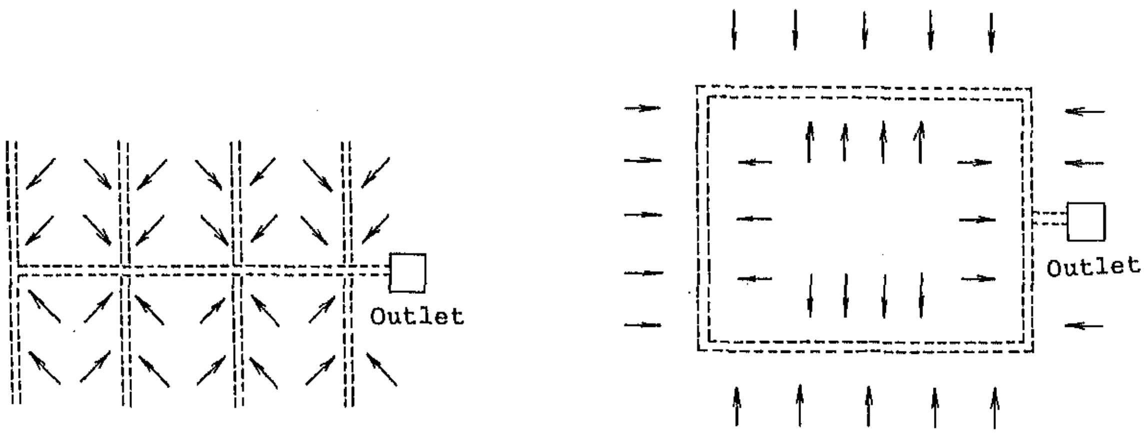


Fig. 6.3.4 Relation Between Trench Interval and Design Groundwater Level

(3) Trench Arrangement Systems

There are 2 types of trench arrangement systems as described below and these 2 types are illustrated in Fig. 6.3.5.

a. Open System : Comb-shaped Arrangement
b. Closed System : Closed-in Subject Area



a. Open System   b. Closed System

Fig. 6.3.5 Conceptual Representation of Collection Network

6.3.3 Examination of Drainage Amount

(1) Groundwater Inflow Amount

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

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

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

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

The calculation results of sensibility analysis are shown in Table 6.3.4

Table 6.3.4 *Groundwater Inflow Volume to Collection Facility : Wadi Musherib*

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

The test run results of these 3 cases show the strong sensitivity in the area between the profile A-A" and B-B" given in Fig. 6.3.6, reflecting a high velocity of groundwater flow table from Khayl groundwater mound to Wadi Musherib. The effect on the south side at the collection facility is small.

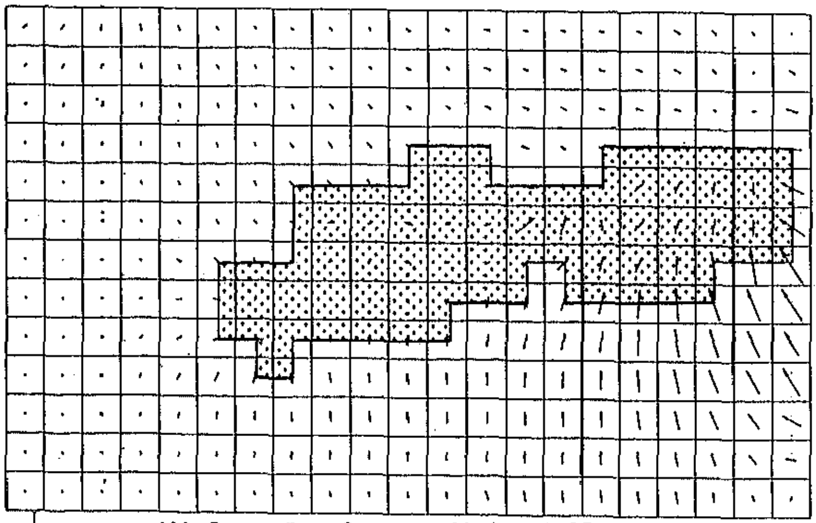
The estimated inflow volume of Case 1 and Case 2 are 1.05×10^6 m^3/year and 1.17×10^6 m^3/year respectively. As Case 3 generates the large inflow into the above-mentioned area of high sensitivity and, thus, causes a strong influence on the outer boundary condition, the solution in Case 3 can not be adopted.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

(2) Discharge Amount in Collection Facility Installation Area

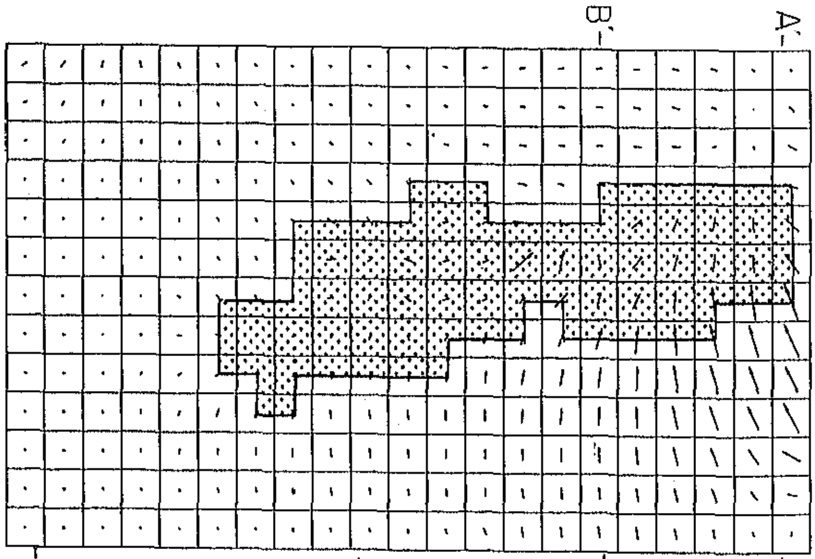
The discharge amount in the collection facility installation area is calculated by the following equation based on the simulation results shown in Fig. 6.3.6.

$$Q_2 = A \cdot \varepsilon = 130(\text{ha}) \times 100(\text{mm/year}) = 1.3 \times 10^5 \ m^3/\text{year}$$

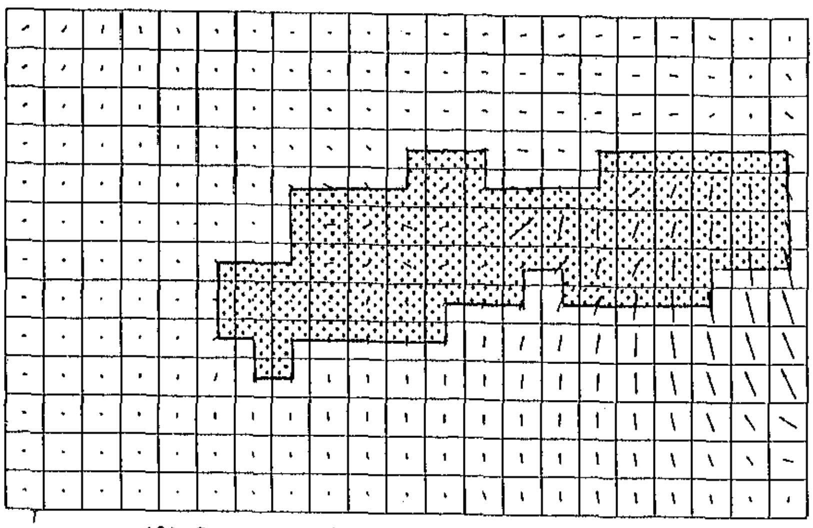
Where, Q_2 : Flow Volume in Collection Facility Installation Area
A : Size of Collection Facility Installation Area
ε : Groundwater Recharge Volume



(1) Inner Boundary Condition:0.25m



(2) Inner Boundary Condition:0.5m



(3) Inner Boundary Condition:1.0m

Fig. 6.3.6 Groundwater Flow Vector Map of Sensibility Analysis for Wadi Musherib

(3) Design Drainage Volume

The sum of the above-mentioned groundwater inflow volume (1.17×10^6 m^3/year) and the flow volume in the subject area (1.3×10^5 m^3/year) is the normal drainage volume i.e. 1.3×10^6 m^3/year. The design drainage volume is set at 1.5×10^6 m^3/year to give a safety margin.

At present stage, it will be quite difficult to account the flow amount of water vein system formed by vugs, fissures, karst channels etc. If the collection trench will unpredictably be subject to a large inflow amount due to the water vein system, collection system will be reinforced by an additional bypass pipe to the stormwater trunk line.

6.4 Basic Policy for Rayyan Drainage Plan

6.4.1 Basic Framework of Drainage Facilities Plan

(1) Inland Depression Type Drainage Facilities

The Rayyan area is a basin with a gentle gradient formed by limestone dissolution. In the case of an inland depression area such as this, the provision of a facility to convey the groundwater collected by the collection facility to the final disposal destination is required. The basic composition of the drainage facilities should be as follows.

a. Collection : Blind Trench
b. Transfer : Pressurised Transportation using a Pump
c. Disposal : Mangrove Lagoon Park
Wadi Musherib Stormwater Trunk Line

While the mangrove Lagoon park is a likely place for the reutilisation of the drained groundwater, the Wadi Musherib Stormwater Trunk Line is a likely place for dumping.

Since the groundwater in Rayyan has a high salt density high salt tolerant plants will be adopted for irrigation reuse; especially mangroves are suitable and there is no salt accumulation problem. The stormwater drainage trunk line, currently under construction by the MPW, is planned to be extended to the Wadi Musherib Dam and is the most likely place for dumping due to the short transfer distance involved.

(2) Design Groundwater Level

Table 6.4.1 shows the current groundwater level and the land use of the area. Most of the area consists of abandoned agricultural fields. However, as it is adjacent to the housing area of Old Rayyan, it can be used for housing, farms and grazing for race horses, etc. Standing water currently covers 11.2 ha, increasing the high salt density in the groundwater and the accumulation of salt in the soil around the standing water. The implementation of groundwater level lowering measures is strongly required to correct this critical situation.

Table 6.4.1 Relation Beween Groundwater Level and Land Use: Rayyan

Ground Water Depth From Ground Surface	(Year)	0 - 1 (m)	1 - 2 (m)	2 - 3 (m)
Area	83		48.0	110.0
(ha)	86	43.0	86.0	95.0
Built up Area (ha)	86	0	2.0	13.0
Cultivated Area	86	3.9	10.5	3.2
Standing Water	83		0	
Area (ha)	86		11.2	

Although this area was not chosen as a subject area for the urgent drainage project of the 1983 ASCO Study, it is an area in Doha where the largest damage has been incurred due to the high rise of the groundwater level between 1983 and 1986.

The design groundwater level is set at 1.3 m below the ground surface in view of the following.

a. When the groundwater level is lowered by 1.0 m, the effects of the soil moisture movement due to the sun's heat virtually become non-existent in terms of salt accumulation in soil or causing high salt density in the groundwater. The design groundwater level is set at 1.3 m to give a safety margin.

b. A non-saturated zone in the soil is important for soil bacteria activity which supplies nutrition for plant growth.

6.4.2 Examination of Collection Trenches

(1) Collection Trench Installation Depth

Since good permeability has been confirmed by the test pumping results at the test sites, an excavation depth of 4 m, which is the same as that for the test work, should be set as the standard depth for trench installation.

(2) Trench Interval

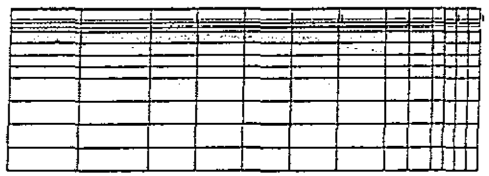
The trench interval is calculated based on the cross-section 2-dimensional inflow analysis of the 12 cases shown in Table 6.4.2

Table 6.4.2 Calculation Conditions

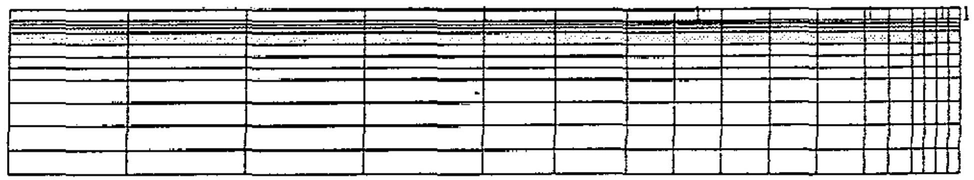
Groundwater Recharge Volume	Distance from Collection Trench to Central Line (L/2)		
	100 m	200 m	300 m
2000 mm/yr	Case 1	Case 2	Case 3
1500 mm/yr	Case 4	Case 5	Case 6
1000 mm/yr	Case 7	Case 8	Case 9
700 mm/yr	Case 10	Case 11	Case 12

Fig. 6.4.1 shows the calculation results of hydraulic head distribution. The relation between the degree of groundwater level lowering and the trench interval is shown in Table 6.4.3.

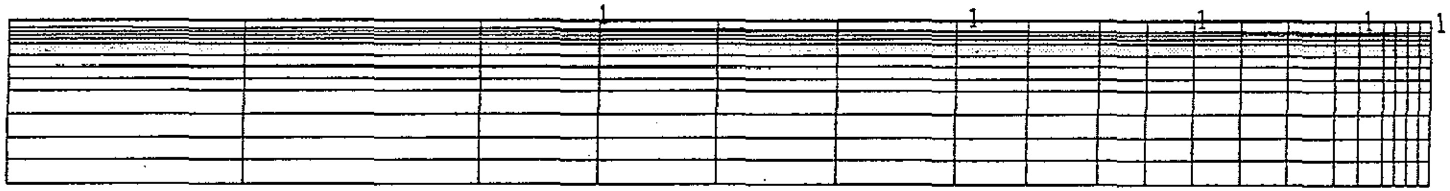
In view of the current existence of standing water, the assumed ground surface is considered to be the same as the groundwater table. The groundwater recharge amount is considered to be some 1,500 - 2,000 mm/year which is almost equivalent to the standing water evaporation volume. In this case, the corresponding trench interval is 520 - 615 m, as shown in Fig. 6.4.1.



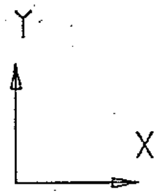
(1) 100m Model



(2) 200m Model



(3) 300m Model



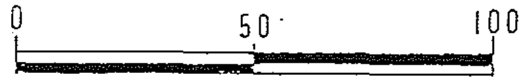


Fig. 6.4.1 Calculation Results on the Drawdown Effect around the Collection Trench using Two Dimension Profile Model: Rayyan

Table 6.4.3 Degree of Groundwater Level Lowering given Constant Groundwater Recharge Volume

Case	Recharge Volume (mm/year)	Distance from Trench 20	100	200	300(m)
1	2,000	2,707	2,609	-	-
2	"	2,496	2,222	1,926	-
3	"	2,286	1,635	1,054	0,859
4	1,500	2,756	2,682	-	-
5	"	2,597	2,317	2,271	-
6	"	2,440	1,954	1,518	1,374
7	1,000	2,804	2,755	-	-
8	"	2,699	2,512	2,415	-
9	"	2,595	2,272	1,983	1,887
10	700	2,833	2,799	-	-
11	"	2,759	2,629	2,561	-
12	"	2,687	2,463	2,262	2,196

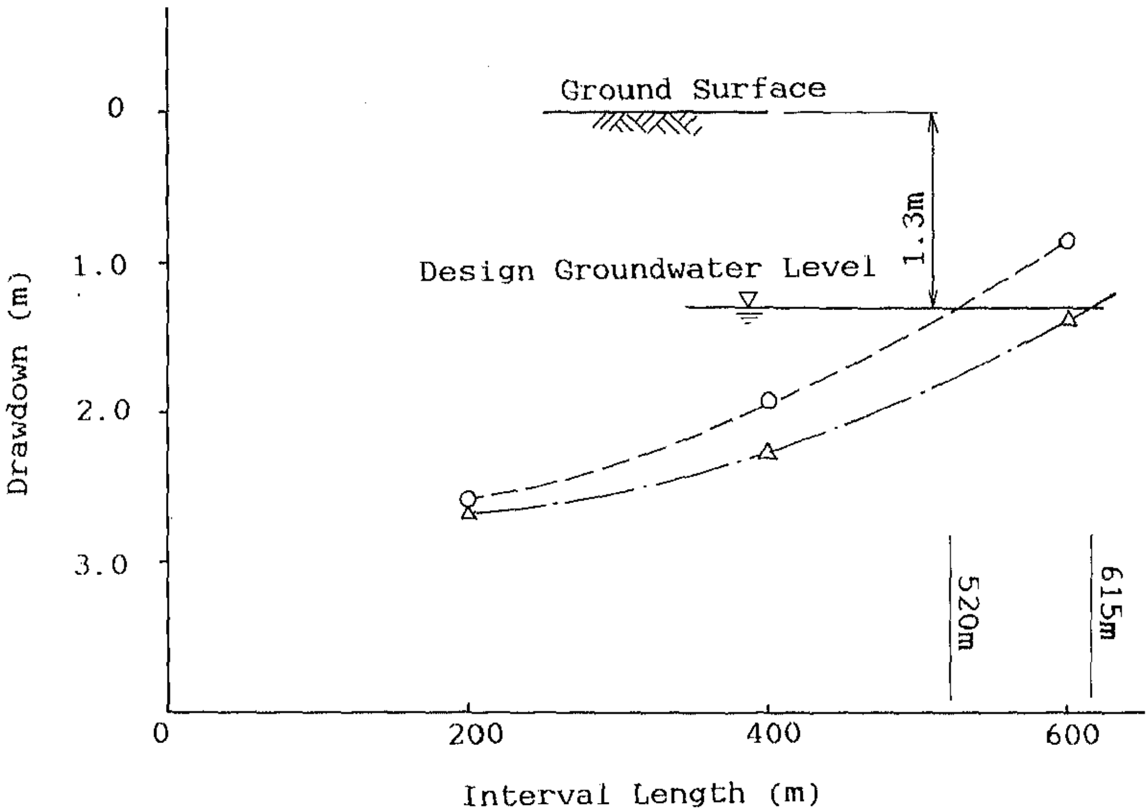


Fig. 6.4.2 Relationship between Trench Installation Pitch and Drawdown: Rayyan

6.4.3 Examination of Drainage Volume

(1) Groundwater Inflow Amount

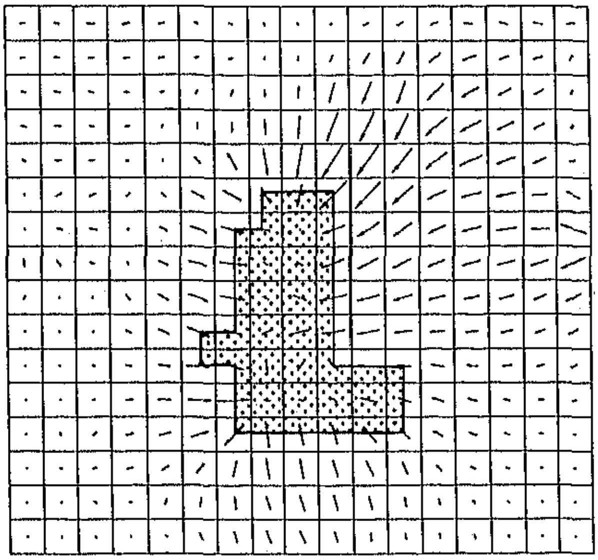
For the calculation of the groundwater inflow amount from outside the design collection area, the method used in the case of Wadi Musherib was also employed. The sensibility analysis was subsequently made on three cases of dummy groundwater level lowering amounts by trenches i.e. 0.5 m, 1.0 m and 2.0 m to evaluate the degrees of influence at the inner boundary conditions. Fig. 6.4.3 and Table 6.4.4 shows the calculation results of the sensitivity analysis.

Table 6.4.4 Groundwater Inflow Volume to Collection Facility: Rayyan

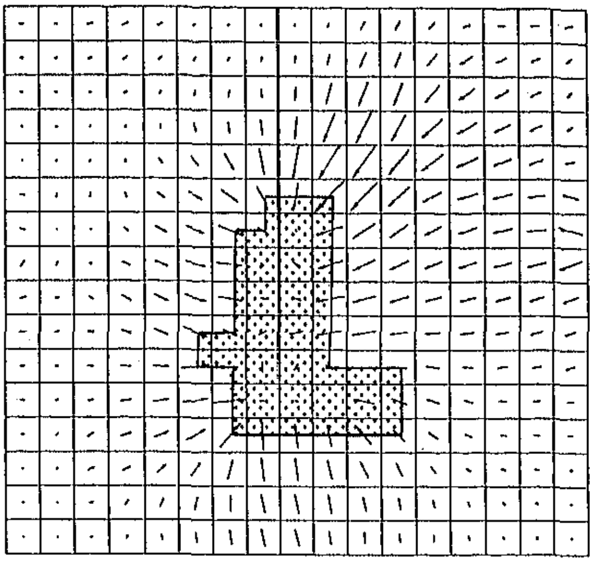
Case No.	Inner Boundary Condition	Estimated Groundwater Inflow Volume
1	0.5 m	0.87 million m^3/year
2	1.0 m	1.26 million m^3/year
3	2.0 m	1.99 million m^3/year

The simulation results to reproduce the current condition of groundwater level from 1983 to 1986 show that the inflow volume from outside the calculation domain ranges from 4.0 X 10^5 m^3/year to 5.0 X 10^5 m^3/year and that the inflow to the collection facility is 7.6 X 10^5 m^3/year.

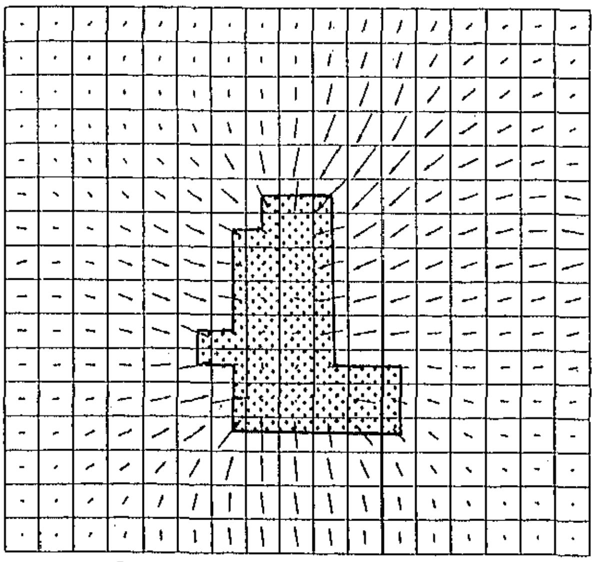
The inflow volume of Case 1 is insufficient as it is only 1.14 times higher than the current inflow volume. In comparison, the effect of Case 3 on the outer boundary condition appears to be too strong to be adopted. Therefore, it is judged that the inflow volume of Case 2 (1.26 x $16^6 m^3$/yr) is appropriate in view of the assumed homogeneous and uniform porous media.



(1) Inner Boundary Condition;0.5m



(2) Inner Boudary Condition;1.0m



(3) Inner Boundary Condition;2.0m

Fig. 6.4.3 Groundwater Flow Vector Map of Sensibility Analysis for Rayyan

(2) Discharge Amount in a Drainage Facility Installation Area

Based on simulation results reproducing the current groundwater level, it is found that the evaporation value among the source term is particularly high in the collection facility installation area. The water volume corresponding to this high evaporation volume should be provided by the leakage from lower layer or the water vein system, of which existence contradicts the assumed uniform and homogeneous aquifer. In view of these considertions, the discharge amount in the collection facility installation area is calculated by the following equation.

$$
\begin{aligned}
Q_2 &= A \cdot \varepsilon \\
&= 65(\text{ha}) \times 1{,}850(\text{mm/year}) \\
&= 1.20 \times 10^6 \ \text{m}^3/\text{year}
\end{aligned}
$$

Where, Q_2 : Flow Volume in Drainage Facility Installation Area
A : Size of Drainage Facility Installation Area
ε : Recharge Volume Equivalent to Evaporation Volume

(3) Design Drainage Volume

The sum of the above-mentioned groundwater inflow volume (1.26×10^6 m^3/year) and the flow volume inside the area (1.20×10^6 m^3/year) is the normal drainage volume i.e. 2.46×10^6 m^3/year. The design drainage volume is set at 3.0×10^6 m^3/year to allow a margin for urgent drainage.

6.5 Basic Policy for New District Drainage Plan

6.5.1 Local Characteristics

The New District consists of newly reclaimed land along the coast. There is a steep cliff of some 10 m in height to the west of the old coastline.

This area is divided into several zones, such as the embassy zone, low density housing zone, high density housing zone, public land and the area currently under reclamation.

The groundwater level in the area is as shallow as sea level and, therefore, is presumably affected by the tide. Since no observation wells exist, the 3 boring holes shown in Fig. 6.5.1 were introduced in order that groundwater level observation could be conducted, as well as a geological survey.

Since the area is located at the coast, there is concern in regard to the high construction cost caused by the necessary dewatering and water-proofing work for building foundations and also in regard to the negative effects of the shallow groundwater level on vegetation. However, concrete damage originating from the rising groundwater level has so far not been observed.

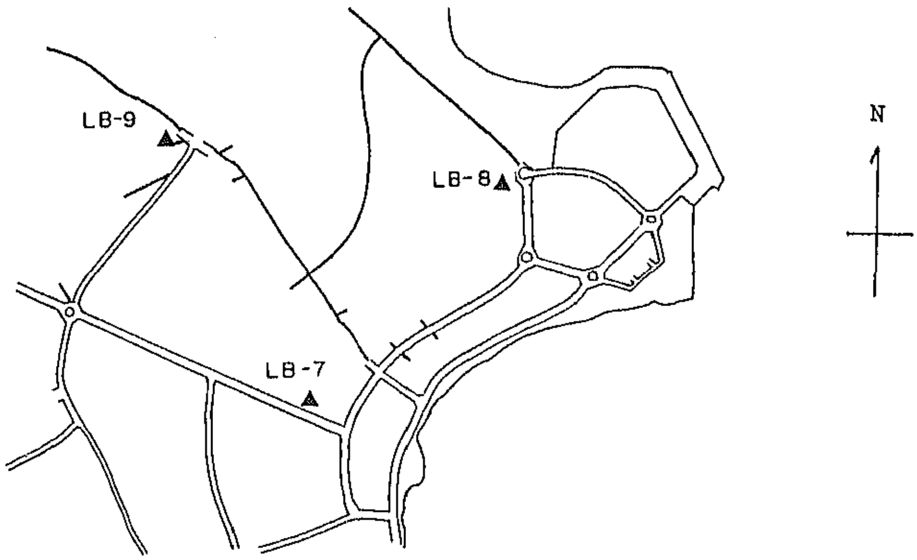


Fig. 6.5.1 Monitoring Well Arrangement at New District

6.5.2 Planning Direction for Coastal Type Drainage Plan

The situation of New District does not demand the urgent preparation of a groundwater drainage plan. Here, a coastal type drainage plan, which could be implemented if the groundwater level critically rises in the future, is examined.

(1) Classification of Coastal Type Measure for Rising Groundwater Level

1 Preventive Measures

When the groundwater level is originally shallow and is affected by tides, the water quality is poor. It is important that those structures and plants which are adaptable to these conditions be selected in view of protecting them from damage. The preventive measures consist of the following.

- Wide application of salt-resistant and water-proofing techniques.
- Instruction on plant culture.

2 Groundwater Recharge Reduction Measures

The basic measures are those described in Section 4.3. Highly salt-resistant piping materials should be used in view of the groundwater's possible high salt density.

3 Groundwater Level Lowering Measures

Construction work to lower the groundwater level will be required if standing water or salt accumulation on the ground appears.

(2) Understanding of Causes

Appropriate measures cannot be planned without an accurate understanding of the causes of the rise of the groundwater level. The possible causes are as follows.

1 Increased groundwater inflow from other areas.
2 Increased recharge due to increased water demand in the area.

For example, drainage channels should be constructed if the groundwater inflow from inland increases. In the cases of the cause existing inside the area itself, corresponding measures should be planned.

(3) Introduction of Groundwater Level Lowering Methods

The methods to deal with the entire area in view of extensive causes of the rise of the groundwater level are as follows.

Plan A

The provision of an exclusive drainage channel network to accommodate the surplus irrigation and desalinated water.

Plan B

The provision of open channels at the perimeter of the area. The groundwater level in the area can be controlled by making the water level in these channels lower than sea level.

The construction of dikes at the coastal perimeter of the area and the dumping of groundwater outside these dikes will also prevent the seawater intrusion into the area's groundwater by establishing hydrological equilibrium.

Plan C

The provision of a drainage facility (open channels or blind trenches) in those places where damage is incurred to lower the groundwater level.

6.6 Reuse of the Groundwater and the required Treatment

6.6.1 Reuse of the Groundwater

As mentioned in Section 6.2, various purposes are considered for the possible reuse of the groundwater. These are water use for keeping livestock, irrigation, recreation, and other purposes such as for fire-extinguishing and drinking. The criteria of the water quality for each purpose of the reuse is summarized in Table 6.6.1

Table 6.6.1 Water Quality Assessment for Reuse

Purpose of Water Reuse (Example)	Possibility for Reuse	Water Quality Requirement			Necessary Treatment
		EC	COD	Major ion Composition	
1) Recreational Uses	High	No	(a)	No	Filtration and/or chlorination
2) Irrigation	Moderate	Depends on crops	(a)	(b)	Partial demineralization and desulphation
3) Fish Culture	Moderate	Accilimatization	(a)	(b)	Partial desulphation and aeration
4) Water Uses for Emergency					
o Fire hydrant	High	No	(c)	No	
o City water for drinking	Low	Must satisfy drinking water standard			Complete treatment

Note: (a): The water is to be aesthetically clean and safe, free from harmful bacteria and also free from toxic materials.

(b): Prior to the direct use, major ions have to be reduced with the consideration of the permissible limit of each special use, and partial demineralization or desulphation should be done if necessary.

(c): The water can be reused without any problem.

1) Livestock

Livestock can be kept by using the groundwater. For the normal growth of livestocks and health of human beings, the water for livestock should be free from dangerous diseases and harmful materials. The water can be allowed to contain some extent of salt but the content of salt should be carefully controlled.

2) Irrigation

In general, plants need fresh water for their normal growth. However, some plants can grow even when irrigated by water with salt to some extent. The effects of saline water vary depending on species of plants and agricultural crops and they are summarized in Table 6.6.2.

In particular, mangroves have remarkably high tolerance of salt and can grow even in the seawater. However, the growth is more significant if they are grown in the fresh water.

3) Recreation

One of the easiest methods of groundwater reuse can be recreation purposes. The water can be used in ponds and parks for fishing and boating. The water used for such purposes should be visually clean and sanitarily safe.

4) Fish culture

Some kinds of fresh or seawater fish have high acctimatability to the environmental changes and can be cultured by the groundwater. For the reuse of groundwater for fish cultures, the water should be well treated by contact aeration or other methods in order to remove the organic materials form the water and to enrich the dissolved oxygen in the water. Attention should also be paid to the control of contents of organic nitrogen and phophate compounds in the water. In order to confirm the possibility of the reuse of groundwater for fish cultures and to examine the degree of pollutant contents of the groundwater, it is recommended to keep some kinds of fish with the groundwater.

5) Other emergency uses

i) Fire-extinguishing

Groundwater can be used as water for fire-extinguishing. If the groundwater has a high content of suspended solids (SS), it will be necessary to provide filtration facilities.

ii) Drinking Water

There are two existing desalination plants for seawater near Doha city, at Ras Abu Aboud and Ras Fontas. More than 90% of the potable water consumed in the city is produced at these plants. If these existing plants are damaged by accident and the water supply is stopped, the use of the groundwater for drinking purpose may be considered as an emergency case. The facilities for such purpose are small-scaled and temporary. The operation costs would be expensive.

6.6.2 Treatment of Water

The process of water treatment can be divided into two, simple treatment and complete treatment. The simple treatment is composed of a single simple process or the combination of such simple processes. In order to obtain high quality water, the complete process of water treatment is required. The complete treatment comprises complicated and sophisticated technology.

Table 6.6.2 Salt Tolerance of Plants (after FAO)

Crop	ECe X 10^3 (mmho/cm) 0%	10%	25%	50%	100%
Field Crops					
Barley (Hordeum vulgare)	8.0	10.0	13.0	18.0	28.0
Cotton (Gossypium hirsutum)	7.7	9.6	13.0	17.0	27.0
Sugarbeet (Beta vulgaris)	7.0	8.7	11.0	15.0	24.0
Wheat (Triticum aestivum)	6.0	7.4	9.5	13.0	20.0
Safflower (Carthamnus tinctorius)	5.3	6.2	7.6	9.9	14.5
Soybean (Glycine max)	5.0	5.5	6.2	7.5	10.0
Sorghum (Sorghum bicolor)	4.0	5.1	7.2	11.0	18.0
Groundnut (Arachis hypogaea)	3.2	3.5	4.1	4.9	6.5
Rice (paddy) (Ozyza sativa)	3.0	3.8	5.1	7.2	11.5
Sesbania (Sesbania macrocarpa)	2.3	3.7	5.9	9.4	16.5
Corn (Zea mays)	1.7	2.5	3.8	5.9	10.0
Flax (Linum usitatissimum)	1.7	2.5	3.8	5.9	10.0
Broad bean (Vicia faba)	1.6	2.6	4.2	6.8	12.0
Cow pea (Vigna sinensis)	1.3	2.0	3.1	4.9	8.5
Beans (Phaseolus vulgaris)	1.0	1.5	2.3	3.6	6.5
Fruit Crops					
Date palm (Phoenix dactylifera)	4.0	6.8	10.9	17.9	32.0
Fig (Ficus carica)					
Olive (Olea europaea)	2.7	3.8	5.5	8.4	14.0
Pomegranate (Puncia granatum)					
Grapefruit (Citrus pardisi)	1.8	2.4	3.4	4.9	8.0
Orange (Citrus sinensis)	1.7	2.3	3.2	4.8	8.0
Lemon (Citrus limonea)	1.7	2.3	3.3	4.8	8.0
Apple (Pyrus malus) Pear (Pyrus communis)	1.7	2.3	3.3	4.8	8.0
Walnut (Juglans regia)	1.7	2.3	3.3	4.8	8.0
Peach (Prunus persica)	1.7	2.2	2.9	4.1	6.5
Apricot (Pyrus armeniaca)	1.6	2.0	2.6	3.7	6.0
Grape (Vitis ssp.)	1.5	2.5	4.1	6.7	12.0
Almond (Prunus amygdalus)	1.5	2.0	2.8	4.1	7.0
Plum (Prunus domestica)	1.5	2.1	2.9	4.3	7.0
Blackberry (Rubus spp.)	1.5	2.0	2.6	3.8	6.0
Boysenberry (Rubus spp.)	1.5	2.0	2.6	3.8	6.0
Avocado (Persea americana)	1.3	1.8	2.5	3.7	6.0
Raspberry (Rubus idaeus)	1.0	1.4	2.1	3.2	5.5
Strawberry (Fraggaria spp.)	1.0	1.3	1.8	2.5	4.0
Vegetable Crops					
Beets (Beta vulgaris)	4.0	5.1	6.8	9.6	15.0
Broccoli (Brassica italica)	2.8	3.9	5.5	8.2	13.5
Tomato (Lycopersicon esculentum)	2.5	3.5	5.0	7.6	12.5
Cucumber (Cucumis sativus)	2.5	3.3	4.4	6.3	10.0
Cantaloupe (Cucumis melo)	2.2	3.6	5.7	9.1	16.0
Spinach (Spinacia oleracea)	2.0	3.3	5.3	8.6	15.0
Cabbage (Brassica oleracea)	1.8	2.8	4.4	7.0	12.0
Potato (Solanum tuberosum)	1.7	2.5	3.8	5.9	10.0
Sweet corn (Zea mays)	1.7	2.5	3.8	5.9	10.0
Sweet potato (Ipomoea batatas)	1.5	2.4	3.8	6.0	10.5
Papper (Capsicum frutescens)	1.0	2.2	3.3	5.1	8.5
Lettuce (Lactuca sativa)	1.3	2.1	3.2	5.2	9.0
Radish (Raphanus sativas)	1.2	2.0	3.1	5.0	9.0
Onion (Allium cepa)	1.2	1.8	2.8	4.3	7.5
Carrot (Daucus carota)	1.0	1.7	2.8	4.6	8.0
Beans (Phaseolus vulgaris)	1.0	1.5	2.3	3.6	6.5
Forage Crops					
Tall wheat grass (Agropyron elongatum)	7.5	9.9	13.3	19.4	31.5
Wheat grass (fairway) (Agropyron elongatum)	7.5	9.0	11.0	15.0	22.0
Bermuda grass (Cynodon dactylon)	6.9	8.5	10.8	14.7	22.5
Barley (hay) (Hordeum vulgare)	6.0	7.4	9.5	13.0	20.0
Perennial rye grass (Lolium perenne)	5.6	6.9	8.9	12.2	19.0
Trefoil, birdsfoot narrow leaf (L. corniculatus tenuifolius)	5.0	6.0	7.5	10.0	15.0
Harding grass (Phalaris tuberosa)	4.6	5.9	7.9	11.1	18.0
Tall fescue (Festuca elatior)	3.9	5.8	8.6	13.3	23.0
Crested wheat grass (Agropyron desertorum)	3.5	6.0	9.8	16.0	28.5
Vetch (Vicia sativa)	3.0	3.9	5.3	7.6	12.0
Sudan grass (Sorghum sudanense)	2.8	5.1	8.6	14.4	26.0
Wildrye, beardless (Elymus triticoides)	2.7	4.4	6.9	11.0	19.5
Trefoil, big (Lotus uliginosis)	2.3	2.8	3.6	4.9	7.5
Alfalfa (Medicago sative)	2.0	3.4	5.4	8.8	15.5
Lovegrass (Eragrostis spp.)	2.0	3.2	5.0	8.0	14.0
Corn (forage) (Zea mays)	1.8	3.2	5.2	8.6	15.5
Clover, berseem (Tritolium alexandrinum)	1.5	3.2	5.9	10.3	19.0
Orchard grass (Dactylis glomerata)	1.5	3.1	5.5	9.6	17.5
Meadow foxtail (Alpecurus pratensis)	1.5	2.5	4.1	6.7	12.0
Clover, alsike, ladino, red, strawberry (Trifolium spp.)	1.5	2.3	3.6	5.7	10.0

1) Simple treatment

Various kinds of simple treatment are in practice. These are treatment by simple filtration, desalination treatment and biochemical treatment by use of microorganisms or plants. These simple processes are frequently applied in case the water which is slightly polluted (the value of BOD is less than 20 ppm or the value of COD is less than 30 ppm) is treated to remove a small amount of suspended solids. Water treated by simple processes is normally not of high quality.

If the groundwater is reused for recreation purposes, the water should be transparent, colourless and odourless. It should be treated so as not to include any dangerous diseases and harmful materials. If the groundwater is reused for agricultural purposes, the amount of salt contained in the groundwater should be reduced depending on the kinds of irrigated plants and crops. If the water contains a high salinity of more then 5,000 EC and a high SO_4 concentration of more than 1,000 mg/l, the treatment for desalination would be required to some extent. For such desalination treatment one of the simple treatment methods such as the contact aeration, gravity sand filter or reverse osmosis or the combination of these simple methods should be applied.

2) Complete treatment

Complete treatment is applied for the production of potable water and water for special uses such as washing water in the electronic industry. For the production of potable water from the groundwater, the required processes for the treatment would be as follows:-

i) Separation of sands from the water

If the groundwater pumped up from wells contains sands, sands should be removed from the water.

ii) Contact aeration

The groundwater normally includes a little amount of eutrophic organic materials (nitrogen and phosphate compounds) and the amount of dissolved oxygen is insufficient. The groundwater is sometimes odoriferous. For such groundwater, contact aeration is required.

iii) Gravity sand filter

If the water contains microorganisms, aquatic weeds or other suspended solids, the water is required to be filtered and cleaned.

iv) Desulphation

The groundwater in the Doha and Rayyan areas has a high content of SO_4, which causes serious scale troubles in the course of the desalination and demineralization process. Desulphation is imperative for the treatment of groundwater in those areas.

v) Demineralization

Demineralization is required to reduce TDS to less than 500 mg/l, in order to satisfy the water quality standard for potable water.

Taking the availability of equipment in the market into account, the following equipment are recommended for the above processes.

a) Sedimentation/detention tank or cyclone-type mechanical sand separator.

b) Contact aeration tank of the trickling filter type (concrete made tank filled with crushed stone) or the packed-tower type with plastic materials.

c) Gravity sand filter

Tank made of concrete or steel. Both types of tank can be easily designed and constructed.

d) Desulphation

Prior to the demineralization of the groundwater of high SO_4 content, an anionic exchange process is applied. In Qatar, the Industrial Development Technical Centre has already developed a desulphation method by means of ion exchange treatment under technical cooperation with Italy and succeeded in the use of the process for the demineralization by Reverse Osmosis (RO) as a pre-treatment to avoid scale troubles in the RO process. The ion exchange treatment can be useful for desulphation, but its operation and construction costs are too high in Qatar.

e) Demineralization

The RO process is the most useful and convenient method for the demineralization as a small-scaled process of demineralization if it is combined with the desulphation process. For a large-scaled process, the flush evaporation process is the most economical.

However, owing to the fact that there is no need for the complete treatment of groundwater, therefore, treatment system and construction costs for the facilities of such method will be omitted here.

6.6.3 Treatment of the Groundwater in Wadi Musherib Area

The groundwater in Wadi Musherib Area is characterized by relatively low salinity water with high content of SO_4. As the COD value is not so high, the groundwater could be useful for various purposes if the chlorination is carried out from the sanitary view point. If the COD or BOD values increase in the future, the simple contact aeration process would be effective in addition to the demineralization process.

If the groundwater is used for irrigation purposes, the water could be used without any treatment for some crops with high tolerance of salinity. If it is necessary to reduce the EC value of the irrigation water to around 2,000 micro mhos/cm, then the application of a simple demineralization process would be recommended.

(1) Simple demineralization process

If the groundwater is used for the irrigation of such crops as beans, onions, carrots and strawberries, it is necessary to reduce the salinity content in the irrigation water in order to minimize the damage due to salinity hazard. If the EC value of the water is kept at less than 2,000 micro mhos/cm, the decrease in harvest would be less than 10 percent of the anticipated production under the fresh water irrigation. If such requirement occurs, the installation of a demineralization process would be required in order to remove the total dissolved solids (TDS). As a suitable demineralization process, both the flush evaporation process and the RO process are recommended. The flush evaporation process would be economically preferable if a large amount of seawater is desalinated. On the other hand, the RO process would be suitable for the desalination of a small amount of water with TDS of less than 5,000 mg/l, like the groundwater in the project area.

The reverse osmosis filter used in the RO process can reduce the TDS value of the groundwater from 5,000 mg/l to 500 mg/l. As the required level of TDS of the irrigation water is about 2,000 mg/l, water treated by the RO process can be used to dilute the original groundwater. This would considerably reduce the total amount of treated water for irrigation and the capacity of the RO process can be minimized.

(2) Preliminary estimate of construction costs

In case an amount of 1,000 m^3 of water with TDS of 500 mg/l is produced daily from the groundwater in the area, preliminary estimate of the construction costs of the RO process is as shown below.

Costs for mechanical and electric equipment	QR 4,500,000
Costs for civil works	QR 1,800,000
Total construction costs	QR 6,300,000

Major mechanical and electric equipment are summarized as follows.

Submerged pump	:	1.3 m^3/min x 8m x 5.5kW x 2 units (one unit standby)
Concrete tank	:	100 m^3 x 1 unit
Pumps for desulphation	:	1.3 m^3/m x 25m x 5.5kW x 2 units (one unit standby)
Ion-exchange equipment	:	2.4m(inner dia.) x 3m high x 2 units
Storage tank for desulphation	:	400 m^3 x 1 unit
Pumps for RO process	:	1.4 m^3/min x 30m x 11kW x 2 units (one unit standby)
Cartridge filter for RO process	:	10 m x 2 units
High pressure pump	:	1.4 m^3/min x 230m x 75kW x 1 units
Unit of RO process	:	pressure 55m, percolation membrane
Chlorinator	:	One set
Drinking water tank	:	3.4m(inner dia.) x 4.5m(height) x 1 unit
Electric equipment	:	*Motor pannel and control pannel*
House for RO process	:	18.4m length x 6m width x 3.5m height

(3) Preliminary estimate of operation and maintenance costs

The operation and maintenance costs include the depreciation costs of equipment, salaries for the staff, electricity fees and costs for chemicals and consumable goods. The total annual operation and maintenance costs are estimated at about QR 703,500 (Japanese Yen ¥36,000,000). The production cost for drinking water would be about 2.65 QR/m^3(¥120/m^3).

The breakdown of operation and maintenance costs is summarized below.

a) Depreciation costs of equipment: QR 1,050/day

The depreciation costs of equipment is estimated on the basis that the service life of the equipment is 20 years.

b) Operation costs

- Salaries for the staff	:	QR 480/day (QR 1,200/month)
One operator	:	QR 200/day (QR 5,000/month)
One assistant	:	QR 160/day (QR 4,000/month)
One labour	:	QR 120/day (QR 3,000/month)
- Electricity fees	:	QR 150/day (QR 3,750/month) (2,500 kwh/day x QR 0.06/kwh)

- Cost for chemicals : QR 515/day

Sodium hypochlorite	:	QR 20/day	(Unit: QR 1.0/kg)
Hydrochloric acid	:	QR 190/day	(Unit: QR 12.7/kg)
Sodium hexameta-phosphate	:	QR 120/day	(Unit: QR 0.7/kg)
Caustic soda	:	QR 185/day	(Unit: QR 1.0/kg)

- Costs for consumables and spare parts : QR 450/day

Annual cost for consumables and spare parts is estimated by 3% of the expenses for mechanical/electric equipment and 300 operating days yearly.

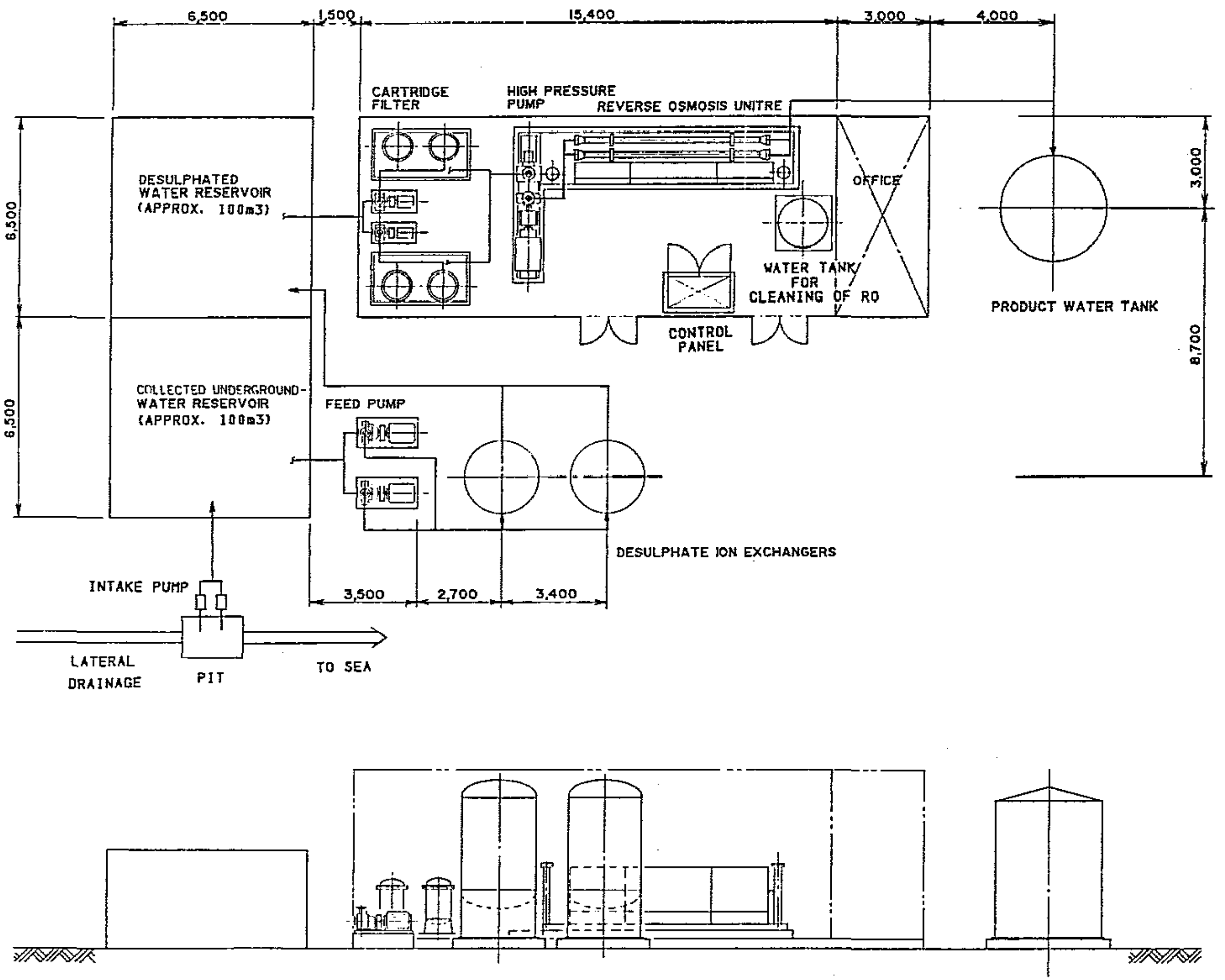


Fig. 6.6.1 SIMPLE TREATMENT FOR GROUND WATER

1.000m3/d PRODUCT WATER

GENERAL PLAN

7. DRAINAGE PLAN AT WADI MUSHERIB

7. DRAINAGE PLAN AT WADI MUSHERIB

7.1 Basic Conditions for Drainage Plan

(1) Project Area for Drainage Schemes

Wadi Musherib which is located almost center of Doha city, has a wadi formation (as named) descending from west to east, with lengths of approximately 4.0 km in the east-west direction and 1.5 km in the north-south direction.

The Project area for drainage schemes at Wadi Musherib, as described in Chapter 6, is the area where the groundwater level is less than 1.5 m below ground surface.

Specifically the project area runs through Wadi Musherib, west along Sadd Road, towards Cable and Wireless Roundabout in the east. It encompasses a strip of width varying 400 to 500 m, length 3,500 m with an area of approximately 150 ha. Ground elevation varies from QND + 4.4 m at Cable & Wireless Roundabout to +7.4 m at Sadd Road with an average gradient of approximately 1/1000.

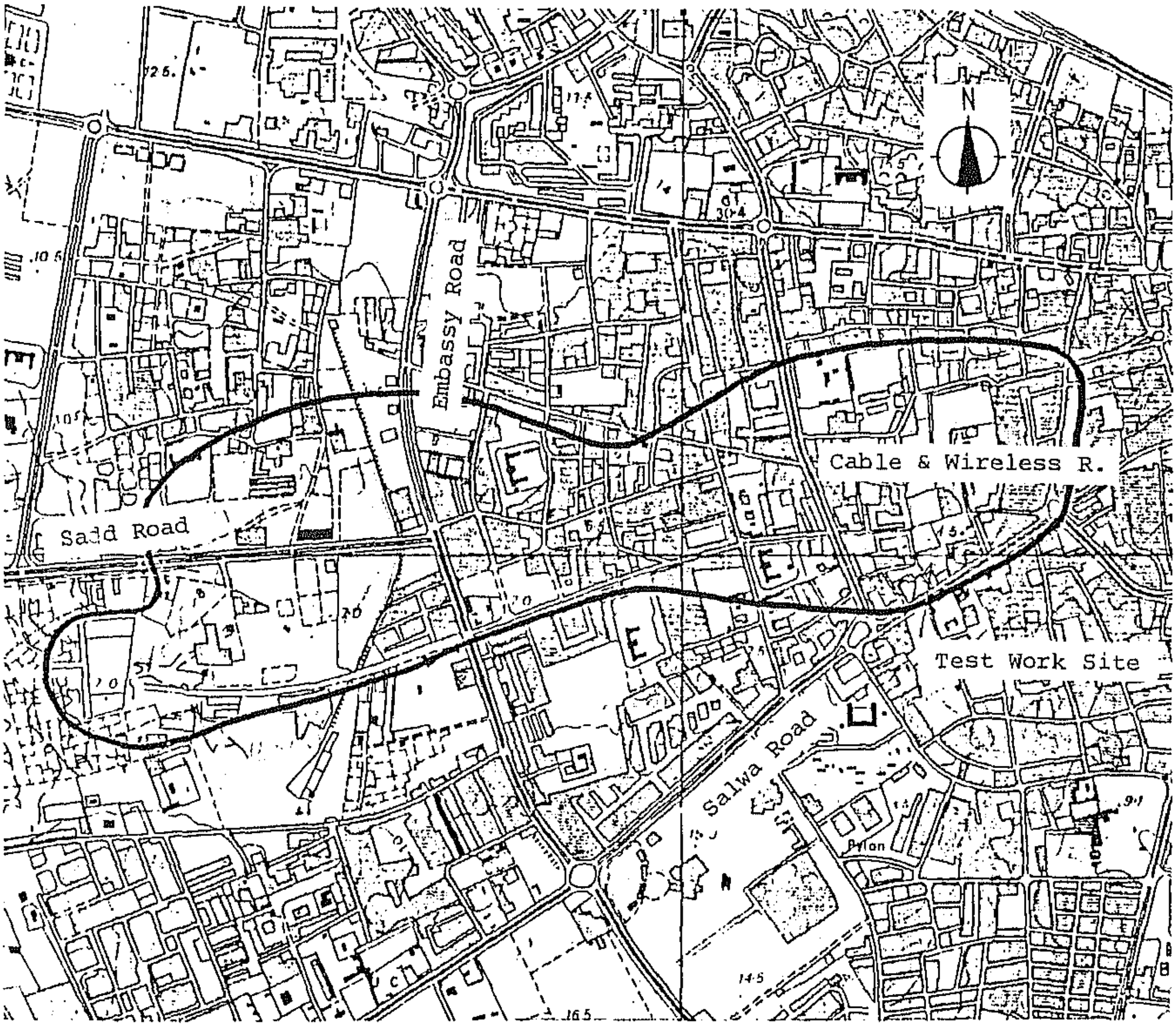


Fig. 7.1.1 Project Area for Drainage Schemes at Wadi Musherib

(2) Proposed Groundwater Level

Groundwater level for all the project area is to be kept below 1.5 m from ground.

(3) Discharge Amount

With the provision of lateral drainage network within the project area and maintaining groundwater level at 5.0 m below ground level at the lateral drains, amount of groundwater to be discharged is 1,500,000 m^3/year in accordance with the groundwater analysis presented in Chapter 6.

(4) Location of the facility

Public roads area were basically used for this project.

(5) Water Quality

Estimates of water quality for the groundwater to be discharged by this drainage plan are as follows;

EC value	5,000 micro mhos/cm
COD value	Max. 5 mg/l
pH	8.0

(6) Staged Construction

When the first phase construction is completed hydrogeological analysis shall be checked by the actual figures of discharge amount and drawdown effect including the areal or local characteristics so that the first and/or second phase schemes can be modified accordingly.

7.2 Alternatives of Drainage Systems

Drainage systems are divided into three subsystems by their functions, i.e. collection, transfer and disposal or re-use and there are alternatives considered for respective subsystems as summarized in Table 7.2.1 below.

Table 7.2.1 Alternatives of Drainage System at Wadi Musherib

Collection	Transfer	Disposal
Lateral Drainage-1 (Perimeter arrangement) Lateral Drainage-2 (Comb arrangement)	Pumping-up Discharge by gravity	Stormwater drainage trunk line Sewerage line Re-use

7.2.1 Collection System

For collection system in this project area two methods were considered suitable as described in Chapter 6, i.e. lateral drains and shallow wells. However, quantity of water abstracted from shallow wells for reuse may decrease should its quality be unsuitable, therefore as a collection system, shallow wells are unreliable. Consequently as a major drainage system large lateral drains were eventually considered.

(i) Lateral Drainage-1
(Perimeter arrangement)
(Refer Fig. 7.2.1)

The outer lateral drains forming the perimeter of the project area will be laid where the groundwater level is at a depth of 1.5 m from the ground level or slightly deeper. Groundwater contour map will be used to identify these locations. In such a way groundwater which would otherwise flow into the project area will be collected by the perimeter lateral drains. In addition to this, lateral drains within the project area will drain the enclosed groundwater, therefore an effective drainage and lowering of level are expected.

Depth of the lateral drains is 4-6 m depending upon location. Such depths posed no problems during the construction of test work trench.

At the same time the stormwater trunk line which is planned in the center of the project area, is to be modified partially. The addition of groundwater drainage pipes are to be provided at the corner of the excavated trench for main stormwater pipes, giving this stormwater drainage an added function of groundwater drainage.

Outline of this scheme

Total length of lateral drains	:	12,900 m
Diameters of perforated pipe	:	350 mm, 450 mm
Manhole pitch	:	100 m
Depth of drains	:	4-6 m

(ii) Lateral drainage-2
(Comb arrangement)
(Refer Fig. 7.2.2)

Project area and method of water collection are the same as for Lateral drainage-1. However, arrangement and relation to the stormwater trunk line are different. In this arrangement the lateral drains cross the trunk line at right angles and connect to a transfer pipe running parallel to it.

This arrangement has an advantage of laying a larger number of lateral drains, because of the ease of connection, therefore achieving an effective lowering of groundwater levels, but has the disadvantage of making the trunk line complicated and less efficient in water collection due to parallel arrangement to the flow line. At the upstream part of the area, the groundwater transfer pipe is considerably lower than the trunk line.

Outline

Total length of lateral drains	:	13,000 m
Diameters of perforated pipe	:	300 mm, 450mm
Manhole pitch	:	100 m

(iii) Shallow well/small lateral drains

At areas where groundwater quality is found to be good enough for use in irrigation, it is possible to construct shallow wells and small lateral drains independently and transfer or disposal are not required for this system.

7.2.2 Transfer System

In this project area, for both alternatives water will be collected by lateral drains which will connect with the stormwater trunk line. The Wadi Musherib Stormwater Trunk Line may also be referred to as the surface water sewerage pipeline.

(1) Transfer pipe line

Two methods are considered for the pipe line, one is main transfer pipe with lateral drains and the other is using lateral drain pipe as transfer. In case of this project area the latter is considerd more efficient because of network arrangement.

(2) Connection to the stormwater trunk line

(i) Pumping up

The water abstracted will be pumped up to the stormwater trunk line.

(ii) Gravity flow

Selecting suitable pipe diameter and gradient, it is possible to connect the groundwater piping to the stormwater trunk line at the same pipe invert level.

However in this case the possibility of reversal flow in the groundwater drain pipe is presumed when stormwater runs in the main pipe because of the difference in diameters. But it is anticipated that stormwater may happen only a few days per year and also considering the recovery of the groundwater level week long movement, this reversal flow can be allowed for groundwater drainage scheme.

7.2.3 Disposal Point

Since the water contamination is not serious at Wadi Musherib area as described before, there is a possible alternative to discharge abstracted groundwater into sewerage line however the capacity of the line and treatment works are limited. On the contrary in case of stormwater trunk line, the groundwater discharge amount can be accommodated. It is therefore considered that disposal to the Doha Bay through stormwater trunk line is the most rational solution.

7.2.4 Comparison of the Alternatives

(1) Cost Estimation

Regarding all the alternatives proposed in Section 7.2, rough cost estimation was made based upon the cost data obtained in Doha and information in Japan. Prior to cost estimation, quantities of the works for each alternative were also calculated.

(i) Unit rates

Unit rates for the works were based upon the following;

a. Data by quantity surveyors in Doha

   For general items in civil and building works, data obtained from Langdon & Every stationed in Doha were used.

b. Data by PENCOL

   Cost of typical drainage work were obtained from PENCOL Consultants through the Civil Engineering Department, M.P.W.

c. Actual cost for Test Work

For reference purpose, contract rates paid to a contractor in Doha for the test trench construction were considered.

d. Statistical data published in Japan

For special items, such as water shut off sheet, PVC pipe, retailing prices in Japan were also considered.

(ii) Combined rates

Basic unit rates were combined into various combined rates in order to simplify the calculation. Principle rates supplied and their contents are as follows;

Table 7.2.2 Unit Rates for Cost Estimation (Wadi Musherib)

Item		Rate (QR)	Contents
Earth work		260	- Excavation, disposal of surplus soil, back-filling, supporting structures, dewatering, etc.
Pipe	ø450	200	- ESVC perforated pipe and installation
	ø300	150	
Concrete		300	- Sulphate resistant cement - Strength grade 25
Manhole		14,239	- Precast concrete manhole (ø900) - Earth work, installation
Gravel filling		45	- Dia. 13-20 mm, 25-40 mm, 50-75 mm with compaction

(iii) Construction cost

From unit rates and quantities of the works, construction cost for both alternatives were derived as follows;
(In these construction costs, land requisition cost and engineering fee are not included.)

Table 7.2.3 Construction Cost for Alternatives at Wadi Musherib

Unit: Qatar Riyal ($x10^3$)

Item \ Alternative		Perimeter Arrangement	Comb Arrangement	Remarks
Pipe laying	Earth work	22,210	22,480	Excavation, disposal of surplus soil, backfilling, supporting structures and dewatering
	Pipe Installation	4,700	4,910	Pipe material, concrete cradle, gravel and concrete bed
Manhole		2,020	1,870	Material, installation and earth work
Road reinstatement		1,820	2,150	
Pump station		0	1,000	Equipment, building and pump pit
Tanker filling station		1,050	1,050	
Total		31,800	33,460	

(2) Comparison of Alternatives

In case of the two alternatives for drainage systems, comparative features for each are derived from the difference of lateral drains arrangement and are summarized as follows;

Table 7.2.4 Comparison Table for Alternatives at Wadi Musherib

Perimeter arrangement	Comb arrangement
Suitable shape to flow from both north and south groundwater mounds.	Drains from center of the project area.
Connection to the stormwater drainage is possible by gravity flow.	Pump up is required for the connection to the stormwater drainage.
	Electric power cost is necessary as running cost.
Interventions with stormwater drainage are few.	Interventions with stormwater drainage are frequent.
Total length of drains is relatively short. (12.9 km)	Total length of drains is relatively long. (13.0 km)
Construction cost is relatively a little lower.	Construction cost is a little higher.

Considering the above features, cost including running cost are almost the same, and natural shape for groundwater drainage that is to place drains parallel to groundwater contour lines is preferable, therefore perimeter arrangement is recommended.

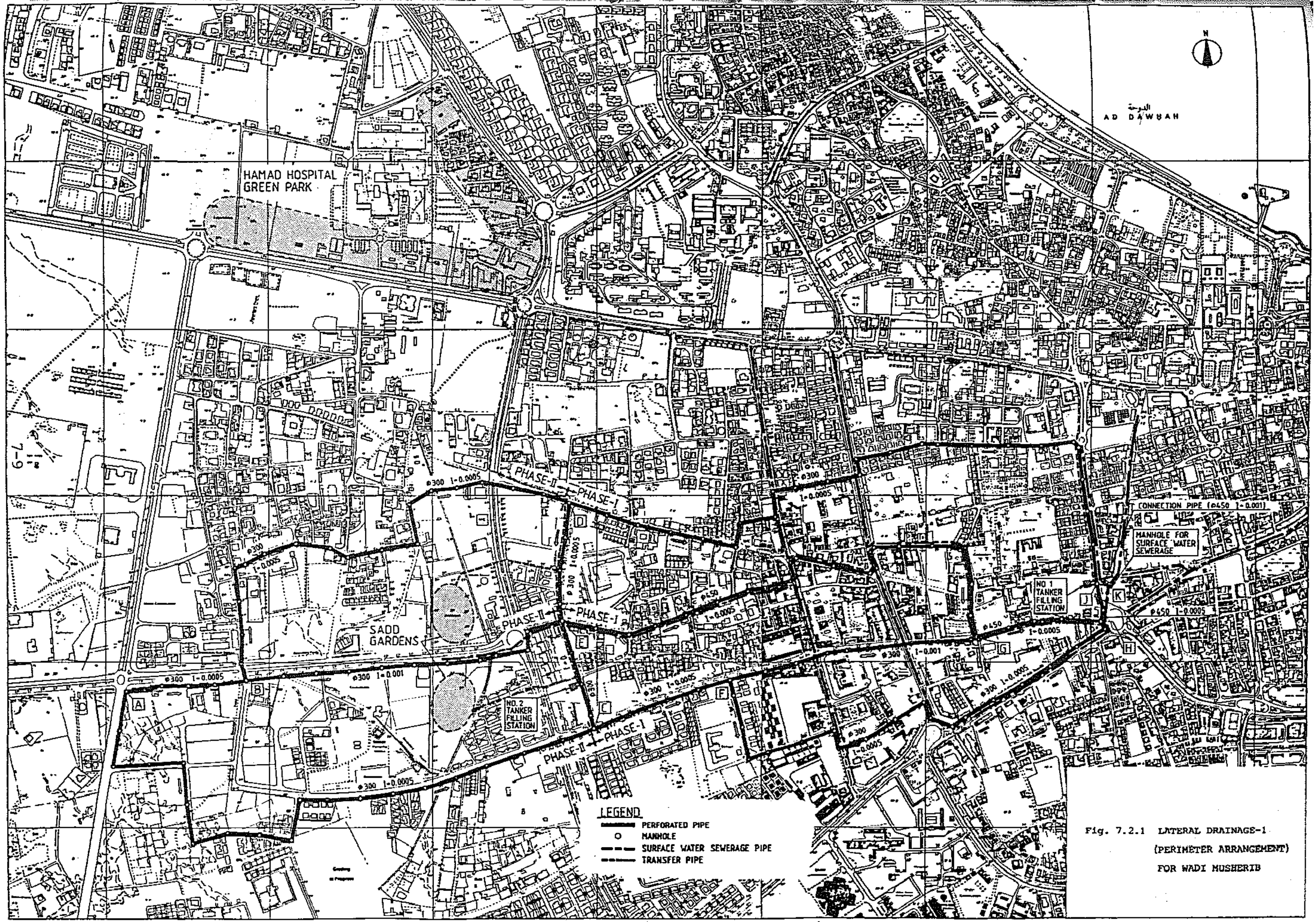


Fig. 7.2.1 LATERAL DRAINAGE-1
(PERIMETER ARRANGEMENT)
FOR WADI MUSHERIB

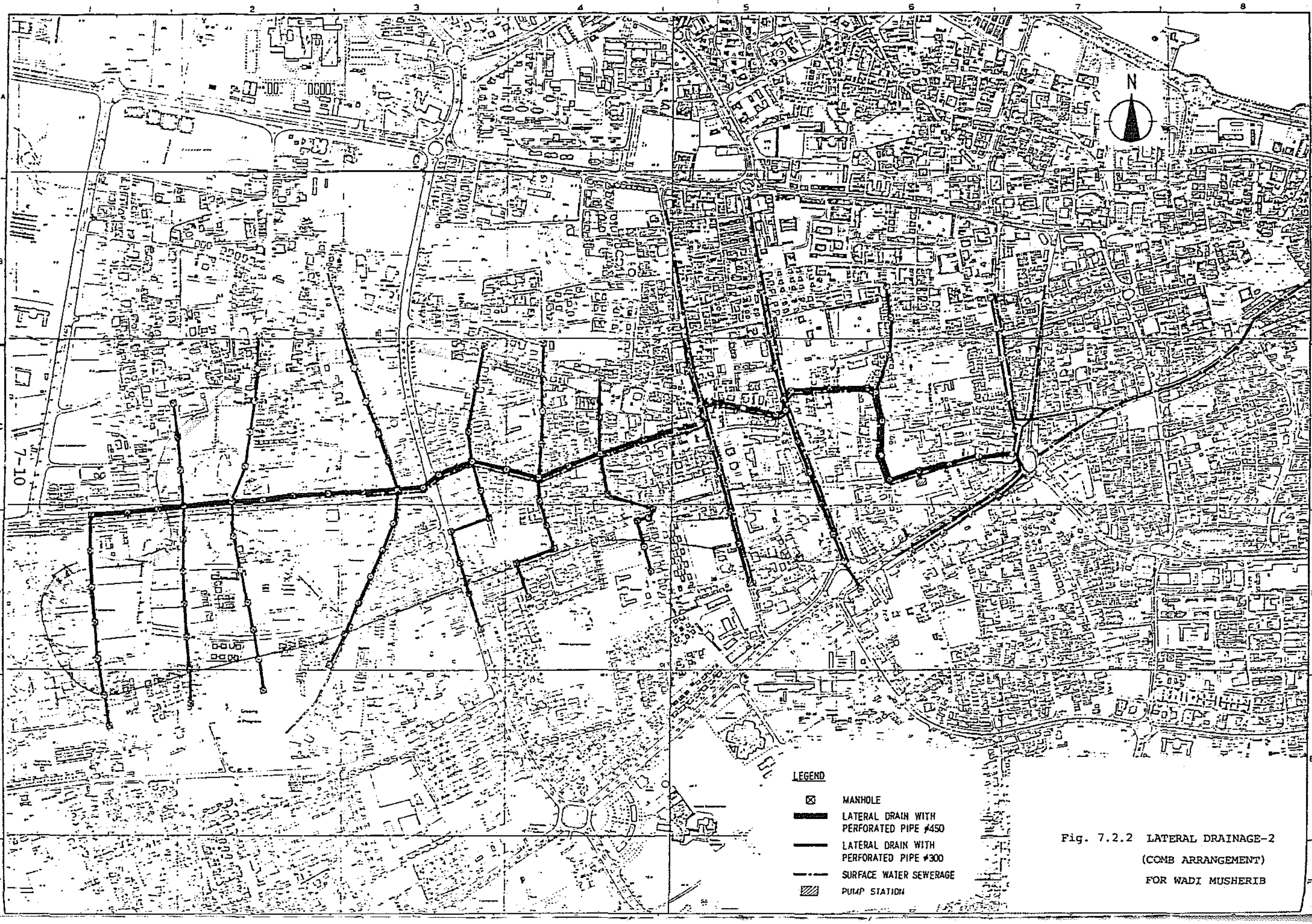


Fig. 7.2.2 LATERAL DRAINAGE-2 (COMB ARRANGEMENT) FOR WADI MUSHERIB

7.3 Preliminary Design

According to the comparison of alternatives in 7.2.4, preliminary design for the perimeter arrangement alternative is performed hereinafter.

7.3.1 Lateral Drainage Facilities

1) Outline of Drainage Facilities

Quantities of the lateral drainage facilities are as follows;

- Perforated pipe	:	ø300 - 10,695 m
		ø450 - 2,180 m
		Total 12,875 m
- Connection pipe to stormwater trunk line	:	ø450 - 30 m
- Manhole	:	142 nos.
- Tanker filling station	:	2 nos.

General plan of the lateral drainage system is shown on DWG. No. DRP-2001. The transversal and longitudinal sections are on DWG. Nos. DRP-2002 thru 2008.

2) Outline of Drainage Plan

The Lateral drainage facilities are designed to be located to cover and surround the project area. At Cable & Wireless Roundabout, the end of the network, they shall be connected to the stormwater trunk line of which the construction is under way.

Lateral drainage pipe is also provided in the central part of the network so that the distance between the drainage pipes located in parallel is at most 500 m. This enables the drainage by the lateral drain and the resultant drop of groundwater level to be more effective.

Since the lateral drainage pipe located in the central part of the network will collect less groundwater than the perimeter pipe once the groundwater is lowered, it shall be used for the purpose of transferring the abstracted water.

The construction of the lateral drainage network may be divided into two phases, Phase-I for the lower part of network and Phase-II for the upper part. This is because the construction of the central drainage pipe may proceed in parallel with that of the stormwater trunk line and thereby reduce the construction cost. For the order of construction, the drawing No. DRP-2001 shall be referred to.

The direction of flow is so determined that the collected groundwater can be obtained from the middle and end of the network in order to reuse the groundwater.

The network is also designed for the collected water to flow downstream.

a. Determination of Route

The lateral drainage pipe shall be placed

- to surround and cover the area where the groundwater level is 1.5 m below the ground level,

- in principle along the secondary roads so that the land acquisition may not be required and the hindrance to traffic by the construction can be minimized,

- where the stormwater trunk line exists, close to the line in consideration of the parallel construction,

- where the elevation of the road is higher than that of the vicinity, at the bottom of the embankment in order to reduce the cost of earth work, and

- to avoid houses and structures in cases when it cannot be placed along the road.

b. Depth of Lateral Drainage Pipe

The groundwater level in the drainage area ranges from QND + 5.5 m (the upper reaches) to QND + 4.0 m (the lower reaches) with a gradient of about 1/2,000.

The invert level of the lateral drainage pipe at the end of the network is set above that of the pipe in the manhole for the stormwater trunk line and thereby the collected groundwater can be discharged into the trunk line.

Thus the invert level of the whole pipeline is set up so that the invert depth of pipe can be kept 4.0 m from the groundwater level with the constant gradient of 1/2000, the same gradient as that of the groundwater.

As a result, the invert level is set ranging from QND + 2.0 m to QND + 0.024 with an earth cover of 4 to 6 meters.

c. Design of Pipe

Since most of the abstracted groundwater, discharge of which is taken as 1,500,000 m^3/year or 0.0476 m^3/sec, is considered to come from outside the project area, pipes on the perimeter of the drainage system are designed to drain the whole abstracted groundwater amount and the discharge of groundwater in the pipe is calculated per linear meter.

The diameter of pipes is calculated for the discharge at the point concerned of the network.

For the calculation of the diameter, the following formula shall be applied, assuming for calculation purposes that the quality of groundwater is considered nearly the same as that of the water supply.

$$Q = AV$$

$$V = \frac{23 + \frac{1}{n} + \frac{0.00155}{I}}{1 + (23 + \frac{0.00155}{I}) \cdot \frac{n}{\sqrt{R}}} \times \sqrt{RI}$$

where, Q = discharge (m^3/sec)
A = cross sectional area of flow (m^2)
I = hydraulic gradient
R = hydraulic mean depth (m)
n = roughness coefficient (0.013)

In this drainage system, perforated pipes shall be used as the lateral drainage pipe. They have two functions of collecting the groundwater and transferring it.

For that purpose, pipes with holes on the upper half shall be used and the cross sectional area of flow shall be taken as half depth of the pipe.

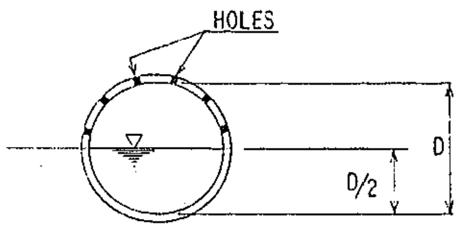


Fig. 7.3.1 Section of Perforated Pipe

Carrying capacities for different diameters of pipe are listed below;

Table 7.3.1 Carring Capacity of Pipe

Diameter (mm)	Hydraulic gradient	Velocity (m/sec)	Discharge (m^3/sec)
ø300	0.0005	0.490	0.0168
ø450	0.0005	0.637	0.0508

d. *Typical Section of Lateral Drainage*

A typical section of the lateral drainage shall be as shown below.

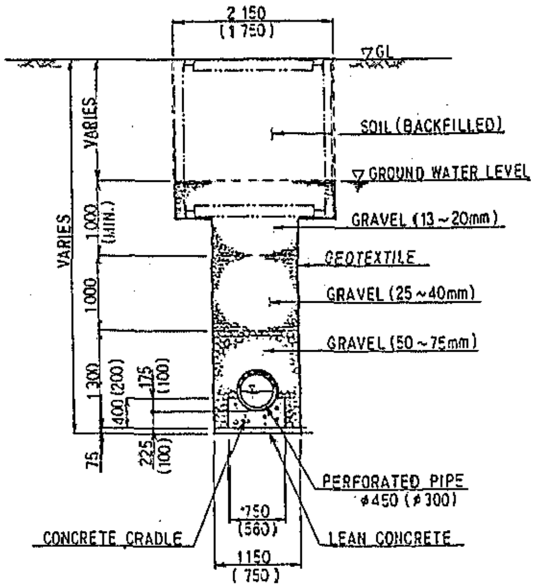


Fig. 7.3.2 Typical Section of Lateral Drainage

At depth of 1.5 to 2.0 meters below the ground, supporting structures shall be provided to prevent collapse of highly weathered soil layer.

At the greater depth, excavation can be done vertically because of the hard limestone layer where no collapse is considered is found there and thereby the earth pressure can be reduced.

After pipe laying and prior to backfilling, geotextile sheets shall be applied to the excavated surface above the groundwater level. The purposes of the geotextile are

- to prevent soil particles from coming into the lateral drain channel when the groundwater is abstracted from the surrounding soil and thereby protect the soil from the deformation such as settlement, and

- to prevent soil particles from coming into the lateral drain channel and thereby keep the holes of perforated pipe from clogging.

Around the perforated pipe, three kinds of gravel having different sizes of 50 to 75 mm, 25 to 40 mm and 13 to 20 mm respectively are filled upward in the order of the size. The third gravel layer (grain size of 13 to 20 mm) shall be at least 1.0 meter in thickness and shall be laid above the groundwater level. On top of the third gravel layer, ordinary (or excavated) soil shall be backfilled.

e. Materials for Pipe

As materials for the pipe, vitrified clay and centrifugal reinforced concrete pipe are considered.

Taking into account the fact that the vitrified clay pipe is usually used in Qatar and is strong against salt attack, extra strength vitrified clay (ESVC) pipe shall be employed.

However, the concrete pipe, which has the advantage over the vitrified clay pipe in view of the availability should it be produced in Qatar in the future, can be considered for the material.

f. Manhole

Manholes shall be provided where the piping direction is changed and several pipes meet and branch. In the straight line, they are located about 100 meter apart.

The distance between manholes is determined taking into account the following;

- The range possible to preform maintenance work of the lateral drain pipes will be 50 to 60 meters from the manhole.

- In case that countermeasures for the land drainage are needed locally (when it is needed to lower groundwater for special purposes or when it is required to be drained in construction sites), it is necessary that the distance has an allowance to facilitate the connection with the proposed network. A distance of around 100 meters is enough for this purpose.

7.3.2 Tanker Filling Station

(1) Outline of the plan

It is expected that the water quality of groundwater from the proposed lateral drainage system at Wadi Musherib can be re-used for irrigation purpose. However for the actual re-use plan, it is necessary to obtain reliable figures of water quality and quantity based on long term observation during the drainage operation. Therefore step by step re-use is considered. For the first stage, total discharge to the stormwater drainage trunk line is considered and groundwater can be partially taken from the lateral drainage line and loaded to road tankers for re-use based on observation results. During this simple re-use system, possibility of total re-use can be studied where direct transfer system by pumps to the consuming places are considered.

Two tanker filling stations are considered, one each in the first and second phases of drainage construction, thereby making it possible to deal with the local water quality variation in the drainage network.

Green belts at center islands of major roads are considered among the suitable places where the abstracted groundwater can be utilized for irrigation. However at present irrigation system for these green belts consists of piping and sprinkler nozzle and thus discharge from road tankers may not be suitable. In conclusion transportation to Hamad General Hospital and Sadd garden, where large scale plantation projects are in progress, is considered.

Locations of tanker filling stations and outline of facilities are shown on the drawings DRP-2001, 2010 and 2011.

(2) Conditions of facility plan

a. Groundwater intake

Quantity of groundwater intake is 300 m^3/day per one station.

b. Road tankers

Road tankers to be used for transportation are 2,000 Imp. gallon tankers as standard vehicles, while in the design of movement plan within the station 3,000 Imp. gallon tankers are considered.

c. Consuming place

Hamad General Hospital on the corner of 'C' Ring Road and Rayyan Road where the distance and returning time for transportation from the No. 1 tanker filling station are 3,000 m and 20 minutes respectively.

(3) Outline of the facility

a. Required land area

Area of 30 m x 30 m is necessary for one taker filling station and arrangement of facilities is shown on the Drawing DRP-2010.

b. Loading system

Groundwater loading system from intake to outlet nozzles consists of the following;

- Intake and pump pit

  Intake pipe and pit are lower than the required level of the lateral drainage network so that the groundwater is taken when necessary and discharged downstream as usual when pumping is stopped.

- Submerged pump

  Pumps transferring groundwater from pit to the elevated tank have the characteristics below.

  Type : Submerged sewerage pump
  Total head: 20 m
  Capacity : 0.71 m^3/min.
  Motor : 7.5 KW

- Pump house

  For automatic operation without the need for full time operator. All the equipment are accommodated in a pump house having an area of 5 m x 6 m.

- Elevated tank

  An elevated tank, 20 m^3 is to be provided in order to buffer the irregular operation of the road tankers.

- Piping and valve

  From the elevated tank, piping with hand operated valve and nozzle discharge into the road tankers.

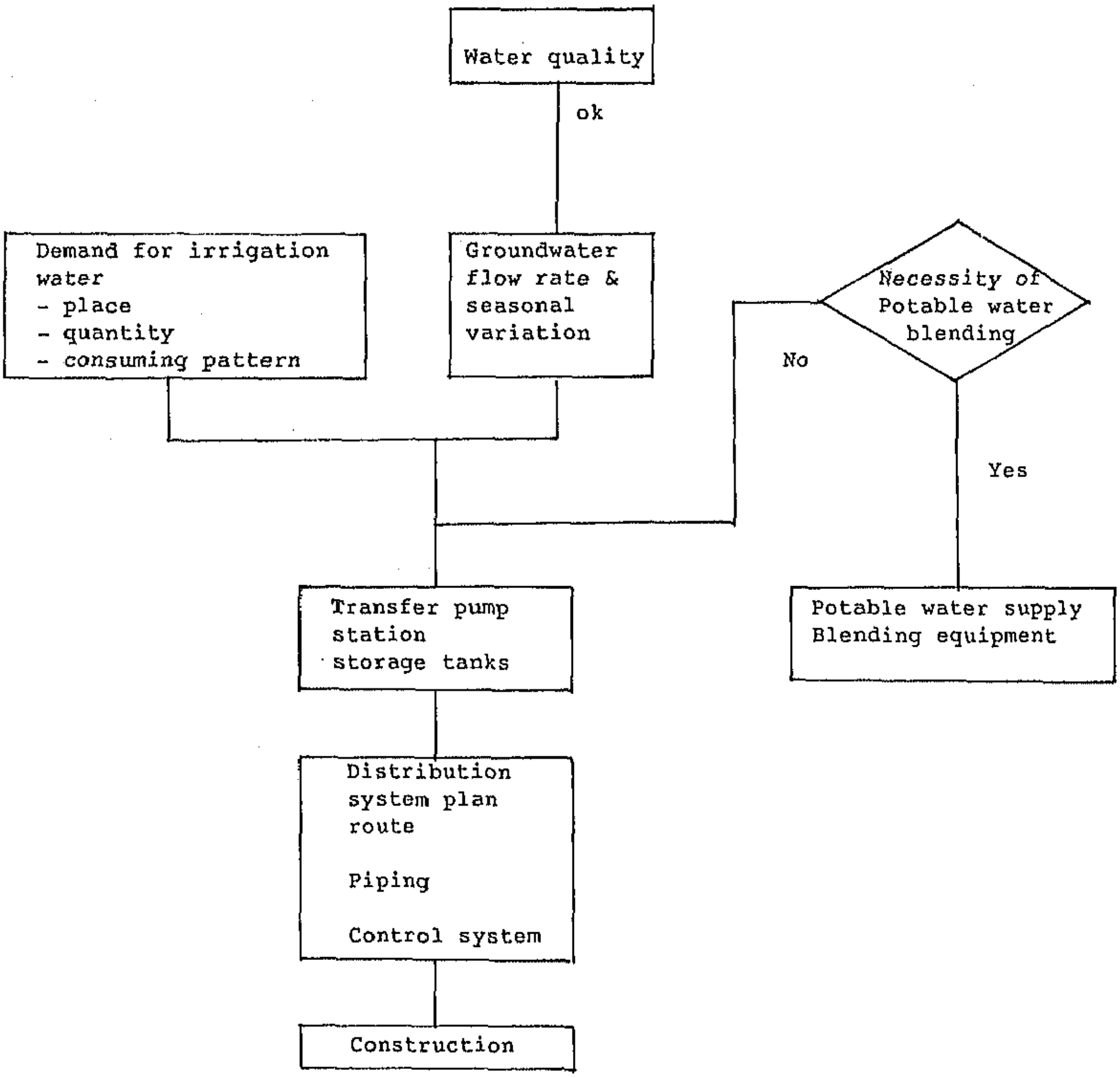
c. Required road tankers

Five number, 2,000 Imp. gallon road tankers are required for 300 m^3/day transportation in 8 working hours.

7.3.3 Direct Transfer Line

Should groundwater intake at tanker filling station and road tanker transportation succeed, and water quality and quantity which shall be monitored for at least two years show good results, direct transfer line without road tankers may then be examined.

Procedures and items for planning are as the flow sheet shown herein below.



Meantime, as an example, routes from tanker filling stations to Hamad General Hospital and Sadd Gardens are shown on the Drawing DRP-2001.

Total length of pipe line	:	3,000 m from No. 1 station to Hamad General Hospital 350 m from No. 2 station to Sadd Gardens
Pipe diameter	:	150 mm
Demand at green park in Hamad General Hospital (estimated by Doha Municipality Planning Section 80 m^3/day)	:	35,000 Imp. gallon/day

7.3.4 Specifications of Construction Work and Material

The standard specifications for civil works, electrical and mechanical works published by Ministry of Public Works are deemed to be adopted in this project. Special notes to be specified in addition to these, are as follows.

(1) Investigation before excavation

Excavation in this project is deep and near to existing structures in the developed city area. Investigation before excavation is essential for the following items

- subsurface conditions
- neighboring building and structures
- necessity of shoring
- groundwater level
- groundwater quality

(2) Dewatering

All the excavation shall be executed in dry conditions with necessary dewatering. Throughout the excavation work, attention shall be paid to excavation wall, that is, soil or rock condition, groundwater level and seepage aspect. Especially when encountering the situation where big flow seems to be connected with a particular source, the reason shall be clarified and adequate action shall be taken as required. "Washing out" or "piping" phenomena shall be carefully checked. Rate of dewatering at initial stage shall be moderate and determined considering the surrounding situation.

Disposal of the water shall be by the stormwater trunk line and sand settling basin shall be provided.

(3) Monitoring points

On both sides of the trench excavation, monitoring points for ground deformation by drawdown shall be selected by consultation with the engineers and measured and recorded before and after the work. These points shall be strong enough for long term observation during drainage operation.

(4) Concrete work

Concrete used in this project shall be dense concrete. Covering to reinforcing steel in concrete shall be more than 70 mm and external surface in the ground shall be coated with an anti salt-attack paint.

(5) Horizontal boring

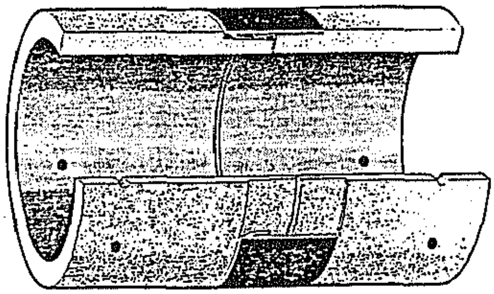
At crossing points with main road as shown on the drawings, pipes shall not be installed in open-cut excavation but horizontally bored from both sides of road. In these parts, steel pipes with internal coating shall be inserted with external grouting method.

(6) Perforated pipe

Pipe to be used in this drainage scheme shall be half perforated Extra Strength Vitrified Clay pipe conforming to BS 65.

Internal diameters used are;

300 mm
450 mm
600 mm



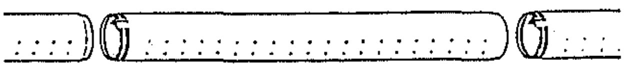


Fig. 7.3.3 Detail of Perforated Pipe

(7) Gravel

In backfilling work of lateral drainage trench, the following three kinds of gravel shall be used.

Nominal dia.	50 - 75 mm
Nominal dia.	25 - 40 mm
Nominal dia.	13 - 20 mm

(8) Geotextile

Geotextile material shall be synthetic fiber (polypropylene) and type for sand piping protection.

7.4 Justification of the Plan

7.4.1 Degree of Emergency

As mentioned in the damage survey, in this Wadi Musherib area the situation developed where groundwater level has almost reached ground surface and standing water has already emerged in a small number of areas. The following damage is reported.

- Seepage to the underground public utilities and increase of the operation and maintenance work and cost.
- By the progress of salt accumulation, bad effect to the vegitation, increase of the corrosion to underground facilities and structures and decrease of their life.
- Increase of dewatering work in underground construction and cost increase therefrom.

On the other hand, in the groundwater investigation following figures showing the steady rising groundwater were obtained.

Table 7.4.1 Areas classified by groundwater level in the Project Area

Standing water	0.2 ha
0 - 1 m	75 ha
1 - 2 m	138 ha

By the above matters, it is evident that a certain countermeasure is urgently required.

7.4.2 Technical Examination

Technical examination of the proposed drainage scheme concerning various points of view have been performed as mentioned in detail in the previous chapters. The examination involving stages of investigation, analysis and design and lasting more than one year can be summarized as follows.

1) Review of previous studies
2) Field investigations
   Damage and land use survey
   Topographic and hydrogeological investigation
   Groundwater and quality
3) Groundwater analysis
4) Studies on countermeasures
   Effectiveness of preventive measures for recharge
   Drainage methods including alternatives
   Possibilities of groundwater re-use
5) Correctness of the proposed drainage scheme
   Drainage effect by simulation analysis
   Realization of the plan by preliminary design

7.4.3 Effect of the Project

Effect by the execution of the proposed countermeasure can be expected in the following categories;

(1) Alleviation of direct damages

- Cessation of salt accumulation in whole project area.
- Recovery from submerging for underground public and private facilities within 1.5 m below ground which are huge quantity in the developed city area
- Increase of durability of underground structures and facilities by reduction of contact with corrosive saline water.

(2) Alleviation and effect of indirect damages

- Recovery of freedom to land use
- Recovery of fine sight on landscape
- Effective reuse of water resources
- Decrease of construction and maintenance cost

(3) Social effect

- Alleviation of social uneasiness brought about by the rising and spreading groundwater year by year.
- Recovery of amenity between people and groundwater by positive re-use of abstracted groundwater

The urgency of the rising groundwater problem is self evident by the damage occurring and the alarming rate of rise. This project, designed to countermeasure the problem cannot be judged solely on an economical basis, but rather its necessity derives from the need to safeguard the functioning and image of the capital city and the livelihood of its citizens. Nevertheless an attempt at economically assessing the project was considered. However such an attempt did not succeed because broken-down statistical data on operation and maintenance works were not available in the respective government authorities concerned, a situation naturally understood in this young and rapidly developing country where most efforts are directed towards construction.

Specifically items (2) and (3), i.e. abstract benefit by indirect effect and social effect can not be assessed practically but their importance is apparent, and it is deemed that necessity of implementation of this project was justified sufficiently.

7.5 Cost Estimation and Implementation Program

7.5.1 Construction Cost

Construction cost is calculated using the quantities of the works and equipments, and the fixed unit prices obtained in the following manner.

Quantities for the earth works, concrete works and equipments are calculated according to the preliminary design.

Unit prices of the works and the cost of procuring equipments are based upon the data from the research in Qatar and Japan.

1) Construction Cost

The construction cost is as shown on Table 7.5.1, which includes the following.

- Lateral drainage pipe
- Tanker filling station

2) Unit Prices and Quantities of the Works

Unit prices of the works are determined according to the result of research as shown on Table 7.5.2 and the construction cost is thereby calculated.

Of the quantities of the work, the representing items are listed on Table 7.5.3.

3) Items Included in Construction Cost

i) Lateral Drainage System

The construction cost for the lateral drainage system include the costs for earth work, material and installation of perforated pipe and manhole, and all the necessary items to complete the work.

ii) Tanker Filling Station (2 nos.)

The construction cost for tanker filling stations includes the cost for civil works, building works, mechanical works and electrical works for the following facilities.

- Elevated tank
- Pump house
- Pump pit
- Pumping unit, valves and pipes
- Pipe supports
- Fence and gate
- Connection pipe to stormwater trunk line (for No. 1 station only)

Table 7.5.1 Construction Cost

Item	Cost (x 10^3 QR)
1. Lateral Drainage	
(1) Pipe Work	28,600
(2) Manhole	2,100
Sub Total	30,700
2. Tanker Filling Station	
(1) Civil & Building	400
(2) Equipments	700
Sub Total	1,100
Grand Total	31,800

Table 7.5.2 Quantities of Works

Item	Unit	Quantity	Remarks
1. Lateral Drain System			
(1) Excavation	m^3	100,800	
(2) Pipe - ø300	m	10,590	ESVC Perforated pipe
- ø450	m	2,154	
- ø450	m	30	Concrete closed pipe
(3) Concrete	m^3	2,820	
(4) Manhole	No.	142	
2. Tanker Filling Station	No.	2	560 m^2 each.

Table 7.5.3 Unit Rates for Cost Estimation

Item	Description	Specification		Unit	Rate (QR)	Remarks
Lateral drain facili-ties	Perforated pipe	ESVC pipe	Ø300	m	150	
			Ø450	"	200	Material and Installation
	Closed pipe	Concrete pipe	Ø450	"	200	
	Excavation	Including dewatering and supporting structures		m^3	200	
	Disposal of surplus soil			"	30	
	Backfilling	Excavated soil		"	30	
	Structural concrete	Sulphate resistant cement, GRADE 25		"	300	
	Lean concrete	Sulphate resistant cement, GRADE 15		"	260	
	Shuttering			m^2	20	
	Gravel	Dia 13-20 mm, 25-40 mm 50-75 mm with compaction		m^3	45	
	Resurfacing of road	Asphalt pavement		m^2	75	
	Manhole	Precast concrete manhole, ø900 (inner diameter)	H=4-5 m	no.	6,000	Material and installation
			5-6 m	"	7,000	Excluding earth work
			>6 m	"	8,500	
Tanker filling station	Embankment			m^2	10	
	Internal road	Asphalt pavement		"	75	
	Gate	Width : 6.0 m Height: 2.0 m		no.	5,250	
	Intake pipe	Concrete pipe ø500		m	500	
	Pump house	Reinforced concrete frame with block wall		m^2	3,500	

7.5.2 Implementation Program

(1) Implementation program

This project consists of the following two major facilities;

- Lateral drainage facility
- Tanker filling stations

The overall term for implementation is three (3) years considering site investigation, detailed design, tendering, equipment procurement, civil works and mechanical and electrical erection works as shown on Table 7.5.5.

The major points to be noted in this program are the following. This project is divided into two construction phases considering volume of the construction work and the relation with Wadi Musherib stormwater drainage trunk line project being executed by Ministry of Public Works. The downstream portion is implemented in the first phase to connect the discharge to the stormwater trunk line, the upstream portion is the second phase.

It is essential that before the commencement of the first phase construction the part down from the connection point at Cable and Wireless Roundabout shall be completed including the pumping system. In both first and second phases, there are parts where lateral drainage pipe are laid along the stormwater trunk line and therefore these works shall be executed at the same time.

Tanker filling stations are located one each in the first and second phase areas. After their completion water quality will be monitored for one or two years and according to the result of monitoring, plan on transfer to direct distributing system without road tanker transportation shall be started in sequential program.

(2) Total cost of the Project

Total cost of the Project is summarized in the table below.

Lateral drainage	33.8 MNQRS
Tanker filling station	3.5 MNQRS
Total	37.3 MNQRS

Above figures consist of;

- Topographic survey and investigation of underground facilities
- Detail design, Tender and Construction Management
- Land acquisition for tanker filling stations
- Equipment procurement and electrical and mechanical erection works

On the other hand following costs are not considered;

- Governmental administrative cost
- Compensation by residents (if any) for inconvenience during construction

Cost breakdown by each fiscal year are tabled in Table 7.5.4 below.

Table 7.5.4 Expenditure for Each Fiscal Year

(Unit: $x10^3$QR)

Item \ Year	1st	2nd	3rd	Total
1. Engineering Services	1,600	1,600	-	3,200
2. Land Acquisition	-	1,150	1,150	2,300
3. Civil & Building Works	-	15,550	15,550	31,100
4. Equipments	-	350	350	700
Total	1,600	18,650	17,050	37,300

Note:

1) Cost of engineering services were devived from 10 percent of construction cost (item 3 + item 4).

2) Land acquisition for tanker filling stations only was considered and unit rate per square meter is 1,000 QRS.

Table 7.5.5 Implementation Program for Wadi Musherib

No.	Description	1st year (1 … 6 … 12)	2nd year (1 … 6 … 12)	3rd year (1 … 6 … 12)	4th year (1 … 6 … 12)	5th year (1 … 6 … 12)
1.	Lateral Drainage					
	(1) Topographic Survey & Underground Facility Survey	Phase-1	Phase-2			
	(2) Detail Design & Tender Documents					
	(3) Tender		Contract	Contract		
	(4) Civil Works					
		Construction of Storm Water Drainage Downstream of Lateral Drainage System	Joint Work of Lateral Drainage and Storm Water Drainage	"		
2.	Tanker Filling Station					
	(1) Detail Design & Tender Documents	No.1	No.2			
	(2) Tender		Contract	Contract		
	(3) Land Acquisition					
	(4) Civil & Building Works					
	(5) Equipments					
	(6) Monitoring of Water Quality & Quantity			←	→	
						Planning of Direct Transfer System →

8. DRAINAGE PLAN AT OLD RAYYAN

8. DRAINAGE PLAN AT OLD RAYYAN

8.1 Basic Conditions for Drainage Plan

(1) Project Area for Drainage Schemes

Old Rayyan area is a topographical depression located west of Doha City and its east, south and north are respectively surrounded by 'D' Ring Road, Rayyan Road and Khalifa Road. Many farms and large scale residences are scattered in this area.

The project area for drainage schemes at Old Rayyan, as described in Chapter 6, is the lowest part where the groundwater level is less than 1.3 m below ground surface.

The project area spreads on both sides of Old Rayyan road with lengths of 700 m and 1,600 m in the east-west and north-south directions respectively, and with an area of 70 ha, as shown in the figure below. The ground elevation varies from QND + 5.3 m to + 8.0 m, in this area.

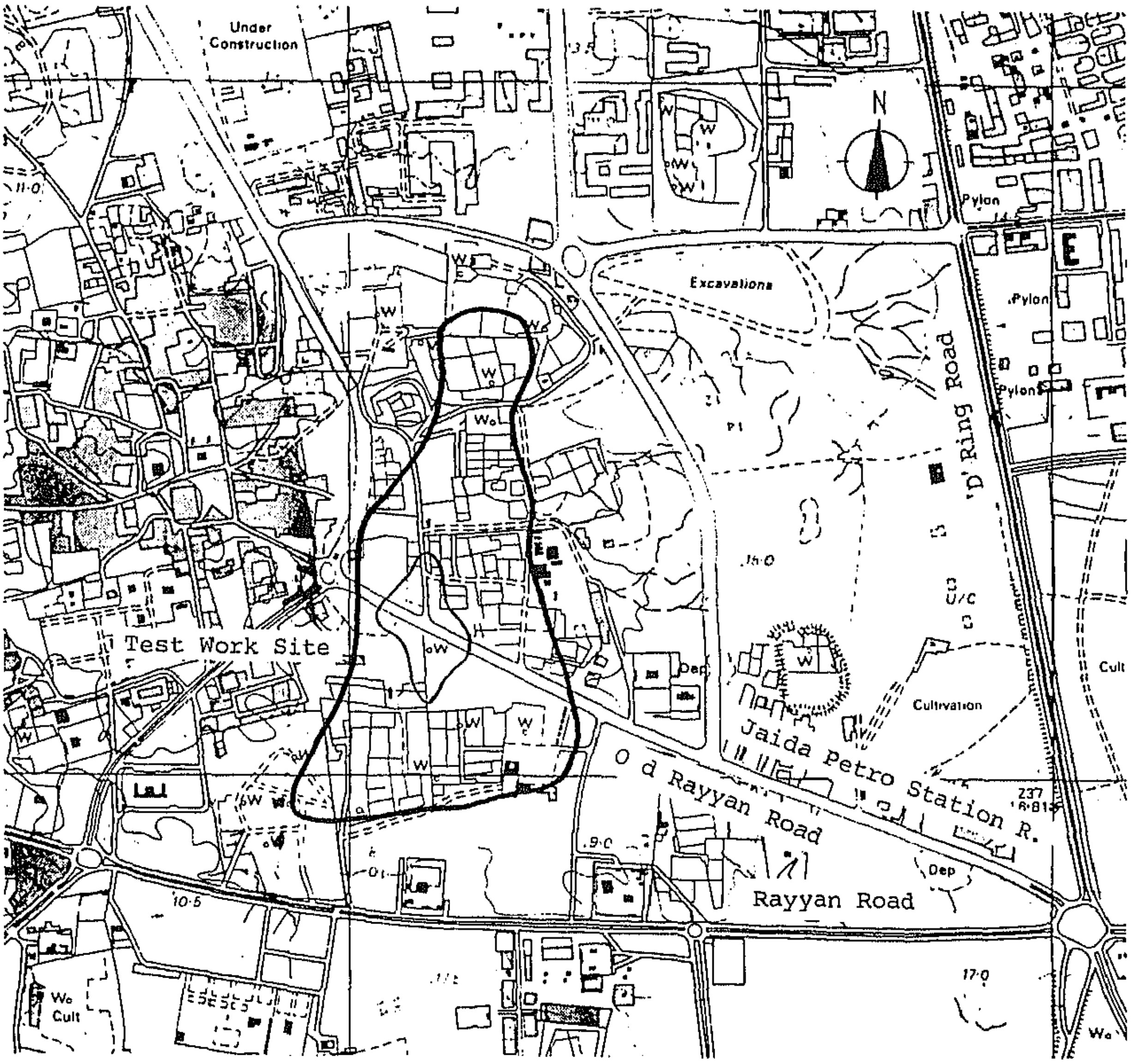


Fig. 8.1.1 Project Area for Drainage Schemes at Old Rayyan

(2) Proposed Design Groundwater Level

Groundwater level for the entire project area is to be kept below 1.3 m from ground level considering the depth of capillary zone and underground facilities.

(3) Discharge Amount

With the provision of lateral drainage network along the perimeter of the project area and maintaining groundwater level at 4.0 m below ground level at the lateral drains, amount of groundwater to be discharged is 3,000,000 m^3/year in accordance with the groundwater analysis presented in chapter 6.

(4) Depth of the Lateral Drainage

Depth of the lateral drainage at Old Rayyan shall basically be (4 m) from ground surface considering the hydrogeological conditions and construction method.

(5) Project Site

As a rule, lateral drainage shall be planned along public roads. However if network arrangement makes this difficult in some places, built-up area shall be avoided as much as possible and cultivation area shall be used instead.

(6) Water Quality

Estimates of water quality for the groundwater to be discharged by this drainage plan are as follows;

EC value	15,000 micro mhos/cm
COD value	Max. 10 mg/l
pH	8.0

8.2 Alternatives of Drainage Systems

Drainage systems are divided into three subsystems by their functions, i.e. collection, transfer and disposal or re-use and alternatives are considered for respective subsystems as summarized in Table 8.2.1 below.

Table 8.2.1 Alternatives of Drainage System at Old Rayyan

Collection	Pumping system	Transfer	Disposal or Reuse
Lateral drainage-1 (Solving standing water)	Pump station-3 (No. 14 P/S)	Pressure pipe	Existing No. 14 Pump station
Lateral drainage-2 (Perimeter arrangement)	Pump station-1 (14 km pipe)	Gravity flow pipe	Musherib Storm-water trunk line
Lateral drainage-3 (Comb arrangement)	Pump station-2 (2.5 km pipe)	Open channel	West bay (via mangrove lagoon)
Existing wells		Road tankers	Desert

8.2.1 Collection of Groundwater

In this area, collection methods considered are lateral drainage and utilization of existing wells. Regarding arrangement there are three alternatives for lateral drainage.

(1) Lateral drainage - 1
(Refer Fig. 8.2.1)

Solving only standing water area is the purpose of this plan and it can be deemed as phase-I of any of the other two alternative. The lateral drainage is located in cross shape at the center of the area. Because of the short length of the drains, amount of abstracted groundwater is limited and long transfer line for discharge is not economical. Therefore this plan is considered to discharge abstracted groundwater to sewerage line when Doha West new sewage treatment work will be completed and the total treatment capacity will be increased or transportation by road tankers until the groundwater drainage phase-II will be implemented.

<u>Outline</u>

Depth of lateral drainage	:	4 m
Diameter of perforated pipe	:	450 mm
Proposed length of lateral drainage	:	1,000 m
Manholes pitch	:	100 m
Estimated discharge	:	500,000 m^3/year (1.0 m^3/min)

(2) Lateral drainage - 2
(Refer Fig. 8.2.2)

Aiming at the area where groundwater level depth is less than 1.5 m from ground, lateral drainage is allocated along the perimeter of this area.

This area is the lowest part of the depression and groundwater flows in, therefore drainage facilities are most effective in collecting groundwater. Connecting line to the pumping station is also used as drainage pipes.

Outline

Depth of lateral drainage	: 4 m
Diameter of perforated pipe	: 300 mm, 450 mm, 600 mm
Proposed length of lateral drainage	: 5,900 m
Manhole pitch	: 100 m
Estimated discharge	: 3,000,000 m^3/year (5.7 m^3/min)

(3) Lateral drainage - 3
(Refer Fig. 8.2.3)

Objective area for drainage is the same as that for the above perimeter arrangement plan, but lateral drainage is allocated totally in the area in comb shape.

Outline

Depth of lateral drainage	: 4 m
Diameter of perforated pipe	: 300 mm, 450mm, 600 mm
Proposed length of lateral drainage	: 6,000 m
Manhole pitch	: 100 m
Estimated discharge	: 3,000,000 m^3/year (5.7 m^3/min)

(4) Utilization of existing wells
(Refer Fig. 8.2.4)

Existing wells in the abandoned farms inside the project area are utilized for collecting groundwater to lower the level. Groundwater is abstracted by individual pumps and collected to the discharge pumpstation.

Number of wells	: 40
Additional lateral drainage line	: 2,000 m
Estimated amount	: 5.7 m^3/min (3,000,000 m^3/year)

8.2.2 Pumping System

The project area in Old Rayan is geographically located at the bottom of the basin structure. When disposing abstracted groundwater from the area, transfer by gravity flow is not possible in either of the sea side or inland directions and pressurised transfer by pumping is inevitable to any disposal point.

(1) Pump station - 1

For lateral drainage-1, pumping system to discharge groundwater into the adjacent No. 14 sewerage pump station is as follows;

Discharge amount	:	1.0 m^3/min
Head	:	10 m
Total head	:	20 m
Delivery pipe	:	80 mm dia.
Pump type	:	Submerged centrifugal pump, discharge bore 80 mm, 2 units
Motor	:	7.5 kw x 2 units
Stand by	:	One unit of 100%

(2) Pump station - 2
(Refer DRP-4002 and 4003)

From Rayyan to West Bay, abstracted groundwater is transferred a distance of approximately 14.4 km by pumping. After the point of intermediate water chamber (6.7 km), water is discharged by gravity flow.

Discharge amount	:	5.7 m^3/min
Actual head	:	21 m
Total head	:	122 m
Delivery pipe	:	250 mm dia.
Pump type	:	Horizontal double suction volute pump 2.85 m^3/min x 3 units Suction bore : 124 mm Discharge bore: 80 mm
Motor	:	110 kw x 3 units
Water hammer protection	:	Fly wheel 40 kg.m^2
Stand-by unit	:	One unit of 50%

(3) Pump station - 3

From Rayyan to 'D' Ring Road, groundwater is transferred a distance of approximately 2.3 km by pumping, where a watershed between Doha city and Rayyan exists and after which it can be transferred by gravity flow.

Discharge amount	:	5.7 m^3/min
Actual head	:	16 m
Total head	:	70 m
Delivery pipe	:	250 mm dia.
Pump type	:	Horizontal double suction volute 2.85 m^3/min x 3 units Suction bore : 125 mm Discharge bore: 80 mm
Motor	:	50 kw x 3
Water hammer protection	:	Fly wheel 40 kg.m^2
Stand-by unit	:	One unit of 50%

8.2.3 Transfer Line

According to the selection of disposal point, the following three alternative methods of groundwater transfer are considered. In case of desert disposal, transfer line is the same as pressure pipe-1 system.

(1) Pressure pipe - 1
(Refer Drawing DRP-4001)

When the disposal point is West Bay, some big undulations exist along the route. Therefore until the escarpment near shore line, pressurized transfer is necessary. Upon the pump operation, one intermediate water chamber is required at the highest point.

As for the pipe material, considering corrosion by transfer of high salinity groundwater and external aggressive soil, corrosion protection or anticorrosion material under high pressure are examined.

Outline

Length	:	14.7 km
Pipe diameter	:	250 mm (until 6.7 km) and 350 mm (7.7 km)
Pressure	:	15 kg/cm^2 (until 6.7 km) and 5 kg/m^2
Intermediate water chamber	:	One at 7.6 km point
Depth of pipe	:	Ground level minus 1.2 m
Pipe material	:	Ductile iron pipe with external protection by 1.1 mm thick PVC tape wrapping in two layers and internal lining by 5 mm thick cement mortar

(2) Pressure pipe - 2
(Refer Fig. 8.2.4)

When Wadi Musherib stormwater trunk line is selected as a disposal point, transfer point is a watershed at 'D' Ring Road.

Required pressure is relatively low because of the short distance and polyvinyl chloride pipes are adopted for the whole length.

Outline

Length	:	2.3 km
Pipe diameter	:	250 mm
Pressure	:	6 kg/m^2
Depth of pipe	:	Ground level minus 1.0 m
Pipe material	:	Poly vinyl chloride pipe

(3) Gravity flow piping
(Refer Fig. 8.2.4)

For the case of disposal at Wadi Musherib stormwater trunk line, underground gravity flow pipeline from Jaida Petrostation on 'D' Ring Road to Wadi Musherib Dam will be applied.

Outline

Length	:	3.4 km
Pipe diameter	:	400 mm
Depth of pipe	:	General Ground level minus 1.0 m Under road Ground level minus 1.5 m
Gradient	:	2.0%
Pipe material	:	Extra strength vitrified clay pipe
Manhole pitch	:	200 m

(4) Open channel and recreation pond
(Refer Fig. 8.2.5)

Open channel from Jaida petrostation to recreation pond at Wadi Musherib Dam is considered, including a small pond on the way.

Purpose of this method is to moderate the water quality by contact air oxidization, and develop the landscape with open channel and green belt.

Outline

Length	:	3.3 km (part of open channel)
Width of channel	:	1.5 m
Depth of flow	:	10 - 20 m
Area of small pond	:	10,000 m^2
Area of recreational ponds at Wadi Musherib Dam	:	34,000 m^2

(5) Road tanker transportation

This is temporary vehicle transportation considered for lateral drainage-1 (elimination of standing water)

Amount to be transported	:	1.0 m^3/min
No. of road tankers	:	8 units/day (5,000 Imp. gallons tanker)
Distance	:	10 km
Operation hours	:	12 hours/day

8.2.4 Disposal Points

Unless the quantity is very limited, there is a problem that high salinity groundwater abstracted from Rayyan may diminish biological treatment capacity at sewage treatment works if disposed there.

Therefore disposal points are either sea or desert.

(1) West Bay

Water shall be discharged into sea directly by way of outfall or through a mangrove lagoon for water quality improvement.

(2) Musherib Stormwater Trunk Line

Transfer line shall be connected to the upstream end of the Wadi Musherib Stormwater Trunk Line in progress at Wadi Musherib, discharging the water into Doha Bay.

(3) Desert

Disposal at desert area was examined but considering the recirculation of discharged water, distance to the possible area is far greater than those for the other two alternatives. Should closer locations be used, shutoff of infiltration by sheet covering is required for a huge area and not economical.

8.2.5 Comparison of the Alternatives

(1) Cost Estimation

Regarding all the alternative in Section 8.2, rough cost estimation was made for comparison purpose according to the cost data obtained in Doha and information in Japan. Cost estimations are shown in Table 8.2.3. Prior to cost estimation, quantities of the works for each alternative were also calculated.

Especially cost for mangrove lagoon project is just indicative cost for civil construction and plantation.

i) Unit rates

Sources of unit rates are referred to in Article 7.2.4 (i). In addition for pump station equipment and special pipe for transfer line, prices currently prevailing in Japan were used.

ii) Combined rates

Basic unit rates were modified into various combined rates in order to simplify the calculation. Principle rates and their contents are as listed in Table 8.2.2.

Table 8.2.2 Unit Rates for Cost Estimation (Old Rayyan)

Item		Rate	Contents	Remarks
Earthwork	For water collection pipe (m^3)	150	- Rock excavation with dewatering, disposal of surplus and backfilling	
	For transfer pipe (m^3)	180	ditto, depth 1.2 m	
Water collecting pipe	ø600 (m)	500	- ESVC perforated pipe and installation	
	ø450 (m)	200		
	ø300 (m)	150		
Distribution pipe	ø400 (m)	180	- ESVC pipe and installation	
	ø250 (m)	326	- Ductile iron pipe and installation	Prevailing prices in Japan
	ø250 (m)	245	- Poly-vinyl chloride pipe and installation	
	ø50 (m)	70	- Chloride vinyl pipe and installation	
	ø350 (m)	489	- Ductile iron pipe and installation	
Manhole	For water collection pipe (unit)	14,746	- Precast concrete manhole (ø900) - Earth work and installation	
	For transfer pipe (unit)	3,630	- Concrete manhole (ø900, D = 1.5 m) - Earth work and installation	
Gravel filling (m^3)		45	- Dia. 13-20 mm, 25-40 mm, 50-75 mm	with compaction
Concrete (m^3)		300	- Sulfate resistant cement, - Strength: Grade 25	
Water shutoff sheet (m^3)		40	- Vinyl chloride	Recreation pond

iii) Construction Cost of alternatives

The cost of each collection system are in Table 8.2.3. The total construction cost inclusive of transfer and disposal systems for various combinations with either of the two collection systems of standing water elimination and comb arrangement, are shown in table 8.2.4.

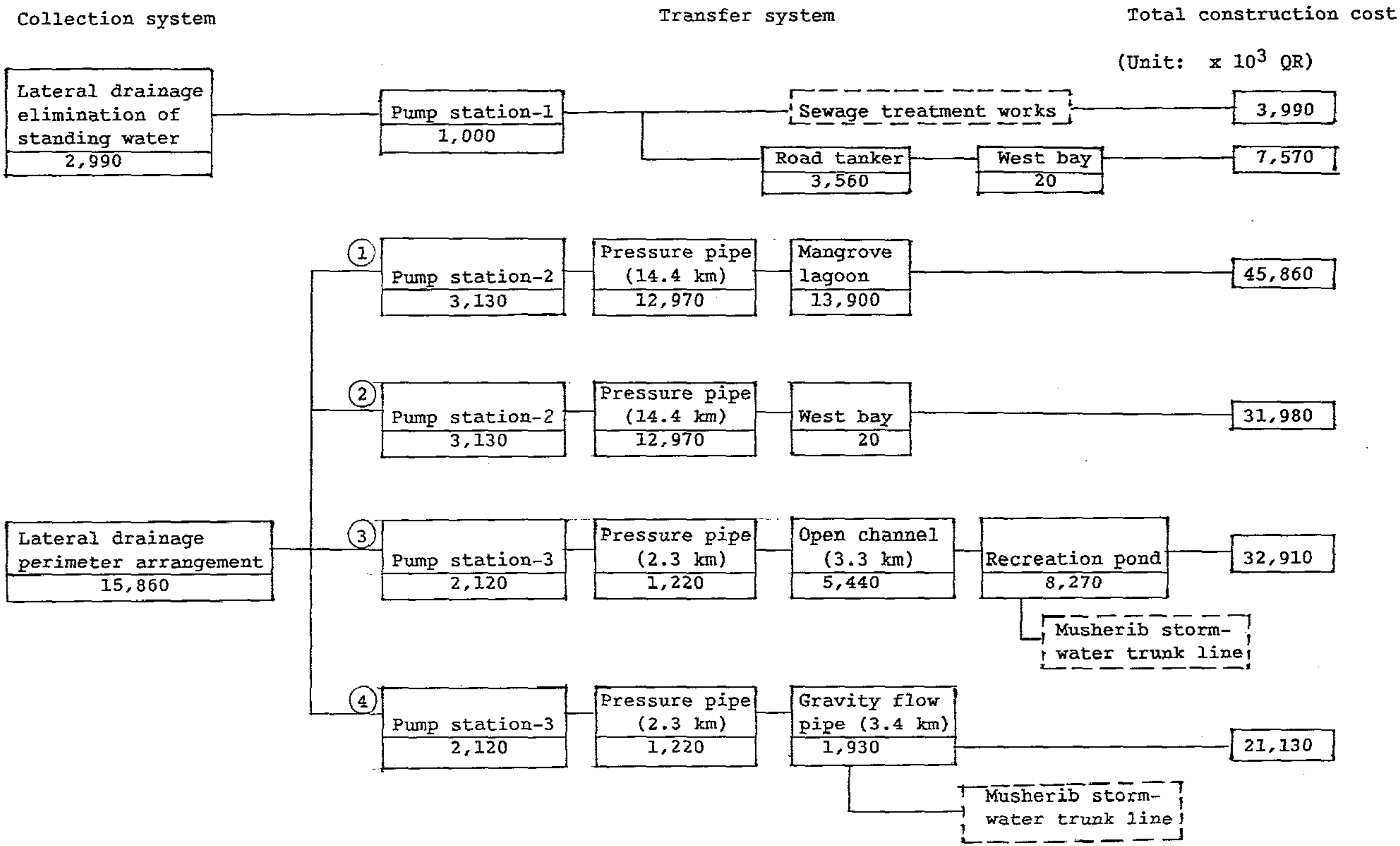
In these construction cost, land acquisition cost and engineering fee and not included.

Table 8.2.3 Construction Cost of Collection System for Old Rayyan

(Unit: x 10^3QR)

Item \ Alternative		Elimination of standing water	Comb arrangement	Perimeter arrangement	Utilizing existing wells
Pipe work	Earth work	1,990	11,630	11,030	6,890
	Installa-tion	700	2,880	2,760	3,600
Manhole		150	870	870	1,070
Road reinstatement		150	380	1,200	530
Well side pumps		-	-	-	1,820
Additional wells					1,780
Total		2,990	15,770	15,860	15,690

Table 8.2.4 Summary of Cost Estimation for Old Rayyan



(2) Comparison of Alternatives

Regarding collection system and transfer-disposal system, features of each alternative are examined here. However alternative plan for elimination of standing water is different in purpose from the others and has been removed from the comparison.

i) Collection system

Table 8.2.5 Comparison Table for Collection System at Old Rayyan

	Perimeter arrangement	Comb arrangement	Utilizing existing wells
Effect of diminishing groundwater level	High	High	Relatively low due to random locations
Collection method	Cutting flow from outside of the area	Collecting ground-water inside the area	Collecting ground-water inside the area
Land use	Allocated under roads and almost no obstruction	Allocated inside the area and somewhat restricting	Small pipes restricting
Length of the lateral drainage	Relatively short	Relatively long	Rather short
Cost	Almost same civil construction cost as the others New land acquisition is small	Almost same civil construction cost as the others Relatively high land acquisition cost expected	Almost same civil construction cost as the others Relatively high land acquisition cost expected

As summarized above, perimeter arrangement is recommendable for collecting system at Old Rayyan.

ii) Transfer and disposal system

Alternatives proposed here have basically different functions other than transfer and disposal of drained groundwater and they therefore cannot be evaluated by one scale. In order to determine the final plan the following parameters shall be considered.

a. Cost
b. Urgency
c. Re-use
d. Pollution control
e. Accordance with other projects

a. Cost
Route-4 (gravity flow pipe method via Jaida petrol station) is considerably cheaper than others.

b. Urgency
Considering the serious situation at Rayyan, at least the standing water shall be eliminated by the immediate implementation of phase-1. And discharge to No. 14 sewerage pumping station or road tanker transportation during phase-2 construction is inevitable.

When adopting Route-3 and 4 connecting to Wadi Musherib stormwater trunk line, implementation schedule thereof is important. Completion date for upstream end at Musherib Dam is not clear and there may be some discrepancy in timing of connection.

c. Re-use
Route-1 (West Bay mangrove lagoon) shall be evaluated by the re-use parameter. As irrigation water for mangrove and date plantation, groundwater from Rayyan is more efficient than sea water.

Route-3 (open channel and recreational pond) aims to contribute a scenic landscape and recreational area for the citizens.

d. Pollution control
It is estimated that quality of groundwater from Old Rayyan shall not require treatment before discharging into sea. Nevertheless Route-1 and 3 have a certain water treatment functions. Route-1 contains the mangrove lagoon where mangrove trees improve COD and other ions by biochemical actions. On the other hand, Route-3 contains an open channel section where water flows on boulders and oxidization of water with air improves the water quality.

e. Accordance with other projects
Doha Municipality has a plan to develop a garden near the Musherib Dam area and the Amir's Office has a plan for mangrove lagoon in the West Bay Development project. Therefore all alternatives, shall have accordance with other projects by authorities concerned.

iii) JICA's recommendation

When considering the construction cost and period, total pipe line system via Jaida Petrol Station is the most effective, but from the point of landscaping, open channel and recreation pond system is highly evaluated. However the plan composed of discharging the abstracted groundwater to the mangrove afforestation lagoon near the seashore offers the best re-use opportunity for the abstracted water in accelerating the growth of mangrove and diversification of mangrove species, and the development of such a large green afforestation park will definately enhance the beauty of Doha City.

In conclusion the JICA study team recommend the lateral drainage in perimeter arrangement and discharge at West Bay coupled with mangrove afforestation.

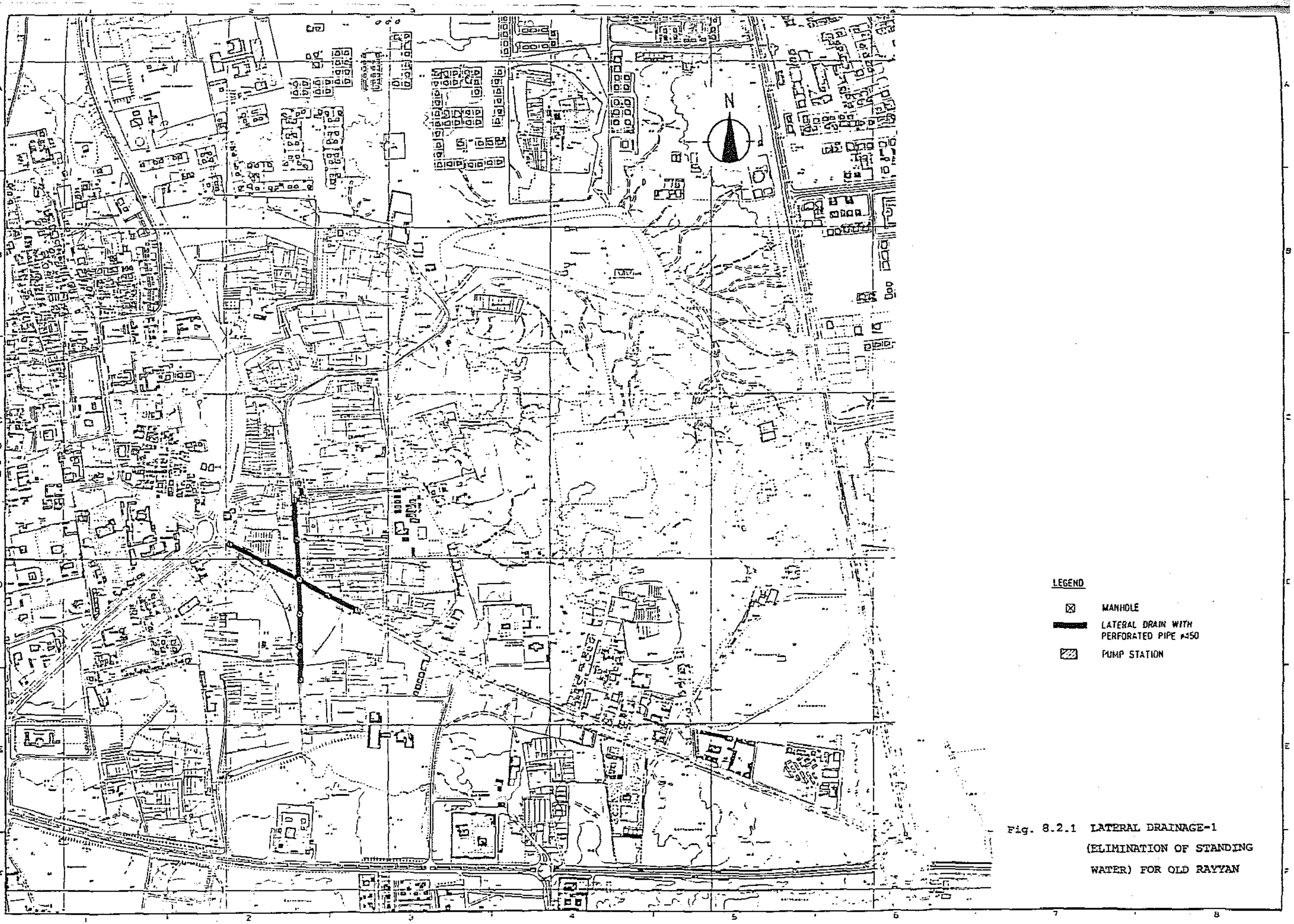


Fig. 8.2.1 LATERAL DRAINAGE-1 (ELIMINATION OF STANDING WATER) FOR OLD RAYYAN

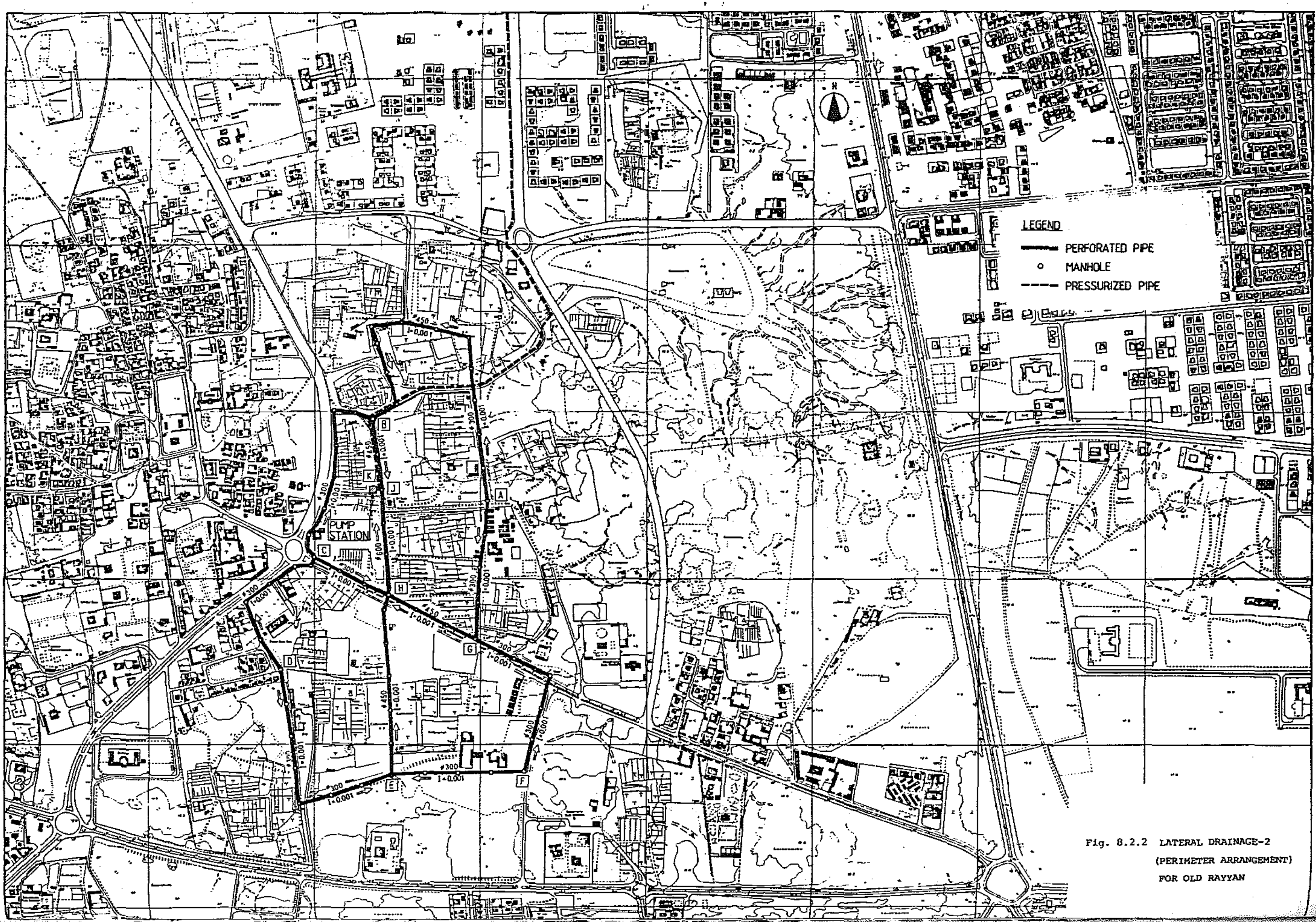


Fig. 8.2.2 LATERAL DRAINAGE-2
(PERIMETER ARRANGEMENT)
FOR OLD RAYYAN

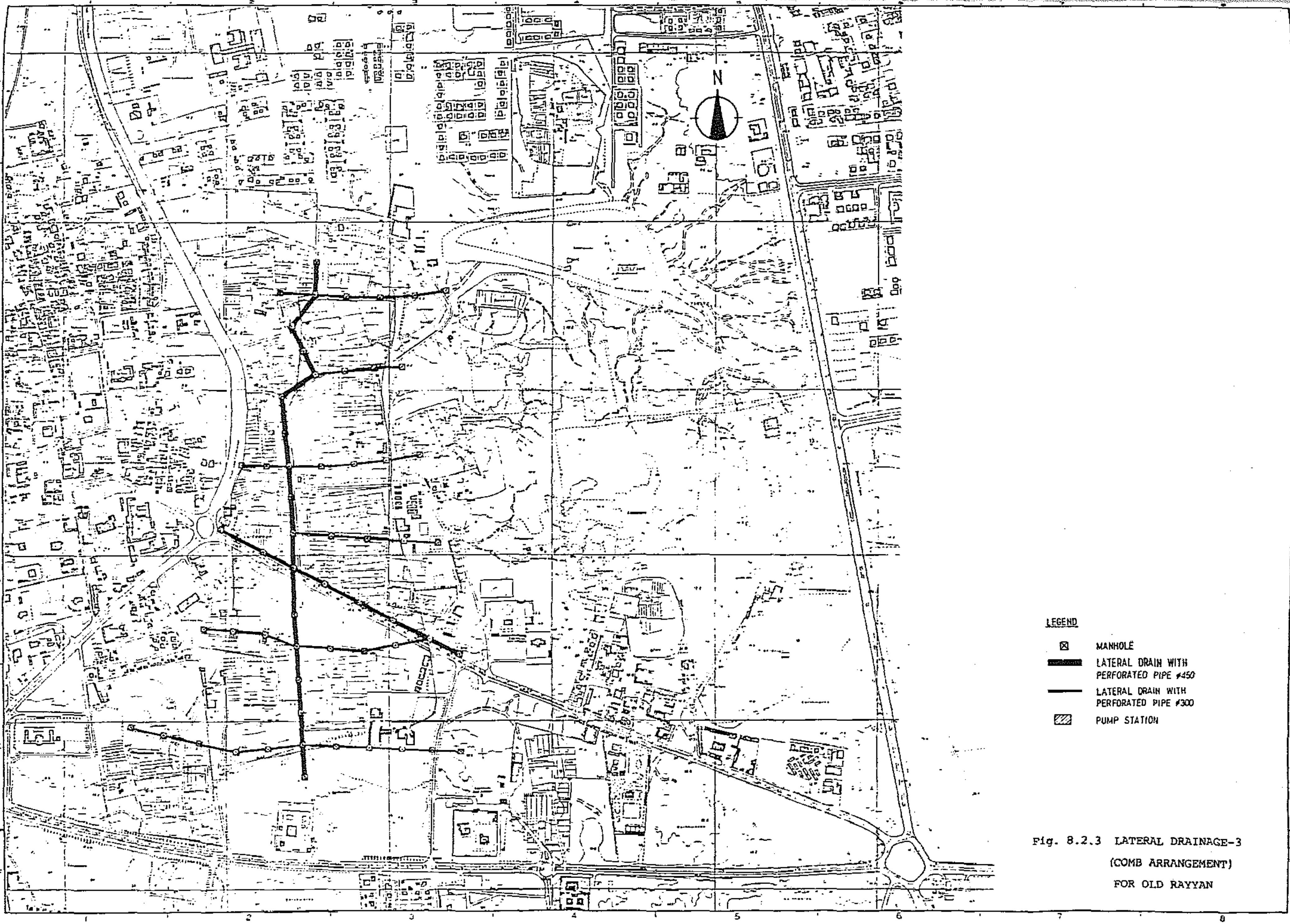


Fig. 8.2.3 LATERAL DRAINAGE-3
(COMB ARRANGEMENT)
FOR OLD RAYYAN

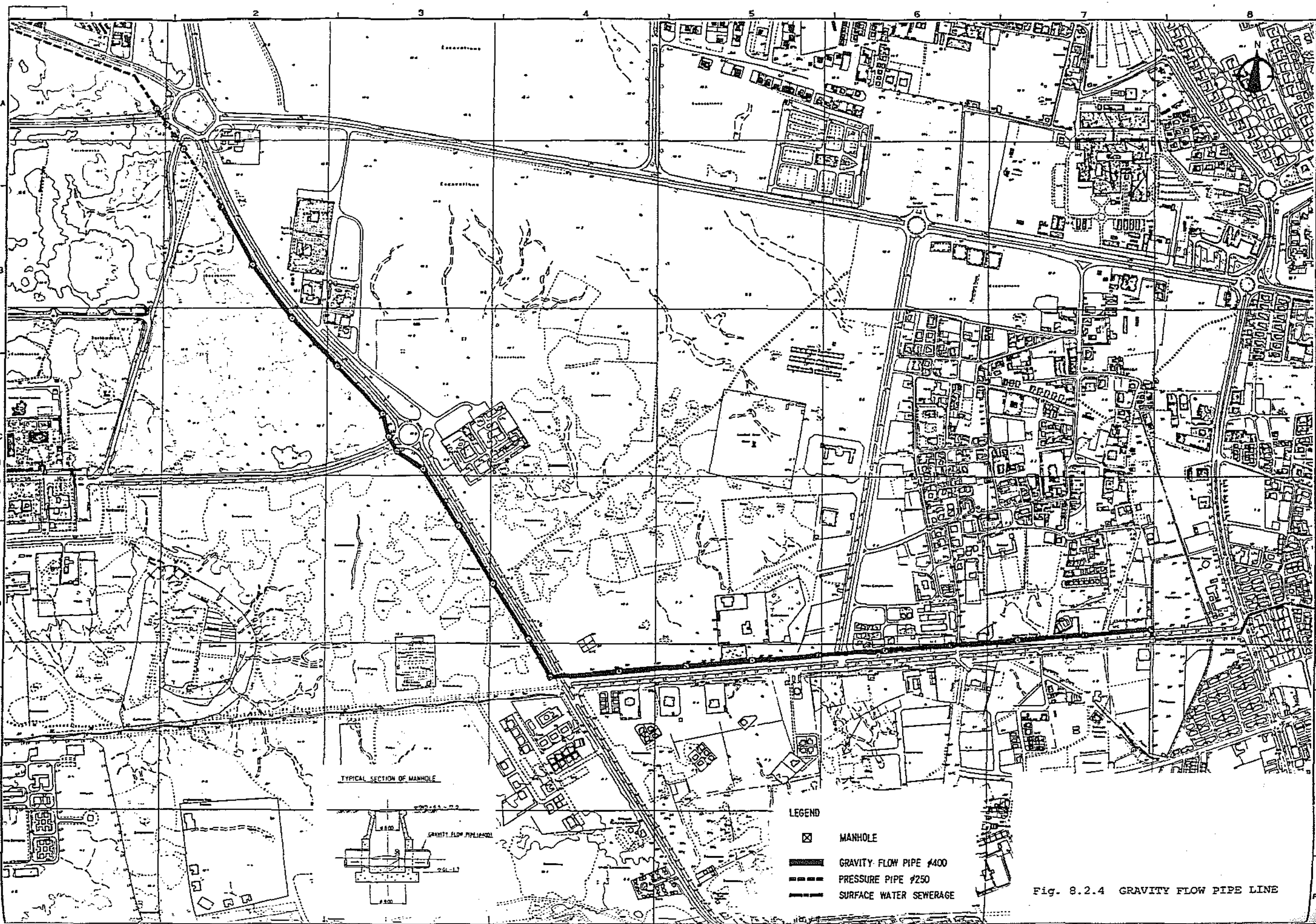


Fig. 8.2.4 GRAVITY FLOW PIPE LINE

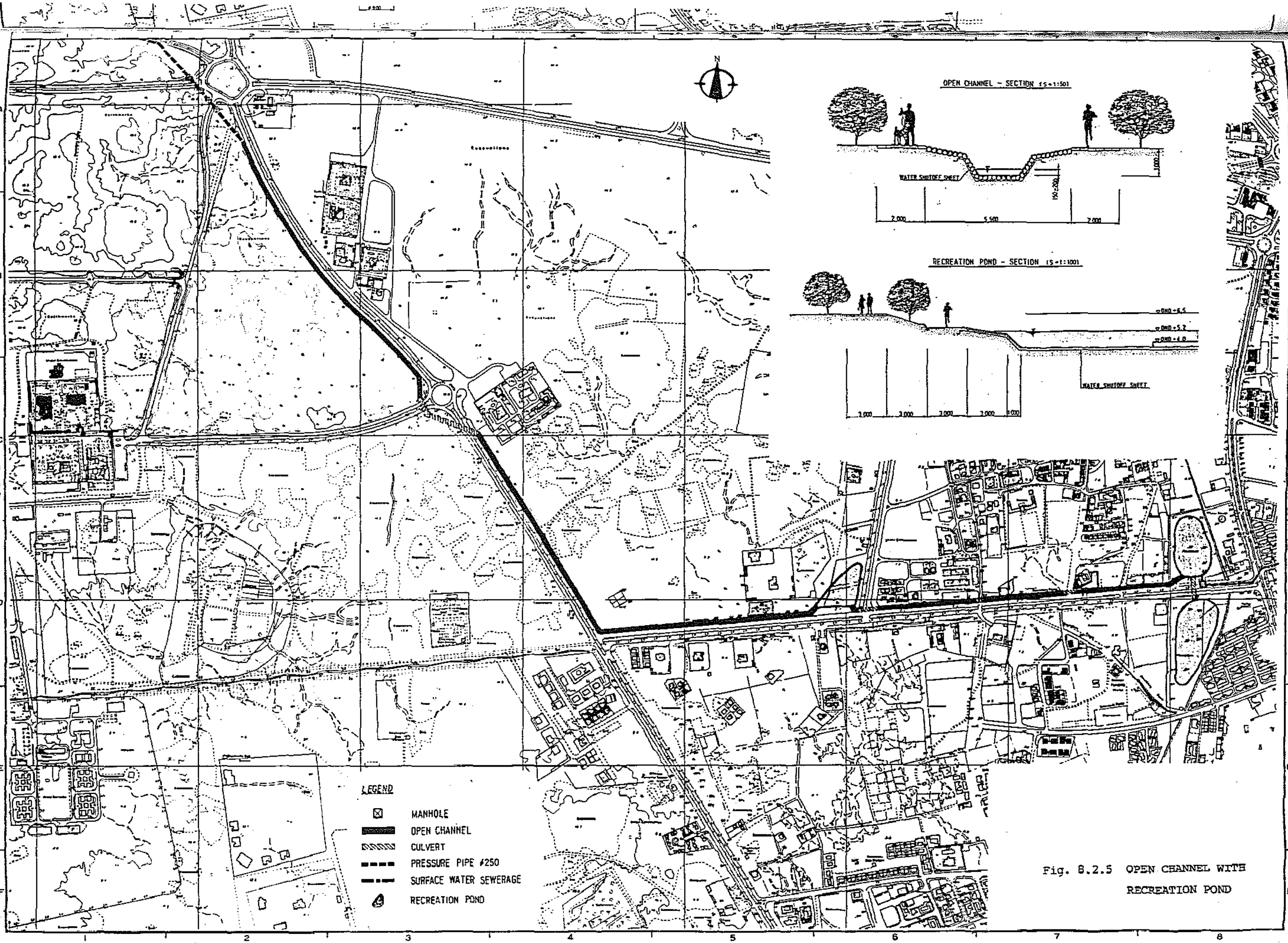


Fig. 8.2.5 OPEN CHANNEL WITH RECREATION POND