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ULAANBAATAR MUNICIPALITY
THE GOVERNMENT OF MONGOLIA

THE STUDY ON WATER SUPPLY SYSTEM IN ULAANBAATAR AND SURROUNDINGS

FINAL REPORT

VOLUME III

SUPPORTING REPORT

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Supporting Report
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I GROUNDWATER

CHAPTER 1 GEOLOGY

CHAPTER 1. GEOLOGY

1.1 GENERAL

1.1.1 Outline of the Investigation

This chapter aimed to realize the capacity of groundwater resources. These were roughly classified into two, alluvial deposit and of basement rocks that would be expected good aquifer. Consequently, geological survey was conducted to clarify the distribution and property of alluvial deposits and fractured zones. Survey items are as follows:

1) collection and review of existing geological data,
2) interpretation of satellite images and aerial photographs,
3) geological field reconnaissance, and
4) making the geological maps for the basement map of hydrogeological map.

1.1.2 Regional Geology

Mongolia is a mountainous country. Basically, its topography consists of mountains, hummocks and high denudation plains, forming three major regional stages on its surface. Mountains (1,500~3,000m) occupy more than 40 percent of Mongolia's total territory, hummocks (1,000~1,500m) 40 percent and denudation plains about 15 percent. Within Mongolia, mountains are found mainly in the northern and western regions, and denudation plains in the south-east; hillocks, equally distributed on its entire territory, are highly developed in the desert, closed-drainage region south of the world watershed.

Tectonically, Mongolia basically comes under the Ural-Mongolian Paleozoic fold belt, and only a portion of it belongs to the Mediterranean - Central Asiatic branch of Tethys. The geological structure of Mongolia contains seven unit of folded zones as the followings (refer to Fig. I.1.1).

I. Mongolian Altai Folded Zone,
II. North Mongolian Folded Zone,
III. Mongol Pre-baigalian Folded Zone,
IV. Central Mongolian Folded Zone,
V. South Mongolian Folded Zone,
VI. South Gobian Folded Zone,
VII. Inner Mongolian Folded Zone.

Geologically, Mongolia contains metamorphic, magmatic and clastic complexes of all geological ages. The surface of the mountain structures usually has Pre-Cambrian and

Paleozoic geosynclinal complexes, characterized to a significant extent by deformations and metamorphic changes. In intermountane hollows and on a considerable part of Gobi, Mesozoic and Cenozoic sediments cover the faulted foundations.

The study area belongs to Mongol Pre-baigarian folded zone that is divided into three sub-folded zones, arranging from northwest to southeast.

(1) North Hentii folded zone is situated northern part of the area which is represented by the Charaa and Mandal Formation of the Riphean System.

(2) Hentii folded zone occupied both side of Tuul River. This zone is characterized by Hentii Series that consists of the Devonian rocks and lower Carboniferous pelitic rocks and middle to upper Carboniferous psammitic rocks in the area.

(3) South Hentii Caledonian folded zone is bounded by the fault with southern periphery of the Hentii Variscan folded zone. This zone is characterized by psammitic rocks predominate in Devonian deposits.

Small masses of granitic rocks occur at places. Its intrusion has had contact metamorphic effect on the surrounding rocks. Most of the original rocks are assumed to have been pelite, psammyte of the middle to upper Paleozoic.

1.2 INTERPRETATION OF SATELLITE IMAGES AND AERIAL PHOTOGRAPHS

1.2.1 General

The satellite images (1/200,000 of scale) were interpreted in the whole Study Area with an area of about 8,000km^2. And also, the aerial photographs (1/32,000 of scale) were interpreted in the Study Area without northern part of Ulaanbaatar.

Definition of Lineament

Lineament is to be defined the linear characteristics that will reflect directly and/or indirectly geological condition and geological structure on the satellite images and aerial photographs. Concretely, lineaments indicate the faults, fractured zones, lithological boundaries, beddings, joints, and schistosities.

1.2.2 Method of Landsat Data Processing

(1) Data Selection

Landsat supplies two kinds of data, MSS (Multiple Spectral Scanner) data and TM (Thematic Mapper) data. The general performance characteristics of MSS and TM are shown below.

Characteristics of MSS and TM

Sensor	Bands	Wave length (μm)	Ground resolution	Swath width
	4	0.5 ~ 0.6		
MSS	5	0.6 ~ 0.7	80 m	185 km
	6	0.7 ~ 0.8		
	7	0.8 ~ 1.1		
	1	0.45 ~ 0.52		
	2	0.52 ~ 0.60		
	3	0.63 ~ 0.69	30 m	185 km
TM	4	0.76 ~ 0.90		
	5	1.55 ~ 1.75		
	7	2.08 ~ 2.35		
	6	10.4 ~12.5	120 m	

Resolution of TM data is higher than that of MSS, and TM data can be purchased by subscene (a quarter scene) unit. Consequently, TM data is excellent to analyze the topographical and geological feature in the Study.

TM data list are show below from EOSAT CO. (U.S.A.).

Landsat Data Lists

Path - Row	Data	Cloud cover assessment (%)				
		Full	Sub			
			1	2	3	4
130-026	06/25/93	0	0	0	0	0
130-026	11/27/89	13	10	10	30	10
130-026	09/24/89	7	10	20	0	0
130-026	01/11/89	0	0	0	0	0
130-027	09/03/90	7	6	16	2	2
130-027	09/24/89	0	0	0	0	0
130-027	06/09/93	15	10	10	10	10
130-027	01/11/89	0	0	0	0	0
131-026	09/10/90	1	0	0	0	3
131-027	09/10/90	0	0	0	0	0
131-027	11/18/89	0	0	0	0	0
131-027	10/01/89	0	0	0	0	0
131-027	08/30/89	1	10	30	2	0
132-026	09/17/90	0	0	0	0	0
132-026	06/18/89	7	10	13	1	5
132-026	12/24/88	0	0	0	0	0
132-027	09/17/90	0	0	0	0	0
132-027	12/24/88	0	0	0	0	0

1	2
3	4

TM subscene numbering

Data were selected according to the following criteria: most recent data, less cloud coverage, and high image quality

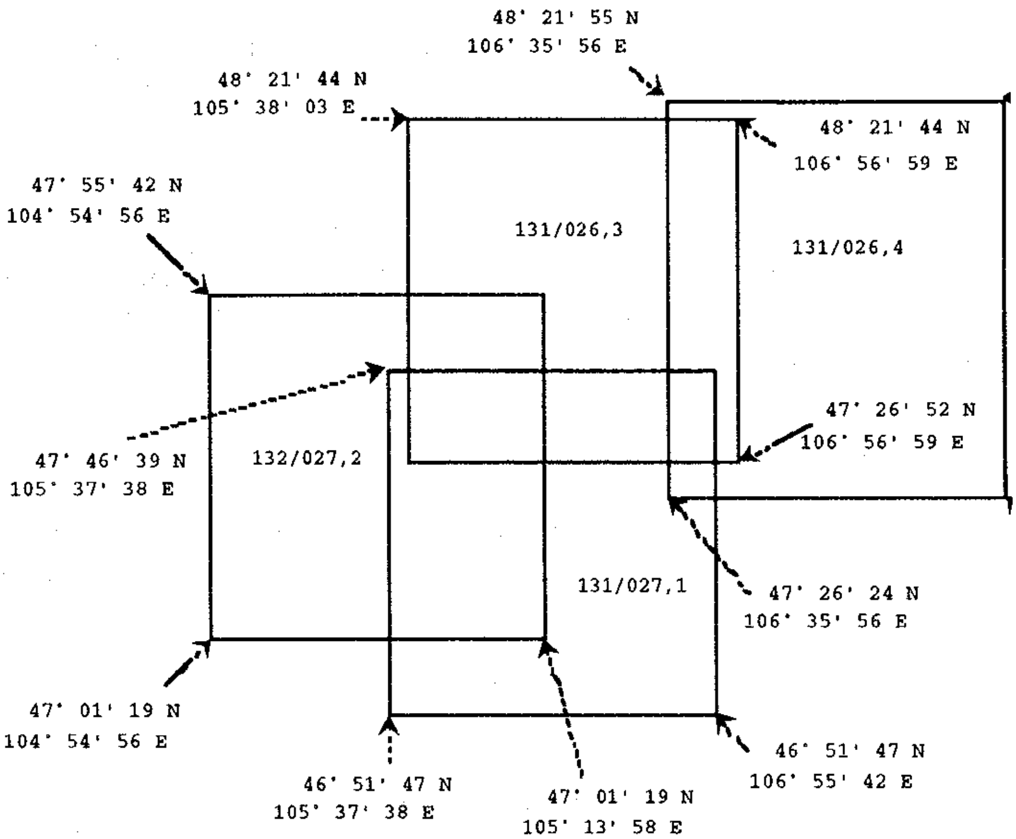
The data are selected finally as follows (refer to the following Figure).

Path 131 — Row 026 3 09/10/90

Path 131 — Row 026 4 09/10/90

Path 131 — Row 027 1 09/10/90

Path 132 — Row 027 2 09/17/90



Locations of Purchased TM Subscene

(2) Production of color composite photo print from CCT

Color composite photo print was produced from purchased CCT (Computer Compatible Tape) data as shown in a work flow (refer to Fig. I.1.2) to make images suitable for topographic and geological interpretation work. Details of the process are explained below.

1) Format Conversion
Format of CCT data does not necessarily fit to our image processing systems. So, their format was converted to make subsequent data processing work efficient.

2) Noise Reduction
Irregular line noises were reduced and replaced by interpolating data on neighboring scan lines.

3) Stripe Noise Correction
Stripe patterns appearing on images due to the uneven sensitivity of sensors were reduced.

4) Geometric Restoration

Geometric transformations caused by earth rotation, deviation from flight course, etc. were corrected.

5) Edge Enhancement

Edge enhancement is a efficient technique for the image interpretation. Fig. I.1.3 shows one of the general image enhancement methods. Based on the processing original image by a laplacian conversion, the subtle brightness variation is changed to a pair of plus and minus brightness elements. Images processed by a laplacian conversion is then overlapped with the original image to make images having enhanced local contrast.

However, too high a threshold does not permit detection of subtle, low amplitude edges. Conversely, low threshold causes noise to be detected as edges. To void this problem, we put weights on the results of laplacian conversion. Fig. I.1.4 shown that method.

gn (i,j) = fn (i,j) - 2 fn (i,j) x h (i,j)

now,

g (i,j) : output image data (n : each spectral band)

f (i,j) : input image data

: laplacian

We used a set of 3 x 3 pixels as an unit.

1	1	1
1	-8	1
1	1	1

h (i,j) : h (i,j) = w (Fmax(In4(imj))

In4 (i,j) : line detection results of band 4

Fmax : maximum filter of surrounding 8 pixels

w : function that filters laplacian

Namely, if the 3 x 3 pixels are aligned as follows,

a	b	c
d	e	f
g	h	i

h (imj) = w x (e-a, e-b, e-c, e-d, e-f, e-g, e-h, e-i)

Weighting function "w" was set as 1/2 for normal line detection values and 3/2 for maximum values.

By using this method, small edges such as noises shown in Figure I.1.4 are not affected much, and large effect is expected for large edges.

6) Enhancement by Histogram Equalization
Histogram equalization was conducted to enhance the image contrast of entire image. As shown in Fig. I.1.5, spacing among dominant frequency levels are adjusted (widened) so that color contrast in the dominant density area is emphasized for the easy image interpretation.

1.2.3 Study Results

Lineaments are classified into three (3) from the view points of clearness and geological displacement as the followings.

Solid line ________	clear and continuous lineaments that fault another lineament and geological structure.
Broken line-----------	not so clear lineaments that continue to the clear lineaments, and/or fault another lineaments.
Dotted line............	clear, but small scale lineaments that develop irrelevantly to the another geological structure.

Fig. I.1.6 shows the result of lineament interpretation.

Lineaments can be divided into some group as the followings.

(1) NE·NEE	This direction harmonize with the Hentii Mountains trend and geological structure, and this may be one of the oldest lineament.
(2) NEE	This direction is characterized by the vertical displacement along the right bank of Tuul River, downstream of Ulaanbaatar. This is included in the NE-NEE direction.
(3) E-W	This direction include of NEE and NWW and is developed clearly with a few number in the north-west and east of Ulaanbaatar. These lineaments supposed to be normal fault of south displacement.
(4) NNW	This direction is developed here and there in the Study Area. This direction faults the NE-NEE lineament system and is characterized by the horizontal displacement along the right bank of Tuul River, downstream of Ulaanbaatar. Besides, these lineament harmonized the river and /or tributaries courses in the upper part of Tuul River.
(5) N-S	This direction is developed in and east of Ulaanbaatar.

(6) Ring-shaped Ring-shaped lineament present the topographical and geological condition as follows.

- contact of intrusive granitic rocks with mother rocks, and Neogene deposits.
- basin (depression) structure which are located near by Nalaih, International Airport, Sergelen, Ulaan Hujiriin Bulan to Tariat, and others.

Generally, these lineaments are clear in the northeast part, but indistinct in the southwest part of the Study Area. This phenomenon may be reflected by the topographical deference in the Study Area where is the intermontane tectonic depression of Hentii Mountains elevation.

Possible Groundwater Resources Area

Almost lineaments will correspond with faults and fractured zones which are expected to be fissure aquifer. Faults and fractured zones may be pervious in itself, and/or they may form the impervious zones which control the groundwater flow. From this point of view, possible groundwater resources may be supposed as the following typical locations shown in Fig. I.1.7.

1.3 GEOLOGY IN THE STUDY AREA

1.3.1 Topography

The Study Area covers an area of about 8,000km^2 and is located in the south of Hentii Mountains along Tuul River, including Ulaanbaatar. Ulaanbaatar is about 1,350 meters of the average height and 250 millimeters of average annual precipitation. Besides, city is surrounded on all sides by the hill and/or mountains, it looks like a long and slender basin along Tuul River.

Tuul River is originated in the Hentii Mountains and flows generally from north-east to south-west with heavily and/or slightly meandering in the Study Area. A total length of the River is 819 Km and a total catchment area is 50,400km^2. The catchment area of upper part from Ulaanbaatar is about 6,300km^2. It flows approximately east to west from near Nalaih to Ulaanbaatar. The River joins with Orhon River that is one of the main tributary of the Selenge River which pours into the Baikal Lake.

Hentii mountains are the part of world watershed between the Arctic and Pacific Ocean basins and the closed drainage basin of Central Asia. The highest point in this mountain systems is the Asralt Hairhan peak, with an altitude of 2,751m above sea level. A characteristic feature of the topography of Hentii Mountains elevation is the intermontane tectonic depression, which is extended and broad in its southwest where Study Area locates.

In the central part of ridges, innumerable traces of ancient graciation in the form of moraine, cirque and gracial lakes are founded.

The Study Area is divided into five (5) regions as shown in Fig. I.1.8.

Mountain 1 region
Mountain 2 region
Hilly region
Undulated region
Lowland region (fluvial region)
Basin (depression region)

(1) Mountain 1 region

It is widely spread in the eastern part of the Study Area with an elevation of about 1,500 to 2,200 meters, and distributed on the right bank of Tuul River in the western part with an elevation of about 1,200 to 1,600 meters. A slope gradient of this area is over 35 degrees. It is mainly characterized by the exposure of Devonian rocks and granites.

(2) Mountain 2 region

It is widely spread on the left bank of Tuul River in the western part of the Study Area with an elevation of about 1,200 to 1,500 meters, and with a slope gradient of 10 to 35 degrees. It is mainly characterized by the exposure of Carboniferous rocks.

(3) Hilly region

It is distributed along the tributaries ,valleys and mountain foots faced to Tuul River with a slope gradient of 3 to 10 degrees. It is mainly characterized by the distribution of Cretaceous rocks, Neogene sediments and talus deposit. This region is gradually changed into the undulated region.

(4) Undulated region

It is distributed along the both sides of Tuul River and it's tributaries. It is higher of 2 to 5 meters high above 2 to 5 meters than with a recent River as if a terrace. It is mainly characterized by the distribution of fan and valley deposits. A slope gradient of this region is under 3 degrees.

(5) Lowland (fluvial region)

It is spread in Tuul River and it's tributaries. There are many swamps here and there in this region. Recent river deposit is mainly distributed in this region.

(6) Basin (depression region)

Basins on a large and small scale are distributed in the Study Area. Eminent depression structure is formed around Nalaih, International Airport and the right bank of middle to downstream of Tuul River. It may be originated by the depression of geological mass movements. Lakes and marshes might be formed after the depression.

1.3.2 Stratigraphy

Geology in and around the Study Area mainly consists of Cambrian, Devonian, Carboniferous rocks, and which are intruded by granitic rocks in Jurassic to Triassic period and covered locally by the Cretaceous rocks, Tertiary and Quaternary deposits. Devonian and Carboniferous rocks organize the Hentii series. These rocks are generally distributed in the direction of north-east to south-west paralleled to the River (refer to Fig. I.1.9-10). Every rocks is unconformable to each other and complexly folded and faulted. Granitic rocks cause a contact metamorphism to the Devonian and Carboniferous rocks which are changed to biotite hornfels. Besides, the Mandal series are distributed outside of Devonian and Carboniferous rocks.

Summarized Geology in and around the Study Area

Era	Period	Symbol	Thickness	Group	Formation	Lithology and Remarks
Cenozoic	Quaternary	al	5-110			river deposit : sand, pebble to boulder (rounded) with clay
		fl	5- 40			fan, talus, valley deposit: clay, sand and pebble to boulder (subrounded to subangular)
		tr	6- 21			terrace : sand and gravel
	Tertiary	N	10-100			Neogene deposit : reddish clay and sand with pebble to cobble
Mesozoic	Cretaceous	K	72-350		Zuunbayan	sandstone and mudstone with coal / fossil
Paleozoic	Permian	P2	300-350		Ulzin	conglomerate, sandstone shale
	Carboniferous	C2-3	1200-1500		Orgiochuul	greywache---sandstone and tuffaceous sandstone with shale
		C1-2	2500-3000		Altan ovoo	flysch---alternation of sandstone and shale
	Devonian	D2-3	1500-1900	Hentii	Gorchy	sandstone with shale, chert, diabase and tuffaceous sandstone
		D1-2	1500-2000			sandstone, slate, phyllite with reddish chert, rarely schistose sandstone, quartzite
Proterozoic	Cambrian to Precambrian	R	3400	Mandal		semi schists, rarely sandstone, chert, quartzite and meta andesite/basalt.
Mesozoic	Jurassic to Triassic	Gr	-		intrusive rocks	porphyriticgranite, granodiorite

The rocks are represented by Mandal group (R3-E1 mn) and distributed on North Hentii Folded Belt and Iroo's fracture to Ulaanbaatar Variss Geosyncline in the southern side and Har Horin's uplift in the western side. These are composed of various kind of metamorphic rocks and divided into three (3) as the followings.

Lower formation (R3-E1 mn1)
Middle formation (R3-E1 mn2)
Upper formation (R3-E1 mn3)

Lower formation (R3-E1mn1)

This is composed of chlorite, sericite, muscovite, siliceous, biotite, and epidote-actinolitic shale (60%); polimictic, feldspathic, micaceous, clayey and limy graywacke (30%); arcose and polymictic sandstone (3%); rarely (about 1%) feldspathic arenite, chert, micro-quartzite, reddish brown shale, meta andesite, meta andesitic basalt, small lens of marble and tuffaceous sandstone. The thickness is about 1100m.

Middle formation (R3-E1 mn2)

This is composed of polimictic, feldspathic, micaceous, siliceous and limy graywacke (70%); chlorite, sericite; chlorite, epidote, and biotite shale(25%); rarely (about 1%) arcose sandstone, chert, quartzite, and meta andesite. The thickness is about 1300m.

Upper formation (R3-E1mn3)

This is composed of polymictic, feldspathic, siliceous and actinolite epidote shale, and quartzite and andesite. The thickness is about 1000m.

(2) Devonian rocks

Devonian rocks represented by Gorchy formation (Dgr), are spreading in a big territory of along the southern Hentii Mountain range, start from Tuul River's big elbow and cross the Tuul River's valley and continue to Zahar and Minj River. These rocks are composed of the complex layers of green colored and fine grained sandstone, siliceous shale with radiolarian chert. Occasionally, there are some layers and lenses of agglomerate, volcanic materials, tuff and crystalline limestone. The thickness of these rocks are 2500-3000 m.

Fossils are found in this group such as *Endaetinosphaera? sp., Entactiniidae.* (Collected by J. Byamba, D. Chagnaadorj. Characteristic by B. B. Nasarov. 1988.)

Gorchy formation is divided into two formation in the territory of Tuul River's left bank and Shohoin Tsagaan Bulag.

Lower to middle Gorchy formation (D1-2)

This formation consists of sandstone and slate with phyllite, reddish radiolarian chert and basic volcanic materials, rarely schistose sandstone, microquartzite. The thickness is 1500-2000 m. Near the contact of intrusive granite, this is suffered the contact metamorphism and turned to biotite hornfels.

Middle to upper Gorchy formation (D2-3)

This is composed of the thick complex layers of sandstone, pelitic sandstone, siliceous shale, radiolarian chert, basic volcanic materials, diabase, and rarely limestone. The thickness is 1500-1900 m.

(3) Carboniferous rocks

Carboniferous rocks consist of Altan ovoo (C1-2) in the lower to middle Carboniferous period and Orgioch uul formation (C2-3) in the middle to upper Carboniferous period.

Altan ovoo formation (C1-2)

This is distributed in the Tuul River valley near the Ulaanbaatar area.

This formation is originated in the flysch which are alternated of sandstone and shale, and rarely interbeded with basic to intermediate tuffs and lens of conglomerate. The thickness is 2500-3000m.

Fault is inferred between this formation and Devonian rocks. Flora and fauna fossils of the lower Carboniferous period were found in this rock (V.A. Amantov, 1961).

Orgioch uul formation (C2-3)

This formation is originated in the greywache which is mainly composed of bad sorted sandstone in the bottom and top, and with rarely interbeded of sandstone and shale in the middle part. The thickness is 1200-1500 m. Fauna and flora fossils were not found in this formation, but this formation is expected to be middle to upper Carboniferous rocks lying on Altan Ovoo formation from the stratigraphycal point of view.

(4) Permian rocks

Ulzin formation (P2 ul) in the upper Permian period is locally distributed in Deendei valley as a block-wedge from Hadat valley to Baga Deendei along the left bank of Deendei valley. It has northeast to southwest strike with nearly vertical dip of 80 to 85 degrees. This is unconformably lying on lower-middle Carboniferous formation (C1-2) and bordering by a fault with the middle-upper Devonian formation (D2-3).

This formation is composed of conglomerate in the northeastern and southwestern part, and sandstone and shale without conglomerate in the central part. Some conglomerate and tuffaceous conglomerate have schistosity caused by northeast faults. The thickness of this formation is 300-350 m.

Fauna fossils were found in the layers of sandstone, shale and conglomerate (collected by B.Banzragch and T.Sengedorj No.630. The characteristic by T. Urantsetseg). The age was determined as a upper Permian by the *Cordaite sp.*. This is supported by the properties of lithology and stratigraphycal structure that correspond with the north-south fracture belt in the geological structure of southern Hentii.

(5) Cretaceous rocks (K)

Cretaceous rocks are represented by Zuunbayan formation in lower Cretaceous period.

It is locally distributed in Nalaih Depression, Tolgoit Hill, Hamba Hill and Buheg River, and composed of sandstone and mudstone with coal. This formation has monocline structure with northeast strike and southern dip of 15-20 degree. These sedimentary rocks are weak in diagenesis and not well consolidated. Consequently, it is expected to deposit in lake, after that these rocks ascended up to the land in a short time without sufficient diagenesis. The thickness of this formation is 72 to 86 meters and 350 to 500 meters in Nalaih Depression.

The age of this formation was determined as lower Cretaceous by some flora and fauna (insects) fossils.

(6) Neogene deposits (N)

These deposits are distributed in and around of Nalaih and Ulaanbaatar Depression and some part of Holiin River.

It consist of unconsolidated reddish to yellowish clay, sand, and pebble to cobble with rarely conglomerate. It is expected to be old talus and fan deposit in Neogene period.

The thickness of these deposits are from several meters to 10 meters. According to a geophysical data, it is expected to be 60-80 meters in the Ulaanbaatar depression.

The age was determined by fauna analysis as Pliocene epoch of Tertiary period.

(7) Quaternary deposits

Quaternary deposits are widely distributed along Tuul River, its tributaries and intermontane valleys. It is mainly composed of terrace deposit, fan deposit, talus deposit and recent river deposit. The age is ranging from lower Pleistocene to upper Holocene.

Quaternary deposits in the Ulaanbaatar area have been studied in connection with the project of urban developments and water supply developments. There are many data of seismic studies and boreholes to investigate the engineering geology, hydrogeology, construction material (Gomanko, 1942; T. Beejin 1986, PNIIS 1984-1988).

Terrace deposits

It is expected to be distributed along Tuul River covered by the fan and talus deposits. Terrace plain is divided into three (3). First plain is high above 35-40, 2nd is 10-12 and 3rd is 2-5 meters compared with a recent river level. It is reported that the age of 1st terrace is Pleistocene epoch, and 2nd/3rd are Holocene. Three quarry sites for construction materials such as sand and gravel are developed in 1st terrace deposit. This deposit can be observed at lower reaches of Tuul River in the western part of Ulaanbaatar.

Fan deposits

It is distributed near the mouth of river and tributaries along Tuul River. It is composed of clay, sand, and pebble to cobble that are sub-rounded to sub-angular with intermediate sorting. This deposit is gradually changing from talus deposit and valley deposit around tributaries.

Talus deposits

Talus deposit is distributed at the mountain foot and composed of clay, sand, and pebble to boulder that are angular to subangular with bad sorting.

Recent river deposits

It is distributed in Tuul River and large tributaries and composed of clay, sand, and pebble to boulder that are rounded to sub-rounded with well sorted. Swamps composed of clay with sand and gravel, are formed here and there in the River and large tributaries.

Others

Lake deposit may be distributed under the alluvial deposit at the depression area of near Nalaih, International Airport and the right bank of middle to downstream of Tuul River. This deposit may be composed of clay and sand with gravel.

1.4 POSSIBLE GROUNDWATER RESOURCES

As the result of various geological surveys, Alluvial deposit and fractured zone in the basement racks are expected to be good aquifer.

Alluvial Deposit

Recent river, fan and valley deposit are mainly composed of sand and gravel with high groundwater table and high permeability, moreover they have large capacity of groundwater basin with sufficient recharge from the large catchment area and/or surface water.

Fractured zone

Fractured zones are developed in the basement rocks in the Study Area. Fractured zones consist of fault breccia and fault clay that may be pervious in itself and /or they may form the impervious zones which control the groundwater flow. Especially, area of North of Ulaanbaatar City (ULBT) is located in good condition for the groundwater resources.

Possible groundwater resource areas are as follows from the geological point of view.

Possible Groundwater Resource

Location	Aquifer type	Geological characteristics	Distance *1 (km)	Depth (m)	Width *2 (Km)	Length *2 (Km)
Upper Source	alluvial	sand, gravel, clay	40-54	5-36	1-3	14
Lower part of Nalaih	alluvial	sand, gravel, clay	28-40	20-30	1-2	12
Buheg River	alluvial	sand, gravel, clay	34-54	40-130	2-10	20
Lower part of Power Plant	alluvial	sand, gravel, clay	34-55	30-130	2-4	21
Ulaan Hujiriin Bulan	alluvial	sand, gravel, clay	55-122	50-130	10-12	67
Ulahiin Bulan	alluvial	sand, gravel, clay	122-147	>50 ?	6-8	25
North of ULBT						
Uliastai	fissure, alluvial	fractured zone, sand, gravel	10-15	169-202	(< 0.5) 1-2	(30)
Selbe	fissure	fractured zone	5-10	30-353	(< 0.5)	(14)
Bayan goliin	fissure, alluvial	fractured zone, sand, gravel	18	32-206	(< 0.5) 1-1.5	(20)
Tahiltiin goliin	fissure	fractured zone	16-22	25-72	(< 0.5)	
Holiin River	fissure	fractured zone	10-15	50-173	(< 0.5)	(31)

*1 : Distance from the Water Supply Department
*2 : ( ) width and Length of fractured zone

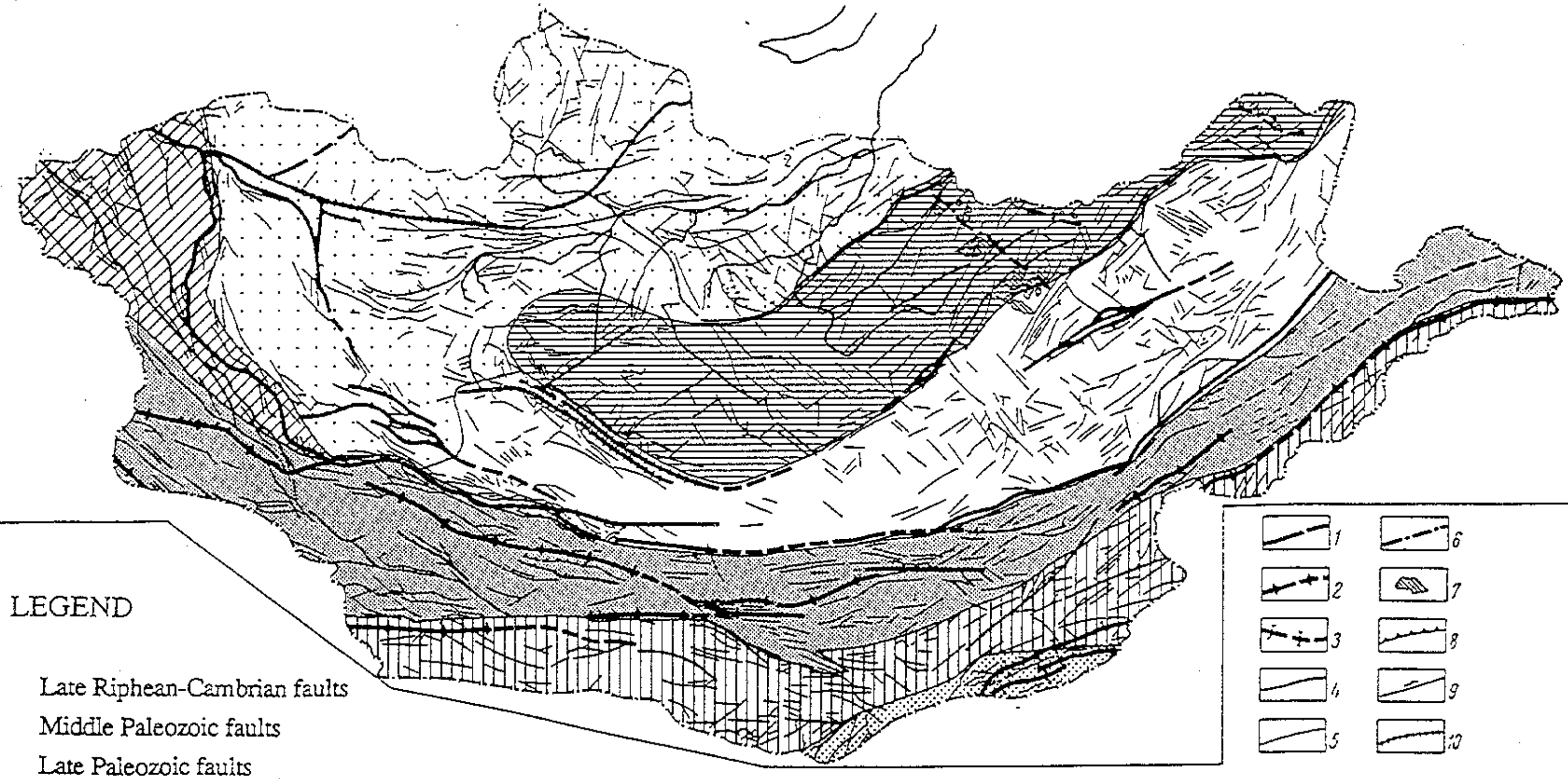


Fig. I.1.1 Geological structure of Mongolia

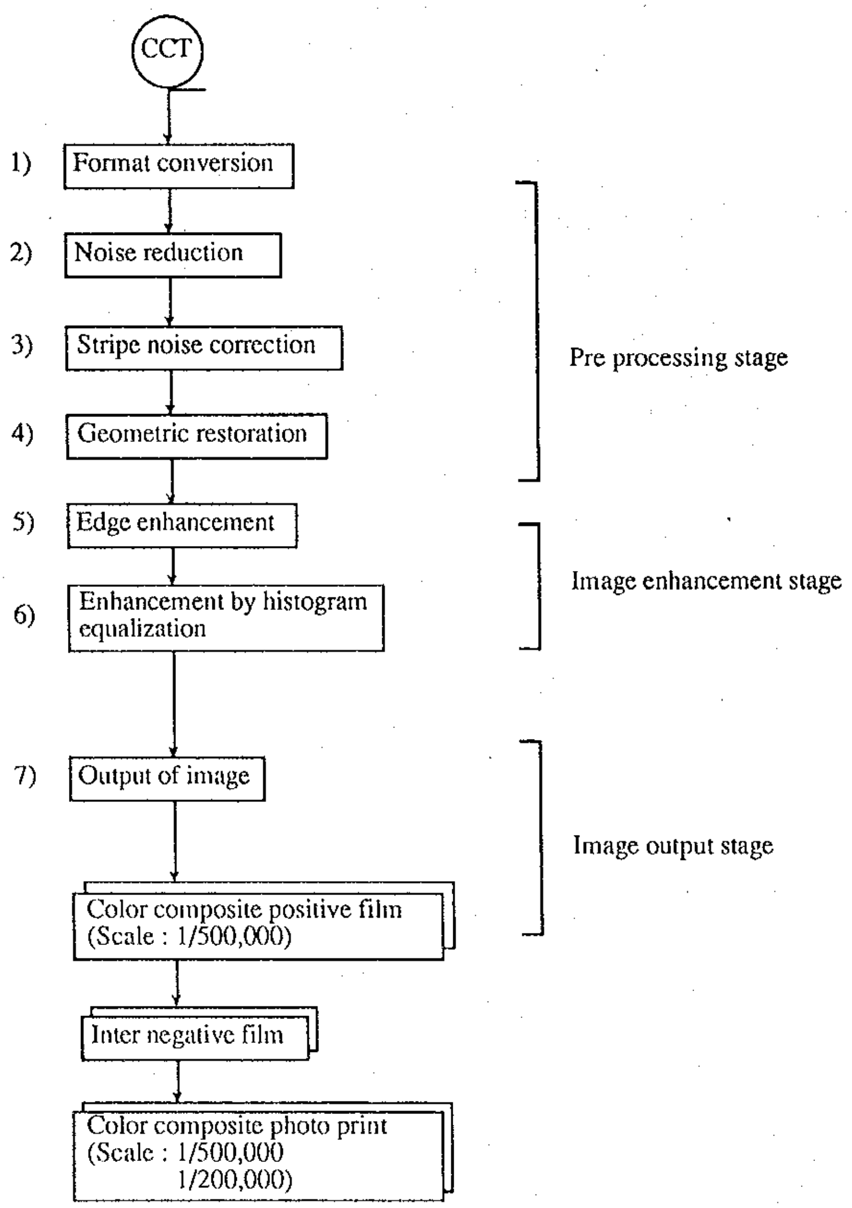


Fig. I.1.2 Work flow of Color Composit Photo Print production

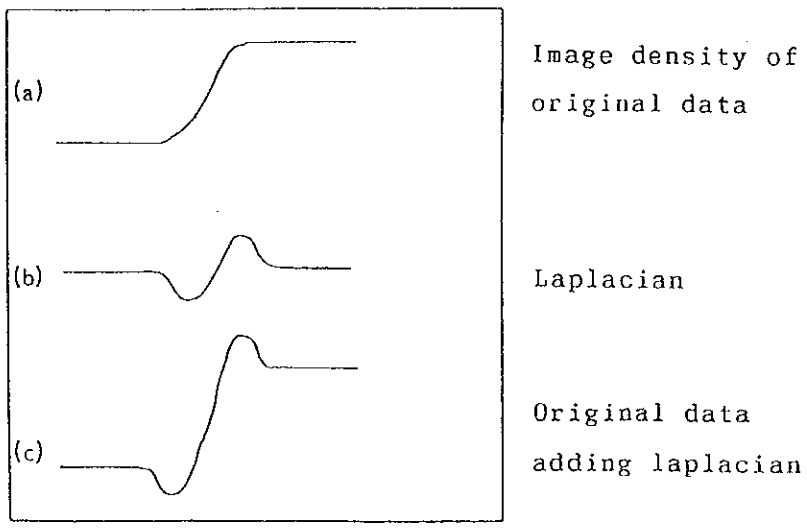


Fig. I.1.3 Image Sharpening Effect by Laplacian

JICA	The Study on Water Supply System in Ulaanbaatar and Surroundings

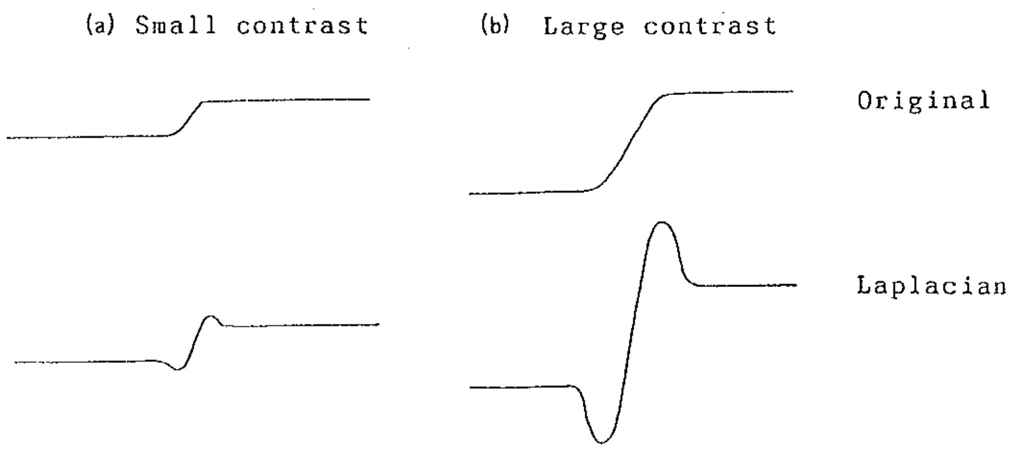


Fig. I.1.4 Image Sharpening Effect by Laplacian with Weight

JICA	The Study on Water Supply System in Ulaanbaatar and Surroundings

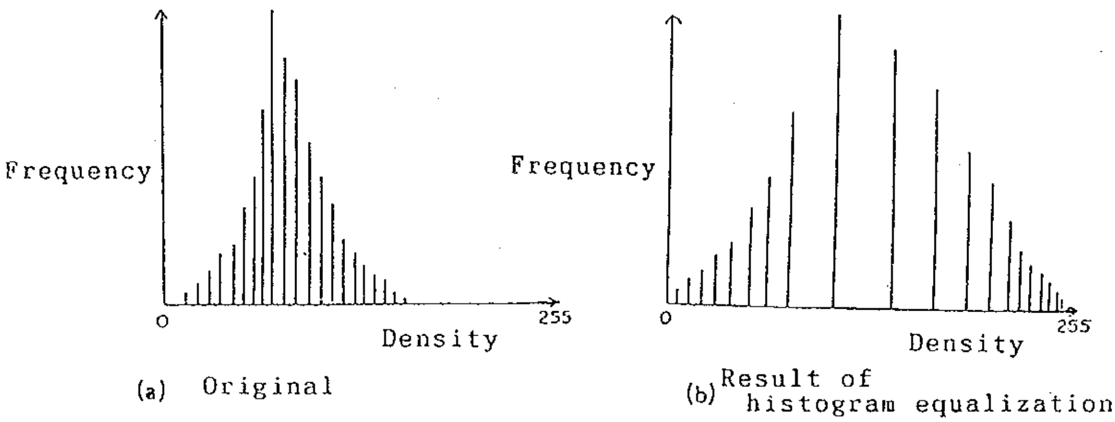


Fig. I.1.5 Histogram Equalization

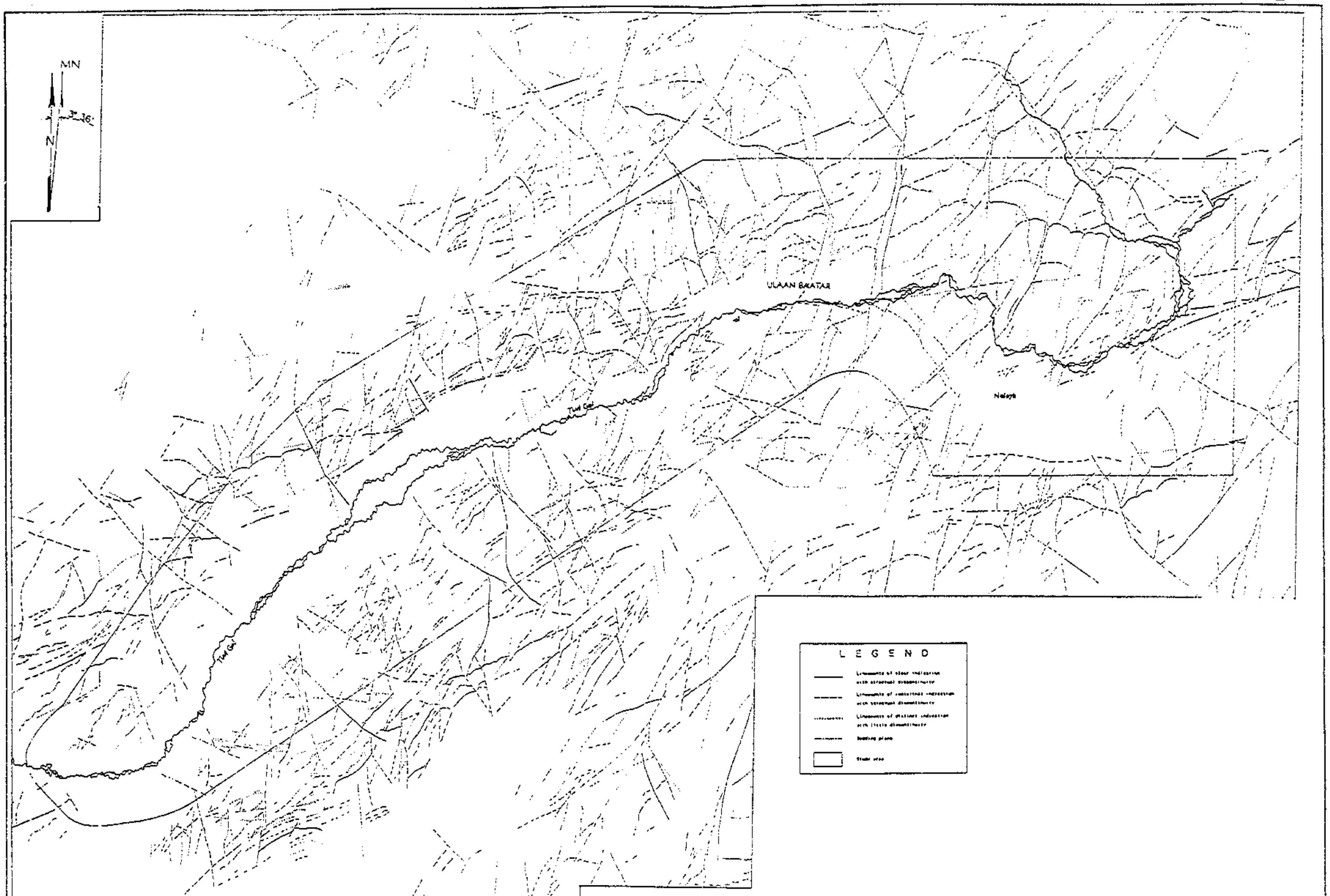
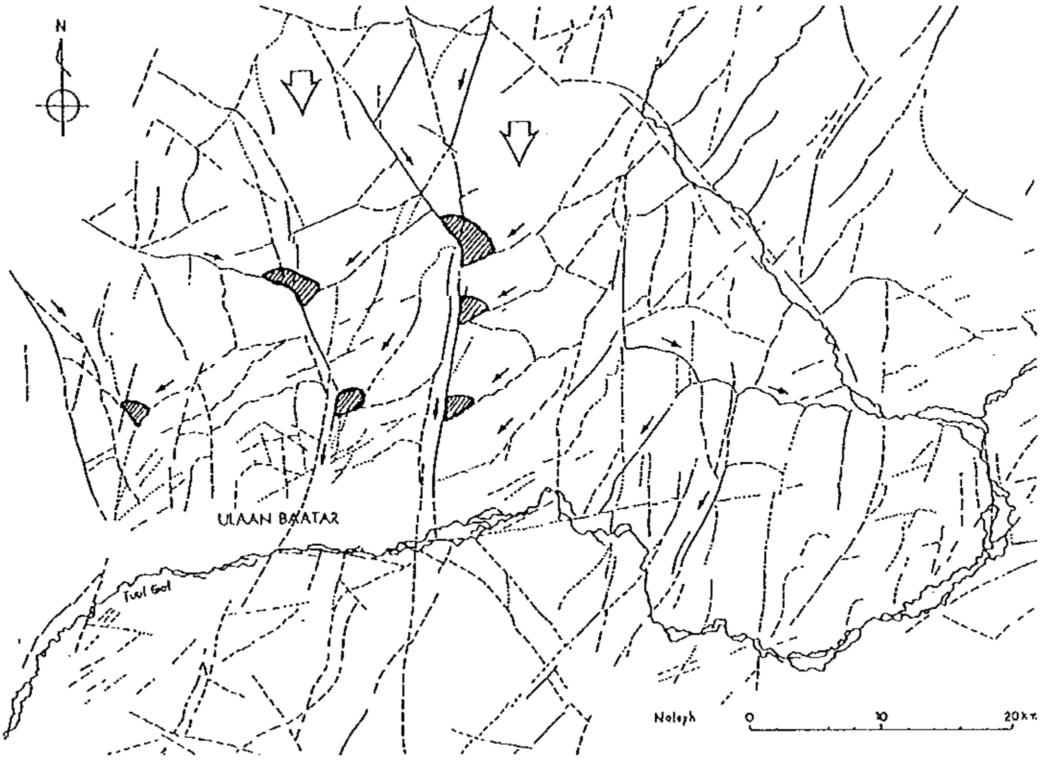


Fig. I.1.6 Major Lineament Map

JICA | The Study on Water Supply System in Ulaanbaatar and Surroundings



: Regional groundwater flow

: Groundwater flow controlled by fault

: Possible groundwater resources

Fig. I.1.7	**Possible Groundwater Resources for Fissured Aquifer**
JICA	The Study on Water Supply System in Ulaanbaatar and Surroundings

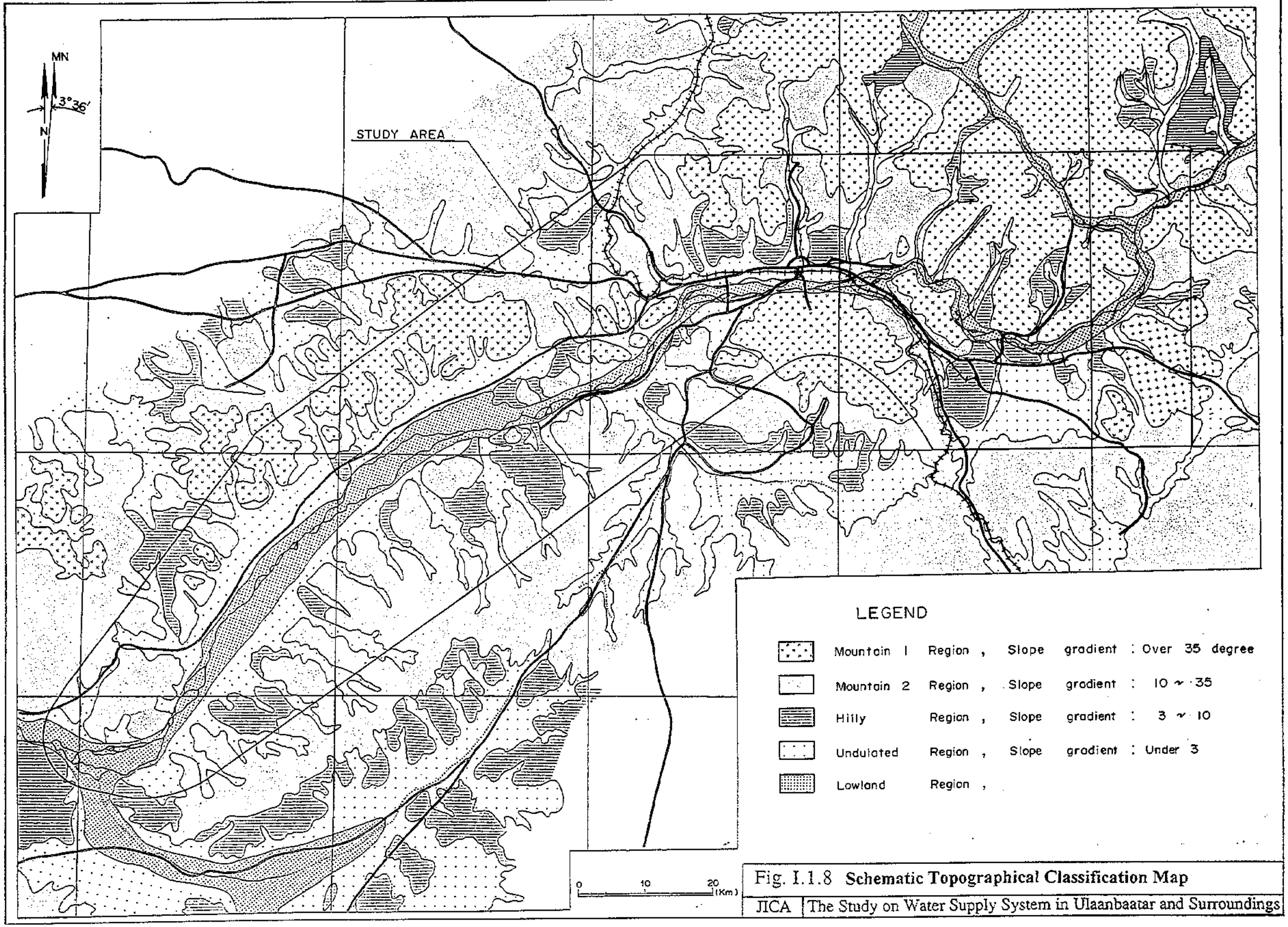
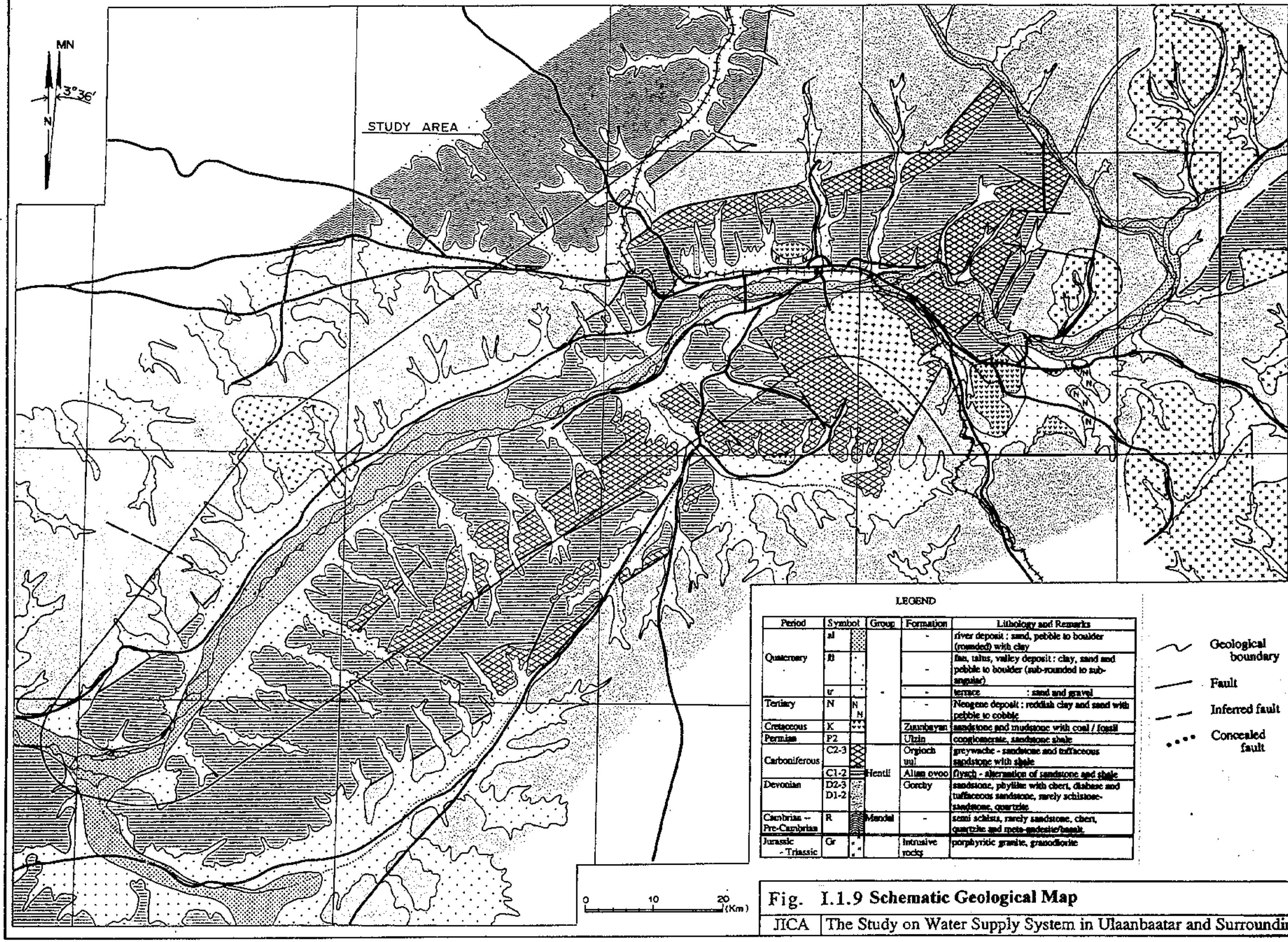


Fig. I.1.8 **Schematic Topographical Classification Map**

JICA | The Study on Water Supply System in Ulaanbaatar and Surroundings



LEGEND

Period	Symbol	Group	Formation	Lithology and Remarks
Quaternary	al	-	-	river deposit : sand, pebble to boulder (rounded) with clay
	fl		-	fan, talus, valley deposit : clay, sand and pebble to boulder (sub-rounded to sub-angular)
	tr		-	terrace : sand and gravel
Tertiary	N		-	Neogene deposit : reddish clay and sand with pebble to cobble
Cretaceous	K		Zuunbayan	sandstone and mudstone with coal / fossil
Permian	P2		Ulzin	conglomerate, sandstone shale
Carboniferous	C2-3	Hentii	Orgioch uul	greywache - sandstone and tuffaceous sandstone with shale
	C1-2		Altan ovoo	flysch - alternation of sandstone and shale
Devonian	D2-3 D1-2		Gorchy	sandstone, phyllite with chert, diabase and tuffaceous sandstone, rarely schistose-sandstone, quartzite
Cambrian -- Pre-Cambrian	R	Mandal	-	semi schists, rarely sandstone, chert, quartzite and meta-andesite/basalt
Jurassic - Triassic	Gr		Intrusive rocks	porphyritic granite, granodiorite

Fig. I.1.9 Schematic Geological Map

JICA | The Study on Water Supply System in Ulaanbaatar and Surroundings

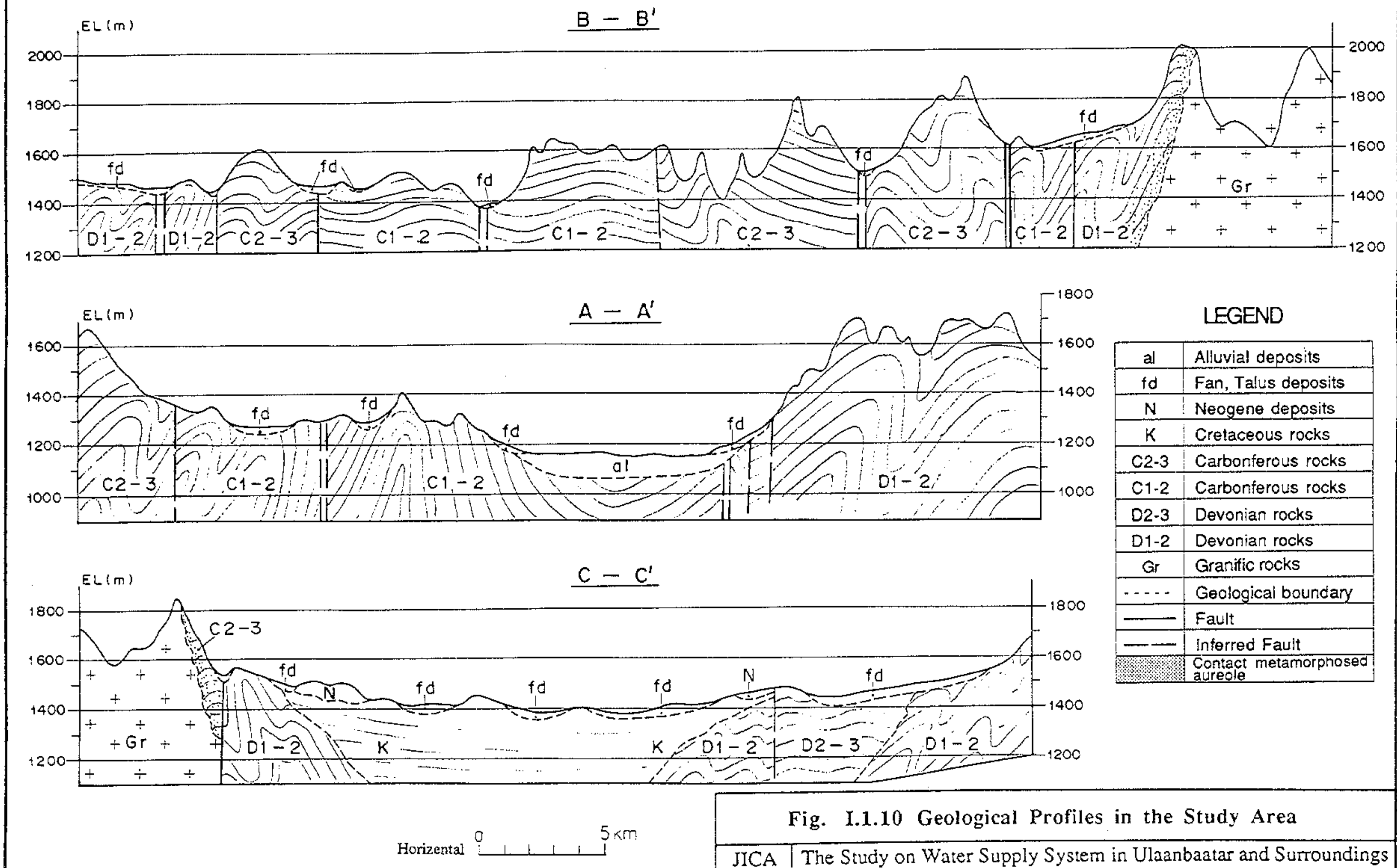


Fig. I.1.10 Geological Profiles in the Study Area

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CHAPTER 2 GROUNDWATER EXPLORATION

CHAPTER 2. GROUNDWATER EXPLORATION

2.1 GEOPHYSICAL PROSPECTING

The purposes of this geophysical prospecting are to estimate the resistivity structures of Alluvium and to realize the fractured zones for groundwater resources and the general hydro-geological condition.

2.1.1 Previous Surveys

Several electrical and magnetic geophysical surveys have been carried out by Mongolia and Russia along profile lines in the Study Area. General information of these surveys is as follows.

Previous Geophysical Surveys in the Study Area

No.	Survey Area	Survey Methods	Number of Profiles	Names of Profiles
1	Upstream of Tuul River	1) Electrical	12	I,II,III: avail. AB: struc. mis. 30,31,32,33,34,35,36,37: avail.
2	Downstream of Tuul River	1) Electrical	8	I,II,III,IV,V,VI,VII,XII: avail. X: loc. mis. XI,A: struc. mis.
3	Gachuurt	1) Electrical 2) Magnetic	18	1,2,4,6,8,10,12,15,17,19,23,25,29,31, 33,35: avail. 27,N-S: struc. mis.
4	Uliastai	1) Electrical 2) Magnetic	6	2,4,6,8,9,10: avail.
5	Bayanzurh	1) Electrical 2) Magnetic	4	0,1,2,0-II: avail.
6	Selbe	1) Electrical 2) Magnetic	11	I,II,III,IV,V,VI,VII,VIII,IX,X,XI: avail.
7	Tolgoit	1) Electrical 2) Magnetic	7	I,II,III,IV,V,VI,VII: avail.
8	Turgen	1) Electrical 2) Magnetic	7	I,II,III,IV,VI,VII,VIII: avail.
9	Buheg	1) Electrical 2) Magnetic	4	I,II,III,IV: avail.
10	Maanitiyn Gozgor	1) Electrical	3	I,II,III: avail.
11	Byartiyn Am	1) Electrical	2	I,II: avail.
12	Humug	1) Electrical	2	I,II: avail.
13	Deendei	1) Electrical	12	1,2,3,4,5,6,7,8,9,10,11: only raw data 12: avail.
14	Central	1) Electrical	?	loc. and struc. mis.

NOTES: 1) "avail."; available
2) "struc. mis."; missing of resistivity section
3) "loc. mis."; missing of location map

The resistivity sections derived from these surveys can be represented by models of three (3) or four (4) layers. The basement resistivities are generally high with values of more than 1,000ohm-m. Low basement resistivities of several hundred ohm-m can be seen along Tuul River and inferred fractured zones along Gachuurt, Uliastai, Selbe, and

Tolgoit Rivers. The basement depth ranges from 20 to 120m along Tuul River. It is shallower upstream, northeast of Nalaih, ranging from 20 to 40m depth. The thickness of the aquifer corresponds approximately to the depth of the basement. The resistivity of the aquifer ranges from less than 100ohm-m to more than 1,000ohm-m.

Data from one of the 12 profiles in the Deendei area was analyzed by the Mongolian team and an additional two (2) profiles were interpreted by the Study Team during the course of this project. These available results of previous surveys have been used in the preparation of this report.

2.1.2 ELECTRICAL SURVEY

(1) General

A vertical Schlumberger electrical survey was used to estimate the depth of basement rocks and the thickness of aquifer.

Specifications of the equipment used in the electrical survey (SYSCAL, BRGM) are shown bellow.

Specifications of Equipment for Electrical Survey

NAME	SPECIFICATION
SYSCAL-R2	TRANSMITTER Output voltage: 10-700V Injection current: Standard accuracy 0.3% Resolution 0.1mA Injection period: Variable RECEIVER Potential difference: Maximum 4V Standard accuracy 0.3% Resolution 10microV(0-8mV),100microV(8mV-4V) Spontaneous potential: Measuring after injection, Maximum 4V Correction +/- 1V range Input impedance: 1Mohm Sampling time : Variable Internal memory: Storage and recall are available Maximum storage: 390
SYSCAL-100W DC-DC CONVERTER	Input voltage: 10-30V DC Output voltage: 110, 220, 330V +/-1% Maximum output power: 100W Maximum output current: 900, 450, 300mA

Electrical surveys were carried out in the proposed areas except Tariat and the southern part of Ulaan Hujiriin Bulan. Mobilization is difficult to the swampy clay in these area. Furthermore, they are apart more than 70km from Ulaanbaatar City. Based on the purpose of this project, a priority is low. Two (2) areas in the vicinities of Buheg, south of Ulaanbaatar City and Terelj in the northeastern part of the Study Area were selected to replace these two (2) areas, as requested by the Mongolian side. The areas in which electrical soundings were made are tabulated below.

Area Code	Area Name	Area Code	Area Name
A	Lower Part of Nalaih	G	Central Water Source
B	Holiin River	H	Industrial Water Source
C	North of Ulaanbaatar	I	Meat Complex Water Source
D	Lower Part of Power Plant	J	Power Plant Water Source
E	Ulaan Hujiriin Bulan	K	Buheg River
F	Upper Water Source	L	Terelj River

The location of 136 stations are shown in Fig. I.2.1. The geodetic positions of stations were determined by a Global Positioning System and the longitudes and latitudes of these stations are presented in Appendix I.2.1. Only 11 stations are easily marked on the topographic map. Survey depths were 100 to 200 meters in plain areas and along rivers, and about 300m in mountainous areas where fractured zones were inferred.

The measured voltage data were automatically converted into apparent resistivities by SYSCAL. Layered resistivity models were derived from the apparent resistivity data by a "ridge-regression" inversion technique. The apparent resistivity curves which were inverted and the layered geoelectrical models which resulted from the inversions are included in Appendix I.2.2. The resistivities and thicknesses of these models are presented in Appendix I.2.3. Results derived from data collected along profiles 7 and 9 in Deendei area are included in this table.

Maps of the earth resistivity at depths of 20, 30, 50, and 100m below ground level are shown in Appendix I.2.4. Data collected from previous surveys has been inverted to determine layered resistivity models and these results have been used at some stations in these figures. These stations are shown on the resistivity maps without the station numbers. In these figures, resistive and conductive zones are marked in red and blue respectively and the contour intervals expand logarithmically (for example, 100, 178, 316, 562 and 1,000ohm-m).

These resistivity maps will be described in the following 13 sections (A through L, and Deendei Area)

(2) Survey Result

1) A. Lower Part of Nalaih

Station 121 and 122, which are located at the northwest part of Nalaih along Tuul River, will be included in the discussion of this area. The resistivities increase towards the north at all four(4) levels (-20, -30, -50, and -100m) in this area, reaching more than 1,000ohm-m. This is in striking contrast to the low resistivities of around 100ohm-m which are seen south of this area at the same depths. It can be concluded that the depth of the basement decreases to less than 20m north of Nalaih and increases to more than 100 meters towards the south around St.30. However, a thick conductive layer in the southern part of the area may be a Neogene lake deposit.

2) **B**. Holiin River

There are two major lineaments in this area, parallel to Holiin River striking NW-SE. One is along Holiin River and the other is 2km southwest of Holiin River. There are also lesser lineaments perpendicular to these along branches of Holiin River and along Chuluutiin Goliin and Bumbatiin Gorhiin Valleys.

There is a highly resistive second layer of more than 1,000ohm-m below a thin conductive surface layer in the center of this area (St.1, 2, and 3). This resistive layer is 50 to 100 meters thick, at most. There is a conductive basement of about 200ohm-m beneath stations 1 and 2. At station 131, which is also located in the center of this area, there is a thick conductive second layer with a resistivity of 262ohm-m. A conductor of this sort is not found beneath station 3, however. This may be that while stations 1, 2 and 131 are located on lineaments, station 3 is not.

While this may indicate a fractured basement, the resistivity of the entire section decreases toward the southeastern part of the area (St.4 and 124). This may imply the presence of a continuation of lake deposit mentioned in Chapter 1. A high resistivity basement is not detected beneath these two (2) stations, and this may indicate that fractured zone and/or deposits have a thickness of more than 100m.

3) C. North of Ulaanbaatar

Gachuurt River

A resistive zone of 300 to 500ohm-m at the -20m level is distributed in the eastern part of this area around Gachuurt River. A resistive zone of more than 1,000 ohm-m at the -30m level is widely distributed in the west side of the river. The depth of basement along Gachuurt River may be 30m or less.

Uliastai River

There is a north-south trending conductive zone of less than 200ohm-m, 20 to 30m beneath the surface, along Uliastai River. At the -50 and -100m levels, a resistivities zone of less than 600ohm-m trend NW to SE around St.20 and 22.

These stations are located near the intersection of lineaments that are interpreted by the satellite images trending east to west and along both sides of Uliastai River.

Selbe River

Resistivities along Selbe River are relatively high (500 to 2,000ohm-m). This may indicate that the basement is shallow along Selbe River. Previous surveys found the resistive basement to be at a depth of 40m or more further upstream along Selbe River. This area is not shown in our figures.

Others

Four (4) layer resistivity structure was obtained along Tolgoi River (St.103 through 105). The third layer of these models is conductive with resistivities ranging from 50 to 220ohm-m. This layer is seen near St.104 and 105 on the -20 and -30m level maps. The resistivities 50 and 100m below surface are high, similar to those near Selbe River.

There are four (4) valleys with a north to south trend in the western part of this area. They are Narangiin (St.99 through 102), Bayan Goliin (St.51 through 55), Tahiltiin Goliin (St.56 through 59), and Turuunii Valleys (St.60 and 61). Above the -50m level, there is a zone of low resistivity (less than 200ohm-m), along Tahiltiin Goliin Valley. There is a layer of 60 to 120ohm-m above a high resistivity basement of more than 1,000 ohm-m, which thickens to the south. This may be caused by the fractured zone along this valley.

4) **D**. Lower Part of Power Plant

The resistivity structure of this area was represented by four-layer models of predominantly LHLH type (low, high, low, and high resistivities from the surface). The third layer is about 100m thick with resistivities of 80 to 450ohm-m. The resistivities of third layer are shown in the -20 to -50m level maps. At the -100m level, there is a high resistivity zone on the southern side of Tuul River which corresponds to the fourth layer. The depth to the top of the fourth layer, which may represent basement rock, is more than 100m.

5) **E**. Ulaan Hujiriin Bulan

While survey stations are sparsely distributed in this area, our interpretation was found to be consistent with the results of three (3) electrical profiles from a previous survey. Maps of the -20, -30, and -50m levels show a high resistivity zone along Tuul River, surrounded by low resistivity zones of around 200ohm-m to the north and south of the river. There is a low resistivity zone of about 100ohm-m north of

Tuul River, where talus and fan deposits are distributed, and resistivities increase to more than 1,000ohm-m to the south.

6) **F**. Upper Water Source

In this area, Paleozoic rocks are distributed on both sides of Tuul River and there are some valleys perpendicular to the River to the south. Resistivities along these valleys are low and they decrease the level to the southeast. A continuity of resistivity basement of these valleys to Tuul River is not clear. On the north side of Tuul River, the 1,000ohm-m resistivity contours of -20 and -30m depth maps are approximately parallel to the river. At the depths of 50m or more, a high resistivity zone of more than 1,000ohm-m spreads southward. The basement resistivity is thought to be about 1,000ohm-m, and the depth to the basement rock is 20 to 30m along Tuul River.

7) **G**. Central Water Source

The configuration of the contour lines is complicated in this area and layered resistivity structures consist of from two (2) to five (5) layers. However, a high resistivity zone is distributed at the east part of the confluence of Tuul and Holiin Rivers. Along Tuul River in the western part of this area, there exist a thick layer with resistivities of 100 to 300 ohm-m, and a high resistivity basement can not be seen except at St.15. These low resistivities may indicate that the basement rocks are heavily weathered or fractured.

8) **H**. and **I**. Industrial and Meat Complex Water Sources

Resistivity maps of this area at depths of 20 to 100m below surface show the consistent resistivities of several hundred ohm-m (150 to 680) which correspond to the third layer of three (3) and four (4) layer models. This layer may be the main aquifer in this area with a thickness of more than 100m, and it probably consists of Alluvium and fractured basement rocks. A high resistivity basement rock can not be seen, as it was in the Central Area.

9) **J**. Power Plant Water Source

Resistivities are relatively uniform 20 to 30m below the surface of this area along Tuul River, ranging from 120 to 550ohm-m. Resistivities increase to the northwest and southeast of Tuul River at depths of 50m or more. There is a conductive zone of less than 200ohm-m near the intersection of Tuul River and Buheg River at the depths of 50m and 100m. This may suggest that the depth to the basement rock is 50m or more around St.63, 64, and 78.

Seven (7) electrical profiles were conducted by Mongolian side at the eastern part of Power Plant area. The resistivity contours of these profiles are quite complex and the basement ranges in depth from five (5) to 60m.

10) K. Buheg River

Resistivities in this area are less than 100ohm-m near surface. These low values may indicate the presence of a shallow water table. Near the center of this area at the -50m level, a local high resistivity zone of around 1,000 ohm-m was detected which is considered to be the basement. This high resistivity zone continued to the depth of 100m might be an aquifer zone with the low resistivities of less than 200ohm-m to the southeast. This area is called the Buheg depression.

11) L. Terelj River

Almost Resistivities in this area are higher than 1,000ohm-m, and some are several thousand ohm-m. This may be a shallow basement with a depth of less than 20m and/or a permafrost (St.48). A zone of less than 500ohm-m can be seen at a depth of 20m in the western part of this area. These resistivities may indicate the presence of thin alluvial sediments along a branch of Terelj River.

12) Deendei Valley

Existing electrical data were collected along twelve profiles in Deendei Valley. JICA Study Team analyzed two profiles (No 7.9) of them. The resistivity sections are shown in Appendix. I.2.5. The basement, shown by dark shading, ranges in depth from nearly zero to 40m. The resistivity of basement is several hundred ohm-m. Fault structures can be seen in the central part of Deendei Valley, shown in profile 9.

(3) Possible Groundwater Resources

A map of basement depth is presented in Fig. I.2.2. Based upon the electrical survey and existing data, Possible Alluvial aquifers are listed bellow.

Alluvial aquifer

1) Buheg Area (St.96 and 97)

2) Confluence of Tuul River and Buheg River (St.63, 64 and 78)

3) Lower stream of Uliastai River (St.18 and 19)

4) Upper Water Source Areas (St.41, and St.114 through 118)

5) Debris fan deposit area in Ulaan Hujiriin Bulan (St.63 and 64)

6) Boundary area of Ulaan Hujiriin Bulan and Lower Part of Power Plant (St.69 and 72)

2.1.3 VLF-EM Survey

(1) General

VLF-EM survey was carried out to find the fractured zones in the Study Area. Survey sites were selected on the basis of the satellite image interpretation, aerial photograph analysis and geological survey.

EM prospecting methods rely on the measurement of secondary fields generated by conducting bodies in the ground which result from primary EM signals. The VLF-EM method is passive, employing the radiation from powerful military radio transmitters as the primary signals. The magnetic component of VLF primary field is horizontal. Local conductivity unhomogeneities will add vertical components to the total field. The total field is then tilted locally on both sides of local conductors.

The Geonics EM16 VLF receiver measures in-phase (tilt angle) and quadrature (ellipticity) components of the vertical magnetic field. The specifications of EM16 are as follows.

Specifications of Equipment for VLF-EM Survey

NAME	SPECIFICATION	
EM16, Geonics	Measured quality	: Inphase and quad-phase components of vertical magnetic field
	Sensitivity	: Inphase +/-150%, Quad-phase +/-40%
	Resolution	: +/-1%
	Output	: Nulling by audio tone
	Operating frequency	: 15-25kHz
	Power supply	: 6 disposable 'aa' cells

JICA Study Team prepared four (4) plug-in crystals (FUO: Bordeaux in France, NDT: Yosami in Japan, NWC: North West Cape in Australia, and UMS: Moscow in Russia) provided with EM16 for this survey. Only the NWC station (22.3kHz, 1,000W) was available for the entire survey period, however.

Exploration depth is limited to about 60 to 70 percent of the skin depth of the surrounding rock and soil. Skin depth is defined as 500*(R/f)1/2 , where "R" is resistivity (ohm-m) and "f" is frequency (Hz). For example, the maximum frequency of

VLF transmitters (20kHz) leads to an exploration depth of 23m in 100ohm-m and 73m in 1,000ohm-m areas.

The VLF-EM survey was conducted 45 profiles at the north of Ulaanbaatar City and along Holiin River (Fig. I.2.3).

Profiles No.	1~31	:	north of Ulaanbaatar City
"	32~35	:	Tuul River
"	36~45	:	Holiin River

In order to verify the existence of fractured zones, profile lines were oriented at approximately N25E across faults and lineaments estimated by satellite image and aerial photograph interpretation. Station spacing varied from five (5) meters near the fractured zones to 20m away from them. Survey profiles were from 500 to 1,200m long. The starting point of each VLF-EM survey profile was determined with a Global Positioning System and topographic map.

VLF inphase and quadrature profiles are presented in Appendix I.2.6. The location of fractured zones and artificial noise sources (power lines, rail roads and so forth,) are indicated on these profiles. The digital VLF-EM data is listed in Appendix I.2.7. An inferred fractured zone map is shown in Fig. I.2.4.

(2) Survey Result

1) Selbe River

VLF-EM data were collected 12 profiles (8 to 19) along Selbe River. Strong narrow anomalies can be seen in the profiles 10, 12 and 13 along the main stream of Selbe River. There are three typical VLF anomalies which are probably caused by fractured zones, for example in profile 13. These inferred fractured zones seem to continue to the south, in spite of weak response, as seen in profiles 16 and 18. A long period VLF anomaly in profile 17 may be caused by the topographical characteristics.

2) Uliastai River

While possible fractured zones were detected by previous surveys along this river, no clear VLF response can be seen in eight (8) profiles. This may be due to the fact that the VLF survey profiles were nearly parallel to the inferred fractured zones along Uliastai River. Some weak VLF anomalies were detected, however, in profiles 21 to 23.

Electrical resistivity section of this area has a thick second layer of around 300 ohm-m above a basement rocks which resistivity is a few thousand ohm-m. The moderate resistivity of the second layer may be caused by a fractured zone.

3) Tolgoit River

VLF anomalies can be seen along this river in the two (2) northern profiles, 5 and 6. These anomalies are probably caused by the east-west trending conductors. This VLF anomaly can be seen in part at the northern end of profile 4.

4) Bayan Goliin Valley

There are three (3) anomalous VLF profiles, 1, 2, and 3, along Bayan Goliin Valley. While a lineament is inferred along the valley around profiles 1 and 2, the direction of profile is approximately parallel to the lineament. The VLF anomalies in profiles 1 and 2 are, therefore, caused by east-west trending fractured zones which continue to profiles 4, 5, and 6. A typical dipole VLF anomaly can be seen in profile 3. This is caused by a fractured zone striking NNW-SSE. The VLF anomalies along this valley are lower in amplitude and broader than those near Selbe River, and this may indicate the presence of deeper conductors.

Layered model of St.53 of electrical survey, which is located near profile 3, have a thick second layer of around 350ohm-m overlying a basement rocks. The moderate resistivity of this layer may imply the presence of fractured zones.

No VLF-EM data was collected along Tahiltiin Goliin Valley, which is west of Bayan Goliin Valley. The electrical surveys of that valley, however, detected a layer of 60 to 120 ohm-m above a high resistivity basement rocks which increases in thickness to the south. This may be caused by fissure water along this valley.

5) Holiin River

10 profiles of VLF were conducted along Holiin River. In five (5) of the profiles (37, 38, 40, 41, and 43), strong typical dipole VLF anomalies can be seen. As mentioned in section 3.2, several lineaments were implied by the satellite image analysis along Holiin River. The VLF anomalies may originate from these fractured zones.

Layered models of St.1, 2, and 131 of the electrical survey have a thick layer with resistivities of 200 to 300ohm-m. These stations are located along an inferred lineament and the low resistivity of this layer may indicate the presence of fractured basement rocks.

(3) Possible Fissure Aquifer

On the basis of the VLF-EM and electrical surveys, possible fissure aquifers are listed below.

1) Selbe River (VLF profile 12)

2) Holiin River (VLF profiles 37 and 38)

3) Bayan Goliin Valley (St.53 and VLF profile 3)

4) Uliastai River (St.18, 20 and 22)

5) Tahiltiin Goliin Valley (St.56 through St.59)

2.1.4 Selection of Possible Groundwater Resources

According to the results of geological survey, interpretation of satellite images and aerial photos, electrical resistivity survey, and VLF-EM survey, possible groundwater resources are listed below.

Possible Groundwater Resources

Location	Aquifer type	Geology	Distance *1 (km)	Depth (m)	Width *2 (Km)	Length *2 (Km)	Hydro-geological condition	Construc-tion cost	Running cost	Priority
Upper Source	alluvial	sand, gravel, clay	40-54	5-36	1- 3	14	fairly good	Medium	Mediu m	
Lower part of Nalaih	alluvial	sand, gravel, clay	28-40	20-30	1- 2	12	fairly good	Low	Mediu m	1
Buheg River	alluvial	sand, gravel, clay	34-54	40-130	2-10	20	fairly good	Medium	Mediu m	
Lower part of Power Plant	alluvial	sand, gravel, clay	34-55	30-130	2- 4	21	fairly good	Medium	Mediu m	2
Ulaan Hujiriin Bulan	alluvial	sand, gravel, clay	55-122	50-130	10-12	67	fairly good	High	High	5
Ulahiin Bulan	alluvial	sand, gravel, clay	122-147	>50 ?	6- 8	25	fairly good	High	High	6
North of ULTB										3
Uliastai	fissure, alluvial	fractured zone, sand, gravel	10-15	169-202 11-40	(< 0.5) 1-2	(30)	good	Low	Low	
Selbe	fissure	fractured zone	5-10	30-353	(< 0.5)	(14)	good	Low	Low	
Bayan goliin	fissure. alluvial	fractured zone, sand, gravel	18	32-206 5-49	(< 0.5) 1-1.5	(20)	good	Low	Low	
Tahiltiin goliin	fissure	fractured zone	16-22	25-72	(< 0.5)		good	Medium	Mediu m	
Holiin river	fissure	fractured zone	10-15	50-173	(< 0.5)	(31)	good	Medium	Mediu m	4

*1 : Distance from the Water Supply Department
*2 : ( ) width and length of fractured zone

Priority groundwater development areas shall be selected from the hydrogeological and economical points of view as the followings.

Hydrogeological condition

Aquifer has to satisfy the following elements.

capacity ; large width of groundwater basin---distribution of alluvial deposit and fractured zone

essential element ; high permeability, transmissivity, specific yield etc.

external element ; large precipitation, large recharge volume, a few existing water utilization etc.

Economical condition

Low construction cost

Low running cost

Good water quality

From the hydrogeological and economical points of view, the following areas are recommended for the possible groundwater resources.

- The surrounding area of Upper Water Source
- Lower areas, which include Lower part of Power Plant, Ulaan Hujiriin Bulan and Buheg River.
- North of Ulaanbaatar City

(1) The surrounding area of Upper Water Source

The area consists of Upper Source and Lower part of Nalaih.

A part of the upper area has been already developed as Upper Water Source but may be able to expand the development area considering the capacity of alluvial aquifer in Tuul River valley. It is necessary to carry out the test well drillings.

(2) Lower areas

Lower part of Power Plant and upper part of Ulaan Hujiriin Bulan are excellent places where have large alluvial aquifer and indicate very high specific capacity from the exploration boreholes of previous studies.

Buheg River is one of the tributary's basin where half of the exploration boreholes recorded high specific capacity and the aquifer was expected to be thick.

(3) North of Ulaanbaatar City

The area is expected to be the existence of fissure aquifer. Uliastai River, Selbe River, Bayan goliin valley and Tahiltiin goliin valley may have a potential of local water source. A exploration borehole for a fissure aquifer in Bayan goliin valley recorded the yield of 18liters/sec. and the high specific capacity of 518m^3/day/m. Another borehole in Bayan goliin valley produced 31 liters/sec from the alluvial aquifer.

2.2 TEST WELL DRILLING AND PUMPING TEST

Test well drilling, well logging, and pumping test were conducted to investigate the geology, pumping discharge of groundwater, groundwater level, and water quality.

2.2.1 Selection of Sites and Well Construction

(1) Selection of sites

Drilling sites were determined and located in the priority possible groundwater resources selected on the basis of geology, hydrogeology, and economical condition.

Deep well

The wells of 200 meters depth were conducted to explore the fissure aquifer. The locations are as follows.

Uliastai River ; one (1) well
Selbe River ; two (2) wells
Bayan goliin valley ; one (1) well

In these areas, fractured zone may be distributed from the results of satellite image interpretation and geophysical survey. Besides, high specific capacity were reported by the pervious studies.

Shallow well

The wells of 30 and 50 meters depth were conducted to the alluvial aquifer in the following areas.

Buheg River ; four (4) wells
Lower part of Power Plant ; three (3) wells
Lower area of Upper Water Source ; four (4) wells

(2) Test well construction

15 test wells were constructed for the Study and these wells can be divided into three(3) types, namely Type A, B and C. Type A wells are located in the north of Ulaanbaatar to explore the fissure aquifers. Type B wells are located in the alluvial plane of Buheg River. Type C wells are located in the alluvial plane of Tuul River. Fig. I.2.5 shows the locations of the wells.

The specifications of each type were as follows. Some wells' specifications were changed due to geological condition. Type A and B wells were constructed by rotary method. Type C wells except C-5 were constructed by percussion method. C-5 well was constructed using a rotary machine.

Six (6) water level recorders were installed in the test wells of A-4, B-2, C-2, C-4, C-5 and C-7.

Designed specifications of test wells are stated below.

<u>Type A</u>	
Depth	200 meters
Borehole diameter	12.5 inches
Casing program	8 inches casing and screen pipes
<u>Type B</u>	
Depth	50 meters
Borehole diameter	14 inches
Casing program	10 inches casing and screen pipes
<u>Type C</u>	
Depth	30 meters
Borehole diameter	14 inches
Casing program	10 inches casing and screen pipes

Some well were changed it specifications due to the geological condition.

Table. I.2.1 shows the results of the test well drilling.

2.2.2 Geological Data

Geological sampling of cuttings and geophysical loggings for all fifteen (15) wells were conducted to investigate the geological and hydrogeological condition on possible new groundwater resources areas. These results are shown in drillhole log of Appendix I.2.8.

(1) Lithology

Lithology of each well is as follows.

1) Well number A-1

Alluvial deposit is distributed 3.2 meters of the depth from the ground surface that consist of sand and gravel with clay.

Basement rocks are composed of shale and/or fine sandstone, and alternation of sandstone and shale. These rocks are siliceous and partly tuffaceous. Fractures are eminently formed at 95 to 125 meters and 135 to 145 meters that are expected to be a water passage.

2) Well number A-2

Alluvial deposit is distributed 38.3 meters of the depth from the ground surface that consists of sand and gravel with clay.

Basement rocks are composed of medium sandstone, siliceous fine to medium sandstone with quartzite, and siliceous slate. Fractures are slightly formed at 130 to 201.8 meters and eminently formed at 155 to 165 meters that are expected to be a water passage.

3) Well number A-3

Surface soil is distributed about 0.1 meter of thickness. Basement rocks are composed of tuffaceous sandstone, siliceous fine sandstone, shale, fine to medium sandstone, and alternation of sandstone and shale from the top to the bottom of drill hole. Fractures are formed at 94 to 113, 120 to 128, 133 to 197 meters that are expected to be the water passage. Especially, sandstone of 124 to 154 meters is expected to be a good water passage because of slightly weathered portion with fractures.

4) Well number A-4

Alluvial deposit is distributed 18.0 meters of the depth from the ground surface that consists of sand and gravel with clay. It may be recent river deposit.

Basement rocks are composed of dark gray siliceous tuffaceous sandstone and greenish gray tuffaceous siliceous fine sandstone. Fractures are slightly formed at 60 to 80 meters and 99 to 124 meters where the drilling mad lost. These portions are expected to be a water passage.

5) Well number B-1

Alluvial deposits are distributed to the bottom of well. The surface is covered by sand and gravel with clay layer of the thickness of 15 meters. The gravel varies rounded to subangular with bad sorted from granule to cobble. The second layer distributed from 15 to 21.5 meters is clay with gravel which perform an confining bed. The third layer distributed from 21.5 to 45 meters is sand with gravel which perform an confined aquifer. The forth layer distributed from 45 to 50 metes is gravel with sand, and also take a part of confined aquifer.

6) Well number B-2

Alluvial deposits are distributed to the bottom of well. The surface is covered by brownish gray sand and gravel with clay layer of the thickness of 5 meters. The second layer distributed from 5 to 32.5 meters is gray to brown sand and gravel with clay. The third layer, characterized by the typical river deposit, distributed from 32.5 to 42.5 meters is mixed with brown clay, sand, and gravel. This layer may be the alternation of clay, sand, and gravel. The forth layer distributed from 42.5 to 50 metes is sand and gravel with clay.

7) Well number B-3

Alluvial deposits are distributed to the bottom of well. The surface is covered by sand and gravel layer of the thickness of 17.5 meters. The gravel varies rounded to subangular with bad sorted from granule to pebble. The second layer distributed from 17.5 to 47.5 meters of the depth is sand and gravel with clay. The gravel varies rounded to sub-rounded with very bad sorted from granule to boulder. The third layer distributed from 47.5 to 65 meters is coarse sand and rounded gravel which may be a good aquifer.

8) Well number C-1

Alluvial deposits composed of sand with gravel layer and sandy gravel layer are distributed to the depth of 21 meters and basement rock underlie alluvial deposit. Gravel of each layer varies rounded to subrounded with bad sorted from pebble to cobble. Sandy gravel layer may be a good aquifer. Basement rock expected to be D1-2 formation of Devonian age is composed of the alternation of sandstone and shale.

9) Well number C-2

Alluvial deposits are distributed to the depth of 20 meters and basement rock underlie alluvial deposit. The surface layer of alluvial deposits composed of clay with roots. The second layer distributed from 1 to 4 meters of the depth is brownish gray sandy clay with gravel. The third layer distributed 4 to 10 meters of the depth is brownish gray sand and gravel. The fourth layer distributed 10 to 12 meters of the depth is sand and gravel with clay. The fifth layer distributed 12 to 20 meters of the depth is bluish gray sand and gravel. Gravel of each layer varies rounded to subrounded with bad sorted from pebble to cobble. Basement rock expected to be D1-2 formation of Devonian age is composed of the alternation of sandstone and shale.

10) Well number C-3

alluvial deposits are distributed to the depth of 28 meters and basement rock underlie alluvial deposit. The surface layer of Alluvial deposits distributed from ground surface to 3 meters of the depth is composed of clay with gravel and roots. The second layer distributed from 3 to 6 meters of the depth is brownish gray sand and gravel. The third layer distributed 6 to 28 meters of the depth is bluish gray sand and gravel with clay which gravel varies rounded to sub-rounded with bad sorted from pebble to boulder. Basement rock expected to be C1-2 formation of Carboniferous age is composed of the alternation of sandstone and shale.

11) Well number C-4

Alluvial deposits are distributed to the depth of 14 meters and basement rock underlie alluvial deposit. The surface layer of alluvial deposits distributed from ground surface to 1 meters of the depth is composed of clay with roots. The second layer distributed from 1 to 3 meters of the depth is brownish gray sand with gravel. The third layer distributed 3 to 14 meters of the depth is sand and gravel which gravel varies rounded to sub-angular with bad sorted from pebble to boulder. Basement rock expected to be C2-3 formation of Carboniferous age is composed of shale.

12) Well number C-5

Alluvial deposit is distributed to the bottom of well. The surface is covered by clay layer of the thickness of 1 meter. The second layer distributed from 1 to 30 meters is sand and gravel. Gravel varies rounded to subrounded with bad sorted from granule to pebble. This is the typical recent river deposit which may be a good aquifer.

13) Well number C-6

Alluvial deposit is distributed to the bottom of well. The surface is covered by clay layer of the thickness of 0.5 meter. The second layer distributed from 0.5 to 4 meters is light gray gravel with clay. The third layer composed of sand and gravel is distributed from 4 to 32 meters of the bottom of well. Gravel size varies granule to cobble with rounded to subrounded. This is the typical recent river deposit which may be a good aquifer. Lithology defer from main portion from 10 to 11 meters which includes clay.

14) Well number C-7

Alluvial deposit is distributed to the bottom of well. The surface is covered by clay layer of the thickness of 0.5 meter. The second layer distributed from 0.5 to 6 meters of the depth is sand and gravel with clay. The third layer distributed from 6 to 12 meters is sand and rounded to sub-angular gravel. The forth layer distributed from 12 to 18 meters is gravel with sand which may be a good aquifer. The fifth layer distributed from 17 to 19 meters is sand and gravel with clay. The deepest layer is sand and granule to cobble gravel with bad sorted. This layer may be also a good aquifer.

15) Well number C-8

Alluvial deposit is distributed to the bottom of well. The surface is covered by clay layer of the thickness of 0.5 meter. The second layer distributed from 0.5 to 8 meters of the depth is sand and gravel with clay. The third layer distributed from 8 to 30 meters of the bottom of well is sand and rounded to subrounded gravel which may be a good aquifer.

(2) Geophysical Logging

Geophysical loggings consist of Temperature logging, Electrical logging (spontaneous potential, resistivity), and Gamma Ray logging.

Geophysical loggings were conducted in the drilling mud in order to prevent the drillhole collapse because of the distribution of very loose sand and gravel layer, using Geologger 3030 Mark-2 provided by JICA. Accordingly, the result of logging may not reflect the real geological and hydrogeological condition. But a tendency can be realized by these loggings.

1) Well number A-1

Spontaneous Potential (SP) indicates generally a range from 170 to 260mv from the top to bottom of the drillhole. The Resistivity indicates a increase tendency a range of 100 to 1600 ohm-m from 10 to 175 meters of the depth. The section of 90 to 175 meters is characterized by the deference of resistivity between short normal (Sho.) and the long normal (Lon.). The section from about 90 to 175 meters may be a good aquifer. Gamma Ray indicates a non characteristic variety with a range from 40 to 60 cps. Temperature indicates about 6°C below 20 meters in general.

2) Well number A-2

Spontaneous Potential (SP) indicates a range from 100 to 200mv from the top to bottom of the drill hole. The section of 90 to 201.8 meters is characterized by the deference of resistivity between short normal (Sho.) and the long normal (Lon.). This phenomenon point out that the section from about 90 to 201.8 meters may be a good aquifer. Temperature indicates about 6 °C in general.

3) Well number A-3

Geophysical loggings of this drill hole are not characteristic which may indicate a similar condition of fractured zone from 22 meters of the depth to the bottom of well. Temperature indicates 6 to 7 °C that may be the temperature of drilling mud.

4) Well number A-4

Spontaneous Potential (SP) indicates a increase tendency from 25 to 134 meters of the depth (range from 270 to 400mv). The section of 0 to 25 meters indicates the comparatively high SP characterized by the distribution of alluvial deposit.

Resistivity of the both short normal (Sho.) and long normal (Lon.) indicate a increase tendency a range of 0 to 1800 ohm-m from 5 to 134 meters of the depth. The section of 0 to 25 meters indicates the comparatively low resistivity characterized by the distribution of alluvial deposit. Gamma Ray indicates comparatively high cps of 60 to 80 below 55 meters. The section from about 55 to 134 meters may be a crashed zone that suggests a good aquifer. Temperature indicates 4 to 4.5 °C.

5) Well number B-1

Spontaneous Potential (SP) indicates a increase tendency from 12 to 38.5 meters of the depth (range from 440 to 560mv). On the other hand, resistivity of the short normal (Sho.) and long normal (Lon.) indicates the low range of 100 to 200 ohm-m from 13 to 50 meters of the depth comparing with another section. These phenomenon point out that the section from about 13 to 38 meters may be a good aquifer. Temperature indicates 6 to 7 °C in general.

6) Well number B-2

Spontaneous Potential (SP) indicates a increase tendency from 16 to 42 meters of the depth (range from -20 to 5mv). On the other hand, resistivity of both short normal (Sho.) and long normal (Lon.) indicates a decrease tendency with a range of 50 to 800 ohm-m from 10 to 42 meters of the depth. The section of 10 to 32 meters is characterized by the deference of resistivity between short normal (Sho.) and the long normal (Lon.). The section from about 10 to 42 meters may be a good aquifer. Gamma Ray indicates a non characteristic variety with a range from 40 to 60 cps. Temperature indicates 3.5 to 4.5°C in general.

7) Well number B-3

Spontaneous Potential (SP) indicates the low range of 80 to 160mv from 45 to 65 meters of the depth comparing with the upper section. Similarly, resistivity of the both short normal (Sho.) and long normal (Lon.) indicates the high range of 50 to 1000 ohm-m from 45 to 65 meters of the depth comparing with the upper section. Besides, the section of 47 to 58 meters is characterized by the deference of resistivity between short normal (Sho.) and the long normal (Lon.). The section from about 47 to 58 meters may be a good aquifer. Gamma Ray indicates a non-characteristic variety with a range from 30 to 50 cps in general. Temperature indicates 8 °C in general.

8) Well number C-1

Spontaneous Potential (SP) indicates a increase tendency from 10 to 22 meters of the depth (range from 200 to 700mv). On the other hand, resistivity of the short normal (Sho.) indicates the low range of 20 to 200 ohm-m from 10 to 20 meters of the depth comparing with another section. The section of 10.5 to 14 meters is characterized by the deference of resistivity between short normal (Sho.) and the long normal (Lon.). These phenomenon point out that the section from about 10 to 22 meters may be a good aquifer. Temperature indicates 2 to 3°C in general.

9) Well number C-2

Spontaneous Potential (SP) indicates a increase tendency from 10 to 24 meters of the depth (range from 0 to 300mv). On the other hand, resistivity of the short normal (Sho.) indicates the low range of 0 to 200 ohm-m from 13.5 to 24 meters of the depth comparing with upper section. These phenomenon point out that the section from about 10 to 24 meters may be a good aquifer. Temperature indicates 2 to 3°C in general.

10) Well number C-3

Spontaneous Potential (SP) could not be conducted because of the machine trouble. Resistivity of the short normal (Sho.) indicates the low range of 200 to 800 ohm-m from 11 to 30 meters of the depth comparing with upper section. Electric Conductivity indicates the low range from 22 to 30.5 meters of the depth comparing with upper part. Temperature indicates 2 to 4°C in general.

11) Well number C-4

Spontaneous Potential (SP) indicates a increase tendency from 10 to 17 meters of the depth (range from 0 to 400mv). On the other hand, resistivity of the short normal (Sho.) indicates the low range of 200 to 450 ohm-m from 13.5 to 16.5 meters of the depth comparing with another section. Resistivity of the long normal (Lon.) indicates the high range of 1200 to 1900 ohm-m at the same section comparing with another section. These phenomenon point out that the section from about 10 to 16.5 meters may be a good aquifer. Temperature indicates the unreliable data from 5.5 to 9 °C which may be the value of drilling mud.

12) Well number C-5

Spontaneous Potential (SP) and Electric Conductivity could not be conducted because of the machine trouble. Resistivity of the short normal (Sho.) indicates the low range of 100 to 500 ohm-m from 8 to 28 meters of the depth comparing with upper section. Temperature indicates the unreliable data from 5.5 to 9 °C which may be the value of drilling mud.

13) Well number C-6

Spontaneous Potential (SP) indicates a range of 200 to 600mv at 13.5 to 31 meters of the depth. Resistivity of the short normal (Sho.) indicates the low range of 0 to 100 ohm-m from 13.5 to 31 meters of the depth comparing with the upper section. The section from about 13.5 to 31 meters may be a good aquifer. Temperature indicates 5 to 6 °C in general.

14) Well number C-7

Spontaneous Potential (SP) indicates a increase tendency from 13.5 to 30 meters of the depth (range from -100 to 600mv). On the other hand, resistivity of the short normal (Sho.) indicates the low range of 10 to 150 ohm-m from 13.5 to 30 meters of the depth comparing with the upper section. These phenomenon point out that the section from about 13.5 to 30 meters may be a good aquifer. Temperature indicates 5 to 6 °C in general.

15) Well number C-8

Spontaneous Potential (SP) indicates a decreasing tendency from 10 to 30 meters of the depth (range from 300 to 450mv). Resistivity of the short normal (Sho.) indicates the low range of 50 to 400 ohm-m from 13.5 to 30 meters of the depth comparing with another section. The section from about 13.5 to 30 meters may be a good aquifer. Temperature indicates 6 to 8°C in general.

2.2.3 Pumping Test

(1) Methodology of Pumping Test

Three (3) types of pumping tests; step drawdown test, constant discharge test and recovery test were conducted for test wells after completion of drilling work and air lifting development.

1) Pumping

Submersible pumps were used for pumping.

The pump was installed in the cased well with rising main and delivery pipe.

2) Method of Test

Each test was carried out following the standard method.

Step drawdown test	:	At least 7 round steps (discharge increased and decreased) and duration of each step is 120 minutes.
Constant discharge test	:	24 hours measurement was conducted as soon as the water level in the well has recovered its static water level after completion of the step drawdown test.
Recovery test	:	The test starts immediately after completion of the constant discharge test and continues until water level in the well recovers its static water level.

However, in order to meet the hydrogeological conditions at each well, discharge rate, test duration, number of steps and time interval were altered by Hydrogeologist of JICA Study Team.

3) Measurement

The static water level in the well is measured immediately before any pumping test commences. Throughout the duration of each test, the water level in the borehole was measured and recorded as following observation time schedule listed below;

Time from start of pumping or pumping rate increase (minutes)	Time interval between observations (minutes)

The flow of all water pumped from well during pumping test is measured by a triangular weir. Discharge rate is recorded during the pumping test at intervals corresponding to those for water level measurement.

4) Method of Analysis

i) Aquifer Constants

Major aquifer constants necessary for aquifer are transmissivity, storage coefficient (specific yield of an unconfined aquifer) and permeability. These aquifer constants were estimated by using the results of the constant discharge test and recovery test. For the above estimation. Theis and Jacob methods were applied. The aquifer constants are given by the following formulas;

a) Theis Method

Transmissivity (T) = $Q \cdot W(u)/4\pi s$

Where	Q	= pumping rate (m^3/day)
	W(u)	= well function of u
	s	= drawdown (m) at matching point

Permeability (K) = T/L

Where	T	= transmissivity (m^2/day)
	L	= thickness of aquifer (total length of screen pipes)

b) Jacob method

Transmissivity (T) = $0.183 \cdot Q /$

Where	T	= Transmissivity (m^2/day)
	Δs	= drawdown on one log cycle

Permeability (K) = T/L

Where	T	= transmissivity (m^2/day)
	L	= thickness of aquifer (total length of screen pipes)

(2) Pumping Test

Two type of pumping tests, namely Step Drawdown Test and Constant Discharge Test, were conducted at the all drillholes. In general, the step drawdown test consists of seven(7) stages and the duration of pumping at each stage was two hours. Twenty four (24) hours constant discharge test followed it after the recovering of water level. The results are shown below. The data of pumping tests are shown in Appendix I.2.9.~10.

Hydrogeological constant

Drilling number	Pumping Rate		Static water level	Pumping water level	Drawdown	Specific capacity	Trans-missivity	Permeability coefficient
	(liter/sec)	(m^3/day)	(G.L.- m)	(G.L.- m)	(m)	(m^3/day/m)	(m^2/day)	(cm/sec)
No. A-1	10.5	907	12.4	58.75	46.35	20	23	(4.1×10^{-4})
No. A-2	0.6	52	11.8	82.05	70.25	1	<1	(4.61×10^{-6})
No. A-3	25	2160	5.61	53.42	47.81	45	40	(6.52×10^{-4})
No. A-4	16.7	1443	3.48	52.22	48.74	30	31	(7.97×10^{-4})
No. B-1	3.9	337	- 2.00	11.53	13.53	25	35	2.46×10^{-3}
No. B-2	6.3	544	0.45	5.64	5.19	105	122	8.56×10^{-3}
No. B-3	22	1901	2.70	10.04	7.34	259	354	1.86×10^{-2}
No. C-1	10.8	933	0.75	8.69	7.94	118	142	1.49×10^{-2}
No. C-2	5.6	484	1.71	8.53	6.82	71	59	6.21×10^{-3}
No. C-3	2.9	251	2.47	16.90	14.43	17	13	2.74×10^{-3}
No. C-4	4.4	380	1.08	7.23	6.15	62	91	1.91×10^{-2}
No. C-5	8.5	734	5.47	26.00	20.53	36	37	3.89×10^{-3}
No. C-6	25	2160	1.93	3.69	1.76	1227	873	6.12×10^{-2}
No. C-7	36.7	3171	1.80	3.37	1.57	2020	2410	2.54×10^{-1}
No. C-8	4.4	380	1.20	8.06	6.86	55	50	5.26×10^{-3}

Table I.2.1 The Results of the Test Well Drilling

Well No.	Location	Elevation	coordinate X	coordinate Y	Drilled Depth	Screen Depth from	Screen Depth to	Pumping Rate		S.W.L	P.W.L	Draw-down	Specific Capacity	Trans-missivity	Permeability Coefficient	Producing Laver	Depth to Bedrock	Remarks
		(m)	(Long.E)	(Lat.N)	Gl-(m)	Gl-(m)	Gl-(m)	(l/sec)	(m3/day)	Gl-(m)	Gl-(m)	(m)	(m3/day/m)	(m2/day)	(cm/sec)		Gl-(m)	
A-1	Uliastai River	1442.50	107-03'22"	48-00'25"	183.5	84.0	177.5	10.5	903	12.4	58.75	46.35	19	23	(4.10E-04)	Bedrock		
A-2	Selbe River	1431.50	106-54'20"	48-03'23"	201.8	102.8	196.3	0.6	52	11.8	82.05	70.25	1	<1	(4.61E-06)	Bedrock		
A-3	Bayan Goliin	1374.60	106-42'48"	47-58'28"	200.3	95.5	123.0	25.0	2164	5.61	53.42	47.81	45	40	(6.52E-04)	Bedrock	0	
						134.0	178.0											
						183.5	194.5											
A-4	Selbe River	1425.20	106-54'03"	48-03'02"	134.0	49.5	134.0	16.7	1441	3.48	52.22	48.74	30	31	(7.97E-04)	Bedrock	18	
	Sub Total				719.6													
B-1	Buheg River	1305.50	106-45'00"	47-38'18"	50.0	22.5	39.0	3.9	337	(2.0)	11.53	13.53	25	35	2.46E-03	Alluvium	>50	Flowing well
B-2	Buheg River	1297.00	106-42'56"	47-39'45"	50.0	16.0	21.5	6.3	540	0.45	5.65	5.2	104	122	8.56E-03	of	>50	
						38.0	49.0									Buheg		
B-3	Buheg River	1230.50	106-35'02"	47-43'52"	65.0	22.0	33.0	22.0	1901	2.7	10.04	7.34	259	354	1.86E-02	River	>65	
						43.0	54.0											
	Sub Total				165.0													
C-1	Lower Area	1392.30	107-21'59"	47-48'52"	30.5	10.0	21.0	10.8	935	0.75	8.69	7.94	118	142	1.49E-02	Lower	21	
C-2	of Upper	1386.60	107-19'51"	47-49'10"	24.0	11.0	22.0	5.6	485	1.71	8.53	6.82	71	59	6.21E-03	Layer	20	
C-3	Water	1370.70	107-15'10"	47-50'52"	31.0	24.5	30.0	2.9	253	2.47	16.9	14.43	18	13	2.74E-03	of Alluvium	28	
C-4	Source	1331.70	107-09'55"	47-55'12"	22.3	9.1	14.6	4.4	382	1.08	7.23	6.15	62	91	1.91E-02	Tuul River	14	
C-5	Buheg	1226.60	106-35'20"	47-46'17"	30.0	13.5	24.5	8.5	734	5.47	26	20.53	36	37	3.89E-03		>30	
C-6	Lower Part	1204.50	106-30'36"	47-45'52"	32.0	13.5	30.0	25.0	2160	1.93	3.69	1.76	1227	873	6.12E-02	Alluvium of	>31	
C-7	of Power	1174.20	106-17'20"	47-43'35"	30.0	13.5	24.5	36.7	3168	1.8	3.37	1.57	2018	2410	2.54E-01	Tuul River	>30	
C-8	Plant	1173.00	106-18'10"	47-42'50"	30.0	16.0	27.0	4.4	382	1.2	8.06	6.86	56	50	5.26E-03		>30	
	Sub Total				229.8													
	Grand Total				1114.0													

S.W.L ; Static Water Level
P.W.L ; Pumping Water Level

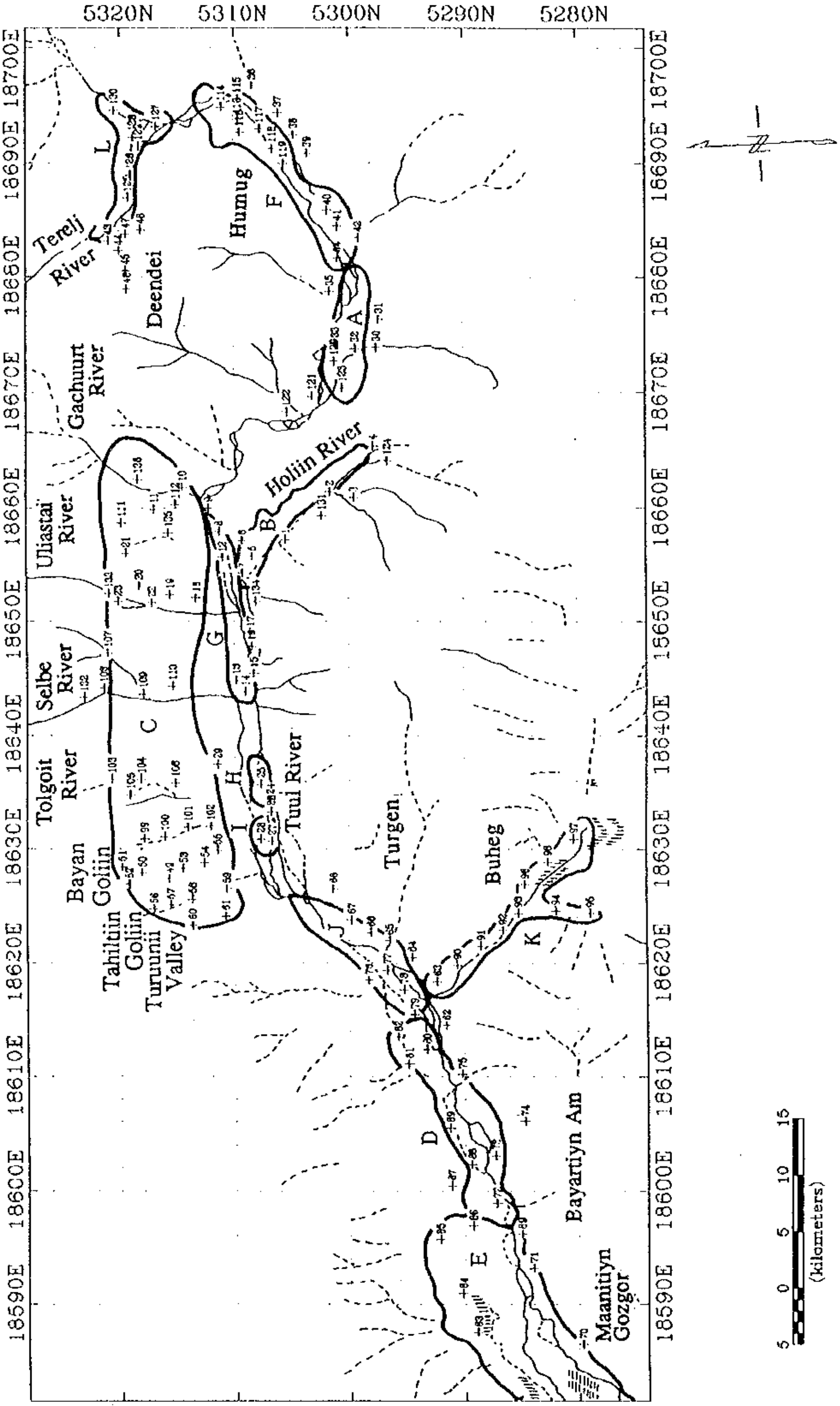

Fig. I.2.1 Location Map of Electrical Sounding Stations

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Fig. I.2.2	**Basement Depth Map**
JICA	The Study on Water Supply System in Ulaanbaatar and Surroundings

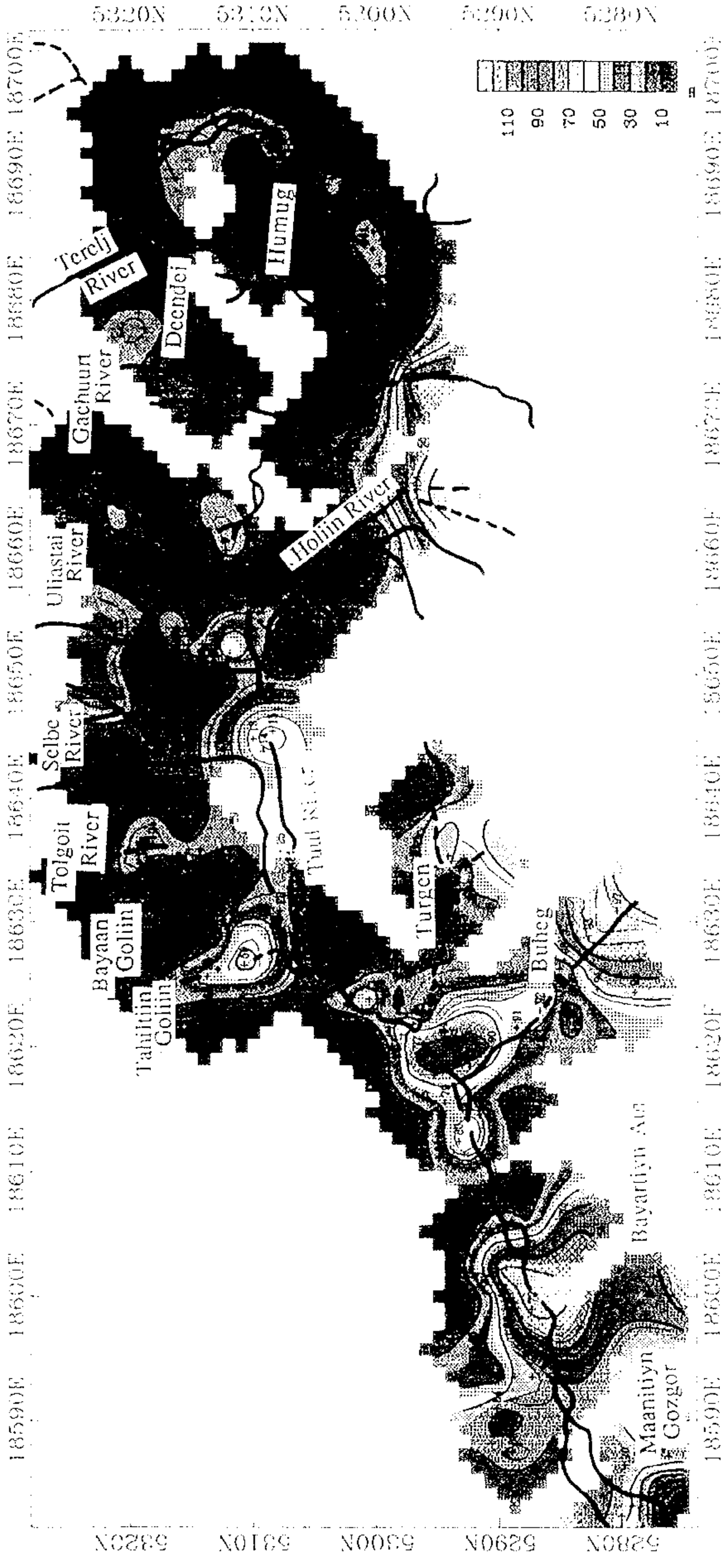

Fig. I.2.2	**Basement Depth Map**
JICA	The Study on Water Supply System in Ulaanbaatar and Surroundings

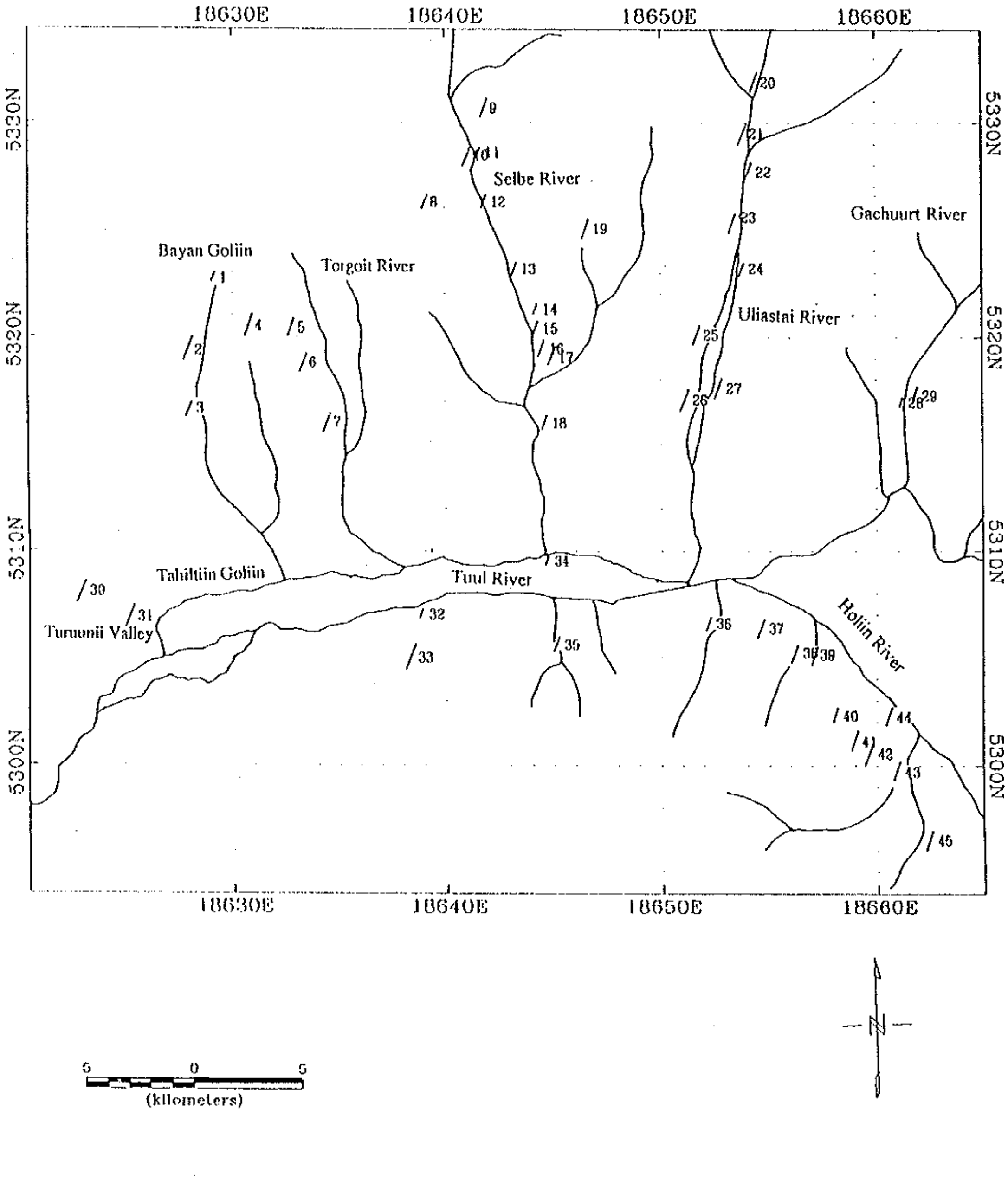

Fig. I.2.3 Location Map of VLF-EM Survey Profiles

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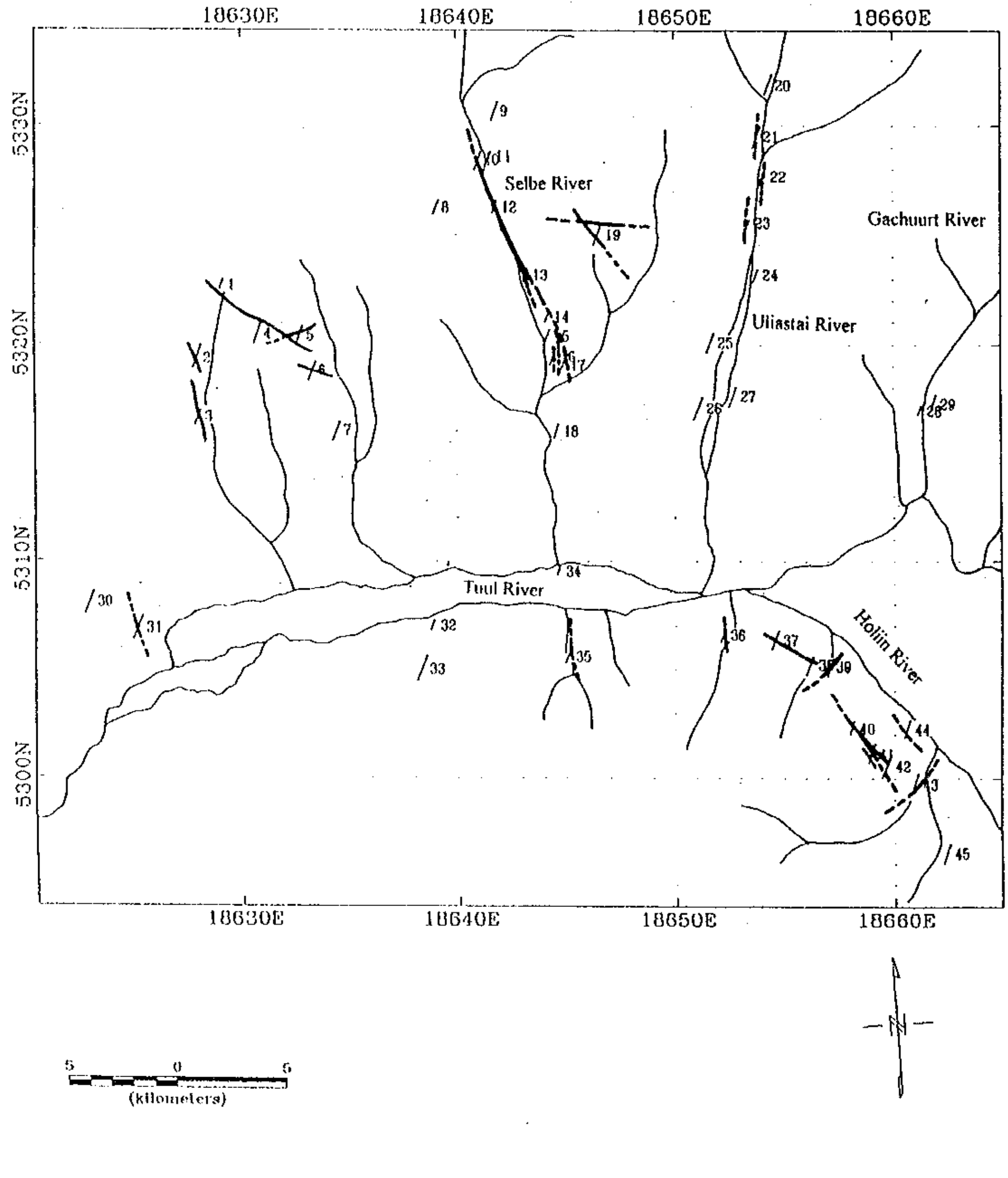

Fig. I.2.4	Fractured Zones Inferred by VLF-EM Survey
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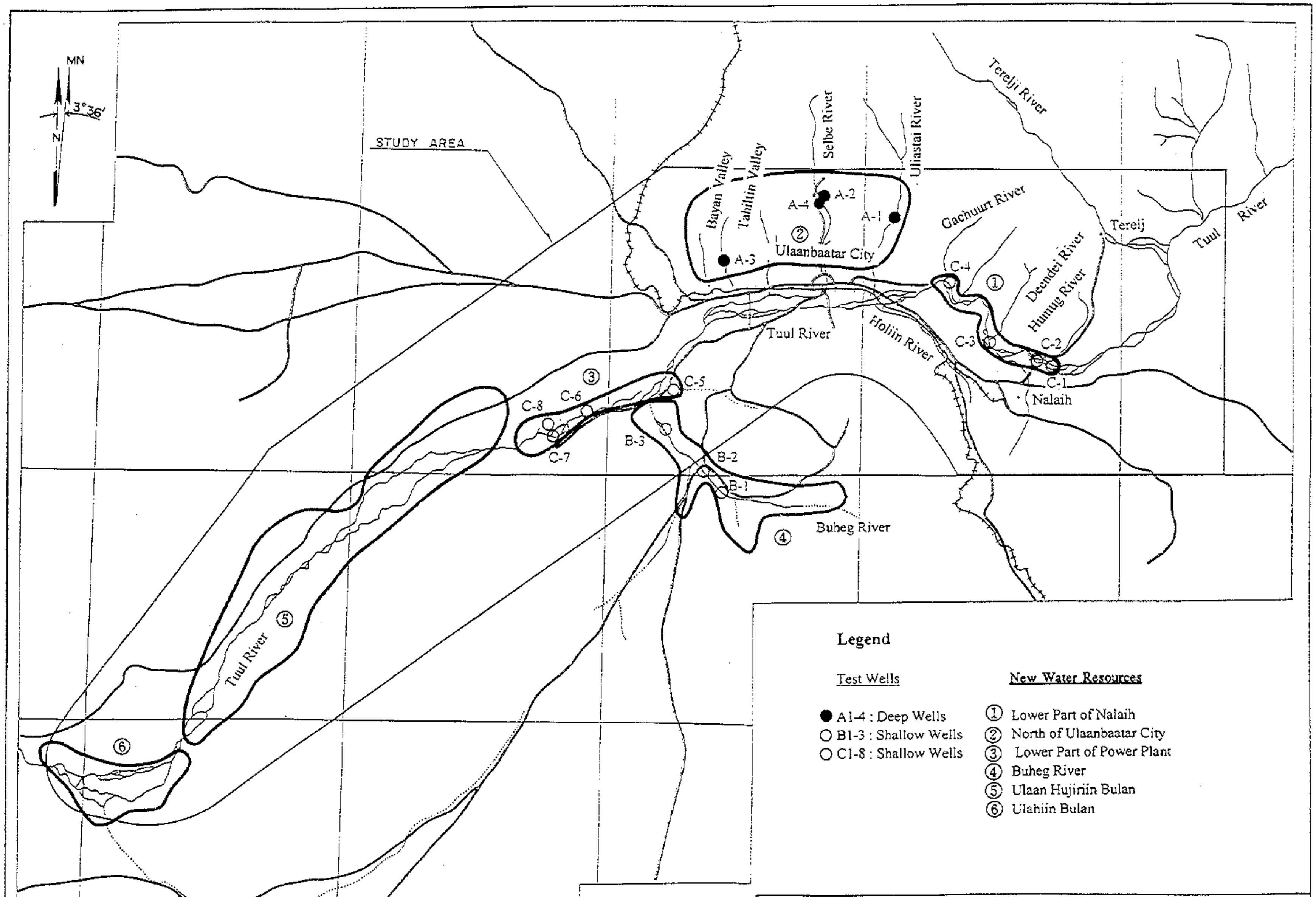

Fig. I.2.5 Locations of test wells and new water resources

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CHAPTER 3 HYDROGEOLOGICAL CONDITION IN THE AREA

CHAPTER 3 HYDROGEOLOGICAL CONDITION IN THE AREA

3.1 GENERAL

Devonian and Carboniferous sediments intruded by granitic rocks are widely distributed in the area. The porosity of these rocks are very low and they are practically impermeable. Therefore they can be considered to be the basement rocks in the area from a hydrogeological point of view. Cretaceous sediments covered the basement rocks locally. Neogene and Quaternary deposits are distributed along Tuul River basin.

3.1.1 Devonian sediments (D), Carboniferous sediments (C) and Mesozoic intrusive rocks (Gr).

The sedimentary rocks in the area are mainly composed of sandstone, chert and mudstone. They are practically impermeable. However it has been reported that there are pervious zones due to fractures. The results of the field survey and satellite image analysis suggest the existence of these fractures. There are fractured zones in Granite as well.

More than fifty(50) boreholes, which were drilled for previous surveys, penetrated into these consolidated rocks in the area. Yields of the exploration wells ranged widely due to probable underlying structure. Maximum one was 18 liters/sec.(1555 m^3/day) and the specific capacity was 518 m^3/day/m. The fissure water may be useful for regional water supply.

There are many springs issuing from fractures in basement rock. However, these are not mentioned in this report because it is practically difficult to develop on a large scale for water supply system in Ulaanbaatar City.

3.1.2 CRETACEOUS SEDIMENTS (K)

Cretaceous sediments consist of sandstone and mudstone with coal and are distributed in Naraih area and the north hill of Ulaanbaatar City area. The collected data of boreholes drilled in this area show that groundwater supply potential of the formation is not satisfactory. The maximum yield was 6.7 liters/sec. (579 m^3/day) and the specific capacity was 33 m^3/day/m. The TDS (Total Dissolved Solid) of groundwater in this area ranged from 0.4 to 0.9 g/liter, higher than the value in other areas.

Groundwater in the distribution area of Cretaceous sediments have not sufficient potential and it is not suitable for drinking water.

3.1.3 Neogene deposits (N)

Neogene deposits are locally distributed in the north bank of Tuul River and some parts of the Holiin River valley. They consist of loamy sand and clay mainly. The maximum yield of the boreholes penetrating into Neogene deposits was 15 liters/sec (1458 m^3/day) and the specific capacity was 240 m^3/day/m, while other wells in Neogene deposits area yield from 0.2 to 3.7 liters/sec.(17 to 320 m^3/day).

3.1.4 Quaternary deposits (Q)

Quaternary deposits in the Study Area are classified as follows.

Terrace deposits
Fan deposits
Talus deposits
Recent river deposits

The deposits are most interesting from a viewpoint of groundwater development. The deposits, which mainly consist of gravel, sand and clay, are widely distributed along Tuul River and have a thickness of over 100 meters in the maximum. The maximum yield of the exploratory wells in the area was 78.8 liters/sec.(7092 m^3/day).

The production wells of the existing four(4) water sources, which are Central Water Source, Industrial Water Source, Meat Complex Water Source and Upper Water Source, have been pumping groundwater from the area distributed the river deposits.

3.2 AQUIFER TYPES

There are two types of water-bearing formations in the area, namely highly fractured aquifer and alluvial aquifer.

3.2.1 Fracture Aquifer

Many exploration boreholes were drilled in the tributary's valley of Tuul River. Some of them penetrated into basement rock and encountered fractured aquifers. The data collected by Mongolian Geological and Geophysical Exploration Company (GGEC) were summarized in Table I.3.1 According to the data, 14 of the 62 exploration wells setting screen pipes in basement rock yielded more than five liters/sec (432 m^3/day). Five of the 14 wells produced more than 10 liters/sec (864 m^3/day). These productive wells are distributed at random reflecting the irregularity of subsurface geological and hydrogeological structure.

3.2.2 Alluvial Aquifer

Alluvial aquifers which are distributed along Tuul River and its tributaries are unconfined aquifers having the water table. The results of exploratory drilling for previous surveys were summarized in Table I.3.2. The table shows that the depth to the basement ranges from five meters, Huandei and Deendei, to more than 90 meters, the downstream of Ulaanbaatar City. The thickness of the alluvial deposits tends to increase at the downstream. In Buheg the depth to the basement varies from 34 to 70 meters.

The map of the basement depth that is presented as the result of the geophysical prospecting by JICA team coincides approximately with the exploratory drilling results.

The alluvial deposits can be divided into two layers, upper and lower. The upper layer is Late Quaternary to Recent deposits. The lower layer is Middle to Late Quaternary deposits. The screen pipes of the production wells for the four(4) water sources and exploration boreholes were installed through these two layers mostly. The production wells of the Power Plant No.4, the screen pipes of which installed in the lower layer only, yield 30 liters/sec (2500 m^3/day) per one well.

3.3 AQUIFERS IN THE AREA

3.3.1 General

1) Regions

The area where distributes Quaternary deposits can be divided into some regions. The important regions for development of groundwater resources are as follows.

(1) Upper Part (of Ulaanbaatar), which consists of Upper Water Source and Lower Part of Nalaih.
(2) Central Part, which includes Central Water Source, Industrial Water Source, Meat Complex Water Source and Power Plant No.3 Water Source.
(3) Lower Part (of Ulaanbaatar), which consists of Power Plant No.4 Water Source, Lower Part of Power Plant and the downstream area.
(4) Buheg River
(5) The tributaries' valleys of Tuul River in the North of Ulaanbaatar.

Groundwater occurs also in fractured zones of basement rock in the North of Ulaanbaatar. This is the principal basement rock aquifer in the area.

2) Hydraulic properties of the aquifer

Availability of groundwater depends on two important functions of the aquifer, namely the transmission and the storage of water. These are affected by permeability and porosity of the aquifer. The former is indicated by the permeability coefficient, that is the volume flow rate of water through a unit cross-sectional area of a porous medium under the influence of a hydraulic gradient of unity. The transmissivity or flow in m3/day through a section of aquifer 1 meter wide under a hydraulic gradient of unity is used as a convenient quantity in the calculation of groundwater flow instead of the permeability coefficient. The transmissivity, T, and permeability coefficient, k, are related to each other as follows

$$T = kH$$

where H is the saturated thickness of the aquifer. Normally T and k are determined by aquifer tests. If aquifer tests are not carried out or T and k are unknown, specific capacity, which is the discharge per unit of drawdown, is sometimes used to estimate hydraulic properties of the aquifer empirically.

The porosity is defined as the percentage pore space within a given volume. However the capacity of an aquifer to yield water is of greater importance than its capacity to hold water as far as supply is concerned. Even the pore space of a rock or soil may be saturated, only a certain proportion of water can be removed by drainage under gravity or pumping. The ratio of the volume of water that can be drained by gravity to the total volume of the aquifer is refereed to as the specific yield.

Ranges of permeability coefficient for soils and rocks, specific capacity and groundwater supply potential, examples of the specific yield of some common types of soil and rock, and the relationship between the specific yield and particle size distribution are given below for reference.

<u>Ranges of permeability coefficient for soils and rocks</u>

Permeability Coefficient										
m/day	10^4	10^3	10^2	10^1	1	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}
cm/sec	10^1	1	10^{-1}	10^{-2}	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}

Relative permeability				
Very high	High	Moderate	Low	Very low
Clean gravel	Clean sand and sand and gravel	Fine sand	Silt, clay and mixtures of sand, silt and clay	Massive clay
Vesicular and scorioceous basalt limestone and dolomite		Clean sandstone and fractured igneous and metamorphic rocks	Laminated sandstone, shale and mudstone	Massive igneous and metamorphic rocks

Specific Capacity and Groundwater Supply Potential

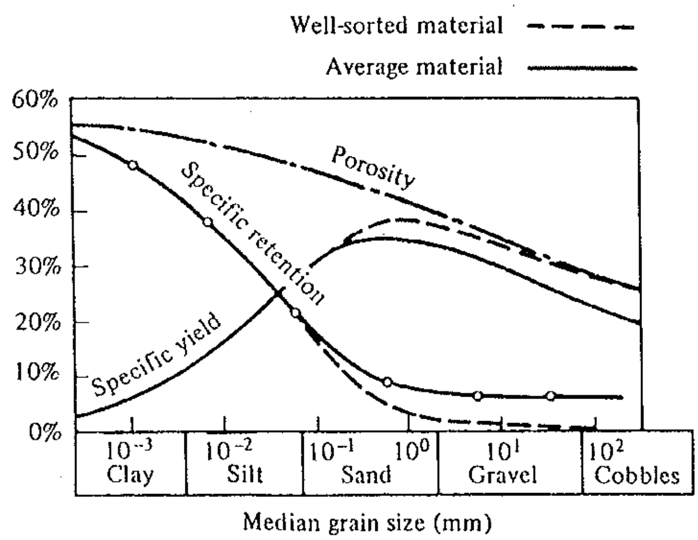
Specific Capacity liters/sec./m	(m3/day/m)		Groundwater Supply Potential
		Very high	Withdrawals of great regional importance
10	(864)		
		High	Withdrawals of lesser regional importance
1	(86)		
		Intermediate	Withdrawals for local water supply (private consumption's, etc.)
0.1	(8.6)		
		Low	Smaller withdrawals for local water supply (private consumption's, etc.)
0.01	0.86)		
		Very low	Withdrawals for local water supply with limited consumption
0.001	(0.086)		
		Imperceptible	Sources for local water supply are difficult (if possible) to ensure

Based on *Krasny, Jiri. 1993. GROUND WATER. vol.31, no.2, pp.231*

Examples of the specific yield of some common types of soil and rock

Material	Specific yield (%)	
Gravel		15-30
Sand		10-30
Dune sand		25-35
Sand and gravel	15-25	
Silt		5-10
Clay		1-5
Sandstone		5-25
Limestone		0.5-10
Shale		0.5-5

Relationship between the specific yield and particle size distribution



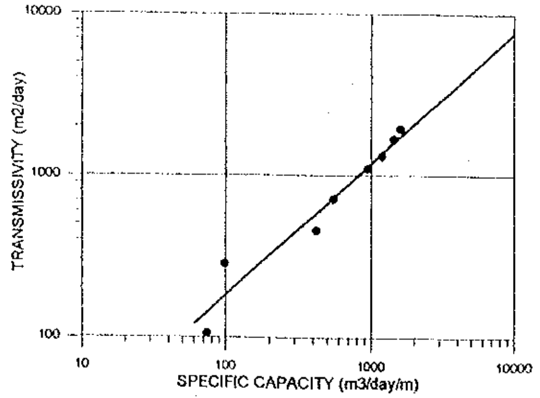
3.3.2 Upper Part of Ulaanbaatar

The alluvium of this area consists of sand and gravel with clay and ranges from 14 to 36 meters thick. The width of this alluvium ranges from 0.8 kilometers near Terelj Bridge to 2.5 kilometers in Uublan. The alluvium can be divided into the upper layer and the lower layer. It is reported the upper layer is more permeable than the lower layer. Exploration wells for previous studies in this area penetrated the alluvium, namely both the upper and the lower layer, and were installed perforated pipes through two layers. Consequently each layer's permeability coefficient has not been estimated, though the permeability coefficient of the alluvium was determined by pumping tests. Most of exploration wells have been used as production wells of Upper Water Source. Fig. I.3.1 shows the cross section of the area.

The permeability coefficients obtained range from 5.56×10^{-3} cm/sec to 1.02×10^{-1} cm/sec and averaged 4.8×10^{-2} cm/sec. Specific Capacity ranged from 74 to 1606 m3/day/m. Values of transmissivity can be calculated on basis of these well data. The results and the correlation between specific capacity and transmissivity are shown below. The relation may be used to determine transmissivity and permeability coefficient in the area empirically.

No. on Map	Exploration Well No.	Permeability Coefficient		length of screen		Specific Capacity	Calculated Transmissivity
		m/day	cm/sec	from	to	m3/day/m	m2/day
35	1	54.4	6.30E-02	4	28	1192	1306
36	2	84.2	9.75E-02	3	26	1606	1937
38	4	88	1.02E-01	4	23	1439	1672
40	6	42.4	4.91E-02	6	32	949	1102
44	10	15.2	1.76E-02	6	36	415	456
45	11	4.8	5.56E-03	6	28	74	106
46	12	14.2	1.64E-02	5	25	98	284
47	13	28.3	3.28E-02	6	31	545	708
	Ave.	41.44	4.80E-02				
	Min.	4.80	5.56E-03				
	Max.	88	1.02E-01				

Relation of specific capacity to transmissivity in wells completed in Tuul River



The previous study (by PNIIIS) estimated a value of specific yield at 0.15.

Deposits of alluvium in Upper Water Source area are thicker than deposits of Lower Part of Nalaih. The production wells of Upper Water Source are from 24 (Well No.12) to 40 meters (Well No.29) deep. The tops of screen pipes vary from four(4) to 28.5 meters below the ground level and the bottoms range from 11.5 to 28.5 meters. One of three types of submersible pump, that is, the capacity of 63, 120, and 160 m3/h, has been installed in each production well.

Four(4) test wells, C-1,2,3 and 4, were constructed in Lower Part of Nalaih. Test well C-1 and C-2 encountered the basement rock at 20-21 meters below the ground level. C-3 encountered the basement rock at 28 meters and C-4 encountered the basement rock at 14 meters. The aquifer of Lower Part of Nalaih may range from 15 meters (downstream) to 20 meters (upstream) deep on average. The permeability coefficient of the lower layer was obtained by the pumping tests. The values ranged from 6.21×10^{-3} to 1.49×10^{-2} cm/sec and averaged 1.07×10^{-2} cm/sec. The permeability coefficient of the upper layer is expected nearly same as the value of Upper Water Source because of the geological conditions and therefore the transmissivity in the area is estimated to be around 520 m2/day or more.

3.3.3 Central Part

The area extends from Gachuurt to Songino. The alluvium of the area consists of sand and gravel with clay. The alluvium is divided into two layers, upper and lower. The upper layer ranges around 10 meters to 20 meters thick and the lower layer ranges 10 to 30 meters or more thick in places. The width of this alluvium ranges from 1 kilometers in Gachuurt to 4 kilometers in Songino blan. Fig. I.3.2 shows the cross section of the area.

The previous study by PNIIIS estimated specific yield and permeability coefficient of the aquifer. Specific yield of the upper layer was estimated at 0.2. Specific yield of lower layer was estimated at 0.15. Permeability coefficients of the upper layer vary from 1.22×10^{-1} cm/sec to 2.85×10^{-1} cm/sec and average 1.79×10^{-1} cm/sec. Permeability coefficients of the lower layer vary 2.63×10^{-2} cm/sec to 6.71×10^{-2} cm/sec and average 4.48×10^{-2} cm/sec.

In this area the alluvial aquifer was developed and used for water supply system of Ulaanbaatar and industrial water. There are 94 production wells for three water sources, which are Central Water Source, Industrial Water Source and Meat Complex Water Source, and nearly 100 wells were constructed for industrial water including Power Plant No.3 Water Source. Fig. I.3.3 shows the locations of these wells.

The depth of production wells for Ulaanbaatar water supply system ranges 18 to 53.5 meters. In the eastern area of Central Water Source, 22 wells have been constructed and averaged 25.5 meters deep. The capacity of the intake pump is 10, 25, 40 or 63 m3/hour and total pumping capacity of the 22 wells is 21,048 m3/day in the area. Specific capacity vary from 199 m3/day/m to 2359 m3/day/m and average 830 m3/day/m. 35 wells in the middle area of Central Water Source averaged 31.4 meters deep. The pump capacity is 25, 63 or 120 m3/hour and total pumping capacity is 50,040 m3/day in the area. Specific capacity vary from 441 to 3888 m3/day/m and average 1506 m3/day/m. 14 wells in the western Central Water Source averaged 31.7 meter deep. The intake pump capacity is 25 or 63 m3/hour and total pumping capacity is 18,432 m3/day in the area. Specific capacity vary from 240 to 1503 m3/day/m and average 824 m3/day/m.

The production wells of Industrial Water Source and Meat Complex Water Source are from 21.6 to 53.5 meters deep and average 32.3 meters deep. The installed pump capacity is 63, 120, 160 or 200 m3/hour.

The depths of wells for Power Plant No.3 Water Source are about 40 or 50 meters except one, which is 35 meters. It is reported that 10 wells are working in summer and 13-14 wells in winter usually. From 1993 November to 1994 September, the withdrawal from the wells averaged 1,108,900 m3 per month, varying from 750,600 (July. 94) to 1,450,000 (April. 94), or 36,500 m3/day. The estimated pumping rate per well ranges from 1,250 m3/day (July. 94) to 3,450 m3/day (April. 94). The pump capacity of the wells is mainly 160 or 210 m3/h (or 3840-5040 m3/day).

3.3.4 Lower Part of Ulaanbaatar

This area is composed of Power Plant No.4 Water Source, Lower Part of Power Plant and the downstream area. The alluvium consists of gravel-pebble with boulder, sand and sandy clay. The thickness is from 20 to 64 meters or more. The aquifer of downstream tends to be thick compare to other area. The width ranges from 1 kilometers near Altanbulag Bridge to 5 kilometers in the downstream area. Fig. I.3.4 shows the cross section.

34 exploration wells were drilled for previous studies. The depth of these wells range from 10 to 93 meters and average 49 meters. Yield from these wells are ranged from 630 to 6800 m3/day and averaged 4542 m3/day (2639 m3/day per one meter of drawdown). Permeability coefficient varied from 1.34×10^{-2} cm/sec to 1.61×10^{-1} cm/sec and averaged 7.53×10^{-2} cm/sec.

For Power Plant No.4 Water Source, 12 production wells have been constructed in Songino Valley. The wells were designed to be 63 meters deep and 2520 m3/day discharge. In 1993 the actual withdrawal from the production wells averaged 501,100 m3 per month or 16,400 m3/day.

Three (3) test wells, C-6,7, and 8, were constructed in the area. The depths of wells were 30-32 meters and none of the boreholes encountered the basement rock. Yields from the wells were 2160 m3/day (C-6), 3168 m3/day (C-7) and 382 m3/day (C-8). Specific capacity, transmissivity and permeability coefficient obtained by the pumping tests were as follows.

Well No.	Specific capacity (m3/day/m)	Transmissivity (m2/day)	Permeability coefficient (cm/sec)
C-6	1227	873	$6.12x10^{-2}$
C-7	2018	2410	$2.54x10^{-1}$
C-8	56	50	$5.26x10^{-3}$

C-8 was located somewhat far from the main stream of Tuul River.

3.3.5 Buheg Valley

The area is 20-30 kilometers south-west of Ulaanbaatar City area. The catchment area of Buheg River is about 1,621 m2. Groundwater has been developed and used in Zoonmod, the capital of Tov Aimag, located in north-eastern Buheg watershed. The aquifer in the downstream of the capital is not developed on a large scale except near the junction of Buheg and Tuul River. There are farms using groundwater in the area of the junction. The aquifer consists of sand and gravel. Fig. I.3.5 shows the cross section of the area.

Four (4) test wells, B-1,2,3 and C-5, were constructed along the downstream of Buheg River. The result of geophysical exploration carried out in Phase I, 1993, showed that the alluvium of the area was thicker relative to other areas. B-1 and 2 were drilled up to 50 meters and B-3 was drilled up to 65 meters. All of them did not reach the basement rock. Yields from the test wells ranged from 3.9 liters/sec (B-1) to 22 liters/sec (B-3). Specific capacity, transmissivity and permeability coefficient of the test wells were as follows.

Well No.	Specific Capacity (m3/day/m)	Transmissivity (m2/day)	Permeability Coefficient (cm/sec)
B-1	25	35	$2.46x10^{-3}$
B-2	104	122	$8.56x10^{-3}$
B-3	259	354	$1.86x10^{-2}$
C-5	36	37	$3.89x10^{-3}$

According to the data of exploration wells drilled in the past, the specific capacities of the five (5) exploration wells completed in the alluvial aquifer ranged from 31 to 562 m3/day /m.

B-1 was a flowing well. According to the data collected by GGEC, one of exploration wells was also a flowing well. Multiple water-transmitting layers may exist within the alluvial aquifer.

The specific yield of the aquifer is expected at 0.1, considering geological and hydrological condition of the alluvial deposits.

3.3.6 North of Ulaanbaatar

There are some tributaries of Tuul River in the North of Ulaanbaatar. The principal tributaries are Bayan Goliin, Selbe and Uliastai. The maximum width is 2 kilometers or more. The thickness of alluvium is 8-40 in places. Eight (8) exploration wells in Bayan Goliin, 26 exploration wells and nine (9) exploration wells in Uliastai have been inventoried. Summarized hydrologic data of the exploration wells cased to draw water from alluvium and the exploration wells drilled in basement rock are as follows.

Source	Number of wells	Pumping rate (liters/sec)		Specific capacity (m3/day/m)	
		Mean	Range	Mean	Range
Alluvium of Uliastai	2	2-3	2.5	52-115	83.5
Alluvium of Selbe	8	1-9	4.5	5-202	73.4
Alluvium of Bayan Goliin	3	1-31	13.3	18-362	168
Basement rock of Uliastai	7	0.5-5	2	2-21	13.4
Basement rock of Selbe	17	0.1-11.7	2.7	1-115	25.6
Basement rock of Bayan Goliin	4	2-18	9.2	35-518	328

Four (4) test wells, A-1,2,3 and 4, were constructed in the area. All test wells were drilled into basement rock up to the depth of 134-200 meters and sealed off unconsolidated layer with blank casing pipe. Each well location and the obtained hydraulic properties are as follows.

Well No.	Location	Pumping rate liters/sec (m3/day)	Specific capacity m3/day/m	Transmissivity m2/day	Permeability coefficient * cm/sec
A-1	Uliastai	10.5 (903)	19	23	(4.10×10^{-4})
A-2	Selbe	0.6 (52)	1	<1	(4.61×10^{-6})
A-3	Bayan Goliin	25.0 (2164)	45	40	(6.52×10^{-4})
A-4	Selbe	16.7 (1441)	30	31	(7.97×10^{-4})

*)Permeability Coefficient were calculated based on the geologic columns obtained.

Each well location was determined by the geophysical prospecting conducted in Phase I, which were electrical survey and VLF-EM survey. The results of the test wells showed that these geophysical prospecting was useful to decide the location of a production well even though it is not perfect.

A-1,3 and 4 may be utilized for supplying water to local area. However it is difficult to develop on a large scale

3.4 WATER LEVEL FLUCTUATIONS

3.4.1 General

Changes in groundwater level are caused by various factors, some are the artificial and others are the changes of natural conditions. Most of the natural conditions are seasonal or daily variations such as precipitation, evaporation, water level of a river and atmospheric pressure. The artificial conditions are, for example, the pumping rate from wells, irrigation, construction works in subsurface.

Fluctuations of water level in an unconfined aquifer follow the change of water volume in the aquifer. In other words a decline in groundwater level means a reduction of water volume in an unconfined aquifer. Therefore observation of water level is important for the sustainable groundwater development and management.

In this study continuous records of water levels were obtained (Appendix I.3.1) and three times of water level measurements were carried out. Fig. I.3.6 shows the locations of wells observed. The results are described below.

3.4.2 Continuous Measurements

In the Phase I study, the four(4) sets of water level recorders (Model W-761) were installed on existing wells, which are No.19 well in Upper Water Source, No.69/19a and No.15 in Central Water Source and No.1 in Meat Complex Water Source, to record groundwater levels continuously. Selected locations can represent the aquifer condition in each area.

The results from Sep. 93 to Oct. 94 are shown Fig. I.3.7. The water levels in the four wells fluctuated 2-5 meters. The highest water levels occurred in August and the lowest water levels occurred at the end of March or the beginning of April. From June to September, the aquifer is recharged by rainfall and the surface runoff resulting from the rain. From October the water levels decrease gradually. In 1993 Tuul River froze toward the end of December, after that the water levels had fallen successively to the lowest levels. After the frozen river started melting in March, the water levels increase steadily from April. In April and May, the aquifer is recharged by the river runoff resulting from melting of the snow in the upper reaches. Fig.I.3.7 indicates that the time of river runoff started after winter is important to recover water level in the aquifer.

No.15 well of Central Water Source and No. 19 well of Upper Water Source are located on the side of Tuul River. Consequently, their fluctuations in water levels are directly affected by the discharge of Tuul River as shown by Fig. I.3.7. The water levels in No.1

well of Meat Complex Water Source and No.69/19a well of Central Water Source show generally gentle fluctuations. These wells are located in the area somewhat far from the Tuul River. The sharp rising of the water level of No.1 of Meat Complex Water Source in the middle of August may result from recharge by the runoff of Selbe River and Tolgoit River.

After completion of the drilling work, six sets of the water level recorders were installed on the wells constructed, A-4, B-2,C-2, C-4, C-5 and C-7. The data which are obtained during winter, 1994-1995, will give more information about the groundwater condition.

3.4.3 Groundwater Table

Groundwater levels of the selected 36 wells in the area were measured three times, Sep. 1993, Apr. 1994 and Sep. 1994. in co-operation with the Water Supply Department.
Table I.3.3, Fig. I.3.8 and Fig. I.3.9 show the results. The water level decreased 1.48 meters on an average from Sep. 1993 to Apr. 1994. The maximum decrease of the water level between the first and the second measurement was 4.38 meters of No.16 well under pumping. The second measurement was conducted on April 25, 1994. According to the continuous water level record, the water level of No.15 well had started recovering and increased by 2.7 meters from April 3 to 25. Therefore, the level in No.16 well during the period is estimated to have decreased lower. The third measurement was carried out on Sep. 29, 30 and Oct. 1, 1994. On the average the water level increased 1.77 meters in the area. The maximum increase occurred in No.16 well and the difference was 4.21 meters. The water table in Ulaanbaatar City area is estimated to vary generally about 2.5 meters or more as shown in Fig. I.3.9. The water level in each well has been affected by the each pumping condition.

3.4.4 Long-Term Water Level Fluctuations

The data of recorded water levels in some observation wells and production wells were collected. Fig.I.3.6 shows the locations of these wells. The summarized data of the observation wells, which are No.25 and No.26 around Meat Complex Water Source and No.9 and No.10 in Central Water Source, were shown in Fig. I.3.10 and Fig. I.3.11. Fig.I.3.2 shows the relationship between the water level in a production well and the rainfall. Although the pumping conditions are unknown in the production well, the general tendencies were shown by the recorded data. The data of recorded water levels in some production wells are shown in Appendix I.3.2 for reference.

The fluctuation of the water level in an unconfined aquifer shows the change of water volume stored. Fig. I.3.10 and Fig. I.3.11 (or all the data of water level fluctuation) indicate the following. The volume of water stored in the aquifer has an annual cycle. In winter rainfall and Tuul River runoff recharge lesser to the aquifer, and consequently the groundwater volume in the area decrease. After winter the water volume of the aquifer recovers resulting from starting to recharge by rainfall and river runoff. The data of long-term water level fluctuation do not show a tendency to decrease in volume of water stored for the present. The annual rainfall and the river discharge rather affect the volume of water stored in the aquifer. That means an intake volume of groundwater should be controlled depending on the seasonal variation of rainfall and river runoff.