6 HYDROGEOLOGY

6.1 GENERAL

6.1.1 Outline of the Study

After the establishment of Altai City in 1940, the first well was constructed in 1956 and many wells were drilled during 1960's and 1980's. Various hydrogeological studies, including drilling of test wells and observation wells, also have been carried out in Sukhyn Khooloy, Kharzat, and Olon Nuur areas. Those studies were done mainly during 1980s by governmental organizations such as Ministry of Energy, Geology and Mining, Ministry of Nature and Environment, and Institute of Water Policy. In addition to summarizing the result of these past studies, the Study Team carried out the following work during the Study in cooperation with the Groundwater Development Company in Gobi Altai Aimag.

- Collection and analysis of the existing data.
- Hydrogeological field survey.
- Measurement of groundwater levels (the work comprises periodic measurement of the observation wells and continuous recording by the water level recorders installed on some wells).
- Analysis of the pumping test data of the JICA test wells.
- Water quality analysis of the JICA test wells and the selected wells.

6.1.2 General Characteristic

A number of test wells, production wells and exploration boreholes have been drilled in the Study Area. Most wells are, however, not in use or abandoned now. A well inventory for the Study Area was established as shown in Table 6.1, which includes 99 deep boreholes and the 10 test wells drilled for this Study. Locations of the wells are shown in Figure 6.1. The drilled depth ranges from 12 meters to 200 meters. Wells are almost concentrated in the central to the southeastern part of the Study Area, that is, Kharzat to Olon Nuur, while fewer wells are located in the northern area, Sukhyn Khooloy. The details of these boreholes are described in the following sections.
Table 6.2 shows the summarized hydrogeological description in the area.

6.2 AQUIFER TYPE

There are two types of hydrogeological units that are expected to be an aquifer, namely basement rocks and unconsolidated deposits of Tertiary and Quaternary Formations.

6.2.1 Aquifers in the Basement Rocks

Proterozoic and Paleozoic formations are mainly composed of metamorphic, carbonate and granitic rocks which are compact, hard and practically impermeable with poor porosity. These formations are considered to be the basement rock from hydro-geological point of view. Many geological logs of these formations, however, show the development of joints and fractures formed by weathering, tectonic movements, etc. Moreover, the results of the field reconnaissance and interpretation of topographic map, aerial-photographs and satellite images point out the existence of lineaments that correspond to fault and fractured zones in the mountain area.

Fractured zones such as fault and shear zones developed in the basement rock facilitate the discharge and flow of fissure water. This sort of fractured zones form fissure aquifers. The drilled depth of exploration boreholes for the past studies ranges from 12 to 175meters. Many boreholes penetrate the consolidated rocks. It is considered that most screen pipes of these boreholes are installed in the consolidated rocks although there is little information about the position of the screen pipes. It was reported that the pumping yield of wells drilled in the fracture zones ranges from 1.6 to 14.4liters/sec.

6.2.2 Aquifers in the Unconsolidated Deposits

The Deposits forming aquifers consist of Tertiary and Quaternary formations.

Tertiary formation is widely distributed in Sukhyn Khooloy and Olon Nuur area underlying Quaternary sediments. It mainly consists of reddish brown compact clay with sand and gravel layers of Neogene age. The groundwater table is high in this area, where sporadic presence of small swamps and concentration of salt minerals are common. According to the past studies the pumping yield from the Neogene deposits ranges from 0.2 to 0.4liters/sec. That means the groundwater potential is low.

Quaternary formation is mainly composed of permeable deposits of alluvial fan, talus, and recent river. Alluvial aquifer is distributed in the area of rather thick quaternary deposits consisting of sand, loam, and gravel. Judging from the geological logs of boreholes, results of pumping test, and other surveys, this alluvial aquifer is classified into unconfined aquifer. The potential of the groundwater varies depending on the thickness of quaternary deposits, particle size of deposits and precipitation, etc. The thickness of Quaternary deposit is shown as an isopach map in Figure 6.2 which is the summary of collected data. The thickness varies from 2 to 70 meters. It tends to be thicker toward the intermediate zones between Kharzat and Olon Nuur areas and in geomorphological depression in Sukhyn Khooloy area. In this deposit, layers of different particle size lie nearly in parallel to the basement rock.

6.3 AQUIFER CHARACTERISTICS

6.3.1 General

From a geologic and geomorphologic viewpoint, the Study Area can be divided into two main areas. They are Sukhyn Khooloy, and Kharzat and Olon Nuur.
Sukhyn Khooloy in the north of Altai City and Kharzat in the south of the City are separated by the basement rocks of Sertengyn mountain range distributed from east to west in the Study Area. Kharzat and Olon Nuur can be separated by a fault inferred by this study. The distriution of the three aquifers are shown in Figure 6.3. The hydrological constants for each area are also compiled in the table below.

Area		Depth (m)	Pumping Rate (liters/sec.)	Specific Capacity (m^3/day/m)	Transmissivity (m^3/day/m)	Hydraulic conductivity (m/day)
Sukhyn Khooloy	Max.	193	10.4	187.2	307.1	14.7
	Min.	28.2	0.2	1.8	1.3	0
	Average	94.8	3.3	40.9	66.1	3.3
Kharzat	Max.*	200.3	17	864	1055	21
	Min.	12	0.01	0.33	1.3	0.01
	Average*	66.7	3.3	72.2	109	3
Olon Nuur	Max.*	175	7	454	590	16
	Min.	46	0.05	1.32	3	0.11
	Average*	104.2	2.7	61.2	119.8	3.4

*: Extraordinarily high value was removed.

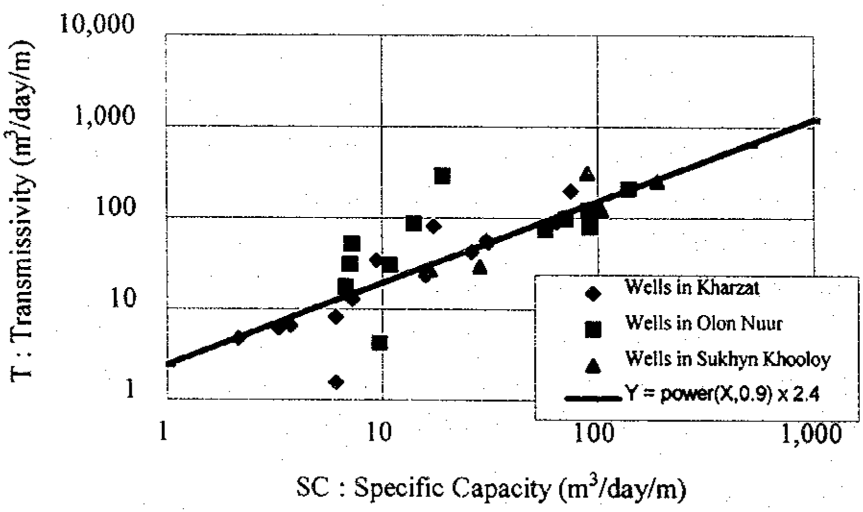
In Kharzat, the fractured basement rocks are covered with comparatively thin quaternary sediments. An aquifer occurs both in the fractured rocks and the overlaying sediments as a single hydrologic unit.

In Olon Nuur the quaternary sediments are thick and overlay the Neogene deposits. An aquifer occurs in the quaternary sediments.

The Isopach Map of the aquifer, Figure 6.3, was drawn based on the collected water level data, the result of the study, and the isopach of the Quaternary deposit.

For Kharzat and Olon Nuur, distribution maps of transmissivity and hydraulic conductivity, Figure 6.4 and 6.5, were drawn. These maps were based on the collected data and the estimated figures obtained by the relation of specific capacity and transmissivity shown below.

Relation of Sc to T in the area



6.3.2 Altai City Area and Kharzat

The previous studies by the Mongolian side revealed that the groundwater in Kharzat is stored both in Quaternary deposits and the permeable fractured rocks. Although the groundwater storage formation is heterogeneous, the recorded continuous water level fluctuations indicate that the body of Quaternary deposits and the fractured rocks can be considered a single aquifer system of one hydrologic unit with a regional extent.

Although many boreholes and wells were drilled in the city area and Kharzat, most boreholes and wells are not in use at present. Four (4) wells in Kharzat are working as production wells operated by Altai City Public Services Department. Pumping yield of boreholes drilled for the past studies varies widely from 0.01 to 12.4liters /sec. The mean pumping rate is 3.15liters/sec. Relatively high yield occurs in the northern part of the city area (No.32 to 37 boreholes; 3.6-8.0liters/sec) and Kharzat (No.59 to 65 boreholes; 6.3-12.4liters/sec). The geological logs of these boreholes indicate that most of these boreholes penetrated consolidated rocks and the water bearing formation is the weathered or fractured zone in the rocks. Specific capacity also ranges widely from 1 to 864m^3/day/m. In addition to the northern part of the city area and Kharzat, the southern part of the city area bordering Kharzat shows higher specific capacity than other area. Hydraulic conductivity of wells around the city area have not been calculated. Boreholes in Kharzat show hydraulic conductivity ranging from 0.07 to 9.4m/day. Higher hydraulic conductivity occur in the central area of Kharzat.

Some deep test wells were drilled in and around Altai City.
Three test wells (A-1, A-2, and A-3) were drilled for the purpose of reaching a fractured aquifer. A-1 is located on the western edge of Altai City. A-2 was constructed about 5 km to the northeast of the Altai City, the depth of which is 193 m. A-3 was drilled until a depth of 150 m in Khadaasan Valley.
As described already in the section of the result of pumping test, these wells can yield only limited quantity and poor quality of water for water supply.

6.3.3 Olon Nuur

It is reported that about 20 boreholes were drilled for the past studies. None of them is in use at present. Pumping rate ranged from 1.2 to 7.1liters/sec. The average rate was 2.51 liters/sec. Specific capacity varied widely from 1 to 93m^3/day/m. The range of hydraulic conductivity in the area was from 0.1 to 16.3 m/day. Higher values occurred generally in the area bordering Kharzat, where the thickness of quaternary deposits is expected to be more than 50 meters.

During the Study, two test wells, B-5 and B-6, were constructed in the area. The pumping tests of the both wells showed a good result with high yield.
Figure 6.6 is the result of the geophysical logs of the two wells. The curves of resistivity, gamma, and SPR show almost similar pattern in a part where the most productive layers may exist. The productive layer spreads continuously with some extent. The distribution map of transmissivity (Figure 6.4) may indicate the extent of

the aquifer.

Neogene deposits that underlay Quaternary deposits are not considered an exploitable aquifer.

6.3.4 Sukhyn Hooloy

Aquifers occur sporadically in Quaternary deposits. Some dug wells have been used by dwellers in the surrounding area and 11 boreholes were drilled for the past hydrogeological studies. Pumping yield of the boreholes ranged from 0.18 to 10.4liters/sec (15.6m^3/day - 899m^3/day). The mean pumping rate was 3.59liters/sec. The borehole (No.7) yielded the maximum volume in the area. In addition, it showed the maximum specific capacity in the area, 187m^3/day/m. Other boreholes (No.6, 8, and 9) around No.7 borehole showed comparatively high specific capacities as well, (90 to 104m^3/day/m). According to the geological logs of these boreholes, thick quaternary deposits are distributed over the entire area. Hydraulic conductivity ranges from 4.57 to 8.3m/day in this area. The groundwater potential seems to be high in this limited part and low in the other parts because of thin alluvial sediments and thick impermeable clay stratum.

The JICA test wells (B-2, B-3, and B-4) were constructed in the eastern end of the area, northeast of Altai City, where the ,thick Quaternary deposits had been most expected. However, underlying Quaternary deposits, which were not so thick or permeable as they were expected. As a result the test wells were drilled into Precambrian rocks underlaying the Quaternary deposits. Screen pipes were also installed over the consolidated rocks because geophysical logging indicated the existence of fractured zones in the consolidated rocks. According to the result of the pumping tests, transmissivity ranges from 1 to 5 m^2/day and hydraulic conductivity ranges from 0.03 to 0.21 m/day in the area. The values indicate the aquifer has very low productivity.

6.4 GROUNDWATER TABLE

6.4.1 General

Groundwater table fluctuates depending on natural and artificial conditions as listed below.

The natural condition	The artificial condition
seasonal and daily change in precipitation evaporation level of surface water atmospheric pressure	pumping rate from wells construction work and others.

Fluctuation of groundwater table in unconfined aquifer represents the change of water volume in the aquifer. Therefore, continuos measurement of groundwater level is indispensable for groundwater development and management. Groundwater levels of most wells in the Study Area, however, have not been measured since the wells were constructed.

The Study Team installed the automatic water level recorders provided by JICA on selected wells to observe continuous water level fluctuations. In addition, with a portable water level gauge provided by JICA, the Study Team measured periodically water levels of 17 wells including the wells where the water level recorders were installed. The names and locations of these observation wells are shown in Figure 6.7. The measurements of water levels were carried out from July 1997 to October 1998 in cooperation with the Groundwater Development Company in Gobi Altai Aimag.

The map of the depth to water table, Figure 6.8, and the water level contour, Figure 6.9, were drawn on the basis of the collected data including the previous studies.

6.4.2 Groundwater Table Fluctuation

The result of the water level measurement is shown in Table 6.3 and Figure. 6.10 (1) – (4).

To graph the result, the observation wells were divided into three groups as follows;

Group A: Relatively deep wells in the area from Altai City to Olon Nuur. No.1, 4, and 5 belong to this group. Well depth ranges from 30 to 70 meters.

Group B: Shallower wells in the above area and the northeast of Altai City that is the downstream of streams from Kharzat and Olon Nuur. This group comprises No.2, 6, 10, and some dug wells in the area. The depth ranges from 1 to 6.6 meters.

Group C: Wells in Sukhyn Khooloy The depth ranges from 1.1 to 4.5 meters.

Figure 6.10 (1), (2), and (3) are the hydrograph of Group A, B, and C, respectively. Figure 6.10 (4) was prepared to compare these three groups and natural factors, rainfall and temperature.

The wells that belong to the same group have generally a similar tendency of water level fluctuation as shown in the figures. However, Figure 6.10 (4) indicates that there is a difference in tendency between the wells of Group A, which are relatively deep, and the shallower wells of Group B and C.
The water levels of Group B and C start going down soon after the end of rainy season, which was July in 1997 and 1998. Meanwhile the levels of Group A continue to rise until the end of October. From the beginning of February, the levels of Group B wells commence to increase while the levels of Group A keep decreasing until the middle of April. The details are as follows;

Group A:
Observation well No.4 (Power Station) is on the edge of the city area. No.1 and No.5 are located near production wells in Kharzat. They are almost three kilometers away from the city area. Though there is a distance, the tendency of water level fluctuation of these wells are almost consistent with each other. The water level change of No.5 is apparently greater because the well is affected by pumping of production wells nearby.
In general, the water level rises from spring to autumn and decreases in winter. The aquifer is recharged from rainfall during the rainy season, from June to August, and the recharge may stop in winter because of the freezing of ground. See Figure 6.10 (4).
The water level of No.1 constructed in Kharzat shows that the level drops and recovers in an annual cycle. The recovery reaches to the level observed the year before. It means the amount of water stored in the aquifer has not changed on an anual basis. In No.5, however, the water level in October 1998 has not recovered up to the level recorded in October 1997. It is possible that the water level is falling down sharply in the limited area around the production wells.

Group B

Observation wells in Group B are distributed in almost the same area as the area of Group A. However, there is a time lag between the fluctuation pattern of water level of the two groups. The water level starts to rise in the middle of February and becomes stable from May to the end of July. From August to the beginning of February, the level decreases. The water level is probably affected by rainfall directly.

The time lag of water level change between Group A and B suggests that the upper layer of the aquifer is directly recharged by rainfall soon after raining and the lower layer of the aquifer is recharged through the upper layer. It is considered that the upper layer is unconfined and the lower one is semi-confined.

Group C

Most wells in Group C are shallow dug wells in Sukhyn Hooloy. Therefore, the water in the wells was frozen in winter. General tendency of the fluctuation is comparatively similar to that of Group B. The water level shows a temporary rise after rainfall.

The groups of shallower wells, B and C, seem to be influenced considerably by two natural factors, namely rainfall and temperature. For example, the hydrograph of No.6 named water supply well (depth is 6.6 meters) shows that the water level rises in a few days after rainfall exceeds seven millimeters per day. The trend of the running average lines of daily temperature agrees generally with the fluctuation of the well No.6 except rainy periods. Around the middle of February, maximum ground temperature rises above the freezing point, and then the water level begins to go up.

The ground temperature affects evaporation from the ground and the freezing of the ground also affects the water flow underground. The characteristics of water level fluctuation of each group are considered to reflect these two factors.

6.5 GROUNDWATER QUALITY

Water quality analysis of the eight existing wells and the ten test wells was conducted. The result is described in detail in Chapter 8. This section deals with the stiff diagrams, which show similarities and differences between the collected groundwater samples.

Figure 6.11 (1) is the stiff diagrams of the test wells. The diagrams show clearly the difference between the wells in the north of Altai City and the wells in the south of the city, near Olon Nuur. The former are A-1, A-2, A-3, A-4, B-1, B-2, B-3, and B-4; the latter are B-5 and B-6.

The water quality of A-1 to 4 and B-1 to 4 is characterized by very high value of sulfate ion. This group also shows higher values of magnesium and calcium ion. These wells have been drilled into the consolidated basement rocks.

B-5 and B-6 are located near Olon Nuur. The stiff diagrams of the two wells are similar to the one of Kharzat Intake Well (SW-6 refer to Figure 6.11(2)) but magnesium content is a little higher than Kharzat (Figure 6.12).

Figure 6.11 (2) shows the water quality of the wells selected by the Study Team. All of them have higher value of bicarbonate iron than sulfate ion. Six out of eight wells are shallow dug wells and two other wells are cased wells in the south of Altai. The higher bicarbonate type probably indicates that the water stays shorter period in underground than the higher sulfate type that appear in wells drilled into consolidated rocks. In this sense the groundwater in Kharzat and Olon Nuur may be comparatively fresh.

The shapes of the diagrams resemble each other in the area from Altai City to Kharzat, that is, Park Well, Kharzat Intake Well, and School Well. The diagram size of the shallowest School Well is slightly larger than the those of the others, which means the total concentration of major ions is higher.

Figure 6.12, the map plotted with the stiff diagrams, shows differences between groundwater in Sukhyn Hooloy and Kharzat.

6.6 EXISTING GROUNDWATER UTILIZATION

In the Study area, 13 wells are in use at present as shown below:

Owner	Number of well	Remarks
APSD	4	at Kharzat water source
Power station	1	about 4km from Kharzat water source
Veterinary hospital	1	about 4km from Kharzat water source
City planning office	1	about 4km from Kharzat water source
Private company	2	Altai camel, Entum
Unknown	4	in Sukhyn Khooloy, little consumption, for livestock

APSD: Altai City Public Service Department

The existing groundwater utilization was surveyed as a part of the water supply facility study. The result is described in detail in chapter 9. The capacity of intake pumps installed in the production wells is 25 m^3/hour x (80 m – 100 m). Two production wells are pumped up by turns or simultaneously at present. The total yield of Kharzat production wells is about 960 m^3/day in an average and 1,150 m^3/day in a maximum at present. Other wells are not located in Kharzat water source and their data were lost.

6.7 RECHARGE VOLUME

The average annual groundwater flow through an aquifer can be quantified by considering the disposition of the rain that falls on the recharge area. The recharge volume to Kharzat and Olon Nuur is estimated in this section.

Figure 6.13 shows the catchment area of Kharzat and Olon Nuur. Both of them are sub-catchment areas of Esuitiin Sair river catchment area.

Area	Catchment area	Annual Precipitaion	> 8mm/day in a year	Recharged precipitaion	Recharged volume
Kharzat	about 70km^2	181.6 mm	34 mm	14% of total 25.4mm/year	4,870 m^3/day
Olon Nuur	about 80km^2	181.6 mm	34 mm	14% of total 25.4mm/year	5,567 m^3/day

The area of Kharzat is about 70 km^2. The annual average precipitation is reported at

181.6 mm. About 64 % of precipitation concentrate during rainy season from June to August. The result of the continuous water level observation indicates that rainfall affects water level if it is over eight millimeters per day. It probably means that rainfall of seven millimeters or less flow out from ground surface.

In 1998, the total of rainfall that is over eight millimeters per day was 34.4 mm. The value is 25 % of the total rainfall in the rainy season that accounts for 64 % of annual precipitation. Therefore, 16 %, or 0.64 multiplied by 0.25, of annual precipitation is the roughly estimated recharge to underground. Two percent of precipitation is considered to become interflow and to move laterally above water table. Consequently, 14 % of annual precipitation, or 25.4 mm, recharge to the aquifer. The estimated total recharge volume becomes 1,778,000 m^3/year, or 4,870 m^3/day in Kharzat area.

The area of Olon Nuur is about 80km^2. The similar estimation as described above can be applied to this area. The estimated total recharge volume is 2,032,000 m^3/year, or 5,567 m^3/day in Olon Nuur area.

6.8 GROUNDWATER POTENTIAL

6.8.1 General

(1) Alluvial Aquifer

The result of the hydrogeological study described above indicates that the Sukhyn Khooloy is less feasible for the development of groundwater resources in terms of both quality and quantity.

The consideration of water budget in Kharzat area suggests that it is possible to further exploit the area although the area already produced about 1,150 m^3/day in maximum presently. In addition, this study revealed that a productive and usable aquifer occurs also in Olon Nuur. This aquifer may be exploited after the yield of Kharzat aquifer reaches the limit in future. At present, the aquifer in Kharzat is most practicable to develop for future water demand in Altai City.

1) Fissure Aquifer

The productivity of A-4 well is excellent, but the quality becomes problem as described already. Therefore, the aquifer developed by A-4 cannot be expected to be usable at the moment. The fissure aquifer in the study area is generally less feasible than alluvial aquifers because of the poor water quality. The water quality of A-3 is better than the others, but still some items are over the Mongolian water quality standard. Consequently these aquifers are less practicable compared with Kharzat and Olon Nuur aquifer.

(2) Alternative Water Resources

A large amount of water may become necessary to meet water demand in the future, after Kharzat and Olon Nuur aquifer is developed. In such a case, Zavkhan River will be considered as the new source of water supply.

A study on groundwater of the riverbed in Zavkhan has been conducted by a Mongolian governmental organization. According to the result, the riverbed in Zavkhan is exploitable for water supply. It is not difficult from a hydrogeological and technical point of view to develop this water source. However, the consideration and examination of the development plan from an economic viewpoint should be necessary. This issue is discussed in chapter 2.

6.8.2 Priority Site to be developed

The result of the hydrogeological study revealed the following points about the aquifers in the area.

- Water quality of the aquifer in Sukhyn Hooloy is generally poor and some items exceed greatly the Mongolian drinking water standard.
- Yield of the aquifer in Skhin Hooloi is not expected to be exploitable.
- Water quality of the fissure aquifer is also poor.
- Yield of the fissure aquifers varies widely.
- Water quality of the aquifer located in Olon Nuur, which is developed by B-5 and B-6 in the Study, is near the Mongolian standard.
- Yield and productivity of B-5 and B-6 is higher than that of the other test wells.
- Water quality of Kharzat aquifer is the best in the area.
- Kharzat aquifer produces about 1,150 m^3/day in maximum at present though the recharge volume is estimated about 4,870 m^3/day.

These points suggest that the first thing to be considered is to make the best use of Kharzat aquifer. The Olon Nuur aquifer whose potential was confirmed by B-5 and B-6 in this Study should be developed after the Kharzat is fully exploited.

6.8.3 Groundwater Storage in Kharzat and Olon Nuur

Based on the Isopach map of the aquifer, the volume of groundwater storage can be roughly calculated as follows;

(1) Kharzat

The area of the aquifer;

Thickness	0	10	20	(meters)
The area	26.5	11.1	2.5	(km^2)

The volume of the whole aquifer is estimated by the following simplified expression;
$26.5 \times 10^6 \times 5 + (11.1+2.5) \times 10^6 \times 10 = 268.5 \times 10^6$ (m^3)
Generally, effective porosity of the aquifer material is estimated to be within a range of 0.1 to 0.15;
Then, the groundwater volume stored is ;
$268.5 \times 10^6 \times (0.1 \sim 0.15) = 26.9 \times 10^6 \sim 40.3 \times 10^6$ (m^3)

This volume covers the amount extracted by a continuous pumping for more than 49 years when the daily discharge is 1500m^3.

(2) Olon Nuur

The area of the aquifer;

A thickness	0	10	20	30	40	(meters)
The area	29.4	11.8	8.5	3.1	0.13	(km^2)

The volume of the whole aquifer is estimated as follows;;
$29.4 \times 10^6 \times 5 + (11.8+8.5+3.1+0.13) \times 10^6 \times 10 = 382.3 \times 10^6$ (m^3)
Effective porosity of the aquifer material is estimated to be with in a range of 0.1 to 0.5;

Then, the groundwater volume stored is ;
$382.3 \times 10^6 \times (0.1 \sim 0.15) = 38.2 \times 10^6 \sim 57.3 \times 10^6$ (m^3)

6.8.4 Groundwater Potential of Kharzat Water Resource

The following simple equation is representing amount of groundwater flow through an aquifer;

Recharge to the aquifer – Discharge to the aquifer = Change in groundwater storage

If discharge exceeds recharge, the amount of water stored will be reduced and the water level will fall. It continues until the storage becomes exhausted.
Therefore, the groundwater development potential in an area will be evaluated on the basis of the storage of the aquifer and the natural recharge to the aquifer.

In the Kharzat area, the estimated groundwater storage is about $27 \sim 40 \times 10^6$ m^3 and the estimated recharge volume is 4,870 m^3/day on annual average. The record of the water level fluctuations indicates that the recharge to the aquifer occurs mostly in rainy season. Although the pumping from the aquifer reduces the groundwater storage in winter, the storage has a large surplus and recovers in the next rainy season. The present yield from the aquifer is 1,150 m^3/day in maximum. Therefore, more than 3,000 m^3/day is considered still available for water supply. However, when the development plan is implement newly, it should be avoided that a large amount of water is pumped up from the only one production well. It may cause the local reduction of water level and the deterioration of water quality. Even if a number of production wells are constructed the continuous monitoring of water level and quality in the area is recommended.

6.9 PROGRAM FOR GROUNDWATER UTILIZATION

6.9.1 General

There are four production wells in Kharzat and any two out of the four wells are operating at present. The maximum total pumping volume is about 1,150 m^3/day, that is, the discharge rate from one well is 575 m^3/day. This volume is close to the volume planned originally by the Mongolian side. However, the actual pumping rate from a well can be more than 575 m^3/day in some cases because these two wells are not operated at the same time usually. Until now the actual pumping rate and pumping water level have not been recorded at the production wells. Monitoring of the data is essential for the proper groundwater management.

According to the water budget estimation in the previous section, more than 3,000 m^3/day is still available from the aquifer within natural recharge. So long as the extraction is kept less than natural recharge, the points to be paid attention to are pumping operation and location of wells in a well field. Pumping wells should be located not too close to each other and should be operated not to cause excessively low pumping water level. When pumping wells are too close, interference creates additional drawdowns with corresponding higher pumping lifts. A decline in the pumping water level leads to an increase in the pumping head and reduced discharge.

6.9.2 Program of Groundwater Utilization

In the Master Plan, four intake(production) wells in Kharzat have been planed to pump up 600-800 m^3/day with a drawdown of 4-6 meters. According to the collected data, specific capacity of the aquifer ranges from 104 to 432 m^3/day/m. Based on the relation between specific capacity and transmissivity, it is estimated that the value of transmissivity ranges from 157 to 565 m^2/day.

The optimum pumping yield for a well is examined with Theis non-equilibrium equation on the basis of the following assumed figures.

1) Transmissivity is 360 m^3/day/m that is the mean value in the area.
2) Storage coefficient of the aquifer that is semi-confined is 0.005.

Storage coefficient of confined aquifers range from 0.0005 to 0.005 and the values of specific yield which is an unconfined storage coefficient, range from 0.01 to 0.3. The lower layer that is a target of development can be considered semi-confined as described in the section of water level.

The above-assumed figures can be applied first to the present condition as described below.

Assume that there are two intake wells which are 100m apart working simultaneously.

When the annual average of pumping rate of the wells is 480 m^3/day, the drawdown in one cased well with the inside diameter of 0.2 m is calculated to be 2.39 m after 365 days of pumping. The interference drawdown caused by the other intake well is calculated to be 0.92 m. Therefore the total drawdown in the intake well will be 3.31 m.

While actual water levels in the present intake wells are unknown, the figure can be considered reasonable compared with of 4m the original planned figures by the Mongolian side. These planned figures were likely determined by the pumping test conducted when the well was constructed, though the detailed data on the test were not obtained during the study. The isopach map shows that the thickness of Kharzat aquifer is 10 to 20 meters or more. The drawdown in the aquifer should not exceed four meters ideally. If the actual present drawdown is more than the estimated drawdown, it is possible that the well performance has been deteriorated by some factors. For example, when a pump operates continuously for long periods, the filter zone of a well may be plugged by fine particles and it causes loss of well efficiency. This is quite likely because some of the wells were constructed have been there for almost 20 years. In that case the well has to be cleaned to restore its original performance.

The table below shows the estimated drawdown in a well located in the center of the well field when it is surrounded by one to four wells respectively. The table also shows the projected water demand in 2005 and 2015. The conditions for the calculation are,

- the pumping duration is 3650 days
- the wells with the inside diameter of 0.2m are located in a straight line and the one in the center is focused on
- the wells are operated simultaneously with the same pumping rate

When the wells are operated, the drawdown should be kept around 6m (ideally 4 meters) while satisfying the projected water demand. At present there are four intake wells including one that is under repair. The table indicates that the operation of three wells is sufficient for water demand in 2005. Therefore, one well can be used as a spare. In 2015, if the intake wells are operated attentively with a water level monitoring, four wells are adequate for the water demand. In that case, it is recommended that a spare well will be constructed anew.

	Year	1997-98	2005	2015	2015
	Water demand (average, m^3/day)	960	1140	1500	2140
Total number of wells					
2	Pumping rate / well (m^3/day)	1500	570*2	750*2	1070*2
	DD* (Pumping)	-2.63 m	-3.12 m	-4.11 m	-5.87 m
	DD* (Interference)	-1.17 m	-1.38 m	-1.82 m	-2.6 m
	Total drawdown of the center well	-3.80 m	-4.50 m	-5.93 m	-8.47 m
3	Pumping rate / well (m^3/day)		380*3	500*3	714*3
	DD* (Pumping)		-2.08 m	-2.74 m	-3.91 m
	DD* (Interference)		-0.92*2 m	-1.21*2 m	-1.73*2 m
	Total drawdown of the center well		-3.92 m	-5.16 m	-7.37 m
4	Pumping rate / well (m^3/day)			375*4	535*4
	DD* (Pumping)			-2.06 m	-2.93 m
	DD* (Interference)			-0.91*2 m	-(1.30*2+1.03) m
	Total drawdown of the center well			-4.67 m	-6.56 m
5	Pumping rate / well (m^3/day)			300*5	428*5
	DD* (Pumping)			-1.64 m	-2.35 m
	DD* (Interference)			(-0.73-0.64)*2 m	-(1.04+0.91)*2
	Total drawdown of the center well			-4.38 m	-6.25 m

DD; drawdown   Well location; every 100 m on a straight line
Pumping duration: 3650days

The calculation in the above table is based on the Theis non-equilibrium equation.

$$s = \frac{Q}{4\pi T}\int_u^\infty \frac{e^{-u}}{u}du$$

$$\int_u^\infty \frac{e^{-u}}{u}du = -0.5772 - \ln u + u - \frac{u2}{2!\cdot 2} + \frac{u3}{3!\cdot 3} - \frac{u4}{4!\cdot 4} + \cdots$$

$$u = \frac{r_2S}{4T\pi}$$

where

s : drawdown
Q: discharge rate
T: transmissivity
S: strorativity
t: duration of pumping
r: distance from the center of the well
u: unit of well function (dimentionless)

When two or more wells are mutually interfering, the general rule is that the total drawdown is the sum of the individual drawdowns. The individual drawdown is obtained when "r" is the distance from another pumping well.

Table 6.1 Well Inventory (1/4)

Map No.	Code No.	Area	Coordination: Coordinate X	Coordination: Coordinate Y	Elevation (m)	Depth (m)	Screen (m)	Pumping Rate Q(liter/sec)	S.W.L (GL-m)	Drawdown(m)	Specific Capacity (m^3/day/m)	Transmissivity (m^2/day)	Thickness of permeable formation (m)	Permeability coefficient (m/day)	Stratigraphy (m): Quaternary Deposi	Stratigraphy (m): Neogene Deposits	Stratigraphy (m): Consolidated Rocks	Geologic Column	Construction Year
1	20	Sukhyn Khooloi	96° 13' 55"	46° 30' 50"	2155	28.2		2.41	2.72	10.96	19	(34) *		4.1	0- 3.0	3.0- 28.2		○	1981
2	3		96° 11' 40"	46° 29' 48"	2200	64.0		3.40	0.10	10.40	28	29	34.1	0.9	0-34.2	34.2- 64.0		○	1984
3	1644		96° 10' 00"	46° 29' 00"	2172	76.0		3.60	6.5	25.0	12	(23) *			0-3.0	3.0-76.0			
4	2		96° 13' 40"	46° 28' 48"	2072	84.0		1.20	5.40	6.20	17	27	9.3	2.89	0-14.7	14.7- 82.0	82.0-84.0	○	1969
5	102		96° 08' 44"	46° 27' 45"	2164	69.3			Dry				17.8		0-17.8		17.8-69.3		
6	8		96° 09' 25"	46° 26' 50"	2111	131.0		6.00	4.20	5.00	104	122	26.8	4.6	0-31.0	31.0-129.6	129.6-131.	○	1984
7	107		96° 10' 16"	46° 26' 28"	2110	102.0		10.40	1.10	4.80	187	251	45.6	5.5	0-45.6	45.6-102.0			1980
8	124		96° 11' 24"	46° 26' 04"	2118	170.0		2.00	46.5	1.92	90	307	37.0	8.3	0-37.0	37.0-170.0			
9	106		96° 12' 00"	46° 25' 37"	2140	44.8		4.10	3.2	3.50	101	(153) *	10.4	(14.7) *	0-10.4		10.4-44.8		
10	56		96° 19' 32"	46° 26' 23"	2012	35.1		0.18	22.2	7.4	2	(5) *			0-3.0		3.0-35.1		1982
11	11*		96° 17' 10"	46° 25' 21"	2005	96.7		2.61	+0.2	35.20	6	(13) *	6.5	(2.0) *	0- 6.5	6.5- 75.4	75.4-96.65	○	1064
12	1619*		96° 10' 30"	46° 23' 30"	2228	40.0		0.50	16.00						0- 7.0		7.0-40.0	○	1985
13	10*		96° 10' 40"	46° 22' 03"	2296	102.0		0.01							0-37.0		37.0-102.0	○	1964
14	1		96° 11' 54"	46° 20' 39"	2315	63.8		0.22	+1.5	39.3	0		30.5		0-30.5		30.5-63.8		1964
15	2		96° 12' 58"	46° 21' 05"	2247	128.2		1.53	60.0	1.13	117	(174) *	57.5	(3.0) *	0-46.0		46.0-128.2		1964
16	3881		96° 13' 50"	46° 22' 00"	2190	45.0		0.1	14.0	26.0	0		10		0-10.0		10.0-45.0		
17	4*		96° 13' 56"	46° 21' 29"	2200	97.4	59.0-67.5	1.24	43.60	9.80	11	(21) *	28.8	(0.7) *	0-28.8	28.8- 57.5	57.5-97.4	○	1964
18	333*		96° 14' 00"	46° 22' 00"	2185	82.0		1.25	50.0						0- 7.0	7.0- 45.0	45.0-82.0	○	
19	3731		96° 14' 15"	46° 19' 55"	2263	57.0							14.0		0-43.0		43.0-57.0		
20	1618*		96° 14' 30"	46° 21' 15"	2198	90.0		0.60	44.30				49.5		0-49.5	49.5-70.0	70.0-90		1980
21	3*		96° 14' 34"	46° 21' 46"	2178	29.3									0-29.0		29.0-29.3		1964
22	9*		96° 14' 36"	46° 21' 03"	2200	117.1	47-56,63-72	1.60	44.0	3.35	41	(68) *			0-50.0	50.0- 70.0	70.0-117.1	○	1981
23	87		96° 14' 42"	46° 21' 07"	2197	49.1		1.88	21.9	9.5	17	(31) *			0-33.8		33.8-49.1		
24	88		96° 14' 46"	46° 21' 04"	2198	57.7		0.35	23.9	0.1	233	(324) *			0-8.0	8.0-29.6	29.6-57.7		
25	89		96° 14' 50"	46° 21' 15"	2195	41.0		0.40	19.9	0.2	150	(218) *			0-4.0	4.0-37.1	37.1-41.0		1981
26	3875		96° 14' 52"	46° 22' 25"	2168	70.0		0.20	17.0	53.0	0		20.0		0-20.0		20.0-70.0		
27	85a		96° 14' 58"	46° 20' 55"	2204	69.8			40.6						0-47.5	47.5-55.5	55.5-69.8		

Note: Code No. with and without * correspond to well to use groundwater and well for hydrogeological study , respectivel (-)*:Estimated value

Table 6.1 Well Inventory (2/4)

Map No.	Code No.	Area	Coordination: Coordinate X	Coordination: Coordinate Y	Elevation (m)	Depth (m)	Screen (m)	Pumping Rate Q(liter/sec)	S.W.L (GL-m)	Drawdown(m)	Specific Capacity (m^3/day/m)	Transmissivity (m^2/day)	Thickness of permeable formation (m)	Permeability coefficient (m/day)	Stratigraphy (m): Quaternary Deposit	Stratigraphy (m): Neogene Deposits	Stratigraphy (m): Consolidated Rocks	Geologic Column	Construction Year
28	1628*		96° 15' 00"	46° 22' 00"	2168	24.0		1.00	8.60	3.00	29	(49) *			0- 3.0		3.0-24.0	○	
29	1078*		96° 15' 00"	46° 20' 50"	2206	12.0		2.00	4.00	1.00	173	(248) *	12.0	(20.6) *	0- 4.0		4.0-12.0	○	1974
30	3018*		96° 15' 08"	46° 21' 45"	2170	70.0	25.0-40.0	1.17	0.04	26.52	4	7	46.6	0.14	0-23.4		23.4-70.0		
31	1630		96° 15' 08"	46° 21' 45"	2170	65.0									0-25.0		25.0-65.0		
32	3001*		96° 15' 10"	46° 22' 40"	2163	50.0		3.60	2.00	2.75	113	(169) *			0- 2.0		2.0-50.0	○	1990
33	2824*		96° 15' 10"	46° 22' 10"	2166	50.0		8.00	9.00	6.20	111	(167) *			0-11.0		11.0-50.0	○	1964
34	1650*		96° 15' 10"	46° 22' 10"	2166	83.0	10.7-20.0	1.50	10.65	24.35	5	(11) *	(12.5?)		0- 4.0(12.5?)		4.0(12.5?)-83.0	○	1970
35	1656*		96° 15' 15"	46° 22' 30"	2165	42.0		8.00	6.80	4.30	161	(232) *	>42.0		0-22.0		22.0-42.0	○	
36	136*		96° 15' 19"	46° 22' 01"	2165	90.0	75-80,82-87	7.10	9.00	20.00	31	(52) *							
37	136a*		96° 15' 21"	46° 21' 57"	2165	90.0	49.3-59.5	3.60	9.25	12.75	24	(43) *						○	1983
38	2812*		96° 15' 30"	46° 22' 20"	2164	45.0		0.80	6.00	10.00	7	(14) *	23.0	(0.6) *	0- 8.0		8.0-45.0	○	
39	1676*		96° 15' 30"	46° 22' 10"	2164	50.0		1.00	3.00	23.50	4	(8) *	7.0	(1.1) *	0- 3.0		3.0-50.0	○	
40	1677		96° 15' 45"	46° 23' 00"	2160	38.8		1.00	3.0	22.0	4	(8) *	9.0	(0.9) *	0-9.0		9.0-38.8		
41	1677*		96° 15' 45"	46° 23' 00"	2160	53.0		0.75	3.00	14.00	5	(10) *	19.0	(0.5) *	0- 9.0		9.0-53.0	○	1990
42	94*		96° 15' 55"	46° 22' 30"	2155	60.0		1.50	4.00	1.00	130	(191) *			0- 8.0		8.0-60.0	○	1990
43	1675*		96° 16' 00"	46° 22' 30"	2152	62.0		2.60	3.00	13.00	17	(31) *			0- 4.5	4.5- 7.5	7.5-62.0	○	1975
44	38*		96° 15' 40"	46° 22' 30"	2161	20.0		1.40	4.00	10.00	12	(23) *	>20.0		0- 2.0		2.0-20.0	○	1975
45	8*		96° 15' 30"	46° 20' 40"	2197	64.0									0-18.0	18.0- 60.0	60.0-64.0	○	1964
46	93a		96° 15' 33"	46° 20' 57"	2190	39.1		0.17	26.2	0.2	73	(115) *			0-30.7	30.7-36.8	36.8-39.1		1990
47	5*		96° 15' 35"	46° 21' 25"	2178	60.0		2.30	6.85	13.90	14	(26) *	13.0	(2.0) *	0-13.0		13.0-60.0	○	
48	51		96° 15' 35"	46° 21' 09"	2185	55.8		1.42	26.28	16.79	7	13	29.5	0.43	0-30.3	30.3- 38.5	38.5-55.8	○	
49	688*		96° 16' 00"	46° 21' 00"	2181	60.0		5.50	7.95	0.10	4752	(4891) *	13.0	376.2) *	0- 7.0	7.0- 13.0	13.0-60.0	○	
50	55	Kharzat	96° 16' 00"	46° 20' 28"	2195	70.2		2.80	33.70	9.34	26	42	19.5	2.14	0-23.6	23.6- 50.7	50.7-70.2	○	
51	4		96° 16' 28"	46° 21' 11"	2162	70.8		3.20	8.40	17.32	16	23	57.6	0.4	0-13.2		13.2-70.8	○	
52	1626*		96° 16' 30"	46° 20' 30"	2185	25.0			3.50	1.70			12.0		0-12.0		12.0~25.0	○	
53	6*		96° 16' 39"	46° 21' 25"	2152	75.8		4.20	7.40	8.45	43	(71) *			0- 5.0		5.0-75.8	○	1964
54	3		96° 16' 44"	46° 21' 05"	2155	70.0		1.17	7.54	26.98	4	(8) *	23.4	(0.3) *	0-23.4		23.4-70.0		

Note: Code No. with and without * correspond to well to use groundwater and well for hydrogeological study , respectivel (-)*:Estimated value

Table 6.1 Well Inventory (3/4)

Map No.	Code No.	Area	Coordination		Elevation (m)	Depth (m)	Screen (m)	Pumping Rate Q(liter/sec)	S.W.L (GL-m)	Drawdown(m)	Specific Capacity (m^3/day/m)	Transmissivity (m^2/day)	Thickness of permeable formation (m)	Permeability coefficient (m/day)	Stratigraphy (m)			Geologic Column	Construction Year
			Coordinate X	Coordinate Y											Quaternary Deposit	Neogene Deposits	Consolidated Rocks		
55	103		96° 16' 55"	46° 20' 13"	2190	121.0									0-17.8	17.8-80.8	80.8-121.0		
56	16		96° 17' 15"	46° 20' 07"	2185	41.8									0-21.0	21.0-30.6	30.6-41.8		1980
57	20		96° 17' 20"	46° 20' 30"	2164	76.0		5.50	13.00	15.70	30	56	21.0	2.66	0-34.0	34.0- 47.0	47.0-76.0	○	
58	12		96° 17' 22"	46° 21' 14"	2142	41.0		1.60	4.25	22.42	6	2	5.0	0.31	0- 5.0		5.0-41.0	○	
59	7*		96° 17' 25"	46° 20' 47"	2150	74.0		6.90	3.20	0.69	864	(1055) *	51.5	(20.5) *	0-15.0		15.0-74.0	○	1975
60	21		96° 17' 26"	46° 20' 42"	2153	48.0		6.30	8.56	8.36	65	89	39.0	2.29	0-36.0		36.0-48.0	○	
61	4924		96° 17' 28"	46° 20' 55"	2148	62.0		12.00	6.74	2.40	432	(565) *	49.0	(11.5) *	0-14.0		14.0-62.0	○	
62	100		96° 17' 30"	46° 20' 50"	2149	73.6		11.40	8.71	18.82	52	(85) *	59.0	(1.4) *	0-14.0		14.0-73.6	○	
63	90		96° 17' 30"	46° 20' 03"	2186	74.0		0.10	42.0	6.6	1	(3) *			0-32.1	32.1-47.6	47.6-74.0		1975
64	694*		96° 17' 38"	46° 21' 10"	2142	46.0		12.40	3.00	2.70	397	(524) *			0-15.0		15.0-46.0	○	1974
65	8761	Kharzat	96° 17' 44"	46° 20' 39"	2151	79.8		8.70	14.72	7.20	104	(157) *	14.1	(11.2) *	0-14.1		14.1-79.8		1980
66	45		96° 17' 50"	46° 20' 46"	2148	76.4		0.53	13.66	7.42	6	8	62.7	0.13	0-22.1		22.1-76.4	○	1975
67	23		96° 17' 51"	46° 20' 27"	2161	75.8		5.80	10.32	28.83	17	81	52.5	1.54	0- 9.0	9.0- 45.4	45.4-75.75	○	
68	31		96° 17' 52"	46° 21' 20"	2137	57.7		1.20	0.85	31.31	3	6	46.8	0.13	0- 8.2		8.2-57.7	○	
69	35		96° 17' 55"	46° 22' 05"	2110	59.0		1.30	4.30	33.53	3	6	50.6	0.12	0- 4.4		4.4-59.0	○	
70	54		96° 18' 57"	46° 21' 28"	2125	33.0									0- 3.5	3.5- 18.6	18.6-33.0	○	1964
71	41		96° 18' 51"	46° 21' 02"	2142	79.8		0.80	1.48	32.11	2	5	67.4	0.07	0- 8.0	8.0- 11.5	11.5-79.8	○	1980
72	40a		96° 19' 20"	46° 20' 45"	2149	40.6		11.10	0.61	16.32	59	81	20.1	4.01	0-22.6		22.6-40.6	○	1981
73	42		96° 20' 06"	46° 20' 20"	2162	94.7		0.83	5.33	7.58	9	34	25.9	1.32	0-25.9	25.9-94.7			1990
74	39a		96° 18' 45"	46° 20' 19"	2157	73.0		4.20	7.73	11.72	31	53	20.3	2.63	0-28.0		28.0-73.0	○	
75	123		96° 18' 39"	46° 20' 15"	2158	90.0	22.5-64.8	6.70	8.0	28.6	20	(36) *	43.0	(0.8) *	0-43.0	43.0-66.0	66.0-90.0		
76	44b		96° 19' 49"	46° 19' 46"	2158	60.0	41.37-54.0	3.00	24.26	3.41	76	196	60.0	3.3	0-60.0				
77	117		96° 18' 37"	46° 19' 30"	2201	79.0	44.04-60.55	2.40	41.00	1.50	138	207	22.0	9.4	0-60.0	60.0-79.0			
78	8818	Olon Nuur	96° 19' 00"	46° 19' 02"	2235	46.0	10-21,30-41						17.0		0-17.0		17.0-46.0		
79	32		96° 19' 56"	46° 18' 18"	2245	147.0	21.0-33.0								0-32.9	32.9-147.0			1981
80	1620*		96° 18' 00"	46° 18' 00"	2302	102.0			30.20						0-90.0		90.0-102.0	○	
81	33		96° 20' 45"	46° 19' 50"	2164	106.0									0-19.2	19.2-67.2	67.2-106.0		1990

Note: Code No. with and without * correspond to well to use groundwater and well for hydrogeological study , respectivel (-)*:Estimated value

Table 6.1 Well Inventory (4/4)

Map No.	Code No.	Area	Coordination		Elevation (m)	Depth (m)	Screen (m)	Pumping Rate Q(liter/sec)	S.W.L (GL-m)	Drawdown(m)	Specific Capacity (m^3/day/m)	Transmissivity (m^2/day)	Thickness of permeable formation (m)	Permeability coefficient (m/day)	Stratigraphy (m)			Geologic Column	Construction Year
			Coordinate X	Coordinate Y											Quaternary Deposit	Neogene Deposits	Consolidated Rocks		
82	115	Olon Nuur	96° 22' 00"	46° 19' 46"	2155	101.4	16.2-68.2	1.20	5.17	31.51	3	0	3.0	0.1	0-3.0	3.0-63.6	63.6-101.4		
83	34		96° 21' 30"	46° 19' 39"	2160	55.9		2.00	11.27	15.83	11	30	14.1	2.16	0-10.7	10.7-41.8	41.8-56.0	○	1980
84	25		96° 20' 21"	46° 19' 30"	2190	175.0		2.70	28.56	2.57	91	120	20.0	6.01	0-48.4	48.4-130.0	130.0-175.	○	
85	26		96° 20' 48"	46° 19' 22"	2190	120.0		5.00	27.46	6.06	71	97	33.9	2.85	0-34.8	34.8-120.0		○	1982
86	111		96° 20' 48"	46° 19' 20"	2185	82.2	15.8-60.7	2.50	15.85	31.65	7	17	60.2	0.3	0-60.7	60.7-82.2			
87	259		96° 20' 36"	46° 19' 02"	2201	80.0		1.50	45.0	10.0	13	0			0-47.0	47.0-			
88	122		96° 20' 37"	46° 19' 00"	2188	120.5	25.8-63.5	7.10	26.78	6.63	93	80	58.2	1.4	0-58.2	58.2-120.5			1982
89	27		96° 21' 16"	46° 18' 51"	2200	150.0		3.10	27.91	4.67	57	75	36.9	2.03	0-42.6	42.6-150.0		○	1964
90	121		96° 22' 08"	46° 18' 47"	2188	100.0	22.4-55.0	1.53	27.00	13.66	10	4	7.0	0.6	0-7.0	7.0-83.5	83.5-100.0		1982
91	105		96° 20' 17"	46° 18' 45"	2215	100.0	29.4-77.2	1.58	40.85	19.20	7	31	70.5	0.4	0-70.5	70.5-100.0			
92	29		96° 20' 16"	46° 18' 41"	2217	64.4	36.0-48.0								0-64.4				1982
93	46		96° 22' 01"	46° 18' 30"	2201	54.0	23.0-35.0	2.1	16.1	0.40	454	(590) *			0-30.0	30.0-54.0			
94	28		96° 20' 46"	46° 18' 26"	2227	140.0									0-55.5	55.5-140.0			1982
95	112		96° 21' 05"	46° 18' 22"	2225	100.0									0-30.0	30.0-54.8	54.8-100.0		
96	72		96° 20' 10"	46° 18' 20"	2240	165.5		0.05	34.6	2.9	1	(3) *			0-30.0	30.0-50.0	50.0-165.5		1990
97	47		96° 23' 09"	46° 17' 53"	2220	145.0		3.17	16.84	14.32	19	288	17.7	16.3	0-17.7	17.7-134.8	134.8-145.	○	
98	50p		96° 24' 03"	46° 17' 25"	2225	150.0		2.50	11.52	15.33	14	87	31.4	2.77	0- 31.4	31.4- 150.0			1975
99	118		96° 23' 26"	46° 17' 13"	2250	80.0	21.0-30.0	1.22	20.80	14.50	7	52	25.6	2.04					
100	A1		96° 14' 50"	46° 22' 19"	2165	200.3	14-194*	3.33	11.12	73.47	4	1	(190) **	0.01	0-4		4-200.3	○	1998
101	A2		96° 18' 19"	46° 24' 19"	2060	193.0	91-187*	0.99	2.60	5.0	17	10	(60) **	0.17	0-5.5		5.5-193	○	1998
102	A3		96° 11' 39"	46° 24' 29"	2150	150.3	12-144*	9.90	3.90	60.13	14	7	(140) **	0.05	0-4		4-150.3	○	1998
103	A4		96° 16' 42"	46° 22' 50"	2120	160.2	16-154*	16.67	4.16	11.49	125	205	(150) **	1.37	0-4		4-160.2	○	1998
104	B1		96° 14' 17"	46° 22' 10"	2175	56.2	8-50*	1.23	20.15	12.38	9	3	(34) **	0.09	0-10		10-56.2	○	1998
105	B2		96° 18' 12"	46° 25' 36"	2030	73.6	31-61*	0.50	11.67	10.94	4	5	(24) **	0.21	0-8	8-36	36-73.6	○	1998
106	B3		96° 18' 26"	46° 24' 55"	2050	131.0	76-118*	0.67	25.22	32.55	2	1	(30) **	0.04	0-45		45-130	○	1998
107	B4		96° 19' 38"	46° 26' 04"	2020	41.6	5-41*	1.23	4.2	10.5	10	4	(35) **	0.11	0-4		4-41.6	○	1998
108	B5		96° 19' 01"	46° 20' 24"	2157	80.0	26-74*	6.7	3.22	19.23	30	39	(30) **	1.31	0-35	35-80		○	1998
109	B6		96° 20' 45"	46° 19' 11"	2190	120.0	24-114*	10.08	24.01	1.04	838	31392	(42) **	747	0-60	60-120		○	1998

Note: Code No. with and without * correspond to well to use groundwater and well for hydrogeological study , respectivel (-)*:Estimated value
*:Top-Bottom;Screen pipes are partially installed. (-)**:Length of the open hole part

Table 6.2 Hydrogeological Description of Formations in the Study Area

Era / Period	System	Maximum thickness (m)	Explanation
CENOZOIC QUATERNARY QIV	Upper Quaternary Recent river deposits.	>20	Distributed in river and stream bed. Mainly sandy loam and loam. And sand, clay, gravel. A scattered and limited aquifer in Sukhin Khooloi.
QII-III	Middle and Upper Quaternary Fan and talus deposits	>100	Distributed widely in the area. Gravel, sandy gravel, sand. Most exploitable aquifer occurs in Olon Nuul, where the deposit is thick.
TERTIARY N2at	Neogene System	>100	Mainly covered by Quaternary sediments in the area. Unconsolidated generally. Very low productive aquifer in Sukhin Hooloi and Olon Nuul. Reddish clay with sand and gravel.
PALEOZOIC DEVONIAN D1-2	Lower and Middle Devonian series	>1000	Distributed in the limited area. Sandstone and conglomerate. No aquifer in Study Area.
CAMBRIAN Lower and Middle E1-2	Tsagaan Olom Series	>1000	Distributed in the south end of Study Area. Mainly carbonate rocks.
PRECAMBRIAN PROTEROZOIC Vht	Vend Series Khantaishir Series		Limited distribution in the mountain range on the south of Study Area.
R1-3gb	Upper-Lower Rephean Series		Distributed in the southwest mountain range of Altai City. Mainly Dunite and Serpentine, Peridotite. Springs occur in places along faults.
PR1 PR1am	Gobi Altai and Ulaantolgoy Series	2950	Distributed widely in the northwest and central mountainous region in Study Area. Fractured aquifers occur in Kharzat and Sukhin Hooloi.
PROTERPZOIC γ R2-3	Intrusive Rock of Riphean Series		Limited distribution in the eastern area.

Table 6.3 The Result of Water Level Observation

WLR No.	Well Name	Depth (MP-m)	M.P. (GL+m)	24-Jun	7-Jul	14-Jul	19-Jul	22-Jul	13-Aug	27-Sep	5-Nov	5-Dec	4-Jan	15-Jan	14-Feb	9-Mar	10-Apr	1-May	19-May	5-Jun	30-Jun	1-Aug	31-Aug, 1-Sep.	1, 2-Oct.	26,27-Oct.
No.1	Intake Well*	70.00	0.09	6.18	6.1		6.05	6.05	5.93	5.94	5.81	5.99	6.1	6.2	6.28	6.4	6.54	6.38	6.21	6.3	6.35	6.18	6.15	5.97	6.00
No.2	School Well	6.00	-0.37	4.9			4.87	4.78	5.05	5.45	5.46	5.48	5.5	5.7	6	5.22	5.14	5.06	5.12		5.21	4.97	5.27	5.50	5.45
No.3	Park Well	31.00	0.65	10.67	10.67			10.7	10.67	10.7	10.7	10.72	10.7	10.7	10.71	9.21	broken	-	-	-	-	-	-	-	-
No.4	Power Station*	30.00	0.55	7.09	7.04		7	6.98	6.93	6.97	7.02	7.05	7.1	7.12	7.15	7.2	7.16	7.16	7.14	7.13	7.05	6.90	6.83	6.86	6.90
No.5	Kharzat Zuun Well*	(50?)	0.00				9.1	8.96	9.05	8.67	8.94	8.96	9.7	9.9	10.1	10.39	10.83	9.62	9.92	10.15	10.57	10.36	10.07	9.59	9.40
No.6	Water Supply*	6.60	0.35	2.7	2.75		2.73	2.69	2.85	3.12	3.21	3.28	3.35	3.35	3.34	3.2	2.95	2.86	2.87	2.98	2.98	2.80	3.03	3.20	3.22
No.7	Brick Well	51.00	0.47	12.25	12.26		12.23	12.24	12.17	12.78	12.23	12.3	12.36	12.4	12.48	11.70△	11.70△	-	-	-	-	-	-	-	-
(No.8)	Gashuny Well	3.35	0.40	2.4	2.68	1.78		2.95	3.08	3.34	3.4	3.4	3.5	3.4	3.4	3.26	3.2	3.15	2.92		2.91	2.95	3.21	3.56	3.78
No.9	Ulaan Sharon	2.20	0.00	1.68	1.57	0.52	1.32	1.3	1.45	1.3	1.37	1.00**	frozen	frozen	frozen	frozen	1.80**	1.90**	0.83		1.40	0.75	1.32	1.44	1.38
(No.10)	Estin Amni	1.80	0.00	0.63	0.81	0.73		0.6	0.83	0.85	0.86	0.73**	frozen	0.73**	frozen	frozen	0.7	0.7	0.31	0.9	0.72	0.00	0.75	0.85	0.80
-	Sukhin Khooloi Ekh	4.20	0.75		3.12			2.94	3.05	3.23	3.3	3.4	3.30**	3.30**	0.65**	frozen	3.26	3.19	3.36		3.30	2.80	2.96	3.24	3.40
-	Ontsogyn Well	1.70	0.00	0.78	0.68	0.59		0.5	0.72	1.3	1.4	1.00**	0.65**	0.65**	frozen	0.65**	1.00**	1.40**		1.05	1.30	0.60	0.91	1.05	1.34
-	Mandaliin Amni		0.00		2.96			2.93	3.08	3.15	3.16	3.1	frozen	frozen	frozen	3.2	3.2	3.4	3.25	3.35	3.15	3.07	2.83	2.71	2.72
-	Boini Well	4.20	0.80		3.39			3.15	3.23	3.54	3.86	4.2	frozen	frozen	frozen	frozen	4.2	4.2	4.15		4.03	3.40	3.50	3.72	3.89
-	Sukhin Khooloi Wel	2.10	0.30	0.89	0.99	1.19	0.72	0.82	1.26	1.4	1.5	1.00**	frozen	frozen	frozen	frozen	1.50**	1.50**	1.3		2.04	0.85	1.42	1.75	1.90
-	Tsagaan Dersny We	4.50	0.70			4.32		4.39	no water	no water	no water	no water	no water	no water	no water	no water	no water	no water							
	Tsagaan Dersny 2																		1.55		1.40	1.07	1.80	1.95	Dry
-	Mountain Hand Dug	1.16	-1.00			0.75		0.74	0.8	0.84	0.85	frozen	frozen	frozen	frozen	frozen	frozen	no water	-	-	-	-	-	-	-

** Partially froze △stucked

Table 6.4 Features of Intake Wells

	Item		Unit	Intake well				
1	Well code			CK-4923	CK-4924	CK-8761	CK-2 (8850)	CK-22
2	Construction year			1979	1979	1986	1995	1986
3	Depth of Well		m	39	62	30	52	45
4	Depth of Installed Pump		m	37.5	22	29	33	42
5	Pumping Rate		l/s	7.5	9.5	6.0	7	7.6
6	Statistic Water Level		m	GL-5.0	GL-7	GL-6	GL-7	GL -8
7	Dynamic Water Level		m	GL-9.0	GL-11	GL-10	GL-13	GL -18
8	Drawdown (SWL - DWL)		m	4	4	4	6	10
9	Specification of Pump			$8x25m^3/hx80$	8x25x100	8x25x180	8x25x100	
10	Depth of Aquifer	Upper	m	GL-10	GL-11	GL-18	GL-14	GL-12
		Lower	m	GL-24	GL-25	GL-28	GL-47	GL-20
	Comment					under repair		abandoned

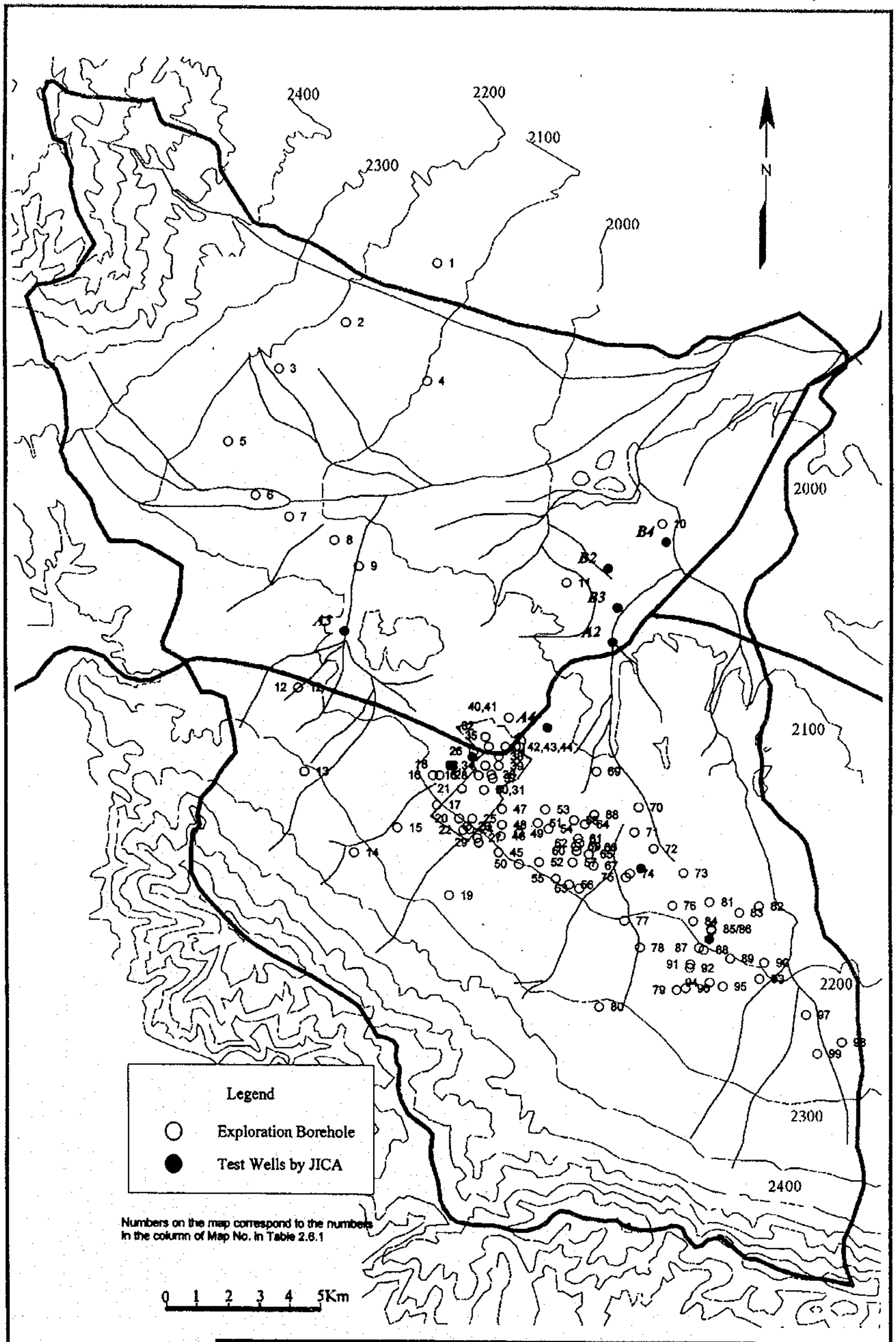


Figure 6.1	Location Map of Exploration Boreholes
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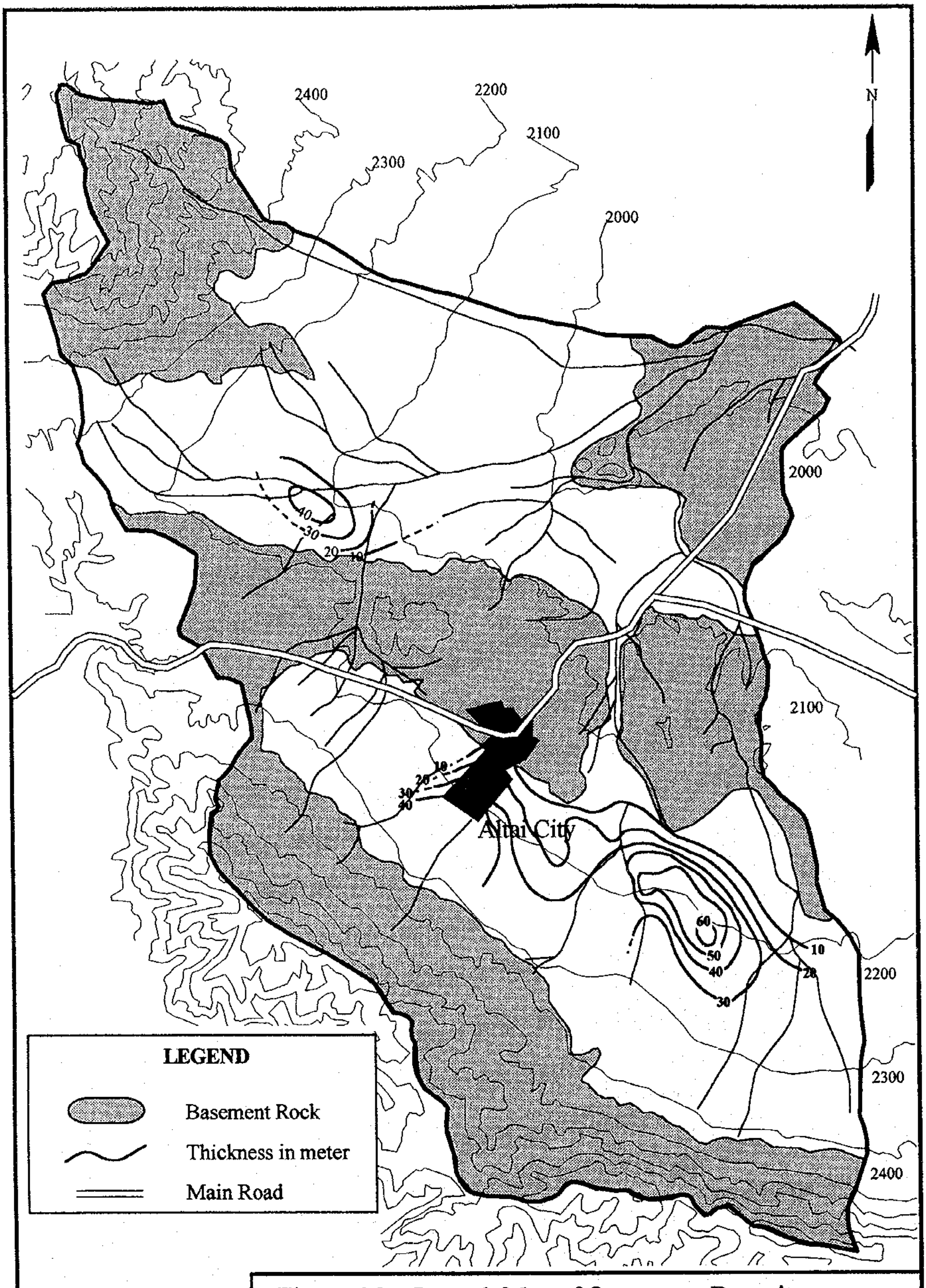

Figure 6.2 Isopach Map of Quaternary Deposits

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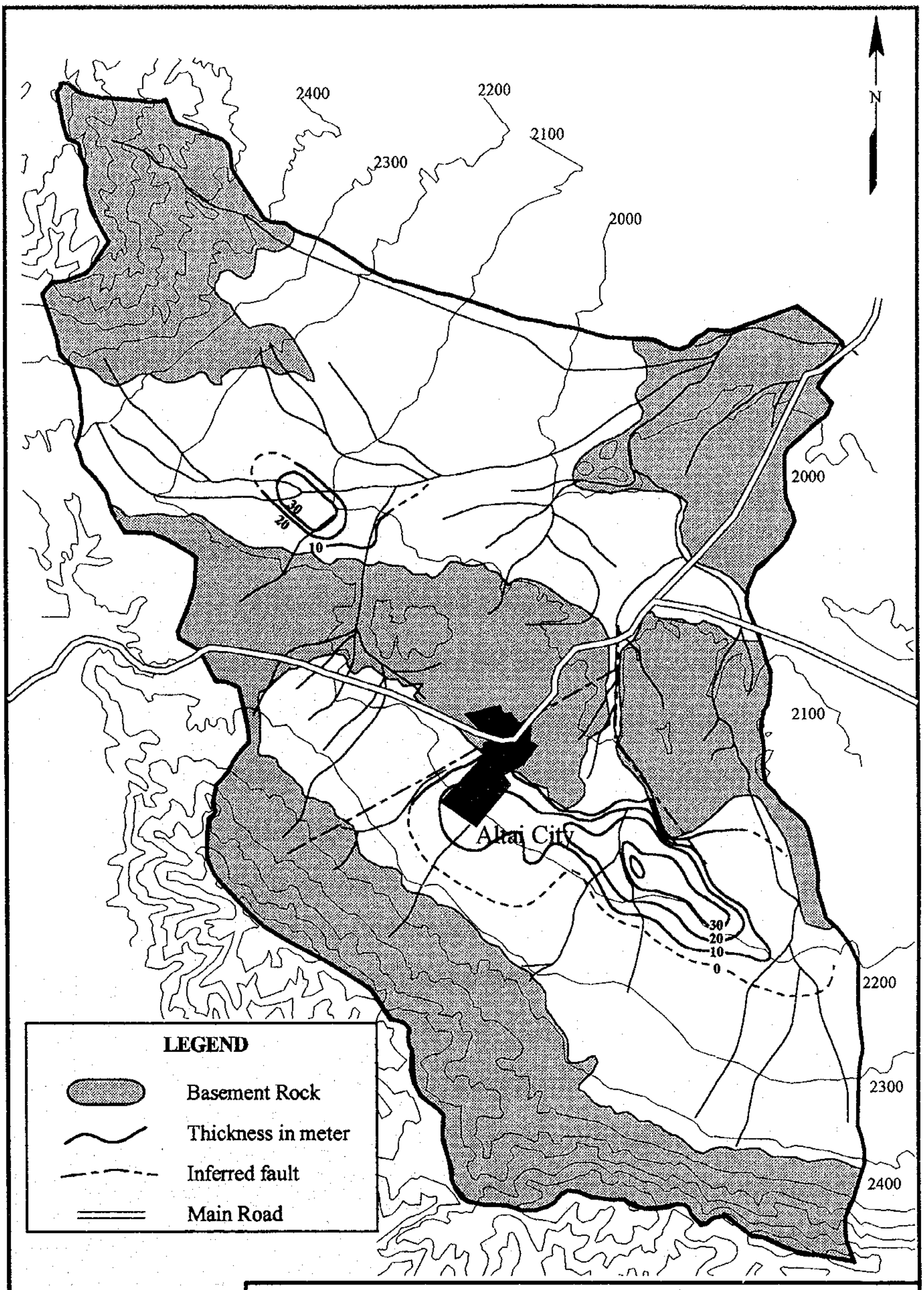

Figure 6.3 Isopach Map of the Main Aquifer

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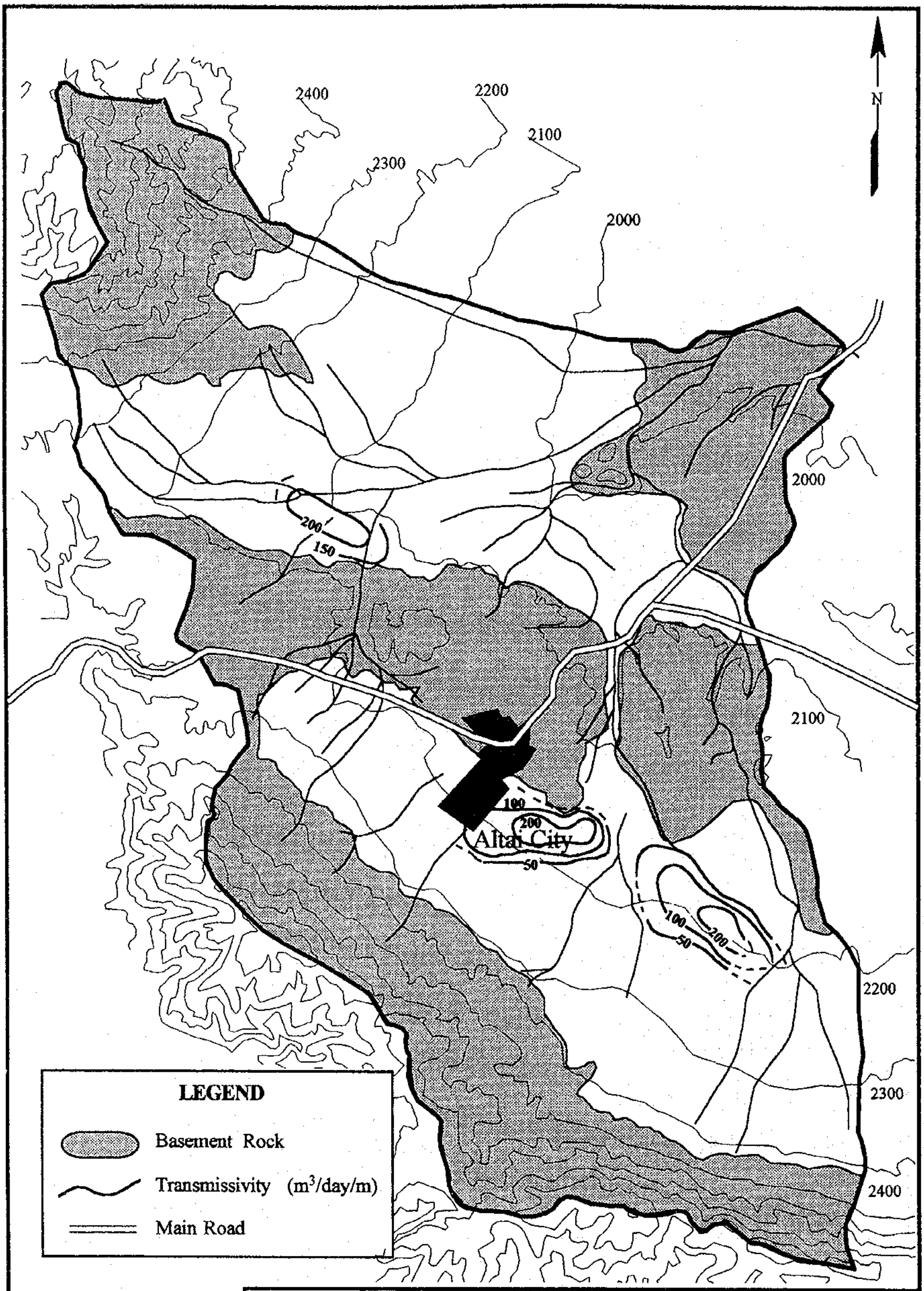

Figure 6.4 Transmissivity

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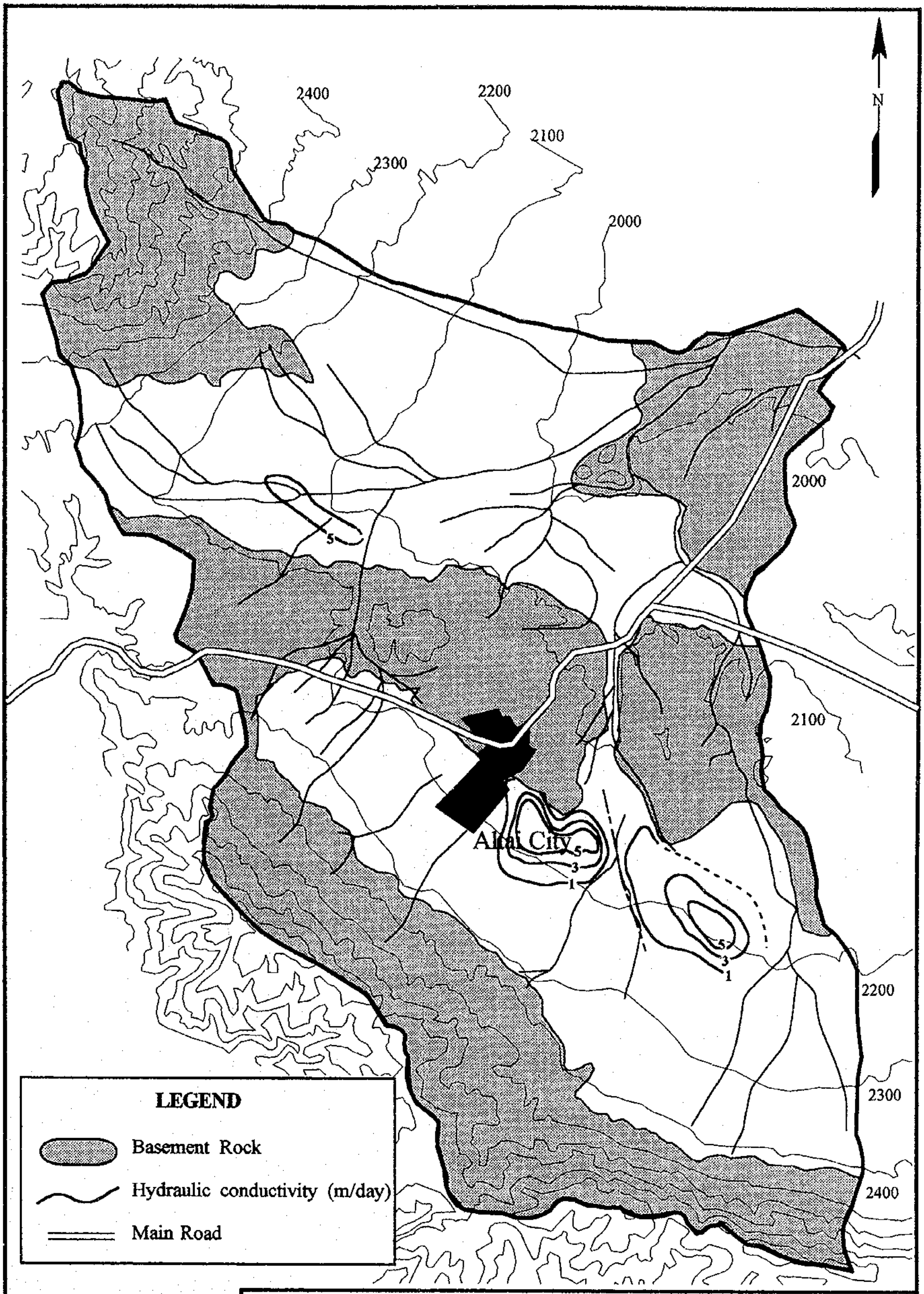

Figure 6.5 Hydraulic Conductivity

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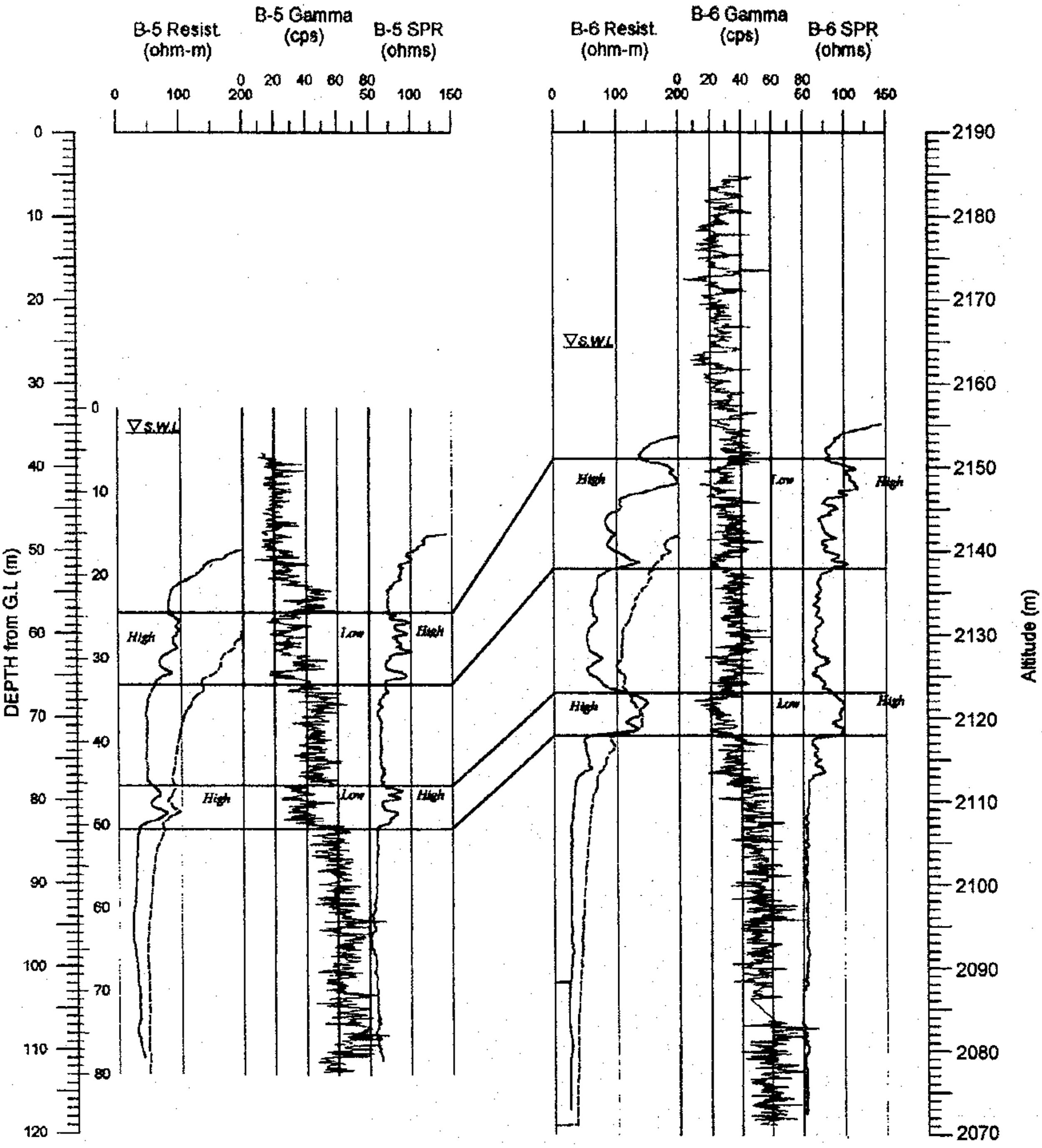

Figure 6.6 Geophysical Log of B-5 and B-6

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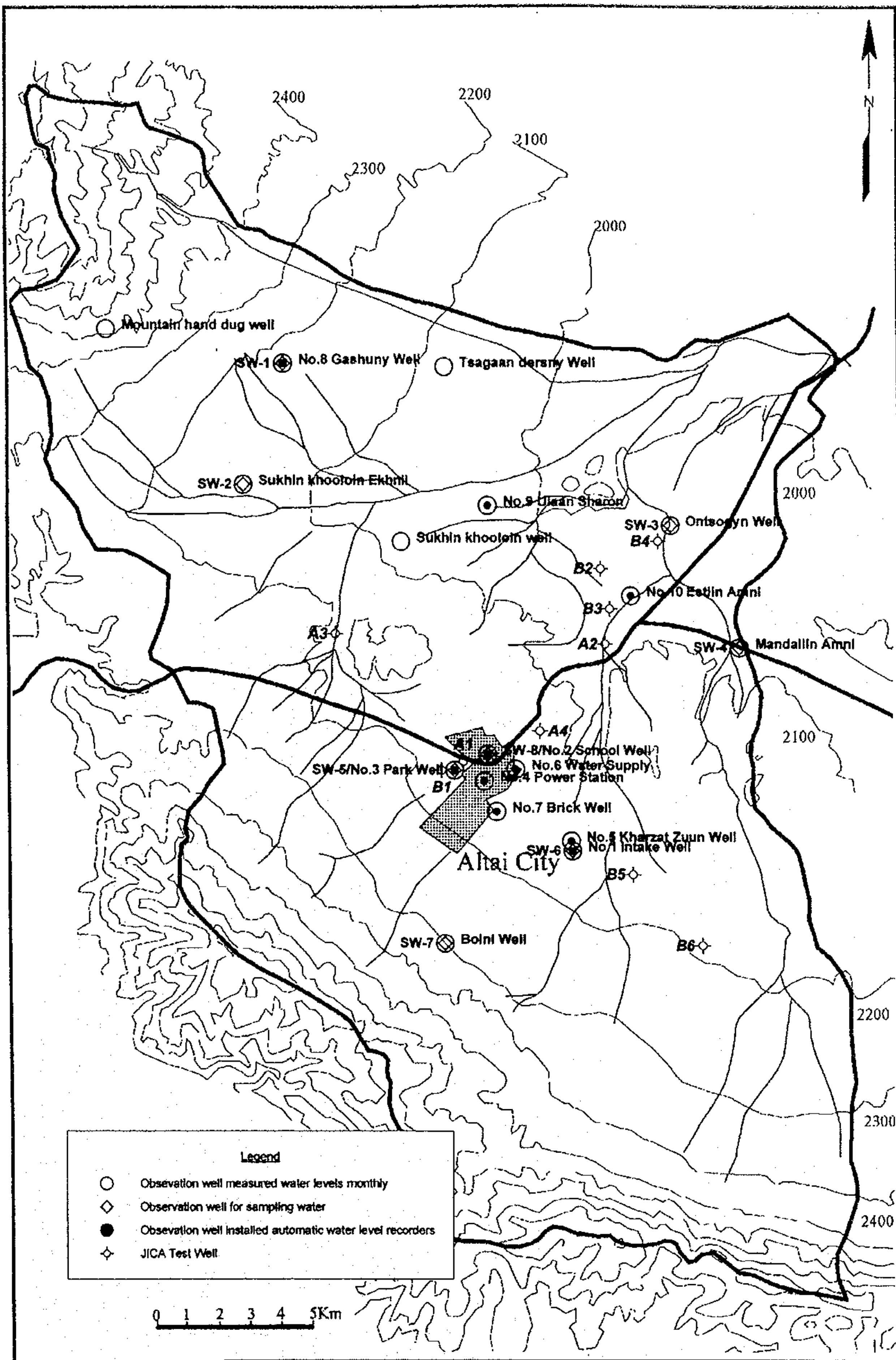

Figure 6.7	Location Map of Observation Wells
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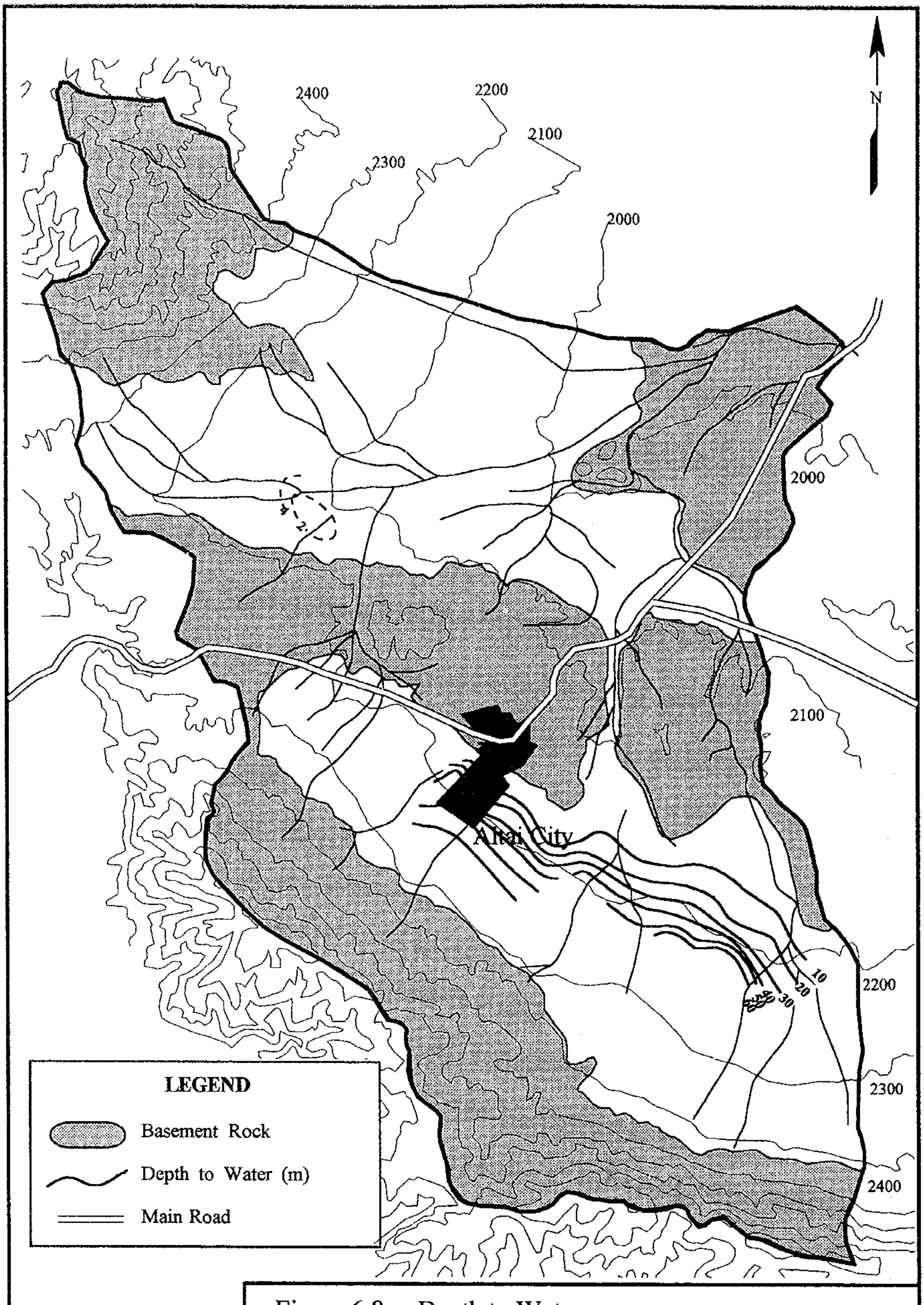

Figure 6.8 Depth to Water

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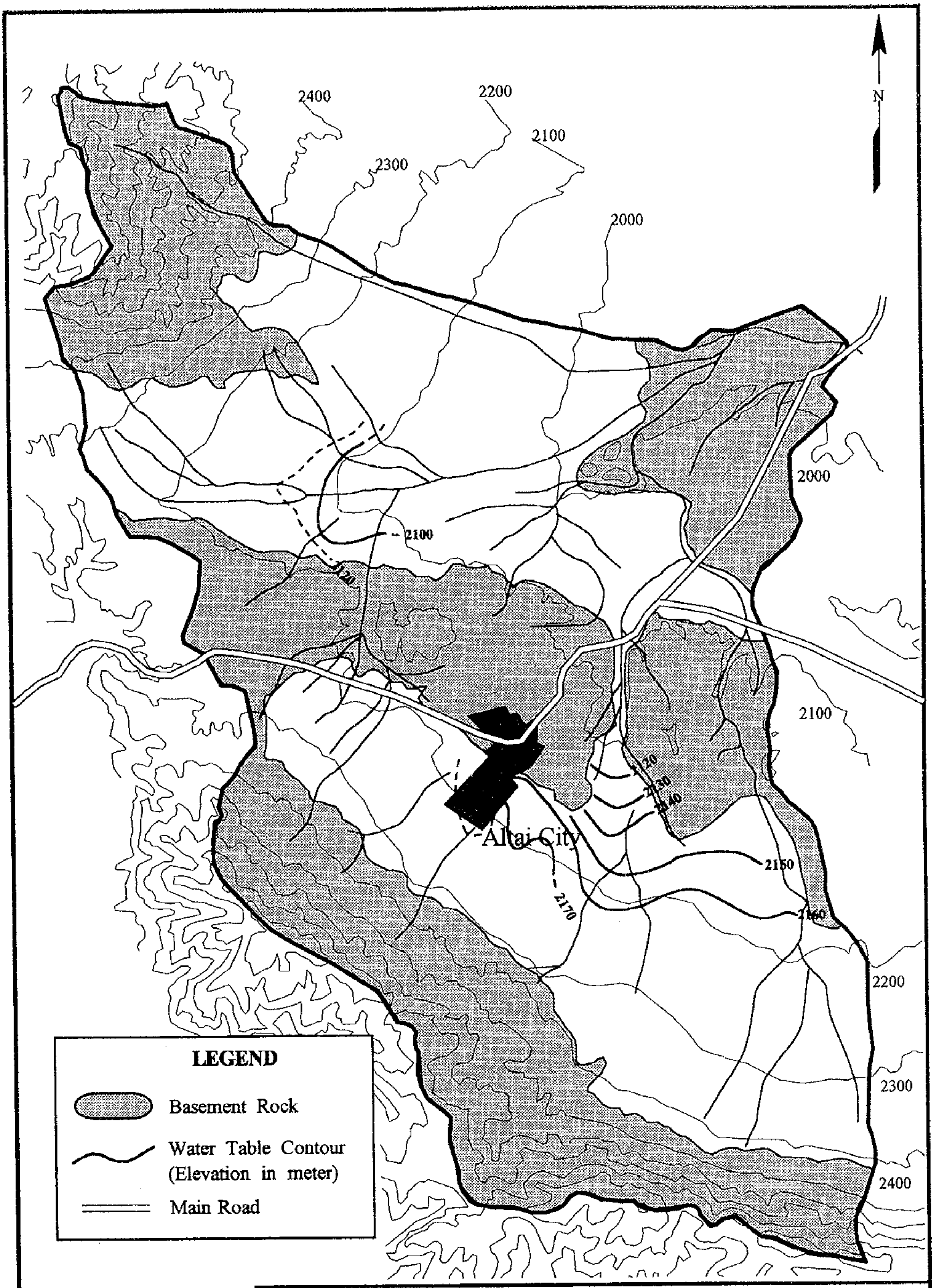

Figure 6.9 Water Table Contour

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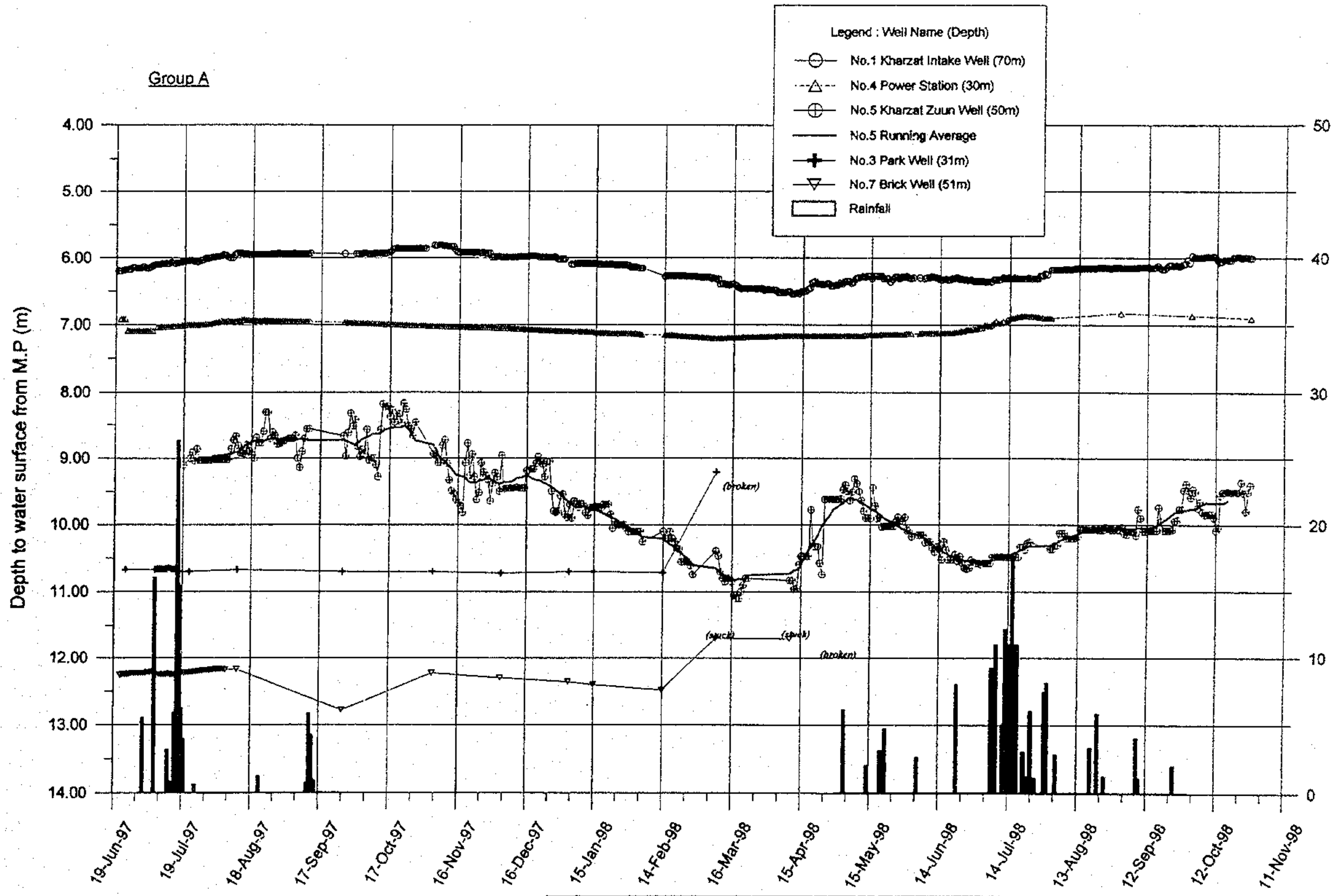

Figure 6.10(1) The Result of the Water Level Measurement of Group A

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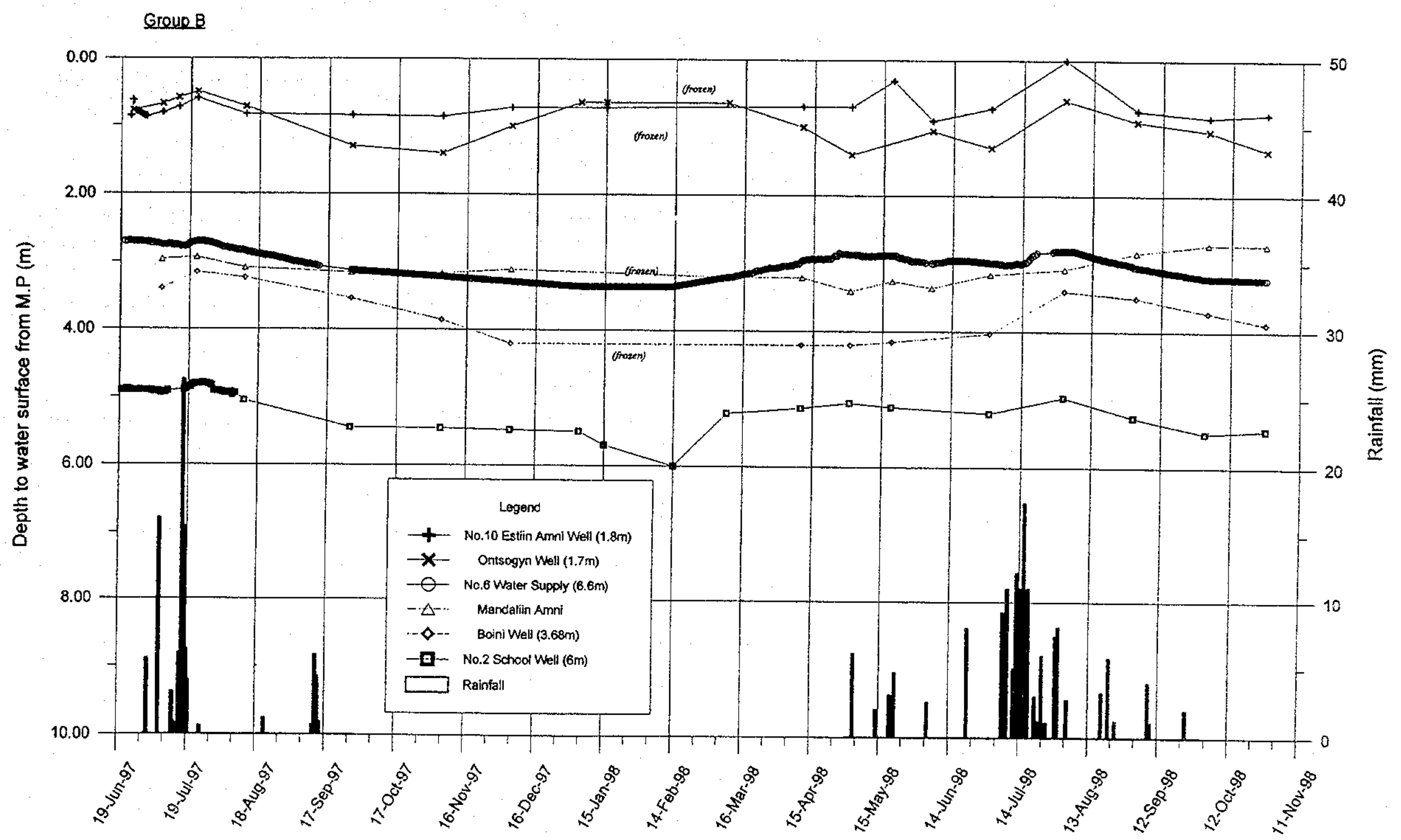

Figure 6.10(2) The Result of the Water Level Measurement of Group B

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Group C

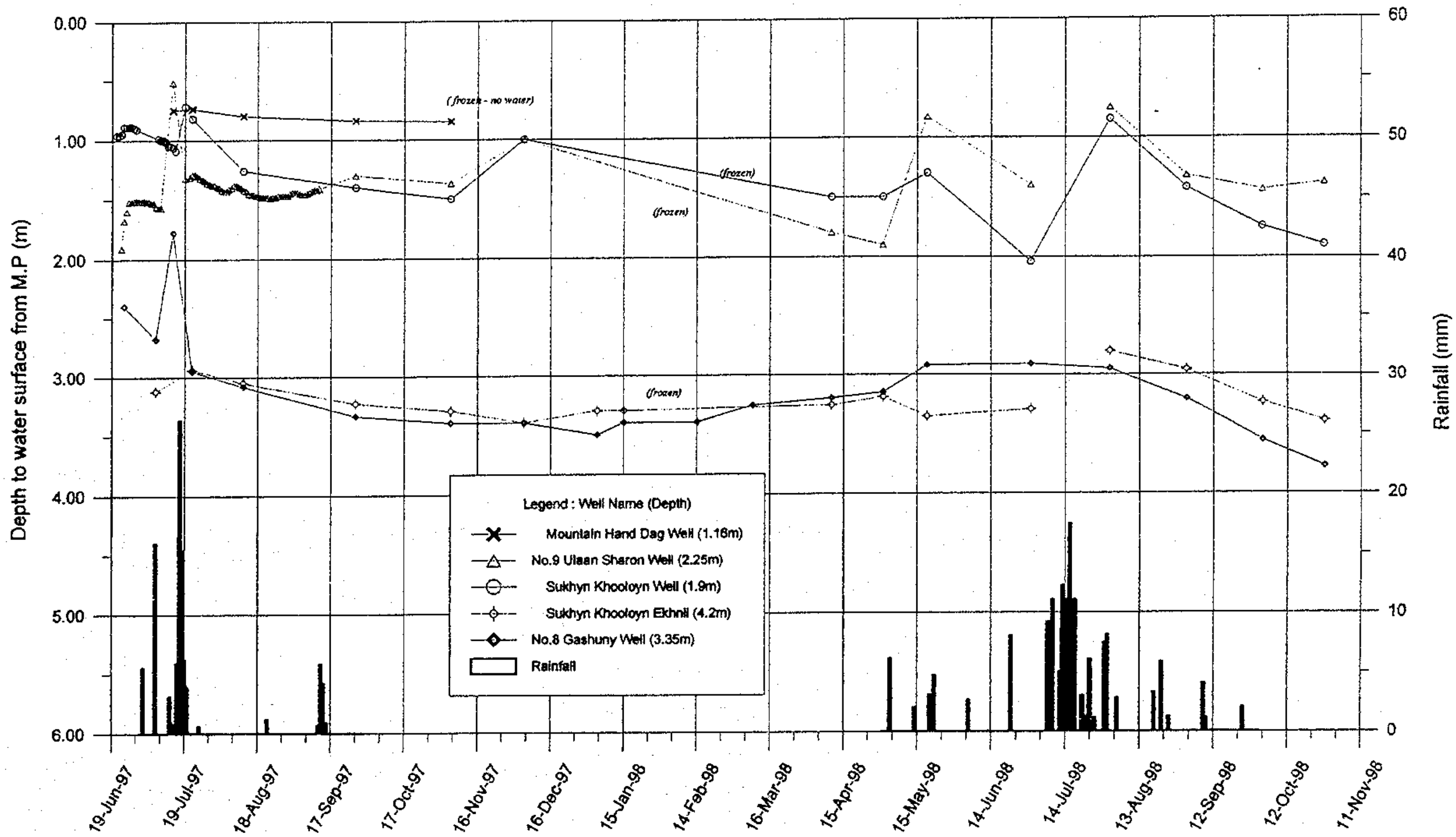

Figure	6.10(3) The Result of the Water Level Measurement of Group C
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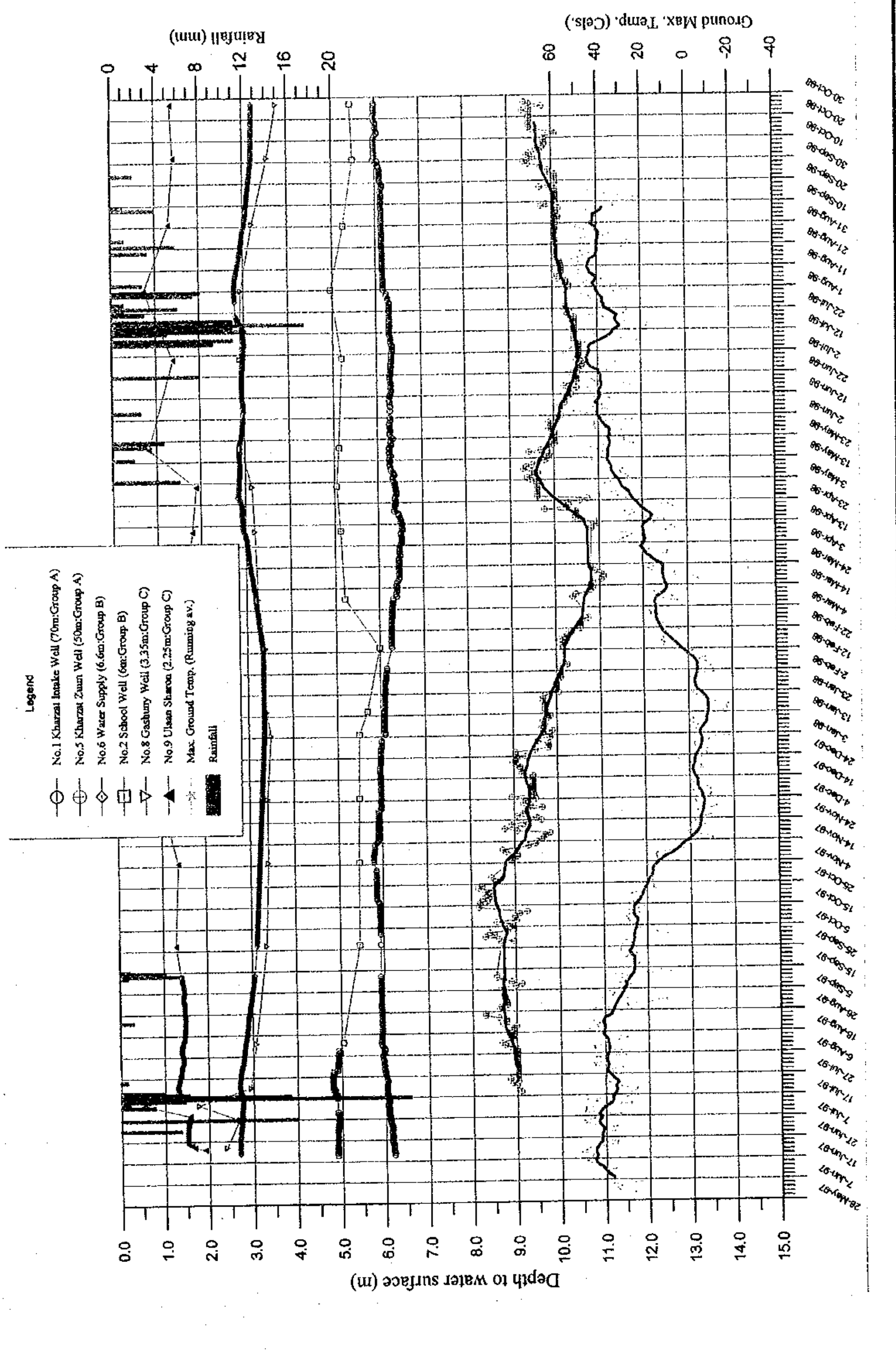

Figure 6.10 (4) Water Level Fluctuation in the Study Area

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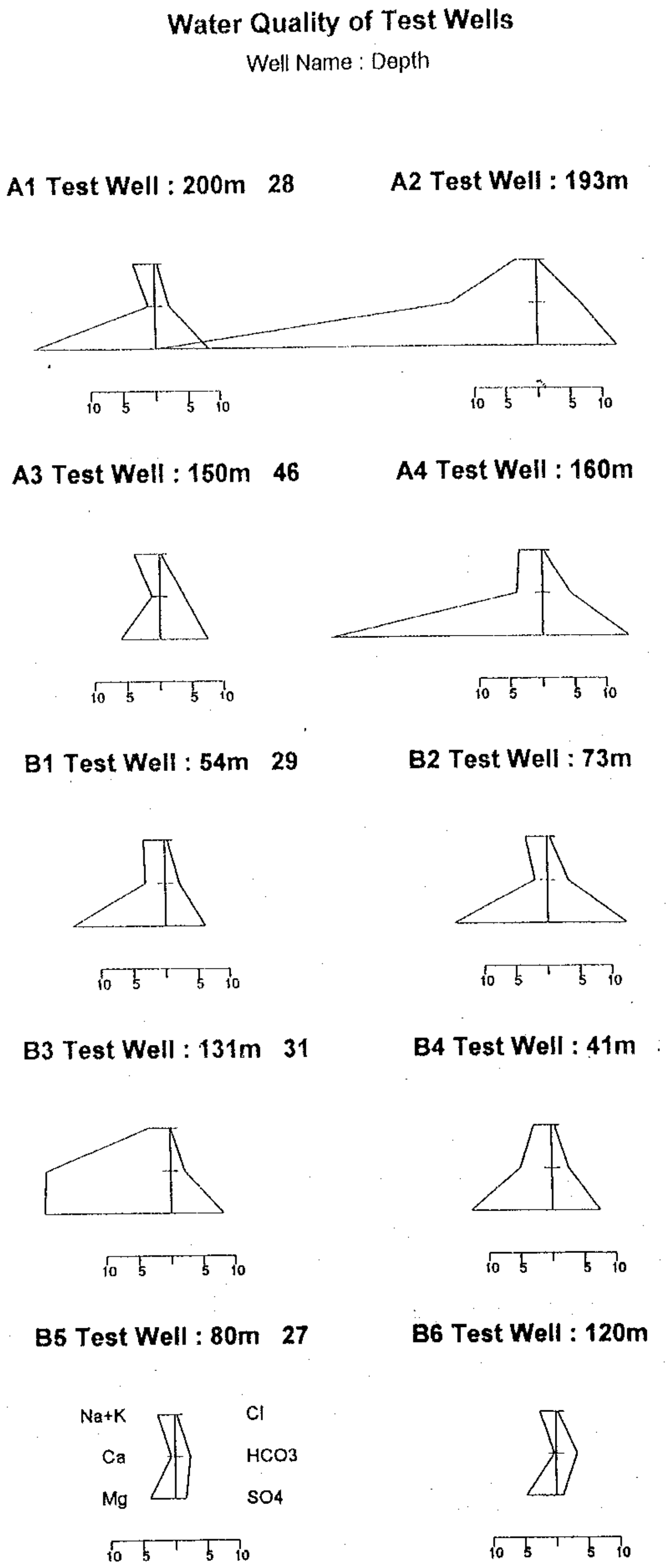

Figure 6.11(1)	Stiff Diagrams of Test Wells
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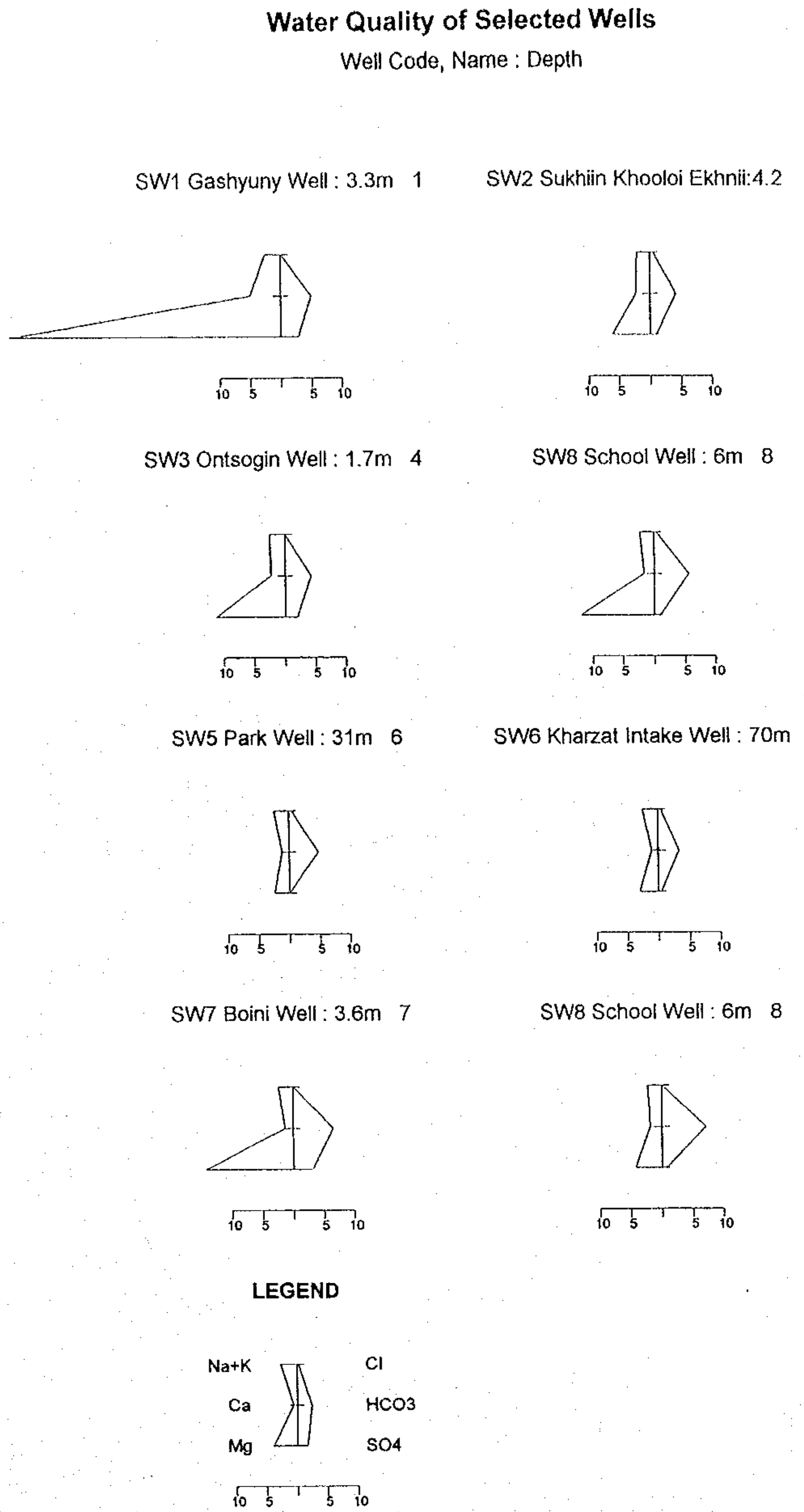

Figure 6.11(2) Stiff Diagrams of Selected Wells

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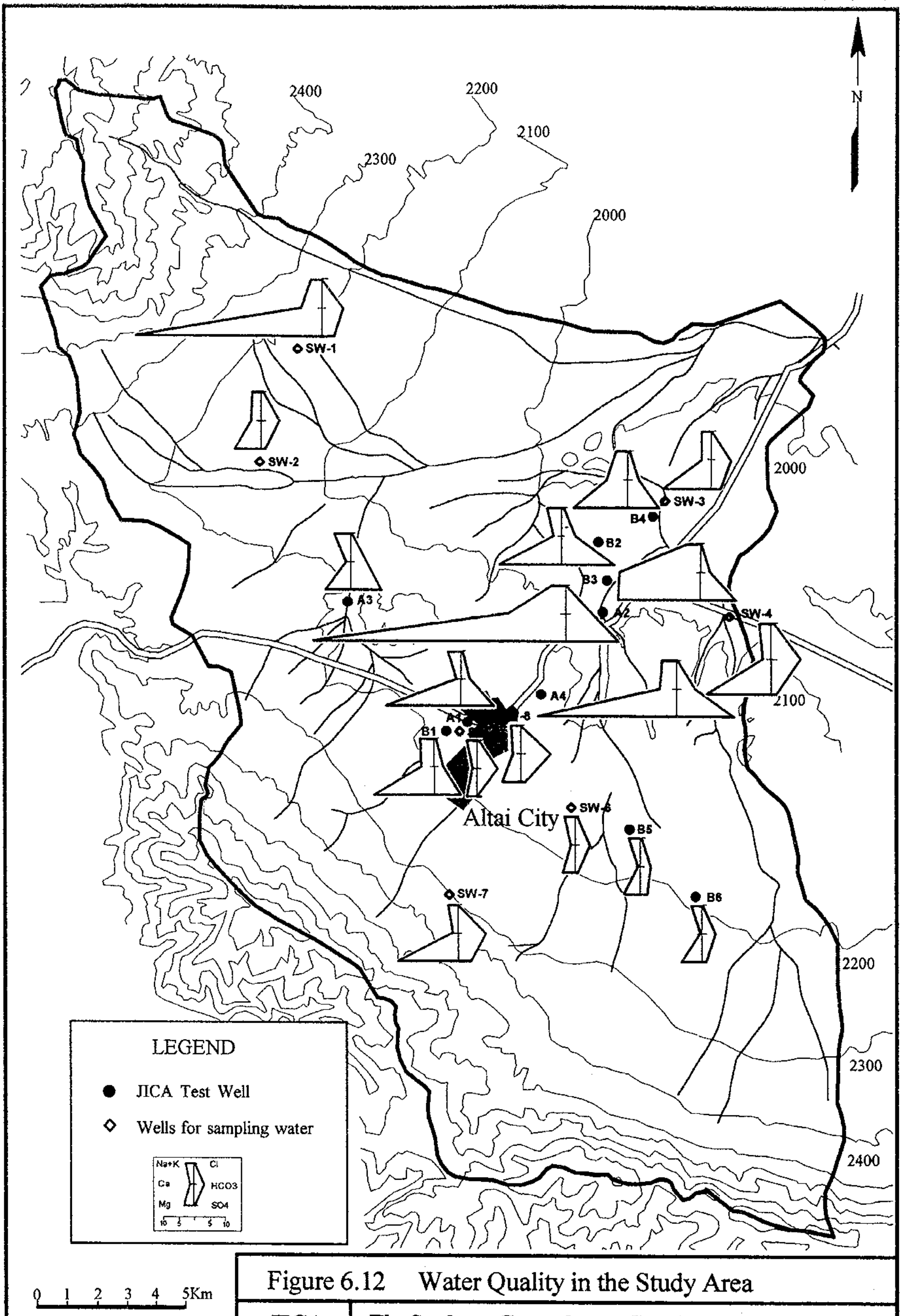

Figure 6.12 Water Quality in the Study Area

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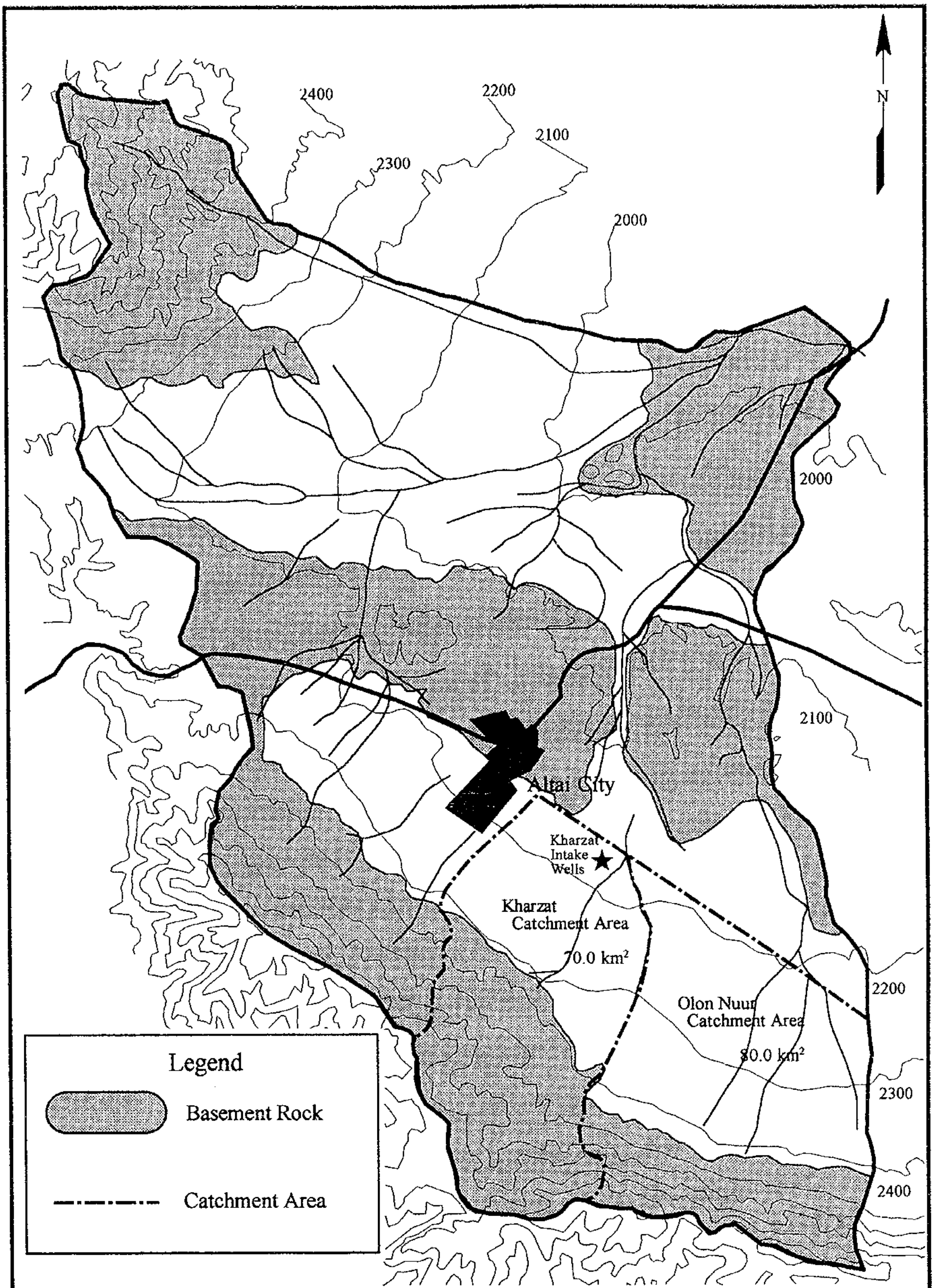

Figure 6.13 Catchment Area of Kharzat and Olon Nuur

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