NO. 2

IRRIGATION AND POWER
DEPARTMENT
GOVERNMENT OF BALOCHISTAN

JAPAN INTERNATIONAL
COOPERATION AGENCY
JAPAN

FEASIBILITY STUDY
ON
THE IRRIGATION WATER RESOURCES DEVELOPMENT
WITH
DELAY ACTION DAMS PROJECT
IN
BALOCHISTAN
IN
THE ISLAMIC REPUBLIC OF PAKISTAN

ANNEX

JUNE 1997

NIPPON GIKEN INC.
SANYU CONSULTANTS INC.

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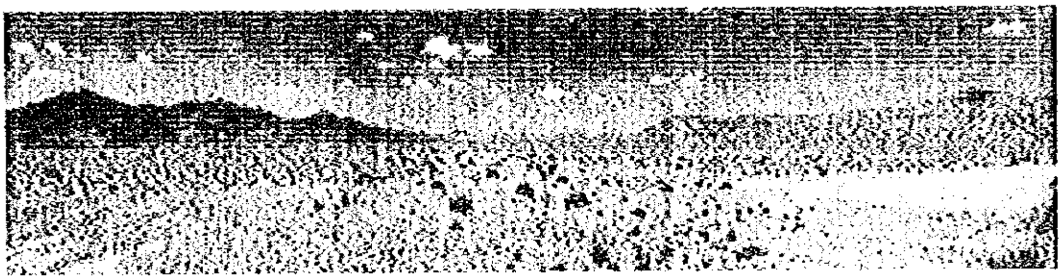

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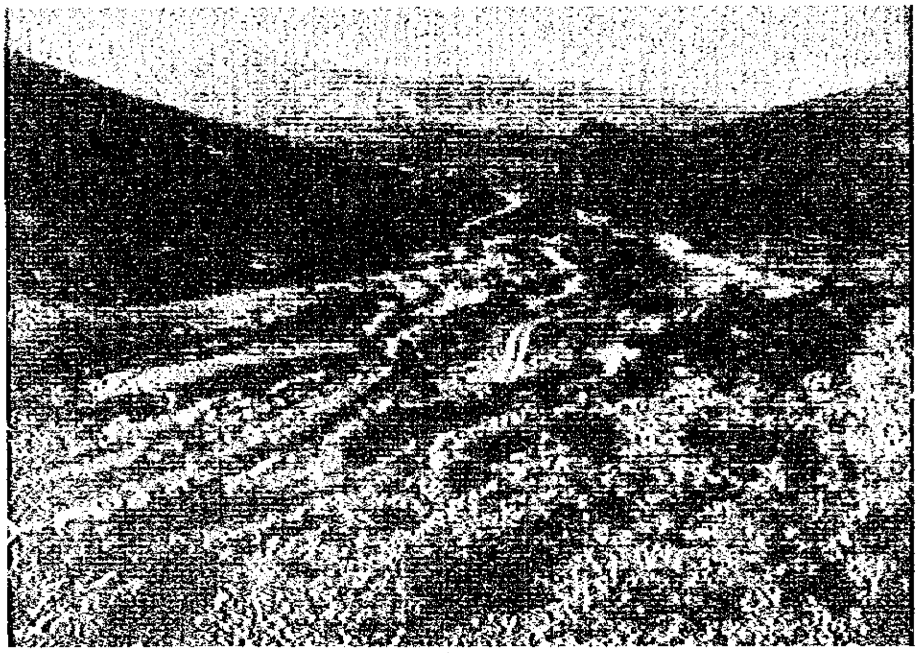
Geology and Hydrogeology



ANNEX A

GEOLOGY / HYDROGEOLOGY

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A.1 GEOLOGY OF PISHIN LORA BASIN

Pishin Lora Basin is divided into eleven sub-basins, which are called Pishin, Kuchlagh, Quetta, Kolpur, Sardar Khel, Mangocher, Mastung, Shirinab, Patki Shah Nawaz, Kalat, and Kapot.

Geoanticlinal Axial Belt runs in the ranges between the south-eastern parts of Kuchlagh Sub-Basin and middle to southern Sub-Basins. This axial belt consists of Alozai Group of Perm-Carboniferous to Triassic (mainly interbedded limestone and shale) Shirinab Formation (mainly limestone and marl with subordinate shale), Chiltan Limestone of Jurassic age, and Parh Group or Parh Series of Cretaceous age (Belmnite Shale, Pab Sandstone, Parh Limestone). Older bed lies usually in the western side, and the younger the more eastern side. The ultrabasic ophiolite rocks (Hindubagh Intrusives) expose in the north-eastern part of Kuchlagh Sub-Basin. They are overlain partly by Dunghan Group of Paleocene age, Gazij Shale and Spintangi Limestone (or Nimargh Limestone / Wakabi Limestone) of Eocene age. Dunghan Group is renamed Brewary Limestone around Quetta District.

Spintangi Limestone and its equivalents lie widely around east Kalat Sub-Basin, and some of which are found as lenses in the central mountain ridges. The lowland of the axial belt (south-eastern Kuchlagh, Quetta, Kolpur, Sardar Khel, Mastung, Shirinab, Mangocher, and Kalat) may be underlain by Gazij Shale which is generally erosive and easily dissected.

Western part of the Basin (north-western Kuchlagh, Pishin, and Patki Shah Nawaz) consists generally of Murgha Faqirzai Shale of Oligocene age, and Shaigalu Sandstone of Miocene age. The area of the shale has low relief of hilly range (Khwaja Amran Range) in the western part, and dissected lowland in the eastern part. Thick clayey / silty strata (Bostan Formation) accumulated on this dissected lowland. While, in east Kuchlagh and the north east Quetta Sub-Basin subsided deep geosynclinorium, and thick molasse (Urak Conglomerate) accumulated in this area.

Pliocene deposit can not be found out in this Basin.

Terrace deposit or older fan deposit (Subrecent deposit) transported by older stream accumulated and were dissected forming hillock areas along the foot slope of steep mountain ranges. Recent streams form alluvial fan deposits, river deposits, floodplain deposits, etc.

A.2 HYDROGEOLOGICAL STRUCTURE OF PISHIN LORA BASIN

Sub-basins and surface / subsurface drainage systems of Pishin Lora Basin are shown in Fig.1 and aquifers and aquitards in the Basin are shown in Fig.A.1.

Most water stored in the fine-grained rocks usually is not readily available. Paleozoic and Mesozoic erathem (representatives are Alozai Group, Shirinab Formation, Chiltan Limestone, and Parh Group) in the Basin is composed mainly of massive and watertight limestone generally so that they are classified into aquitards.

The rocks and/or deposits composed of fine grains of Cenozoic era such as Gazij Shale, Murgha Faqirzai Shale, Bostan Formation, and Alluvial silt and clay are generally aquitards or aquicludes.

Some occur in fractured and nodular limestone such as Paleogene system except shale composed of mainly loose and cavernous limestone (representatives are Spintangi Limestone), and forms partly useful aquifers providing locally important springs. However, groundwater availability depends on its area and depth. Spintangi Limestone extent in the eastern of Kalat Sub-Basin supplies considerable volume of water as Chashma Iskalkoo, etc.

Neogene conglomerate (Urak Conglomerate) and sandstone (Shaigalu Sandstone) form partly aquifer Urak Conglomerate is composed are cavernous matrix of limestone, and develop a lot of pervious fissures between matrixes and hard pebbles / boulders so that it may form useful aquifers in many parts. The Urak Conglomerate in east Quetta and Kuchlagh subbasins occupies about 350 sq.km of highlands. Because of the good outflow from the Urak River, the great extent of the Urak conglomerate may be of significance. Hanna-Urak River flowing from north-eastern side to Quetta valley dissecting this formation with abundant quantity runoff of water may be supplied from springs out of this formation. However, the perviousness of this formation depends on area and depth.

The Dada Conglomerate occupies about ten and few sq.km in the extreme south-west of the basin and can be ignored.

While, alluvial fan deposits distributing widely along the piedmonts is composed mainly of silt traced sand, gravel and boulder so that they may compose excellent permeability and groundwater storage capacity forming very high potentiality as good aquifer in the Basin. The groundwater exploited in the Basin is almost from these deposits. Alluvial fan deposits are considered as important groundwater recharging media because they locate at the effective area for gathering water from the mountain.

Alluvial aquifer dimensions are shown in the Table 1.

The proposed and existing sites of delay action dam on the study are located in the 6 of 11 sub-basins of Pishin Lora Basin mentioned as under.

- Pishin sub-basin
  Proposed DAD sites; nos. 3 (Arambi, Sanzali, Jigda)
  Existing DAD sites; nos. 2 (Tirkha, Khushab)

- Kuchlagh sub-basin
  Proposed DAD sites; nos. 1 (Murgi Kotal)
  Existing DAD sites; nos. 2 (Bostan, Khor Manda)

- Quetta sub-basin
  Proposed DAD sites; nos. 5 (Kach, Dara, Ghtai Shela, Brewary, Waii Dad)
  Existing DAD sites; nos. 1 (Marium)

- Mastung sub-basin
  Proposed DAD sites; nos. 2 (Sakhol, Kud Kocha II)
  Existing DAD sites; nos. 2 (Amach, Kud Kocha I)

- Kalat sub-basin
  Proposed DAD sites; nos. 1 (Iskalkoo)
  Existing DAD sites; nos. 2 (Laghmgir, Gorpad)

- Patki Shah Nawaz sub-basin
  Proposed DAD sites; nos. 1 (Mangi)
  Existing DAD sites; nos. 1 (Sarbund)

The land forms of these six sub-basins are divided largely into three, namely the mountain highlands, the piedmont slopes, and the valley floors. The feature of these land-forms is as under.

1, The mountain highland;
Those are usually composed of the ranges characterised by steep or relatively steep slopes, the principal areas of erosion and incised drainage. It consists of sharp ridges, round summits and narrow valleys. Most of mountain slopes have the tendency of dip-slopes of the folded hard rocks such as limestone.

2, The piedmont plain;
It is the intermediate zone between the mountain highland and valley floor. The topography in this zone is irregular due to interconnected coalescing alluvial fans, cones and branching off streams descending from the mountain highlands. The sediments consist of mainly gravel and sand with subordinate silt and clay. Hydrologically this zone is the principal area of recharge to groundwater reservoir and constitutes the most promising zone for groundwater development.

3, The valley floor;
It includes usually the central part of the respective valley enclosed by the lower limits of the piedmont plain. It has comparatively more gentle slopes due to the sheet flooding from the flanking piedmont plain. Hydrologically the valley floors constitute the principal areas of natural discharge through effluent streams and evapotranspiration. The depth to water is comparatively shallow in the valley floor area.

Groundwater occur mainly in the unconsolidated deposits under the water table condition in the most part of the area of piedmont plain and semi-artesian or artesian conditions in some part of the area covered by impermeable clayey layers in the valley floor. Some lesser quantity of groundwater develops in the consolidated rocks as observed by the presence of a number of springs originating from limestone and conglomerates.

Groundwater quality of the area has a feature of which generally groundwater in piedmont, alluvial fan areas are fresh and deteriorate in down reaches of valley.

The presence of saline is in Bostan Formation, Gazij Shale, and Belemnite Shale which are eroded to form saline alluvial material. Wherever these rocks occur the groundwater in the Alluvium are brackish to highly saline.

A.3 HYDROGEOLOGY OF THE RESPECTIVE SUB-BASIN

a Pishin Sub-Basin

i) General Description

The area forms the northern part of Pishin Lora Basin, which is the lower most valley of the Basin. Mountain ranges and drainage of Pishin sub-basin are as under;

Mountain Range

Location	Name of Range	Range of Crest Altitude
Western border Eastern border Northern border	Khawaja Amran range Sher Ghundi & Ajram Ghar range Arambi range	1500 - 3000 m

Drainage

Principal Stream	Barshor Lora	Pishin Lora
Main Tributaries	from Right Flank	Machka
	from Left Flank	Surkhab Lora (Kuchlagh) Bostan Lora (Kuchlagh) ------> Rokhi Lora Shora Rud (Patki Shah Nawaz)
	from South	Shirinab Lora (Shirinab)

The rocks mainly exposed within the drainage basin range in age from Oligocene to Recent, The base rocks of the area are represented by Murgha Faqirzai Shale of Oligocene age and

Shaigalu Sandstone of Miocene age. The Bostan Formation of Pleistocene age overlies them unconformably.

- Murgha Faqirzai Shale:
  greenish grey, green or khaki shale with subordinate sand-stone and shaly limestone.

- Shaigalu Sandstone:
  interbedded thinly calcareous shale, limestone and calcareous conglomerate, and correlated with Urak Group in Quetta Valley.

- Bostan Formation:
  soft, crumble clay & silt of bright red, maroon, green, cream colours with subordinate sandstone. Conglomerate are also present at some places.

- Subrecent deposits:
  fluviatile sediments deposited by a drainage system older than the present system; generally composed of semi-consolidated gravel, sand, silt & clay; coarse materials dominate the lithology in their outcrops exposed along the base of the mountains; their permeability is rather lower than the Recent.

- Recent deposits:
  fluviatile sediments deposited by the present drainage system; constitute the main groundwater reservoir of the area; the size of the constituent particles decreases away from the mountain ranges.

Hydrogeological Map of Pishin Sub-Basin is shown in Fig.A.2.

Murgha Faqirzai Shale and Bostan Formation form impermeable bed of groundwater basin. Shaigalu Sandstone partly develops pervious fissures.

Fan deposits form excellent groundwater recharging area. Subrecent deposit forms also aquifer in the eastern hillock area.

The aquifers in the valley floor are usually confined by aquitards composed of silt and clay. While, in the area of fan deposit of the piedmont, groundwater is usually unconfined.

In the Fig.A.2, the lower limit of alluvium is shown to a presumable extent.

The specific yields of alluvium are also shown in the figure according to existing well data. They are more than 20% around the upper part of north-eastern to northern piedmont fan deposit area, and eastern Subrecent deposit area, showing some special area around 25%.

Transmissivity and permeability in the sub-basin are;

	Transmissivity	Permeability
in the small scale of fan deposit area	10~20 m^2/d	7E-4 ~ 2E-3 cm/sec
in the large scale of fan deposit area around Qila Abdullah of northern part	100~1500 m^2/d	3E-3 ~ 2E-2 cm/sec
in the central area of fan deposit area of upstream area of Pishin Lora ~ Barshora Lora of northern to north-eastern part	100~300 m^2/d	2 ~ 8E-3 cm/sec
{eastern piedmont of K.K Bund	50~150 m^2/d	2 ~ 5E-3 cm/sec}
in the periphery of upstream fan deposit	500 m^2/d	1 ~ 2E-2 cm/sec
Subrecent deposit	around 100 m^2/d	3 ~ 7E-3 cm/sec
In the central area of valley floor	around 20 m^2/d	around 1E-3 cm/sec
Bostan Formation	around 5 m^2/d	around 5E-5 cm/sec

ii) Geological Profiles

Main geological sections are shown in Fig. A.2 and A.3.

Profile along lines A, C, D, E, and F are described to check the vertical extent of the strata of sands/gravels in the piedmont slope as main aquifers in the Sub-Basin. Line B is to check the aquiters along the parallel direction to the mountain range.

Alluvial fan deposits in the piedmont usually consist of dominant sands/gravels. However as proceeding to valley floor, they inter-finger with the strata of silts/clay gradually increasing their ratio, and finally in the down-reaches of valley floor almost all strata become composed of silts/clay.

Line B is the cross section of the inter-fingering part showing that the strata of sands/gravels and silts/clay alternate each other.

iii) Location and Distribution of Aquifers

The strata of sands/gravels dominantly composing piedmont slope act as useful aquifers and recharging media of surface runoff water from the catchment in the mountain. They are usually unconfined.

The strata of sands/gravels inter-fingered with silts/clay are usually connected with those in the piedmont constituting confined or semi-confined aquifers.

The strata of silts/clay in the down-reaches of valley floor act as aquitards contributing as impervious barrier against groundwater flow from the upstream.

--- Characteristics as Groundwater Basin

The piedmonts act as recharging media and groundwater reservoir, while the down-reaches of valley floor as the barrier against groundwater flow. In consequence, the structure of the groundwater basin is like underground dam so that the runoff from the basin through underground may be very little.

--- Aquitards as Barriers or Impervious Beds to Groundwater Flow

In the eastern side of the Sub-Basin, concealed mountain range lay under the Alluvium around Killi Mirza Mulagizai, and the underground valley between the eastern mountain range and the concealed one is buried by the Bostan Formation which emerges to the surface as proceeding to South forming hillock with so many gully erosions and land-sliding. According to Profile C and D, though basement rocks form impervious bed declining gradually from North to the

South in the mountain side, deeper portion than the altitude 1400 m are covered by very thick uniform clay inferred to be the Subrecent or Bostan Formation.

While in the western side, these clay strata are deficient, and Murgha Faquirzai Shale and/or Shaigule Sandstone are directly overlain by Alluviums.

b Kuchlagh Sub-Basin

i) General Description

The boundaries of the area have been fixed on the basis of surface water drainage and possible underground inflow from Khanozai area.

Mountain Range

Location	Name of Range	Range of Crest Altitude
Toward south	Takatu, Chiltan, Sur Nar, Urghrgai ranges	3310 m in the Chiltan range 3452 m in the Takatu range
Toward north	Singwash, Meshelak Sher Ghund ranges	

Drainage

Principal Stream	Northern	Toghi Nullah --- Surkhab Lora
	Central	Bostan Lora [Baleli River (Quetta)] --- Karakh Lora
	Southern	Karinga Lora ------↑
Tributaries	from east	Khwaja Lora, Tirkha Lora

The rocks exposed in Kuchlagh area are of sedimentary origin and range in age from Triassic to Recent. These rocks are folded and faulted and axes are oriented in NE-SW directions.

- Alozai Group, Shirinab Formation: limestone with subordinate shale exposed in the south of Koh Mehtarzai.
- Chiltan Limestone, Parh Group: exposed in north-eastern ranges of Takatu ranges.
- Intrusive rocks: exposed in the area near Khanozai.
- Brewary Limestone, Nisai Group, Gazij Shale, Nimargh Limestone, Murgha Faqirzai Shale, Shaigalu Sandstone: exposed in Khan Mehtarzai area.
- Urak Conglomerate: partly exposed in the area of north-eastern part.
- Bostan Formation: exposed in the north and north-western part of the area, forming low hills; semi-consolidated; mainly composed of clay and silt with subordinate gravel beds; barrier to groundwater flow in general and will limit the vertical extent of the aquifers as it underlies the alluvium in the valley floor.
- Mainly gravelly deposit develops in the alluvial fans and fine material, mostly silts and clays but at places gravel layers in the valley floor.

The piedmont plains are prominently developed in Takatu range east of Kuchlagh town, whereas these alluvial fans are non-existent towards north and north-west because of soft material forming the rocks in this part of the area. Area between Samungli and Baleli and Bostan represent typical one of the valley floor.

Fig.A.5 shows Hydrogeological Map of Kuchlagh Sub-Basin.

The lowland along river channel of middle to southern part is composed of valley floor deposit, however, in the northern part Subrecent deposit and Alluvial fan deposit reach up to the river channel.

Paleozoic ~ Mesozoic erathem, Murgha Faqirzai Shale and Bostan Formation are impermeable bed of groundwater basin. Spintangi Limestone and Urak Conglomerate are partly aquifer.

Main aquifer in this sub-basin is Subrecent deposit and Alluvial fan deposit. In the case of valley floor deposit, it is usually aquitard because it is composed mainly of silt and clay. The depth to water is the shallowest around Baleli area and area between Kuchlagh town and Bostan railway station. Around Baleli mound camp, artesian aquifers have been encountered. Depth to water increases towards Gowal area. At Khanozai, it shows medium depth and decreases towards Nigandi area.

Groundwater is generally unconfined in the middle to northern part and along the piedmont in the southern part, but confined in the valley floor in the southern part.

In the Fig.A.5, the lower limit of alluvium is shown to a presumable extent.

The specific yields of alluvium are also shown in the figure according to existing well data. They are more than 20% along the piedmont of south-eastern side, and the top of southern fan deposit around 25%. Along valley floor, it is around 15% in the northern part, and less than 10% in the southern part.

Transmissivity and permeability in the sub-basin are;

	Transmissivity	Permeability
in the south-eastern piedmont	100~200 m^2/d	1.5 ~ 3E-3 cm/sec
in the mid-scale of fan deposit area around Bostan	300~700 m^2/d	5E-3 ~ 1E-2 cm/sec
along upstream area of valley floor	20~30 m^2/d	6E-4 ~ 1E-3 cm/sec
along upstream area of valley floor	20~30 m^2/d	6E-4 ~ 1E-3 cm/sec
along downstream area of valley floor	less than 10 m^2/d	less than 1E-4 cm/sec

ii) Geological Profile

Fig. A.6 shows main geological sections of the Sub-Basin. In the Sub-Basins, Alluviums deposit in narrow inter-mountain valley from North-East to South-West. Profile line A is from the eastern piedmont to valley floor in the south-western area, which expresses typically the situation of alluvial fan deposits, changing rapidly from sands/gravels into silts/clay in the valley floor through very narrow inter-fingered area.

Profile B shows the mid-part of Sub-Basin where, sand/gravel deposits of alluvial fan forming lens get into thick strata of silts/clay in valley floor.

As proceeding to north-eastern area, Profile C shows the dominant distribution of sands/gravels strata along the Bostan Nala.

iii) Location and Distribution of Aquifers

In the Sub-Basin, competent aquifers are existing in the north-eastern and in both the eastern and western piedmonts of the south-western area.

c Quetta Northern Sub-Basin

i) General Description

The area is bordered by asymmetrical mountain ranges. There are two drainage basins within the area; (1) the northern basin and (2) the southern basin. The surface water divided between the two basins is located near Landi-hill area. The study site is existing in the northern basin.

Mountain ranges and drainage of Quetta valley are as under;

Mountain Range

Location	Name of Range	Range of Crest Altitude
Northern border	Takatu range	
Northeastern border	Zarghoon range	2500 - 3000 m
In the east	Murdar range	The highest point is
Southeastern border	Degari range	in Zarghoon range with
Western border	Chiltan range	an altitude of 3579 m.
Southwestern border	Kumbelan range	

Drainage

Principal Stream	Sariab Lora Hanna River ------>	Baleli River
Main Tributaries	to Baleli River To Hanna River from Left Flank of Sariab Lora	Spin Tangi ---> Kuchnai Manda Sra Khula Manda Karakhusa Nala

The rocks exposed in the area are sedimentary in origin and range in age from Triassic to Recent. The consolidated rocks in general are considered to be impervious and barrier to the movement of groundwater. The Gazij Shale and Spintangi Limestone overlie Triassic to Lower Tertiary rocks.

- Gazij Shale: impervious and a barrier to the movement of groundwater in general.

- Spintangi Limestone: fractured and jointed; developed second permeability generating of a few springs; not capable of holding and transmitting large quantities of water.
- Urak Group: conglomerates and sandstones; well jointed and fractured; in general have developed secondary permeability of considerable order; a source of effluent discharge of the drainage.
- Bostan formation: semiconsolidated; impervious then a barrier to the movement of groundwater is general.
- Piedmont deposits: exposed at the foot of Takatu, Murdar and Chiltan Ranges.
- Quetta Loess: fine grained deposits; comparatively soft and friable; can hold and transmit groundwater in moderate quantities; distributing in the central part of the area.

The groundwater in the area generally occurs under water table conditions, however artesian conditions were also observed in certain parts of the area. These artesian conditions were generally found in a belt of valley floor almost following the course of Sariab Lora.

Hydrogeological Map of Quetta Northern Sub-Basin is shown in Fig.A.7. Quetta Northern Sub-Basin is drained by Sariab Lora and Hanna-Urak River system which flows out of the area through Baleli - Samungli Gap. Hanna - Urak River drains mainly the area composed of Miocene Urak Conglomerate in the upstream, and Subrecent deposit extents widely in the midstream. Around those areas, Spintangi Limestone and Gazij Shale of Eocene age, Dunghan Limestone of Paleocene age, and basement rocks such as Parh Group, Chiltan Limestone and Shirinab Formation of Paleozoic and Mesozoic age are existing. While, in the Sariab Lora draining area, mainly Chiltan Limestone with subordinate Gazij Shale, Brewary Limestone, and Parh Group (Fort Munro Formation) is existing.

Well-developed alluvial fan deposit in this sub-basin is along Hanna-Urak River system, and that next to this is south-western upstream piedmont of Sariab Lora drainage system. Eastern piedmont is also composed of the belt of fan deposits, width of which is 2 to 3 kilo-meters.

Paleozoic to Mesozoic erathem, Dunghan Limestone (Brewary Limestone) and Gazij Shale is massive and watertight and forms the impermeable bed of groundwater basin.

Spintangi Limestone and Urak Conglomerate are crack developed and cavernous, and partly form the fractured type aquifer supplying the water to Hanna-Urak River.

Subrecent deposit and Alluvial fan deposit form the well groundwater recharging area.

Valley floor deposit is composed of the alternating layers or lens of coarse and fine material. It is generally impermeable silt- or clay-rich and has low recharging ability. Aquifer in the valley floor is generally confined by impermeable silt and/or clay layers. While silt and/or clay layers in the Alluvial fan deposit are usually rare existing and poor continuity, then aquifer in this area is generally unconfined.

In the Fig.A.7, the lower limit of alluvium is shown to a presumable extent.

The specific yields of alluvium are also shown in the figure according to existing well data. They are more than 20% in the top of Alluvial fan deposit and Subrecent deposit locating in the eastern piedmont.

Transmissivity and permeability in the sub-basin are;

	Transmissivity	Permeability
in the Alluvial fan deposit area	in the range of 20~80 m^2/d	1.5E-4 ~ 2E-2 cm/sec
	partly 100~600 m^2/d	7E-3 ~ 3E-2 cm/sec
in the valley floor	4 ~ 5 m^2/d	2 ~ 3E-4 cm/sec

ii) Geological Profile

Fig. A.8 shows geological sections of the Sub-Basin.

Profile lines are mainly along the channel flow from mountain up to valley floor, and around central valley floor to realize in wide aerial extent.

Profile A is from just downstream of Kach Dam through cantonment area to Baleli-Samungli Gap reaching to the entrance of Kuchlagh Sub-Basin showing typically lithological situation from piedmont to valley floor. Piedmont deposits are usually composed of sands/gravels interbedded with subordinate thin lenses of silts/clay. As proceeding to valley floor, silts/clay become gradually richer and inter-finger each other. In the area after Baleli-Samungli Gap, almost all of silts/clay. The parts lower than the altitude around 1500m are composed of very thick clay strata, which seem to be Subrecent, of which upper limits are inclined very gently from mountain to valley floor.

Profile's B and D are from east to south-east piedmont and valley floor. Both cases show the rapidly change of thick strata of sands/gravels in the piedmont into thick silts/clay through narrow inter-fingering area. Comparing to Profile A, it is said that the smaller the catchment area, the more rapidly the sand of sands/gravels change into silts/clay.

Profile C is crossing through the central part of Quetta city from North to South. The northern end is around piedmont front composed of the transported material by Hanna-Urak River, thickness of which reaches to 170 to 180 meters. The southern end lies in the valley floor, which several tens of meter thickness of sands/gravels extending from piedmont are overlain by the confining impervious strata, and further reaches in the central part of valley floor, Alluviums are dominantly composed of silts/clay.

iii) Location and Distribution of Aquifers

Competent aquifers develop in the alluvial fan deposits distributing along the piedmont slope in the northern to north-eastern, the south-eastern, the south-western and the downstream of Brewary area. Among them, the northern to north-eastern is the biggest having their width approximately 10 km. The aquifers of south-eastern have 2~3 km to 5~6 km width. The scale of the Brewary area is small.

In the northern part of Quetta valley floor as shown in Profile C, the strata of sands/gravels are intercalated by silts/clay forming confined aquifers whose piezometric levels are in between the depth of 20 to 30 meters in the central part of Quetta city. However, the piezometric levels are rapidly going down to the northern Hanna-Urak River side.

--- Characteristics as Groundwater Basin

The piedmonts act as recharging media and groundwater reservoir, while the down-reaches of valley floor as the barrier against groundwater flow. In consequence, the structure of the groundwater basin is like underground dam so that the runoff from the basin through underground may be very little.

--- Aquitards as Barriers and Basements of Groundwater Basins

Basement rocks are composed of Urak Conglomerate, Spintangi Limestone, Gazij Shale and Chiltan Limestone. Gazij Shale and Chiltan Limestone form impervious beds. However the other two are usually porous and cavernous forming partly good aquifers. as Very thick strata of clay/silts underlying in the area are also impervious beds as shown in Profiles.

d Mastung Sub-Basin

i) General Description

The area is an elongated valley running between two mountains ranges oriented north-south. It narrows at the northern and southern ends and widens in the Mastung - Pringabad area, attaining a width of about 10 km. Mountain ranges and drainage of Mastung valley are as under;

Mountain Range

Location	Name of Range	Range of Crest Altitude
Northern and eastern border	Chiltan range Kumbelan range	
From Kunak area in the southeast	Kamar range	The highest point is 2740 m in the Kumbelan range
From Mangocher plain in the south	Bidrang High	

Drainage		
Principal Stream	Rud Sariab Mobi Dora	
Main Tributaries	From South From East From West	Pir Ka Khad Kamar, Gaddi, Jal Baghicha Jami, Jal Pash Karm Chammai, Kmbi, Siah Band

The rocks exposed in the area is range from Permo-Triassic to Recent.

- The Shirinab Formation: predominantly grey to black limestone complex characterised by many shale intercalations.
- The Chiltan Limestone: equally compact dark limestone grading into cream-coloured limestone towards the top of the formation.
- The Gazij Shale: several thousand feet thick; predominantly shaly formation with several sandstones and conglomeratic intercalations; exposed west of Mastung; recognized to be the impervious base.
- Fluvial fan deposits: found along the whole length of the Kumbelan range in a strip not more than 3 km wide, and in the southern Khad Kucha area.
- Alluvial and aeolian deposits: covering large parts of the area around Mastung and Pringabad.

Hydrogeological Map of Mastung Sub-Basin is shown in Fig.A.9. Mastung Sub-Basin is long basin from north to south composing western mountain of Shirinab Formation, and eastern steep mountain of Chiltan Limestone (partly Spintangi Limestone). Bostan Formation exists in one part.

Main drainage system is Rod Sariab from south to north, and Mobi from north to south. Both rivers are relatively small. Alluvial fan deposits are well developed along eastern piedmont and southern area. Strong winds blowing from the western gap of sub-basin accumulate eolian deposit and forms sand dune. Valley floor except sand dune area is dominantly composed of fine material.

Shirinab Formation, Chiltan Limestone, and Bostan Formation form the impervious bed of groundwater basin. Spintangi Limestone forms partly fractured and/or cavernous aquifer.

Valley floor deposit is composed of the alternating layers or lenses of coarse and fine material. Aquifer in the valley floor is generally confined.

In the Fig.A.9, the lower limit of alluvium is shown to a presumable extent.

The specific yields of alluvium are also shown in the figure according to existing well data. They are more than 20% in the top of Alluvial fan deposit of the northern, eastern and southern piedmont. It is around 10% in the western piedmont, and less than 10% in the central part of valley floor.

Transmissivity and permeability in the sub-basin are;

	Transmissivity	Permeability
in the northern, eastern and southern Alluvial fan deposit area	100~250 m^2/d	5 ~ 6E-3 cm/sec
valley floor developing aquifer well	40~600 m^2/d	3E-3 cm/sec
in the other valley floor area	2 ~ 3 m^2/d	2 ~ 3E-4 cm/sec

ii) Geological Profile

Main geological sections are shown in Figs. A.10 and A.11.

Alluvial fan deposits distribute in south, along eastern piedmont, and in north. Profile's A, B, and C show vertical situations typically. As shown in Profile A, sands/gravels in south get into thick silts/clay deeply and intercalated with them as proceeding to North. Two confined aquifers can be seen, the depth to which is approximately 200 meters and 250 to 300 meters respectively. These aquifers may be also connecting to the eastern alluvial fan as shown in the Profiles B and C.

While the northern sands/gravels strata extend from the ground surface up to the depth about 100 to 150 meters as unconfined type of aquifers.

The eastern area of Mastung and Pringabad Town is depressing gently, which may collect surface runoff easily. This area is covered with 10 to 15 meter's thickness of sand dune deposits mainly composed of fine sorted sands.

iii) Location and Distribution of Aquifers

Alluvial fan deposits extending in south, along eastern piedmont, and in the northern contribute as excellent aquifers, which are usually unconfined types.

Two deep confined aquifers lie around the depth approximately 100 and 250 to 300 meters in the valley floor from the central to the southern area. Recharge into these aquifers is by lateral inflow from unconfined aquifers.

Sand-dune deposits are mainly composed of loose fine sands so that their permeability may rather well forming like seasonal aquifers in the flood season.

These sand-dune areas and the northern sands/gravels strata overlying silts/clay strata form shallow or medium deep unconfined aquifers so called karez aquifers. While, the above mentioned deeper aquifers form the medium are called the dug-well aquifers and tubewell aquifers.

--- Characteristics as Groundwater Basin

The thickness of the northern aquifers is from 100 to 150 meters, and the eastern to the southern aquifers are some hundreds of meter.

The area around the Gap opening from Mastung to Shirinab Sub-Basin is formed very thick (more than 350 meters) silts/clay strata from top to bottom according to lithological datum of existing well US-MST-2 covered with thin dune sands. In consequence the structure of groundwater basin is like underground dam so that the groundwater runoff from the basin to the other basin through underground may be very little.

Types of aquifers in this Sub-Basin may be classified as under:

1 Karez aquifers (the northern alluvial fan deposits, sand dune deposits)

2 Unconfined aquifers in the eastern and the southern piedmont

3 Dug-well aquifers in the valley floor

4 Tubewell aquifers in the valley floor

5 Seasonal aquifer in the dune sands

--- Aquitards as Barriers and Basements of Groundwater Basins

The basement rocks are composed of Chiltan Limestone, and partly Spintangi Limestone. Though it is not exposed in the ground surface, Gazij Shale is existing in the bottom of buried valley floor. Gazij Shale and Chiltan Limestone are the impervious beds. In valley floor, the very thick clay/silts strata are forming confining strata and impervious beds to the aquifers.

c Kalat Sub-Basin

i) General Description

The area is oval shaped with isolated valleys, enclosed on all side by mountains, except where it drains into Shirinab valley. Mountains ranges and drainage of Kalat sub-basin are as under;

Mountain Range

Location	Name of Range	Range of Crest Altitude
Western extremity	Khallili, Istrab, Lora, Geri, Mari, Morin Koh ranges	The highest point is in Istrab range (2790 m)
Eastern extremity	Harobi, Lashkari Khushta, Siah Koh ranges	The highest point is a peak Harobi (2997 m)
Toward north	Khidh, Zibra ranges	
In the middle area	Chandram, Siah Koh, Chapper, Zawa (islated mountains)	The highest point is 2488 m
Toward southern extremity	Pango range (small hillocks)	

Drainage		
Principal Stream	Mushmunki Jhal ------> Khanni Jhal	Rud Kalan
Main Tributaries	From West	Istrab Jhal, Kharna Chil
	From East	Rangi Kalan Jhal

A piedmont plain represents a major portion of Kalat-Kohing and Dasht-e-Baddu, Dasht-e-Goran and Chappar Plain. The valley floor is poorly developed in Kalat-Kohing, Dasht-e-Goran, Chapper and the Karchhap area near Mangocher. The area in Chapper and Dasht-e-Baddu is interrupted by a few exposures of limestones. Gully erosion creates deep ravines particularly in Chapper area. The lowest point is 1745m.

Consolidated Rocks exposed in the area range in age from Triassic to Pleistocene.

- The Shirinab Formation: dark grey limestone weathered to brown with abundant interbedded shales; resistant, massive; exposed at Marin Koh, Nali area west of the Chapper plain, Chapper ridge and Siah Koh.
- The Chiltan Limestone: thickly bedded; massive; form a portion of Chandram, Siah Koh and Zibra range.
- The Parh Group: thinly bedded fine grained whitish, pinkish limestone with abundant interbedded shale; exposed in Dasht-e-Baddu, toward southern side of Rodinjo, Mali and Gaddazai.
- The Gidar Dhor Sandstone, Shale: exposing only a portion along Kalat-Surab Road.
- The Spintangi Limestone: having very nodular texture occurring widely in the eastern part of the area in Harobi hills, Kapoto and Iskalkoo area.
- The Wakabi Limestone, Shale: makes the western flank of Chappar and Dasht-e-Goran area.
- The Dada Conglomerate: exposes south-west of Dasht-e-Goran.
- Unconsolidated Rocks deposit: occurs under fluviatile environment.

In the area two types of groundwater reservoir are present, first the limestone reservoir, which yield a major quantity of groundwater through springs. These limestones have developed secondary porosity by their originally nodular texture. The nodular Spintangi Limestone which is exposed in a vast area, east of Kalat and in Harobi ranges has developed some channels by fracturing and yields a number of productive springs, that is Dudran, Chashma Kalat, Kalan Iskalkoo. The second reservoir is represented by the gravel of the alluvial channels.

Hydrogeological Maps of Kalat Sub-Basin is shown in Fig.A.12. Spintangi Limestone of Eocene age distributes relatively wide aerial extent in the eastern part of the sub-basin. Alozai Group, Shirinab Formation, Chiltan Limestone and Parh Group of Paleozoic to Mesozoic age lie mainly in the central to western part with Wakabi Limestone of Eocene age along the fault running north to south in the western mountain foot. At the southern end of this range, Dada Conglomerate of Pleistocene exposes in the very small area. The highly erosive Parh Group shale (Belemnite Shale) may underlie in the lowland area. Alluvial fan deposit is widely extent around the outlet area of channel from mountain area, and valley floor deposit in the center of valley.

Paleozoic to Mesozoic erathem, and Wakabi Limestone forms impermeable bed of groundwater basin. Spintangi Limestone is crack developed and cavernous limestone, and forms the most useful aquifer in this sub-basin supplying water from some spring. Alluvial fan deposit also form aquifer, however their thickness in this sub-basin is relatively thin.

Valley floor deposit is composed mainly of fine material, and impermeable.

In the Fig.A.12, the lower limit of alluvium is shown to a presumable extent.

The specific yields of alluvium are also shown in the figure according to existing well data. They are more than 20% in the top of Alluvial fan deposit of the north-eastern and northern piedmont, and Subrecent of eastern part. It shows partly more than 25% especially in the northern part.

Transmissivity and permeability in the sub-basin are;

	Transmissivity	Permeability
in the area of piedmont and valley floor	15 ~ 50 m^2/d	2E-4 ~ 4E-3 cm/sec
in the limited area of Spintangi Limestone	around 1000 m^2/d	around 2E-2 cm/sec

ii) Geological Profile

In the case of Kalat Sub-Basin, the drilling data are very few so that only Profile shown in Fig.A.13 may be possible to be drawn.

It is quite clear from Profile that the elevation of bedrock of eastern side and western side is remarkably different from each other. The elevation of the western bedrock is two hundred and some tens of meter lower than the eastern. The thickness of the alluvium is 70 to 80 meters in the eastern side, and around 200 meters in the western side. Alluviums are composed mainly of sands/gravels strata. The valley floor distributes only along the main stream in the eastern part with width several kilometers.

iii) Location and Distribution of Aquifers

In the Sub-Basin, Alluviums in the eastern part are composed almost all of sands/gravels as shown in Figs. A.12 and A.13. Even in the western part, those distributing along piedmont are also composed mainly of sands/gravels partly interbedded with approximately 10 meter's thickness of silts/clay. These strata form aquifers.

Spintangi Limestone extending widely in the eastern part is usually very porons and cavernous forming partly abundant springs. This formation may supply groundwater to Alluviums.

--- Characteristics as Groundwater Basin

Kalat Sub-Basin is largely divided into the eastern and the western parts, out of which the groundwater in the eastern is fractured aquifers in Spintangi Limestone. Alluvial aquifers which may be supplied directly from Spintangi Limestone are usually small scale both in horizontally and vertically. While, in the western, those are usually unconfined granule aquifers in alluvial fan deposits having relatively large scale. Groundwater in the area of Shale of Parh Group tend to be saline.

--- Aquitards as Barriers and Basements of Groundwater Basins

In the eastern part of Kalat Sub-Basin, Gazij Shale which forms impervious bed may lie under Spintangi Limestone and Alluviums. In the western part, Shirinab Formation, Alozai Group, Wakabi Limestone and Parh Group form impervious beds.

f Patki Shah Nawaz Sub-Basin

i) General Description

The area shows a rectangular shape running between two mountains ranges oriented north-south. Mountain ranges and drainage of the Patki Shah Nawaz sub-basin are as under;

Mountain Range

Location	Name of Range	Range of Crest Altitude
Eastern border	Duna, Morin Koh, Zikki, Tanta	The highest point is
In the North	Bela Spara	2520 m of the Rastari
Western border	Rastari Taing, Mundak	Taing peak

Drainage

Principal Stream	Dhor Jhal ---	Bhalla Dhor --- Shora Rud --- --- Abo-i-Khas or Gurgina Nala
Main Tributaries	From East	Kan Jhal, Patki Jhal, Sarband, Shani Basham, Chhori, Hilti Nala
	From West	Zaingigeti, Gorjandi Jhal, Khush Toda, Yusuf Duni Chur, Talapi Nala

The piedmont plain develops mostly along the foot slope of eastern mountain ranges but along the western range it is very rare. The area of valley floor is in between Shora Rud and the foot of western mountain.

Consolidated Rocks exposed in the area range in age from Triassic to Pleistocene.

- The Shirinab Formation: dark grey limestone weathered to brown with abundant interbedding shales; resistant, massive and exposed in the eastern mountain range.
- The Nimargh Limestone of Eocene: exposed in the eastern mountain range; the secondary permeability of the area and yields some springs.
- The Wakabi Limestone, Shale: makes the resistant to groundwater.
- Shaigalu Sandstone: distributing the western mountain ranges of the area
- Murgha Faqirzai Shale: underlie the alluvial of the valley floor.

All these rocks are far all practical purposes impervious to groundwater except the Shaigalu Sandstone and Nimargh Limestone yielding productive springs which partly aquifer.

Unconsolidated Rocks deposit under fluviatile environment. Main aquifers found in this area is laying the central part as gravelly layers.

Hydrogeological Map of Patki Shah Nawaz Sub-Basin is shown in Fig.A.14. Patki Shah Nawaz Sub-Basin is composed of Jurassic Shirinab Formation and Eocene Nimargh Limestone in the eastern mountain range, and of Miocene Shaigalu Sandstone in the western mountain range. Erosive Murgha Faqirzai Shale of Oligocene age may consist of the bedrock of the lowland. Alluvial fan deposit is widely extent along eastern piedmont. The area of valley floor is relatively small in this sub-basin.

Shirinab Formation and Murgha Faqirzai Shale form the impermeable bed of groundwater basin. Shaigalu Sandstone is partly develops aquifer in the crack developed zone. Alluvial fan deposit is usually aquifer.

In the Fig.A.14, the lower limit of alluvium is shown to a presumable extent.

The specific yields of alluvium are also shown in the figure according to existing well data.

They are more than 20% in the area of eastern piedmont.

Transmissivity and permeability in the sub-basin are;

	Transmissivity	Permeability
in the area of piedmont	50 ~ 500 m^2/d	1E-3 ~ 1E-2 cm/sec
In the area of valley floor	around 3 m^2/d	7E-3 ~ 1E-2 cm/sec

ii) Geological Profile

Fig. A.15 shows main geological sections of the Sub-Basin. In the Sub-Basin, the drilling data are also few so that only Profile along the center of the Sub-Basin from North to South and the line from the Mangi area to downstream is possible to be drawn.

Bedrock along the center line of the Sub-Basin is inferred to be basin-like structure as shown in the Profile. Alluvial fan deposits are extending with width several kilometers in the eastern piedmont. The upper stream side of the alluvium is almost composed of sands/gravels, however their thickness is at most a little over than 100 meters.

c Location and Distribution of Aquifers

In the Sub-Basin, aquifers develop in the Alluviums of the southern and the eastern piedmont. Nimargh Limestone existing in the eastern mountain, like Spintangi Limestone, is porous and cavernous and partly develops springs. Shaigule Sandstone majority distributing in the western mountain also develops aquifers at places.

--- Characteristics as Groundwater Basin

In the Sub-Basin, aquifers in Alluviums are underlain by the basin-like shaped bedrock, and forms good aquifers, however, the depths to the bedrock tend to be shallow in general, maximum thickness of which may be around 100 meters in the central part. The strata of sands/gravels develop usually in the southern and the eastern piedmont, however, those rarely develop along the western piedmont.

--- Aquitards as Barriers and Basements of Groundwater Basins

Murgha Faqirzai Shale usually lies under Alluvium, and forms impervious beds. The depth to the bedrock tends to be generally shallow in this Sub-Basin.

A.4 Interpretation as to Hydrogeology and Topography around Each DAD

Hydrogeological distribution of respective DAD sites and catchment areas are shown in Figs A.16 to 31. Besides, the Topo-Interpretation Maps around the Priority DAD sites and Geological Sections of the Downstream Area of respective Priority DAD which are inferred from the data of In Situ investigation (Drilling shown as Fig.A.50 and Table A.3 and Resistivity Exploration) and of the existing tubewell are shown in Figs. 32 to 49. Respective descriptions are as under.

A.4.1 Existing DAD

A. Khora Manda

The catchment area of Khora Manda DAD is mostly composed of limestones of Jurassic age, of Alluvial sands/gravels in the mountain side, and of silt tracing dense sands/gravels of Subrecent deposits around and just upstream of dam site. In the downstream, piedmont slope is extent widely.

Geological section in the downstream of the DAD is inferred as shown in Figure. Just downstream side of dam site is composed of considerable dense silt tracing sands/gravels strata of Subrecent deposits. Permeability at the dam site is relatively high. Due to good permeability and little siltation on the reservoir bed, water stored in the reservoir infiltrates into the ground in a short duration. Deposits of Alluvial Fan in the downstream of the DAD are very thick, and changes into valley floor mainly composed of silts/clay strata.

The radius of alluvial fan extent in the downstream of the DAD is between 2 and 3 kilo-meters. Topographic gradient is more than 1 in 20 in the upstream side, and approximately 1 in 25 in the downstream side. Radial angle of alluvial fan is approximately 120 degrees assumming that the pivot is at the dam site.

Depth to bedrock has not been confirmed due to lack of data. Bostan Formation may lie from the depth around 150 meters in the valley floor.

Coefficient of Permeability of Alluvial Fan is inferred to be the higher side in the order of E-3 cm/sec, and gradually becomes lower as proceeding to the downstream. Transmissivity of the Fan deposits is around 40 m^2/day estimating from the existing data. Specific yield is approximately 15% around fan front, and a little more than 20% at the uppermost-stream. Depth to groundwater tables is approximately 30 meters as of 1988.

B. Marium

The catchment area of Marium DAD is composed of Conglomerates of Miocene age, forming steep mountain slopes. The catchment area is too small. In the downstream of the DAD, relatively thin talus-like Alluvial deposits are extent widely forming relatively steep slopes.

Geological section in the downstream of the DAD is inferred as shown in Figure. The thickness of Alluviums may be 30 meters at maximum in the valley bottom. Topographic gradient is steep showing approximately 1 in 10.

Coefficient of Permeability of Alluvium is inferred to be in the order of E-3 to E-2 cm/sec.

C. Bostan

The Catchment area of Bostan DAD is composed mainly of Limestones interbedded with Marl, Sandstone, and Shale of Permo-Triassic to Jurassic age, and partly of Paleocene Limestone. In the downstream, piedmont slope is extent widely.

Geological section in the downstream of the DAD is inferred as shown in Figure. The thickness of Alluvial Fan deposits extending in the downstream of the DAD is from 20 to 30 meters, and reaches one hundred and tens of meters at maximum. The surface layers along Bostan Lora are silty to clayey valley floor deposits. Abutment of the dam body is emplaced on Chiltan Limestone of Jurassic age. In the part of river bed, relatively thick river deposit or fan deposits is distributing. Bostan Formation forms hills extending in relief in the other bank side of Bostan Lora, and underlies in the area of valley floor underlain by bedrock.

Alluvial fan in the downstream forms typically with radius about 3 km, and topographic gradient approximately 1 in 20. Radial angle of Alluvial fan is approximately 180 degrees assuming that the pivot is at the dam site. Though depth to bedrock has not been confirmed due to lack of data. It is inferred to be more than 150 meters in valley floor.

Coefficient of permeability is 4 to 5E-3 cm/sec around fan front area, and 7 to 8E-3 cm/sec in the upstream area. Transmissivity is more than 500 m^2/day in the center of Alluvial fan, and in between around 100 and 300 m^2/day around fan front area. Specific yield of fan deposits is approximately 20% or more. Depth to water level as of 1978 was a little more than 40 meters, however as of 1988 it showed approximately 60 meters, that is, approximately 20 meter's drawdown within this duration.

D. Khushab

The catchment area of Khushab DAD is composed of limestone and shale of Cretaceous age, and conglomerate of Miocene age, and partly Ophiolitic Intrusives.

In the downstream of the dam site, wide river bed extend. After passing the isthmus locating around 2 kilometers downstream from the DAD, piedmont slope is extent widely. The basement of isthmus part is Jurassic limestones.

Geological section in the downstream of the DAD is inferred as shown in Figure. Dam body is emplaced on the foundation of Cretaceous limestone and shale, and river deposits of sands/gravels. The thickness of river deposits is confirmed 12 meters at 50 meters downstream from dam axisas a result of test drilling. Coefficient of permeability is 1.42E-3 cm/sec. However, siltation in the reservoir blocks storage water from infiltration into ground. Fan deposits in the downstream may be composed mainly of sands/gravels strata intercalated with silts/clay lenses. The thickness at the layers is inferred to be between 100 and 150 meters. The bedrock of this area may be Ophiolitic Intrusives.

The radius of alluvial fan extent in the downstream of the DAD is approximately 1 kilo-meter. Topographic gradient is approximately 1 in 25. Radial angle of alluvial fan is approximately 180 degrees as the DAD site being the pivot.

Depth to bedrock has not been confirmed by existing data. It may lie from the depth around 150 meters in the valley floor.

Coefficient of Permeability of Alluvial Fan is inferred to be the higher side in the order of E-3 cm/sec., and gradually becomes lower as proceeding to the downstream. Depth to water level is inferred to be in the range of 20 and 30 meters.

E. Tirkha

The catchment area of the Tirkha DAD is composed of clayey strata of Pleistocene Bostan Formation forming aquitard.

Geological section in the downstream of the DAD is inferred as shown in Figure.

To some extent of the downstream from the DAD site, Bostan Formation is exposed. Silt tracing sands/gravels strata of Alluviums as aquifer is distributing along the stream channel,. Groundwater flows as subsoil water in the river deposits. The thickness of river deposits was only 2 meters at 50 meters downstream of the DAD as a result of test drilling. After the way-out of hilly area, small Alluvial fan followed by valley floor is distributing. Sandy strata forming relatively well aquifer lie over silty strata in the Alluvial Fan area. Topographic gradient along river bed is very gentle, and that of Alluvial Fan is between 1 in 80 and 100.

Coefficient of Permeability of river deposits and Fan deposits is inferred to be in the order of E-3 cm/sec.

F. Amach

The catchment area of the Amach DAD is composed mainly of Limestones of Jurassic age, and partly of Miocene Limestone. Valleys enclosed by these mountains are extent relatively in large scale buried by Alluvial sand/gravels. The thickness of Alluvial sands/gravels in river bed of dam site is inferred to reach to around 150 meters. In the downstream, piedmont slope is extent widely.

Geological section in the downstream of the DAD is inferred as shown in Figure. Sands/gravels strata found in the downstream of the DAD get deeply under valley floor deposits, and forms deep confined aquifers. Valley floor deposits consist almost of silts/clay strata in the upstream side, however in the section between Mastung Town and the Gap through Shirirnab Sub-Basin, it consists mainly of sandy or sand-tracing deposit overlain by about 10 to 15 meter's thickness of sands/gravels strata near ground surface as shown in cross section. They may be supplied from mountains of western watershed of Mastung Sub-Basin.

Radius of Alluvial fan exposed in the downstream of the DAD is in the range of 2 to 3 kilo-meters. Topographic gradient is in the range of 1 in 80 to 100. Radial angle of Alluvial fan is approximately 180 degrees assuming that the pivot is at dam site. Depth to bedrock has not been confirmed due to lack of data, however as mentioned before it is inferred to be approximately 150 meters around dam site, and 200 to 250 meters in the downstream side.

Coefficient of permeability of fan deposits is in the order of E-3 cm/sec. Transmissivity may be around 150 m^2/day in Alluvial fan, and less than 10 m^2/day in valley floor. Specific yield is approximately 20% in Alluvial fan, and less than 10% in valley floor. Depth to water level during 1988 to 91 was in the range of 10 to 25 meters.

G. Kad Kocha I

Kad Kocha I DAD is located around 2.5 kilo-meters upstream of proposed Kad Kocha II DAD. The site is situated in the wide valley enclosed by steep mountains composed of Jurassic and Miocene limestone, and emplaced on very thick Alluviums in the river bed which continues to the downstream through Kad Kocha II site.

Geological section in the downstream of the DAD up to Kad Kocha II site is inferred as shown in Figure. The thickness of Alluviums may be approximately 100 meters in the valley bottom. Topographic gradient is approximately 1 in 30.

Coefficient of Permeability is inferred to be in the order of E-3 cm/sec, and transmissivity is in the range of 50 to 100 m^2/day in the Alluvium. Depth to water level may be around 50 meters.

H. Gorpad

The catchment area of Gorpad DAD is composed of marly limestone, shale, and sandstones of Cretaceous age. The DAD is situated on one of the branch stream of Kani Jhal locating around the foot of hills. Alluvial fan having topographic gradient approximately 1 in 30 is extent around there.

Geological section in the downstream of the DAD is inferred as shown in Figure. The thickness of Alluvial fan deposits may be 30 meters at maximum in the valley bottom. The deposits in this area are saline reconsiderably. Though salinity of stored water in the reservoir is in the limit of the allowable for irrigation, in the river bed of the downstream of the the DAD, much salt is remarkably solidified by evaporation in the surface.

I. Lagmgir

The catchment area of Lagmgir DAD is composed mainly of limestones of Permo-Triassic to Jurassic age and partly of Alluviums. The DAD is located at a little upstream from the way out of mountains so that the downstream section 700 to 800 meter's length from the DAD is narrow river bed followed by widely extending piedmont slope.

Geological section in the downstream of the DAD is inferred as shown in Figure. The thickness of Alluvial fan deposits may be in the range of 100 to 150 meters, and changes into valley floor deposits. Alluvial fan in the downstream forms typically with radius about 3 to 4 kilo-meters, and topographic gradient in the range of 1 in 50 to 60 in average. Radial angle of Alluvial fan is approximately 130 degrees.

Coefficient of permeability of fan deposits is in the order of E-3 cm/sec. Transmissivity is in the range of 50 to 100 m^2/day in the center of Alluvial fan, and specific yield of fan deposits is approximately 20% or more. Depth to water level may be approximately 50 meters.

J. Sarbund

Sarbund DAD is located around 4 kilo-meters upstream of proposed Mangi DAD site. The catchment is composed of Eocene and Jurassic limestones. Relatively wide Alluviums forms the valley bottom occupying the large proportion of the catchment area. The DAD is situated at the downstream end of this Alluvium with their abutment founded on Cretaceous limestone.

Geological section in the downstream of the DAD up to Mangi site is inferred as shown in Figure.

Just downstream of Sarbund DAD expose bedrock in the surface.

A.4.2 Priority Proposed DAD

A. Brewary

a Topo-interpretation

Fig. A.32 shows the Topo-interpretation Map of Brewary area. The mountainious catchment of Brewary DAD is composed of hard and massive limestones and highly watertight shale of Jurassic to Eocene age. To the northward of the mountain area, hilly area composed of dense but unconsolidated gravelly Subrecent deposits extends. In the downstream of proposed DAD site, typically shaped alluvial fan extends with radius approximately 3 kilometers and reaches up to Sariab Lora. Along the eastern foot of mountain including this alluvial fan, piedmont slope composed of talus and fan deposits extend from North to South. Among them, that of

Wali Dad has relatively a large scale. In the eastward, flat land compose one part of valley floor of Quetta Valley.

b Geological Section of the Downstream of the DAD

Inferred geological section of the Alluvial Fan area spreading in the downstream of Brewary Site is shown in Fig.A.32. Though the depth to the basement rock of Brewary Limestone is shallow at the drilling point in Phase I, it becomes very deep to the direction of downstream resulting not impossible to be confirmed at the location of resistivity exploration identified No. 2 to 4 within the exploration depth of 100 meters.

Sands/gravels strata with a hundred and several tens of meters thickness in the Alluvial Fan area change rapidly into thick silts/clay strata after passing Sariab Lora. Topographic gradient of the Alluvial Fan is approximately 1 in 50.

The depth to water level, which is a little less than 2 meters at the drilling point, is rapidly going down to the downstream side showing approximately 50 meters around Sariab Lora. Hydraulic gradient is approximately 1 in 35.

Hydrogeologic parameters are: Coefficient of Permeability; 2.5 E-3 cm/sec at the drilling point and 1.2 to 1.9 E-3 cm/sec in the central area of Alluvial Fan. Transmissivity; 25 m^2/day at dam site, around 120 m^2/day around the central Alluvial Fan, 60 to 90 m^2/day at a little further downstream area, and becoming rapidly low values around 5 m^2/day after passing Sariab Lora. Specific Yield; 25% at the uppermost-stream area, 18 to 20% around the central Alluvial Fan, and less than 10% after Sariab Lora.

In the inter-fingering area of silts/clay and sands/gravels strata, Coefficient of Permeability is approximately 1 E-3 cm/sec, Transmissivity 70 m^2/d, and Specific Yield around 15%.

c Main Aquifers Influenced by DAD

As mentioned the above, alluvial fan with radius of about 3 kilometers is formed and supplied gravels, cobbles and boulders from Karakhusa Nala in the downstream of the proposed DAD. Topographic gradient is approximately 1/50, the DAD site situated around the rivet of this fan and the radiating angle of the fan is approximately 100 degrees. The area of this fan is approximately 8 km^2.

At the DAD site, the bedrock is Brewary Limestone overlain by 12 meter's thickness cobble and boulder stratum, of which coefficient of permeability is 2.5E-3 cm/sec. Depth to groundwater level at this point is less than 2 meters. According to the data of existing wells identified as QA-ANK-1 and Animal Husbandry-1, the central part of alluvial fan is composed almost all of gravels, and the depth to bedrock is more than 125 meters. The depth to groundwater level is 26 meter as of February 1987 and the coefficient of permeability is 1.22 to 1.95E-3 cm/sec at QA-ANK-1, and 1.84E-3 cm/sec at Animal Husbandry-1.

d Relation with Beneficiary Area [Specified Area and Unspecified Area]

As beneficiary areas of the proposed DAD, the specified farmland is extending in the southward of the alluvial fan as shown in A.32. This area belongs to the periphery of valley floor where the surface layer is composed of fine grained soil such as silts and/or clay. However, according to the existing well data identified as QA/PGA(PR) locating 1 kilometer upstream from the end of beneficiary areas, gravelly stratum which forms semi-confined or confined aquifers lies under the surface layer and reaches more than 120 meter's depth intercalated with thin clay layers. Depth to groundwater level was 13.2 meters as of December 1985. From the pumping test of this well, the drawdown was approximately 21 meters when 1360 m^3/d pumped up resulting the coefficient of permeability 1.07E-3 cm/sec, transmissivity 72 m2/d, specific yield 15%, and specific storage 7E-5 1/m. In consequence, the unconfined aquifers of alluvial fan may be well connecting to the semi-confined or confined aquifers lying under the beneficiary area so that the recharged water flowing to southward may recharge into the aquifers lying under the beneficiary area. Assuming that groundwater flows equally in the alluvial fan, their volume influencing to the aquifers of the beneficiary area may be concluded that about 40% of totally recharged groundwater can be consumed in that area, because the radiating angle of the fan shape of the alluvial fan relating to the beneficiary area is approximately 40 degrees.

Remaining 60% may be treated as for unspecified beneficiary areas.

B. Dara

a Topo-Interpretation

Fig. A.34 shows the Topo-interpretation Map of Dara area. The central part of mountain area is composed mainly of hard and massive limestones of Jurassic age, and the periphery is highly watertight shale of Eocene age and partly conglomerates of Miocene age. These are seemed to be impervious bedrock. In the downstream of proposed DAD site, after passing through relatively narrow stream channel, typically shaped alluvial fan is extending with radius approximately 2 to 3 kilometers and reaches up to Gnundak Rud - Loe Manda.

Including the above mentioned alluvial fan, piedmont slope composed of talus and fan deposits extents with width approximately 2 kilometers along the foot of mountain.

b Geological Section of the Downstream of the DAD

Inferred geological section of the Alluvial Fan area spreading in the downstream of Dara Site is shown in Fig.A.32. The basement rock was not be found out by the 40 meter's depth of drilling carried out in Phase I. However, relatively thick clay strata are existing in some deep range, and limiting the overlying aquifer. From the central Alluvial Fan to the downstream area where consist of the Alluvial Fan from Kach area, is composed of sands/gravels strata with a hundred and several tens of meters thickness, though it changes once into silts/clay strata around Loe Manda. Topographic gradient is approximately 1 in 20 in the upstream area, and approximately 1 in 40 in the central Alluvial Fan.

Groundwater was not found out by the 40 meters drilling. The depth to water level in a range from the center to downstream of Alluvial Fan may be very deep showing approximately 100 meters. Hydraulic gradient is in range of 1 in 35 to 40 same as the topographic gradient.

Hydrogeologic parameters are: Coefficient of Permeability; 1.5E-3 cm/sec at the drilling point and seems to be around 1.0 E-3 cm/sec in the central area of Alluvial Fan. Transmissivity; 25 m2/d at dam site, 40 to 80 m2/d around the central area of Alluvial Fan, and seems to be bigger the further downstream side is because aquifer becomes very thick, though the coefficient of permeability becomes a little lower value. Specific Yield; 20% at the uppermost-stream area, and gradually going down to the downstream area.

c Main Aquifers Influenced by DAD

As mentioned the above, in the downstream of the proposed DAD, alluvial fan with approximately radius 2 to 3 kilometers is formed and supplied gravels, cobble and boulders from the catchment area. Topographic gradient is approximately 1/20 in the upstream side and 1/30 to 1/40 in the downstream side. The radiating angle of the fan is approximately 60 degrees. The area of this fan is approximately 5 to 6 km^2 and reaches up to Loe Manda. The area beyond Loe Manda is a part of valley floor mainly composed of silts and clay.

At the DAD site relatively thick silts/clay strata lies from the depth around 20 meters to 35 meters. The bedrock and groundwater was not observed by drilling with 40 m depth conducted by Study Team. Coefficient of permeability of the unsaturated gravels layers is 1.5E-3 cm/sec.

The central part of alluvial fan is considered to be composed of very thick sands/gravels strata.

d Relation with Beneficiary Area [Specified Area and Unspecified Area]

As beneficiary areas of the proposed DAD, the specified farmland is extending in the down-reaches of the alluvial fan and a part of valley floor locating downward of alluvial fan as shown in A.34.

Specified beneficiary area locates covering almost all down-reaches of the alluvial fan. Piedmont slope composed of sands/gravels including this alluvial fan are extending so that some of the recharged water from proposed DAD may flow into these areas. Because the piezometric level surface is generally conformed with topographic surface, it is considered that groundwater doesn't flow beyond the topographic depression. If considered as this, the radiating angle of groundwater flow recharged is approximately 90 degrees. As a result, 2/3 of recharged groundwater can be consumed for the specified beneficiary area where is covering all down-reaches of alluvial fan having the radiating angle 60 degrees.

Remaining 1/3 may be treated as for unspecified beneficiary areas.

C. Murgi Kotal

a Topo-Interpretation

Fig. A.36 shows the Topo-interpretation Map of Murgi Kotal area. The mountainious catchment of the proposed DAD is composed of hard and massive limestones of Jurassic age (partly of Paleocene age). This mountain is extending straightway toward south from the DAD site, and dividing the area into Kuchlagh Sub-Basin and Quetta Sub-Basin. Alluvial fans extend in both Sub-Basins. Piedmont slope distributes with width 1 to 2 kilometers including these alluvial fans along the foot of mountains, and the downward forms valley floor. Along Baleli River - Khwaja Lora, a lot of gully erosion develops remarkably shaping so many creeks, and forms badlands.

b Geological Section of the Downstream of the DAD

Inferred geological section of the Alluvial Fan area spreading in the downstream of Murgi Kotal Site is shown in Fig.A.35. Drilling in Phase I was carried out at the storage area of existing dam through siltation material. Seven meters-thickness of siltation was confirmed, however, the basement rock was not be found out within 40 meters-depth. The Alluvial Fans from Murgi Kotal Nala develop to the Kuchlagh Sub-Basin side and Quetta Sub-Basin side. Quetta side is larger than the former.

The Alluvial Fan of Quetta side may be composed of sands/gravels strata with thickness approximately 150 meters probably underlain by Subrecent clay strata. Silts/clay strata become gradually rich toward the downstream side, and dominant around Baleli River. Topographic gradient is approximately 1 in 25.

The depth to water level seems to be in a range 70 to 80 meters at apex of Fan, and a little more than 20 meters at Fan front. Hydraulic gradient may be approximately 1 in 50.

Hydrogeologic parameters are that Coefficient of Permeability may be order of E-3 cm/sec, and Transmissivity may be in a range of 90 to 100 m2/d.

The Alluvial Fan of Kuchlagh side may be composed of remarkably thick sands/gravels strata with thickness at least 150 meters according the basement rock dissects rapidly. However downstream side from Fan front, it changes into Silts/clay strata, and sands/gravels strata are very rare. Topographic gradient is approximately 1 in 25.

The depth to water level seems to be around 50 meters at apex of Fan, and around 20 meters at Fan front. Hydraulic gradient may be approximately 1 in 50.

Hydrogeologic parameters are that Coefficient of Permeability and Transmissivity may be almost same as the Quetta side.

c Main Aquifers Influenced by DAD

As shown in the Fig.A.36, Murgi Kotal Nala which forms the catchment area of the proposed DAD supplies sands, gravels, cobble and boulder, etc. to both alluvial fans. The fan in the side of Kuchlagh is with radius of 1.5 to 2 km, and has the radial angle of approximately 100 degrees assuming that the pivot is at the dam site. Quetta side of the fan is, however with radius approximately 3 km of about 60 degrees radial angle as the rivet of 1 km upstream of the proposed DAD. Murgi Kotal Nala flows toward the DAD site scooping out the foot of the rivet of the latter. Topographic gradient and the area of the former are approximately 1/25 and approximately 2 km^2, while the latter approximately 1/25 and approximately 6 km^2, respectively.

Test drilling was carried out at the proposed dam site in this phase I study. The bedrock and groundwater was not found by the drilling with 40m depth.

Alluvial fans consist mainly of gravels, cobble and boulder, and coefficient of permeability may be in the order of E-3 cm/sec.

d Relation with Beneficiary Area [Specified Area and Unspecified Area]

As beneficiary areas of the proposed DAD, the specified farmland is shown as A.36. In the downstream of the proposed DAD, beneficiary areas cover almost all down-reaches of alluvial fan. In the side of Quetta Sub-Basin, as beneficiary area, the farmland of Killi Chashma occupies one part of the down-reaches of alluvial fan. Both areas are mainly belonging to the periphery of valley floor where the surface layer is composed of fine grained soil such as silts and/or clay. According to the existing well data identified as UN-KLG-10 and UN-KLG-12 drilled in 1978 locating in the downstream of proposed DAD, where the former is situating around the southern part of beneficiary area and the latter at the northward of that along Pishin -

Quetta road. Both are existing in the valley floor. The former was drilled up to the depth 210 meters, but not find out the bedrock and composed mainly of silts/clay interbedded very few with sandy clay lenses from the depth 50 to 90 meters and very thin gravel layer around the depth 210 meters. Depth to groundwater level was 12.2 meters as of date drilling, but pumping test was not carried out, then the permeability may be not good. The latter was drilled up to the depth about 150 meters, and is also composed mainly of silts/clay. Though the gravelly parts are intercalated at some depths because of nearer location to the piedmont, permeability is not good. Bedrock was not confirmed.

In the side of Quetta Sub-Basin, along Baleli River which is running in the southward of beneficiary area, there are some existing wells (UN-QA-27•31 to 34 (around 1 km south-westward from beneficiary area), BL-7 (around 2 km south-eastward of the beneficiary area)) which were drilled between 1969 - 71 up to the depth around 100 meters. According to these data, some gravelly strata having their thickness few meters with silty/clayey strata and confined are interbedded. Depth to groundwater level as of date drilled was in between 11 and 13 meters. From the pumping test of these wells, the drawdown was approximately 4 meters when 660 m3/d pumped up resulting the coefficient of permeability 3.84E-3 cm/sec, transmissivity 186 m^2/d, specific yield 21%, and specific storage 2E-5 1/m.

In the downstream of proposed DAD, specified beneficiary area covers almost all down-reaches of alluvial fan, then the 100% of recharged water from the DAD can contribute to the irrigation in this area. However, as described the above, permeability in the beneficiary area is very bad, then it is concluded that irrigation by tubewells is not suitable for this area but necessary to be supplied from the alluvial fan area.

The beneficiary area in the side of Quetta Sub-Basin occupies around 1/3 of the down-reaches of alluvial fan. Then the 1/3 of recharged water can be supplied to the specified beneficiary area, and the remaining 2/3 may be treated as for unspecified beneficiary areas. However, the reservoir of the DAD will locate at lower elevation than the rivet of the alluvial fan. The bedrock in this point seems to be very deep, then the beneficiary area may be recharged in the case the infiltration from the reservoir may go well, but actually it may be hopeless due to siltation. In consequence, for irrigating to this beneficiary area, it is necessary to be feeder from the reservoir.

D. Kach

a Topo-Interpretation

Fig. A.34 shows the Topo-interpretation Map of Kach area. The mountain area is composed of hard and massive limestones of Jurassic age, shale and limestone of Eocene age and partly conglomerate of Miocene age. Jurassic limestone and Eocene shale are impervious, though

Eocene limestone and Miocene conglomerate are porous and cavernous forming partly aquifer and may supply water to Gnundak Rud. In the right bank, hilly area composed of dense but unconsolidated gravelly Subrecent deposits extend from 2 to 6 km downstream of the existing dam. In the 4 km downstream of the proposed DAD site, alluvial fan extends with radius approximately 5 kilometers and radial angle approximately 30 degrees. The southward of this alluvial fan, also the other alluvial fans extend widely being supplied gravels from the other catchment area, however the foot of mountain is gravelly hills.

b Geological Section of the Downstream of the DAD

Inferred geological section of the Alluvial Fan area spreading in the downstream of Kach Site is shown in Fig.A.37. Because the drilling in Phase I was carried out at relatively upstream side, only about one meter thickness of river deposit confirmed. However, the basement rock may dissect rapidly in the downstream side resulting very thick fan deposits which is approximately 200 meters thickness of sands/gravels strata underlain by Subrecent silty gravel in the upstream side and Subrecent clay in the downstream side.

Topographic gradient is looser than 1 in 50 in the upstream area.

The depth to water level may be gradually deeper and deeper as proceeding to the downstream side resulting very deep around 100 meters around the resistivity exploration point 18. Hydraulic gradient may be approximately 1 in 40.

Hydrogeologic parameters are:

Coefficient of Permeability may be the order of E-3 cm/sec.

Transmissivity may be in the range of 40 to 80 m2/d around the upstream side, and 150 m2/d around the downstream side because of thick aquifer, though the coefficient of permeability becomes a little lower.

Specific Yield is around 20% at the uppermost-stream area, and gradually going down as proceeding to the downstream area.

c Main Aquifers Influenced by DAD

As mentioned the above, alluvial fan with approximately radius 5 kilometers is formed and supplied the gravels, cobble and boulder from the Gnundak Rud from the 4 km downstream of the existing dam. Topographic gradient is approximately 1/40 to 1/50 in the upstream side, the radial angle of the fan is approximately 30 degrees. The area of this fan is approximately 4 to 5 km^2.

The riverbed of Gnundak Rud is composed of shale of Eocene age covered by very thin river deposits with thickness 1 or 2 meters in the upstream of this alluvial fan. However, sands/gravels strata may be rapidly thick from around the way out of hill to the alluvial fan. There is an existing well identified as QA-22 drilled up to the depth 154 meters around the southern edge of this alluvial fan, in which bedrock was not confirmed. The lithology at this point was almost all sands/gravels. Besides, in the area of the other alluvial fan apart about 2 km from the above existing well, another existing well identified as UN-QA-29 drilled up to 183 meters, in which bedrock was also not confirmed. The lithology is mainly sands/gravels. Groundwater level as of 1969 - 1971 was approximately 100 meters.

d Relation with Beneficiary Area [Specified Area and Unspecified Area]

As beneficiary areas of the proposed DAD, the specified farmlands are locating at the left bank of Gnundak Rud around the way out from hill and around the down-reaches of the alluvial fan and its extension to the downward, as shown in A.34.

The radial angle of the alluvial fan from Gnundak Rud is relatively small, and can be considered all recharged water from the DAD as irrigable water for specified area. However, because this alluvial fan contact with another alluvial fan to the southward, the recharged water into this alluvial fan may flow out to another alluvial fan. Permeability of both alluvial fans may be almost same and the distinct boundaries between them are not remarkable. The radial angle of both alluvial fans is approximately 60 to 70 degrees. As a result, 40 to 50% of recharged groundwater can be consumed for the specified beneficiary area.

Remaining may be treated as for unspecified beneficiary areas.

E. Jigda

a Topo-Interpretation

Fig. A.38 shows the Topo-interpretation Map of Jigda area. The mountain area is composed of mainly shale of Oligocene age and forming impervious bedrock. The proposed DAD site located in this mountain area where the relief of the upstream side from tthe dam site is relatively ups and down, but of the downstream side show very low relief. Jigda Nala flows to westward in this mountain, and flows into extending alluvial fans situating from around Killi Jigda rapidly and widely. These alluvial fans are mixed each other forming the width 5 to 6 kilometers piedmont slope along the western foot of the mountain area. In the downward of this piedmont slope, very flat valley floor spreads.

b Geological Section of the Downstream of the DAD

Inferred geological section of the Alluvial Fan area spreading in the downstream of Jigda Site is shown in Fig.A.39. The dam site is situated in the hilly area. According to drilling investigation relatively thick river deposit, changes into Alluvial Fan deposits composed of very thick sands/gravels strata. The thickness of river deposit is approximately 10 meters at the dam site, and gradually going to be thick as proceeding to the downstream side. While, that of Fan deposits seems to reach more than 200 meters. This deposits extent to around Tore Shah locating just before the upstream side of K.K.Bund. However, valley floor deposits composed of silts/clay strata also underlies around Tore Shah area so that the thickness of sands/gravels strata in this area may only 50 to 60 meters.

Topographic gradient of the Alluvial Fan is 1 in 40 in average.

The depth to water level is approximately 6 meters at dam site and almost same depth in the section of river bed. however proceeding to the Alluvial Fan area, it is gradually deeper, and may reach up to around 60 meters. Hydraulic gradient is in the range of 1 in 30 to 40 in the upstream side of alluvial fan, but rapidly changes into very gentle around Tore Shah area.

Hydrogeologic parameters are that: Coefficient of Permeability; in the range of 1 to 2E-3 cm/sec in the river deposits, and 6 to 7E-3 cm/sec in the Alluvial Fan. Transmissivity; in the range of 160 to 170 m^2/d. Specific Yield; 23%.

While around the area of Tore Shah, they show that Coefficient of Permeability is 5E-3 cm/sec, Transmissivity approximately 50 m^2/d, and Specific Yield is 22%.

c Main Aquifers Influenced by DAD

Along the western side of the mountain area, the piedmont slope which is derived from 3 hill torrents as shown in attached figure. with width approximately 5 to 6 km extends. Main aquifers exists in this piedmont forming some groundwater layers. The boundary lines that the recharged groundwater from Jigda Nala may not influence further are shown as in Fig. Topographic gradient of this alluvial fan is 1/45, and the area of this fan is approximately 12 to 13 km^2.

River deposits along Jigda Nala in the mountain area are also relatively thick. According to the test drilling carried out in this phase I study (June 1996), the thickness of river deposits at be proposed DAD site is observed at 9.5 meters, depth to groundwater level is 6.2 meters, and coefficient of permeability is 1.5E-3 cm/sec.

Two existing wells are located around this area. One is in the piedmont slope about 2 km away from the foot of mountain around the northward of Timrak Nala identified as PN-KMT-3 which was drilled at June 1987, another is about 3 km southwest of be beneficiary area identified as Tore Shah which was drilled in May 1988. At the point of PN-KMT-3, depth up to 72 meters gravels layer, between 72 and 110 meters alternation of clay and sands/gravels strata, and deeper than 110 meters gravels bearing thick clay strata up to at least 131 meters. Bedrock was not confirmed. According to the result of pumping test, the depth to groundwater level is 32.2 meters, coefficient of permeability 6.2 to 6.6E-3 cm/sec, Transmissivity 160 to 170 m^2/d, specific yield 23%, and specific storage 1E-5 1/m.

At Tore Shah, located in the valley floor, the uppermost strata with thickness approximately 55 meters is sands/gravels, and deeper than this depth partly gravels intercalating clay strata. The pumping test result as of May 1988, shows depth to groundwater level 46.3 meters, coefficient of permeability 4.59E-3 cm/sec, transmissivity 51 m^2/d, specific yield 22%, and specific storage 2E-5 1/m.

d Relation with Beneficiary Area [Specified Area and Unspecified Area]

As beneficiary areas of the proposed DAD, the specified farmlands are locating at the left bank around the way out of hill named Killi Jigda and the area in the valley floor around the down-reaches of the alluvial fan, as shown in A.38. Beneficiary areas belong to valley floor regarding as far as topographical classification, however the uppermost strata, which is composed of sands/gravels with thickness 50 meters, belongs to alluvial fan deposits from geological view point.

Though the alluvial fan derived from Jigda Nala is as shown in Fig., the boundary from the other alluvial fans regarding to the other catchment is not so clear. As a result, the recharged water from proposed DAD may be radiating to all part of the piedmont area. Permeability is inferred to be almost same, and assuming transmissivity same, the quantity of groundwater runoff is in proportion to the width that groundwater is passing through, and the width is in proportion to a square root of the area. Assuming the influenced area by proposed DAD as shown in Fig., the rate the alluvial fan from Jigda Nala occupies is about 60%, then its square root approximately 55% is recharged into this alluvial fan.

As shown in Fig., because beneficiary area covers almost all down-reaches of the alluvial fan, the recharged groundwater into this fan may be treated all for specified area.

In consequence, 55% is for specified area, and 45% is for unspecified area.

F. *Sanzali*

a Topo-Interpretation

Fig. A.40 shows the Topo-interpretation Map of Sanzali area. The mountain area is composed of Bostan Formation of Pleistocene age covered with relatively thick Subrecent deposits. There may be geological tectonic line along the western edge line of mountain, and the eastern part had probably been upheaved such new Subrecent deposits forms mountain and hill. Hillock area is mainly composed of Bostan Formation covered with very thin surface gravelly layers. Bostan Formation is usually composed of impervious clay, but in this area interbedded partly with sandstone and conglomerate strata with thickness of few to ten and few meters, inclining gently to west-south-west ward. These strata may have relatively excellent permeability, and may recharge into deep aquifers lying in the western area.

Bostan Formation holds low sharing strength in the wet situation, so that a lot of landslide develops along the channel.

b Geological Section of the Downstream of the DAD

Inferred geological section of the River Bed and Alluvial Fan area extent in the downstream of Sanzali Site is shown in Fig.A.41. The dam site is situated in the hilly area.

The thickness of river deposit is in the range of 2.5 to 10 meters. Topographic gradient of river bed is approximately 1 in 40 in the upstream side, and becomes gradually looser as proceeding to downstream reaching approximately 1 in 80.

The depth to water level is usually several meters; Coefficient of Permeability is in the order of E-3 to E-4 cm/sec, Transmissivity seems to be in the range of 3 to 4 m2/d.

While in the area of Alluvial Fan and Valley Floor, their thickness seems o be around 150 meters, whose upper section of thickness of about 80 meters is gravel bearing silty sand, and lower section is silts/clay. Topographic gradient is in the range of 1 in 50 to 60. Depth to water level is approximately 50m. Coefficient of Permeability seems to be around 1E-3 cm/sec, Transmissivity approximately 70 to 80 m^2/d.

c Main Aquifers Influenced by DAD

The colluvial deposits formed by landsliding is loose and mixed with a lot of sands and gravels derived from upstream mountain area or washed out the fine material to the downstream resulting good permeability. As shown in the Fig., these deposits distribute along the channel relatively widely, and forms the small scale of aquifers. According to the test drilling result carried out in this phase I study (June 1996), the thickness of the river deposits at the proposed DAD site is 2.5 meters. The more going to the downstream side, the wider and thicker these colluvial deposits become. Groundwater is flows down into this surface layer.

These groundwater flows into valley floor around Pishin Town. In the central part of valley floor, the maximum depth to Bostan Formation which forms the impervious bed is 140 to 150m overlain by gravels bearing sandy silts having relatively good permeability. According to information on the existing well PLV-19 located around 1 km north from the way out of Sanzal Nala to valley floor, the lithology is the fine alternation of gravels and clay layers showing groundwater at the depth of 85m. Deeper than this, Bostan Clay is underlying. Coefficient of permeability may be around 1E-3 cm/sec.

d Relation with Beneficiary Area [Specified Area and Unspecified Area]

As beneficiary areas of the proposed DAD, the specified farmlands are the small village locating along the channel and relying on Kareze fed from the mother well at the near downstream of the proposed DAD. Depth to groundwater at Mother Well as of November 1996 is approximately 8 meters. Karez has been fed from this one first up to Sualahgai, after that, it is diverged to two directions of Salagal and Sahbizada. Sahbizada Karez is now out of order because damaged by flood. The recharged groundwater is flowing further downstream, and recharge into the aquifers lying under the valley floor, and can irrigate around this farmland where may also be considered as specified beneficiary area. From the distribution of the groundwater level shown in Fig. 3.1.19, the groundwater in this area is flowing toward the Gap of the southern side Rakhi Lora. Then beneficiary area should be pick up from this direction, and the all recharged water from the DAD may be considered to be irrigable to the specified area from hydrogeological view point.

G. Sakhol

a Topo-Interpretation

Fig. A.42 shows the Topo-interpretation Map of Sakhol area. The mountain area is composed mainly of hard and massive limestones of Jurassic age forming Valley with steep slope This valley is buried by thick talus and alluvial deposits, and form relatively wide valley through the gap at the proposed DAD site and continuing to the piedmont slope to the downstream.

The downstream side of the proposed DAD is gradually depressed gently from both directions of north and south due to probably erosion surpassing sedimentation. This area has different features to some extent from the other piedmont where usually forming alluvial fan. Therefore, it is inferred that this area may be composed mainly of impervious fine grained soil such as silts/clay rather than the permeable material. Sand-dune deposits composed of fine sands whirled up and transported by strong western wind in winter season through the Gap between Mastung and Shirinab Sub-Basin covers the piedmont of this area, though the foot of mountain with width few hundred meters consist mainly of sands and gravels derived from the upstream area. The downstream side of sand-dune is valley floor, as shown in Fig. A.10, which is composed of very thick silts/clay strata reaching its thickness around 300 meters and covered with thin eolian deposits.

b Geological Section of the Downstream of the DAD

Inferred geological section of the downstream area of Sakhol Site is shown in Fig.A.43. 40 meters drilling in Phase I was carried out at the center of river bed along dam axis, and confirmed sands/gravel strata up to the depth 35 meters underlain by silty sand. In Phase II, resistivity exploration up to the depth 200 meters was carried out at almost same point as drilling. Then, the silty sand strata seem to continue up to the depth around 200 meters, and the lowest part seemed to be shale. In the downstream area of dam site, sand dune deposits are extent widely forming surface layers in the area underlain by silts/clay strata for the most part. The thickness of sand dune deposits reaches approximately 30 meters as most, and generally even thickness in everywhere.

Topographic gradient of sand dune area is approximately 1 in 100.

The depth to water level was not confirmed by drilling in Phase I, however in the downstream after the point of resistivity exploration 32, groundwater from karezes and dug-well is generally utilized so that water table may be formed within the and dune deposits as subsoil water flow on the underlying silts/clay strata.

Hydrogeologic parameters are that Coefficient of Permeability may be the order of E-4 cm/sec, and Transmissivity may be in a range of 2 to 3 m^2/d because the thickness of saturated aquifer may be only several meters. Specific Yield may be in the range of 10 to 15%.

c Main Aquifers Influenced by DAD

Sands/gravels strata along the foot of mountain with width few hundred meters may be, like as UN-MST-4A shown in Fig. A.10, underlain by silts/clay strata. Then, the recharged groundwater into these sands/gravels strata may be once stored in these aquifers. This is considered from the following 2 reasons; first, relatively many karezes are existing in this area, and second, intake groundwater through karez system is difficult in such a place that aquifers and groundwater table are existing in deep.

Sand dune deposit may be relatively permeable due to composed of loose sands and silts. This deposits may be underlain by impervious silts/clay, then groundwater may flow to the downstream within sand-dune deposits. The influenced area by the recharged groundwater flowing near ground surface from proposed DAD is restricted by the topography. As a result, it is concluded that the area influenced by the recharged water from proposed DAD is the area bounded by dot lines as shown in Fig. A.42. Topographic gradient is approximately average 1/100.

d Relation with Beneficiary Area [Specified Area and Unspecified Area]

As mentioned the above, groundwater flow in this area is subsoil flow. Then, unlike the case of groundwater recharging into relatively large scale of groundwater basin, seasonal fluctuation is very considerable for utilizing such as irrigation water. In this case, there is large time lag between the time recharging and the time intake groundwater in the downstream. As shown in the figure, because beneficiary area locates in the center of the influenced area by the recharge from proposed DAD, if the time recharging and irrigating, and the location of karezes and their mother wells are optimum, it will be utilized effectively, but if not, plenty of groundwater may be flowing down without effective utilization.

H. Mangi

a Topo-Interpretation

Fig. A.44 shows the Topo-interpretation Map of Mangi area. The mountain area is composed mainly of hard and massive Jurassic limestones and Eocene limestone. There are two types of Eocene limestone, one is relatively hard and massive, another is porous and cavernous so that partly aquifers may develop. Inside of this mountain area, relatively wide valley buried by talus and alluvial exists and forms a part of the catchment area of existing Sarbund DAD. Piedmont slope extends widely with width few kilometers along the western foot of mountain area. Further downstream side up to Shora Rud is valley floor covered with silts/clay, but the riverbed of Shora Rud is composed of sands/gravels.

b Geological Section of the Downstream of the DAD

Inferred geological section of the Alluvial Fan distributing in the downstream area of Mangi Site is shown in Fig.A.45. Drilling in Phase I was carried out at the center of river bed along dam axis, and confirmed sands/gravel strata up to the depth 27 meters underlain by shale. Groundwater was not be confirmed. Fan deposits may be gradually thicker as proceeding to the downstream side up to 70 to 80 meters at most as far as the section shown in Fig.A.45 concerned. It may change into silts/clay strata in the downstream area.

Topographic gradient of Alluvial Fan area is approximately 1 in 100.

Groundwater may fluctuate largely seasonally so that it may almost be lost at dam site in dry season. Those in the downstream area seem to be in the range of 15 to 30 meters. Hydraulic gradient is less than 1 in 100.

Coefficient of Permeability shows in very large range from the order of E-4 to E-2 cm/sec depending on places. Simultaneously transmissivity shows wide values from 5 to 500 m^2/d depending on places.

c Main Aquifers Influenced by DAD

The piedmont slope with few kilometers width extend widely in the western side of mountain area. Among them, the one especially supplied sands, gravels, etc. from the catchment area of proposed DAD is as shown in the Fig. Average topographic gradient of the alluvial fan is approximately 1/100, and the area is around 14 to 15 km^2. According to the result of test drilling in phase I drilled in June 1996, the thickness of the sands/gravels at proposed DAD site is 27 meters, and bedrock is shale of Oligocene age. Groundwater was not observed at that time.

Upstream side may be sands/gravels rich, and downstream side silts/clay rich from existing 4 wells data of UN-PS-3 to 5 and KB-BKB-1 along Shora Rud as shown in Fig. A.15. Bedrock is generally shale and/or sandstone of Eocene to Miocene age.

d Relation with Beneficiary Area [Specified Area and Unspecified Area]

As beneficiary areas of the proposed DAD, the specified farmlands are locating at just downstream of the DAD site and the down-reaches of the alluvial fan, as shown in Fig. A.44. Both beneficiary areas belong to piedmont slope and alluvial fan composed mainly of sands/gravels.

Though the alluvial fan derived from the catchment area of proposed DAD is as shown in Fig., the boundary from the other alluvial fans regarding to the other catchment is not so clear. Then, groundwater level and permeability may not change so much each other so that the recharged groundwater from proposed DAD is flowing through this boundary. From the topography, the influenced area by the recharged groundwater from proposed DAD is as shown in Fig., then beneficiary area occupies approximately half of the down-reaches of this area. In consequence, 50% is for specified area, and 50% is for unspecified area.

I. Kad Kocha II

a Topo-Interpretation

Fig. A.46 shows the Topo-interpretation Map of Kad Kocha II area. The mountain area is composed mainly of hard and massive Jurassic limestones and porous and cavernous Eocene limestone. Jurassic limestone forms steep slopes. In the catchment area of proposed DAD, relatively wide valley buried by talus and alluvial are formed and supplied sands and gravels from the mountain slope. Likewise, the middle scale of alluvial fan extends through the Gap of near downstream of proposed DAD. The other alluvial fan from the other catchment area contacts to this alluvial fan. The downward of this alluvial fan is valley floor reaching up to Rud Sariab.

b Geological Section of the Downstream of the DAD

Inferred geological section of the Alluvial Fan area spreading in the downstream of Kad Kocha II Site is shown in Fig.A.47. Drilling in Phase I was carried out at the center of river bed along dam axis, and confirmed all section up to the depth 40 meters sands/gravel strata. Groundwater was not be confirmed. In Phase II, resistivity exploration up to the depth 200 meters was carried out at the isthmian channel point of the just downstream. According to this result, the depth to basement rocks seems to be a little less than 60 meters, and the depth to water table at this point is in between 40 and 50 meters considered from other geological data.

In the downstream side of Alluvial Fan, the basement rocks declines rapidly so that the thickness of sands/gravels strata of Fan deposits may reach almost 200 meters. Topographic gradient of Alluvial Fan is in the range of 1 in 30 to 40.

The depth to water table may be approximately 60 meters at dam site, in between 40 and 50 meters at the isthmian channel, and becomes gradually deeper as proceeding to the downstream reaching probably around 70 meters around Fan Front. Hydraulic gradient may be 1 in 30.

In the Alluvial Fan area, Coefficient of Permeability may be the order of E-3 cm/sec, Transmissivity may be around 90 m^2/d, and Specific Yield may be 15%.

c Main Aquifers Influenced by DAD

Based on the topography, the influenced area by the recharged groundwater from the proposed DAD may be limited in the aquifers of the alluvial fan and of the valley floor continuing from this alluvial fan. Topographic gradient of the alluvial fan is 1/30 to 1/40, the area is 3 to 4 km^2. Sands/gravels strata of the alluvial fan are getting into the silts/clay strata of the valley floor resulting semi-confined or confined aquifers in the part of valley floor, as shown in Figs. A.10 and A.11.

According to the existing well data MST-11 drilled in 1974 located in the valley floor, these semi-confined or confined aquifers have their hydrogeologic properties as the following; Depth to groundwater level was approximately 30 meters as of the date drilled, coefficient of permeability approximately 1E-3 cm/sec, transmissivity approximately 90 m^2/d, specific yield 15%, and specific storage 8E-5 1/m. Unconfined aquifers in the alluvial fan seem to be higher permeability than the above. Some tubewells exist in this alluvial fan. All of them are located along the southern end of the alluvial fan where is convenient to pump up groundwater.

d Relation with Beneficiary Area [Specified Area and Unspecified Area]

As beneficiary areas of the proposed DAD, the specified farmlands are locating around the area covering almost all the down-reaches of the alluvial fan and valley floor, as shown in A.46.

Unconfined aquifers in the alluvial fan are continuing the semi-confined to confined aquifers in the valley floor.

Based on the topography, the recharged groundwater from proposed DAD may flow down through the alluvial fan, and flow into the aquifers in the valley floor. Then, these groundwater may be considered all to be able to irrigate in the specified area.

J. Ghazlona (Arambi)

a Topo-Interpretation

Fig. A.48 shows the Topo-interpretation Map of Ghazlona (Arambi) area. The mountain area is composed mainly of shale of Eocene age which forms impervious bedrock. The downstream from around the proposed DAD is generally low relief hilly area with gradually the width of riverbed widening little by little ranging from some tens of meters to hundred and some tens of meters. Ghazlona Nala finally joins to Arambi Manda. Arambi Manda has generally wide riverbed. The left bank in the upstream side of Arambi Manda from joining point is composed mainly of gully eroded talus. In the downstream of Arambi Manda after joining with Halkai Arambi Nala, very wide riverbed with width reaches 2 km extends.

b Geological Section of the Downstream of DAD

Inferred geological section of the downstream of Ghazlona Site is shown in Fig.A.49. Aquifer is river deposit. The thickness of river deposit may around 10 meters at dam site, and gradually become thicker as proceeding to the downstream. Around the conflux point with Arambi Manda, it seems to reach around 30 meters. Topographic gradient of river bed is in the range of 1 in 50 to 60.

The depth to water table may be several meters in the upstream and ten and several meters in the downstream. Coefficient of Permeability may be the order of E-3 cm/sec, and Transmissivity may be around 5 m2/d.

c Main Aquifers Influenced by DAD

Aquifers to be recharged by the proposed DAD is the alluvium of the riverbed. It is generally composed of cobble and gravels having high permeability. Groundwater flows within the surface alluvial layers because bedrock is impervious shale. The topographic gradient of the river bed is 1/50 to 1/60. The width of the river is 40 meters at the narrowest and approximately 200 meters at the widest.

The groundwater flowing surface layers of Ghazlona Nala river deposits flows into the large scale of alluvium of Arambi Manda.

d Relation with Beneficiary Area [Specified Area and Unspecified Area]

As beneficiary areas of the proposed DAD, the specified farmlands are locating at the left bank around the way out of Ghazlona Nala and the near downstream of joining point of Ghazlona Nala and Arambi Manda. The former is relying only karez for intake groundwater, however the latter both karez and tubewell are the way to intake water. The recharged water is further flowing down to the alluvium in the downstream.

A.4.3 Other Proposed DAD

A. Ghutai Shera

a Topo-Interpretation

The catchment area of Ghutai Shera DAD is composed of Permo-Triassic to Jurassic limestone and Subrecent deposits. Limestones form steep mountains. While Subrecent deposits are semi-consolidated, dense gravelly strata are usually dissected hilly area forming complicated ups and downs in relief.

In the downstream of the DAD site, Alluvial fan is extent with approximately 2 kilo-meters wide.

b Main Aquifers Influenced by DAD

Geological section in the downstream of DAD is inferred as shown in Figure. Alluvial fan with approximately 2 kilo-meters wide is extent in the downstream of DAD site, and change into silts/clay strata in the down reaches of valley floor. Topographic gradient is approximately 1 in 40. At DAD site, river deposits exist up to the depth approximately 4 meters underlain by Subrecent deposits which consist of mainly sands in the upper layers and mainly silts in the lower layers. River deposits are mainly composed of sands/gravels, Coefficient of Permeability of which is approximately 9E-3 cm/sec. According to the existing data QA-ANK-2, sands/gravels up to the depth 54 meters lies over Subrecent clay deposits. Depth to water level was approximately 20 meters as of October 1987. hydrogeological properties were 6.7E-3 Coefficient of Permeability cm/sec, 45 m^2/day Transmissivity , and 23% Specific Yield.

B. Wali Dad

a Topo-Interpretation

The catchment area of Wali Dad DAD is composed of Jurassic limestone and Cretaceous limestone, sandstones, and shale. DAD is situated on Jurassic limestone. Alluvial fan is extent in the downstream with 3 to 4 kilo-meters wide, though the isthmus was formed by small isolated hills at approximately 1 kilo-meter downstream, reaching up to Sariab Lora. Though the shape of Alluvial fan is not typical, its radial angle is approximately 120 degrees, with topographic gradient of 1 in 25 in average.

b Main Aquifers Influenced by DAD

Geological section in the downstream of DAD is inferred as shown in attached figure. The thickness of Alluvial fan deposits is in the range of fifty to one hundred and tens of meters at maximum and changes into valley floor deposits from around Sariab Lora. Between sands/gravels of fan deposits and silts/clay of valley floor deposits, sandy strata are existing. Depth to bedrock is approximately 150 meters around Sariab Lora which was confirmed by existing data. Coefficient of Permeability of fan deposits is 2 to 3E-3 cm/sec. Transmissivity is 50 to 60 m^2/day in mid-fan, and 20 m^2/day around the border of alluvial fan and valley floor. Specific yield is 20% or more in alluvial fan, and 15% in valley floor. Depth to water level is approximately 20 meters around Sariab Lora as of 1988, and becomes deeper gradually to the upstream side.

C. Samaki (Arambi)

a Topo-Interpretation

The catchment area of Samaki DAD is composed of Miocene Sandstone intercalated with Shale which form hydrogeological bed in this area. North-Western mountainside shows remarkable lineation and continue to valley forming Arambi Manda. Talus-like very gentle hills are situated linealy with width few kilo-meter between Arambi Manda and mountains. Streams derived from these mountains cut these hills and pour to river-bed of Arambi Manda.

b Main Aquifers Influenced by DAD

Aquifer to be recharged by the DAD is talus-like deposits, alluvial cone deposits distributing along streams, and river deposits of Arambi Manda. Talus-like deposits include relatively much silt at some places resulting coefficient of permeability not so good.

D. Iskalkoo

a Topo-Interpretation

The catchment area of Iskalkoo DAD is composed of Miocene limestone. This limestone is porous and cavernous in many localities and easily eroded by water forming hilly topography. The dam site is located at the mid-area in the hills. The western side of those hills, where dam site is located, is dissected, and covered by relatively thin Alluviums.