JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

GOVERNMENT OF NORTH WEST FRONTIER PROVINCE
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# THE FEASIBILITY STUDY
# ON
# CHASHMA RIGHT BANK 1ST LIFT IRRIGATION PROJECT

# ANNEX

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NIPPON GIKEN INC.

NIPPON KOEI CO., LTD.

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**ANNEX**

## Contents

# ANNEX A

# TOPOGRAPHY, GEOLOGY AND LAND CONSERVATION

## ANNEX-A

# TOPOGRAPHY, GEOLOGY AND LAND CONSERVATION

### Table of Contents

## List of Tables



## List of Figures

## A.1 Topography And Geology

### A.1.1 Topography

The main topographic features around D. I. Khan District are:

(1) The Mountains of the Sulaiman, Khisor, Marwat and Bhittanni Ranges.
(2) Piedmont Plain.
(3) The Meandering Flood Plain of the Indus River.

The Sulaiman Range rises to 11,000 ft above Mean Sea Level with an average altitude of 6,500 ft. It consists of soft and fragmented rocks. The Khisor and Marwat Ranges are asymmetric and trend north-eastward. They have steep south-eastern faces and gentle north-western slopes. The south-western ends of the two ranges are the Sur Ghar Mountains and the Sheikh Badin Hills, respectively, which are irregular masses that interrupt the linear trends of the two ranges. The north western end of area, the Bhittanni Range is a strongly dissected elongate domal area that is connected with the south-western limb by a curving cliff-like area of uplift. The south-east face of the south western limb is steep and dissected by transverse streams. The upland areas, in the south of Manzai is less uniform and southward the regional structural trend changes from south-westward to southward. The Shirani Hills slope steeply upward from the edge of the plain and behind the first crest is a series of southward trending ridges. All those mountain ranges are generally barren.

The upland areas are separated from the plain by gravel and sand fans. The major belts of such fans are immediately below the valley between The Khisor and Marwat Ranges.

The Piedmont Plain, where the gravel fans grade in slope southward and eastward, has been formed by deposition of the degraded material transported by the streams of the Sulaiman Range. Water flowing along steep gradient at high velocity picks up loosened material and deposits it in the plain due to decrease in the velocity. This plain, which extends from the foothills of the Sulaiman ranges up to the flood plain of the Indus in the east where it ends rather abruptly, has relatively smooth surface into which modern drainage channels are being incised.

The slope of the plain is as much as 1 in 200 over the dune sand area in the north side of study area. In the central of the plain around Nose Nullah, Gumal Nullah, and

Luni Nullah is about 1 in 1000 of its slope, while in south the plain is narrower and slopes eastward at about 1 in 200 ~ 250.

The sand dune has been spread over northern area forming low sand dunes due to wind action. These deposits have been observed near Paniala, Paharpur, Yarik and Pezu giving undulated topographic look to these areas.

The river low land show at least three stages of flood plain evolution. The present river level and the active flood plain are relatively limited, but in this area the river is actively meandering. The modified or abandoned flood plain is somewhat higher and possibly may be separated from the third level. The western edge of the modified flood plain is clearly declined by low cliffs near Bund Korai and Ramak to the south.

This flood plain is the result of the repeated deposition of fine silt, mud and sand from the sediment laden flood waters of the Indus River

### A.1.2 Geology

(1) Geologic location of the study area in Pakistan

Geology of Pakistan is divided largely into four provinces and sub-divided further into smaller provinces as shown in Fig. A.1. The study area is located at just north western corner of INDUS PLAIN adjacent westerly to Wazirisutan and Sulaiman province and northerly to Trans-Indus Salt Ranges of INDUS BASIN.

(2) Geological structure in Northern Pakistan

Main geological backgrounds in Northern Pakistan, of which the study area is at south-western part, are shown in Fig. A.2.

The area of this figure includes the north western extremity of the Indian shield with several outcrops of basement rocks, the Salt Range with a thrusted sedimentary sequence ranging from Lower Paleozoic to Upper Tertiary, the Potwar Plateau with gently folded and thrusted Upper Tertiary terrigeneous sediments (Murrees and Siwaliks), the Hazara Ranges with Mesozoic and Paleozoic sediments, the Peshawar Basin and the lower and higher ranges of Indus-Kohistan with Lower Paleozoic, older metasediments and widespread intrusive granites.

This area constitutes a distinct structural unit separated from the Kashmir Himalayas and from the Kirthar Sulaiman fold belts by the Western Himalayan Syntaxis and the Bannu reentrant, respectively.

The tectonic distortion of the study area is consisting mainly of folding that involved the entire section of rocks from older rocks to at least as young as early to middle Pleistocene. This folding was caused by relative movement that was mainly near the Sulaiman range and was in the Bhittanni · Marwat · Khisor Range area. Most faults that resulted from the movement are moderate to low angle thrusts.

(3) Geology around the study area

General geology around the study area is shown in Fig. A.3.

The study area is in the piedmont plains just between Sulaiman and Trans-Indus-Salt ranges (the Bannu re-entrant) and Indus River.

Geological map of D. I. Khan District is shown in Fig. A.4.

Consolidated rock units, that surround the study area, crop out in the northern part and west of the D. I. Khan, range mainly from late paleozoic to early or middle pleistocene age. These rocks are of sedimentary origin

The unconsolidated deposits or fill in D. I. Khan District range in general from middle to later Pleistocene to Holocene in age and the surficial deposits of Holocene age.

Surficial deposits consist of dune sand south of Gurwali and near Paniala, Paharpur, Yarik, and Pezu; some recent alluvial fans, thin alluvium along modern drainage ways; and the surficial alluvium in the Indus River flood plain and its associated terraces.

Within the main part of the District, the surficial deposits can be divided into two broad types. One is derived entirely from the mountains to the west and the other was laid down by the large rivers that placed the alluvium of the Indus Plain. These two type's interfinger in a transitional zone that parallels the Indus River 8 to 14 miles west of the river. East of the zone, sand deposits are extent. West of the transitional zone, the fill is mainly silty clay that contains beds of fine to medium sand and, near the mountains, gravel that is derived from the consolidated rocks.

The diagrammatic sections of unconsolidated deposits in the area are shown in Fig. A.5.

### A.1.3 Groundwater

From the report on the groundwater resource development project, diagrammatic section of groundwater distribution in 1964 with its vertical total dissolved solid's distributions in D. I. Khan District are shown in Fig. A.5 associated with the unconsolidated deposits. Fig. A.6 and Fig. A.7 show also such horizontal distribution as altitude and depth of groundwater table of the area in 1964 with showing the depth of groundwater at the time phase I of this project (September 1993) in the already irrigated area of Paharpur and CRBC Stage I. From the figure main groundwater flow is from north-west to south-east, namely from Sulaiman, Bhittanni range to Indus river, and the depth of groundwater table in the study area is among 50 and 100 ft.

Permeable beds and extensive aquifer consist mainly of deposits ranging in grain size from silt to medium sand that underlies the Indus River lowland and immediately adjacent areas. This sand contains relatively little clay and constitutes a single aquifer.

Within the area of the piedmont plain, the largest part of the fill consists mainly of silty clay with relatively thin beds of fine to medium sand. The fill has a low bulk permeability, but owing to grain size, saturated sand of individual beds or groups of beds should be capable of yielding. Water bearing strata, a substantial quantity of water is available to wells, reported as tubewells 200 ft to 300 ft can yield 2 to 3 cusecs with only moderate draw down.

### A.1.4 Geotechnical Properties

(1) Existing data

The study area is bounded on the east by CRBC, where the work of the downstream most part of Stage II and Stage III is in progress, executing some site investigation and laboratory tests. Besides, some other drilling logs and soil tests were also carried out for Cross-Drainage Works on CCAD (Chashma Command Area Development) Project around the upstream of CRBC. In Phase I of this Project, for considering the general characteristics of geotechnical and soil mechanical properties in the area, JICA expert tried to have collected those data. These data and analyzed Diagrams are shown in from Table A.1 to Table A.4, and from Fig. A.11 to Fig. A.15.

(2) Geological profile and soil mechanics

1) General

As mentioned before, D. I. Khan District is largely composed of sandy layers and silty clay layers from a geological view point. The former, thickness attaining to 400 m, lies in Indus River low-land, and the latter in mountain side. Among 8 and 14 miles west from Indus River is transitional zone which sandy and silty clay layers are interfinger each other. Fig. A.5 shows the diagrammatic section with showing the distribution of total dissolved solids of groundwater.
As well, the geologic profile along the section of CRBC STAGE II (RD. 265+000 ~ RD. 380+000) is as Fig. A.9 inferred from the borehole drilling logs. Then, main geotechnical distribution along the section is;

| | Classified group | N-value | Main composition & distribution |
|---|---|---|---|
| 1 | Recent<br>Rod Kohi deposits | less than 20 | sand, silt & clay;<br>along recent drainage way |
| 2 | Sub-recent<br>Rod Kohi deposits | from 30 to 40 | sand, silt & clay;<br>along sub-recent drainage way |
| 3 | Sub-recent<br>Piedmont Plain dep. | from 30 to 70 | silt & clay;<br>up to about 50 ft depth |
| 4 | Sub-recent<br>Indus River dep. | more than 50 | mainly sand; more than<br>50 ft up to at least logged depth |

Groundwater table is within the sandy layer with its altitude around 530 ft, where it is remarkably fluctuating in between RD. 305+000 ~ RD. 310+000 with downstream side 10 ft higher than upstream side. This may be taking into account that perennially flowing Rod Kohi dissect the downstream side and supply the water into the ground.
Furthermore Fig. A.10 shows the geologic section near surface at the foot of Khisor Range inferred from logs of drilling for Cross Drainage Structure on CCAD project, where gravel fan deposits derived from Rod Kohi and dune sand is composing thickly.
Dune sand is in general well sorted (poorly graded) fine to medium sand and loose. On the other hand, the gravel fan deposits seem to have relatively high bearing strength.

Fig. A.11 shows Plasticity/Liquid Limit relationship of samples from CRBC STAGE II section tested at WAPDA D. I. Khan laboratory. These are almost plotted in lower side of B line (L.L. 50%) and almost in upper side of A line, that is low to medium plasticity, non-organic, loess-like clay (soil type classification CL). Because soil types in the study area seem not change remarkably except dune sand, above relationship may show the representative property of silty clay in the area.

Moisture content in situ is, as shown in Fig. A.12, generally less than 10%. That of 30 ft depth is only 5% higher than the surface layer because the groundwater table in this area is much deeper than this level, usually fluctuating among 70 and 80 ft. Then the increasing ratio with depth is almost same extent up to the depth 50 ft or more, though it seems to increase rapidly in the depth deeper than this level.

Unit weight in situ is among 100 to 120 lbs/ft$^3$ in wet situation, and dry density is 95 to 105 lbs/ft$^3$; see Fig. A.13.

OMC (Optimum Moisture Content) and $\rho_{dmax}$ (maximum dry density) is as shown in Fig. A.14. OMC is among 12 and 20% and $\rho_{dmax}$ from 105 to 120 lbs/ft$^3$.

The laboratory test as to shearing strength were carried out by both Direct Shear and Quick Triaxial Compression. Direct Shear is regarded as CD (Consolidated and Drained) and Quick Triaxial Compression UU (Unconsolidated and Undrained). Fig. A.15 shows the relationships between C (Cohesion) and $\phi$ (Internal Friction Angle) with regard to both Direct Shear Test and Triaxial Quick. In case of Direct Shear, C is almost less than 6 P.S.I., and $\phi$ is between 15° and 30°, but largely classified into 2 groups shown as shaded area in Fig. A.15. The first group is C less than 2 P.S.I., $\phi$ between 25° and 30°; the second group is C 2 to 6 P.S.I., $\phi$ 15° to 23°. On the other hand, it is clear in case of Quick Triaxial Consolidation. The first group is C 3 to 10 P.S.I., $\phi$ 13° to 18°, and the second group is C 16 to 25 P.S.I., $\phi$ 8° to 12°. The first group is silty soil and the second group is clay.

| | | silty soil | clay |
|---|---|---|---|
| Consolidated & Drained | C | less than 2 P.S.I. | 2 to 6 P.S.I. |
| | $\phi$ | 25° to 30° | 15° to 23° |
| Unconsolidated & Undrained | C | 3 to 10 P.S.I. | 16 to 25 P.S.I. |
| | $\phi$ | 15° to 23° | 8° to 12° |

2) At the locations of main facilities

Studies of geology in the field study of the Phase II were to do the investigation works by borehole drilling and standard penetration test at the following sites.

i) the proposed intake site
ii) the proposed pumping station site
iii) cross drainage facilities' site on the proposed canal alignment.

Drilling locations are shown in Fig. A.16 and data of drill logs are in Fig. A.17 and Fig. A.18. The cross sectional profiles from geological and geotechnical analysis are also shown on Fig. A.19 and Fig. A.20 as to the proposed intake site and the proposed pumping station site respectively. Descriptions from the results are as follows.

i) Proposed Intake Site

The proposed Intake site is located adjacent to the right spur towards existing Chashma Barrage. The area is marked with thick alluvial deposits lay down in the active flood plain areas of the river Indus. These deposits are Sub-recent to Recent in age and have been consolidated with the passage of time.

Ground profile

From the result of three nos. of borehole (BI-1, BI-2 and BI-3) drilling, it is that the recovered material in all of these holes is almost of identical nature, grayish in color and generally comprise of fine to medium graded sands and trace to little silt and little or no mica at places. A geological profile of the proposed intake structure site has been shown in Fig. A.19 based on the information obtained through drilling in bore hole. The soil strata are generally medium dense to dense. Extra ordinary high N value obtained in the top layer of BI-1 and BI-2 up to approx. 6 meter's depth and at BI-3 up to 5 meter's depth are probably indicative of the compaction carried-out during the construction of Chashma closure bund road. In the second layer that has the thicknesses approximately 18 m extending from 192 m up to 174 m above MSL, the N value of matrix generally ranges from 10 to 20 which shows that the soils penetrated are of medium density. Onward to this in the third layer, the N value of matrix is gradually increasing from 20 to 30 in the upper layer of thickness 4 to 4.5m and is always slightly more than 30 up to the drilled depth overall the soils exhibiting medium dense to dense properties and is saturated below MSL 192 m, though which shows partly very high N values probably indicative of gravel layers.

The bearing capacity of the ground

The results obtained indicate that the relative density of strata shallower than 27 to 28m are medium dense showing N value 10 to 30 except the uppermost part, and part of which up to the depth 23 to 24 m is a little loose sandy soil of N 10 to 20. Then the N value of surface ground in this area is assumed to be around 10.

In the case of spread foundation, from the following Meyerhof equation:

$$q_0 = 3.3 \cdot N \cdot B \ (tf/m^2)$$

where $q_0$ : Critical bearing capacity

N : Average N value up to the depth of foundation.

B : Width of foundation

The critical bearing strength of the ground having N value 10 is calculated as 33 $tf/m^2$, and then the allowable strength is 11 $tf/m^2$ assuming the safety factor 3 of the usual time.

The strength ($q_f$) when the penetration (Df) is carried out is expressed as:

$$q_f = q_0 \, (1 + Df/B)$$

The value should be reduced to half in the case the groundwater table is higher than the foundation level and the case the ground is composed of silty sand, but it will be able to be twice in the case the ground is composed of gravels.

The allowable bearing strength of this area will be estimated 5~6 $tf/m^2$.

Next, the case of pile foundation is expressed as the following equation.

$$Rup = \alpha \cdot N \cdot Ap + N'/5 \cdot \phi \cdot L$$

where Rup : Critical end bearing capacity

$\alpha$ : Constant decided by construction procedure

Placing pile 30

Cement mortared pile 20

Cast-in-place pile 15

N : Average N value around the end of foundation pile that the calculation is executed usually in the section lower 1d (d: dia. of pile) and upper 3d than the end.

N' : Average N value of the section for skin friction

Ap : Area of the pile end

$\phi$ : Lap length of the pile

L : Pile length in the ground

a: In the case of bearing plane being 174 m contour level above MSL that is the top of the third layer, the critical bearing strength at the end of pile is :

$$Rup = (15 \sim 30)\cdot 20 = 300 \sim 600 \text{ tf/m}^2$$

Then allowable bearing strength is 100 ~ 200 tf/m² from the safety factor 3.

b: In the case of bearing plane being 170 m contour level above MSL, N of which is more than 30, the critical bearing strength at the end of pile is :

$$Rup = (15 \sim 30)\cdot 30 = 450 \sim 900 \text{ tf/m}^2$$

Then allowable bearing strength is 150 ~ 300 tf/$m^2$ from the safety factor 3.
In any case, the skin frictional bearing strength will be able to add to their end strengths.

From the result, the sand layer encountered onward to 170 m above MSL, N of which is more than 30, seems to be quite suitable for the proposed structure. The relative density at these depths can normally be considered adequate for all but very heavy structures.

ii) Proposed Pumping Station Site

The proposed site is located about 3 km north-west ward from Paharpur, and extend along right bank of the CRBC apart 0.45 to 1.2 km. The drilling locations are situated as shown in Fig. A.20.

The area, on the large scale, has been marked by the soils deposited by the wind action. These deposits cover extensive areas around Paharpur, Paniala, Yarik and Pezu. Geologically these are eolian deposits that give undulated topographic look to the areas where present. They are recognizable as low elongated or crescent-shaped hills having a flat slope windward and steep slope leeward of the prevailing winds. These deposits are sparsely vegetated and have very limited range of grain size, usually fine grained, but at places intermixed with medium range also. These are Recent in age, rich in quartz contents and having no cohesive strength.

<u>Ground profile</u>

On the basis of soil characteristics from at-a-glance picture of the soil penetrated at 5 borehole locations (BP-1, BP-2, BP-3, BP-4, and BP-5), including N values, overall a soil profile has been developed. As is clear from this profile, in all the boreholes the

soils encountered are basically composed of fine and fine to medium sand with pockets of inorganic silts intermixed with clay and sand at places ranging in thickness from few centimeters to two meters at the maximum. These pockets seem to be the result of sheet flow coming from the highlands.
The strata are divided largely into 4, and subdivided further into some small layers.

The layer 1, the top layer from 0 to 4 ~ 5 meter depth, is eolian deposits which is composed of loose to medium, sorted and fine grain sands, the N-value ranging from 5 to generally around 10.

The layer 2 is subdivided into 3. 2-1 layer, the uppermost part, distributing limitedly only around hill-foot, is composed of clayey to sandy silt of thickness 1 ~ 3 m. N is ranging from 15 to 20. 2-2 layer, its top surface undulating almost same as recent topographic feature with thickness 5 ~ 6 m, is composed of medium to a little dense silty to fine sands. The deposit seems to be of eolian nature basically likely as the layer 1. The N value varies among 20 to 30 increasing gradually with depths. 2-3 layer is found at only BP-5 drilled at upland with thickness 8 m. This is composed of such relatively hard fine cohesive material as clayey to sandy silt, and N value is in among 10 and 20.

The layer 3 is further subdivided into 4, and the gradient of its top surface shows approximately half as much as recent topographic feature. This layer is supposed to be the sandbar deposits of Indus river or flood deposits derived from mountainside judged by its composition. 3-1 layer varies remarkably its thickness from 4 to 14 m place to place. This layer is generally composed of fine and fine to medium sand intercalating silty thin layers of less than 1 m thick. 3-2 layer, thickness ranging 2 to 6 m, is composed of silt to fine sand. The top face is remarkably ups and downs, and inferred to be depressed at BP-4. 3-3 layer consists of fine sand or fine to medium sand of thickness 3 ~ 5 m. 3-4 layer, found at BP-1 ~ BP-4 drilled in foothills, is composed of silt and clay. Thickness is ranging from 2 to 3 m. The N values of the layer 3 show around 30 in such fine, cohesive strata as 3-2 and 3-4 layer, and more than 40 in the other sand-rich layer. In case of sand-rich layer, there is gentle to sharp increase about N-value depending upon soil characteristics, as result the lower part is over 50, that is, extremely dense.

Onward to these layers, the layer 4, a very dense sorted fine sand stratum seemed to be subrecent Indus river deposit, is widely distributed with N value around 60 or more.

The groundwater table is present almost constant level at MSL 178~180m with no relation to topographic feature. The average hydraulic gradient between the section of BP-5 and BP-1 is approximately 1 in 1000, which means the groundwater flow of this area is very little perhaps because of few volumes of recharge.

The bearing capacity of the ground

The results obtained indicate that stratum up to few meters has N value 5 ~ 15, and it is considered N near the surface around 5. If the facility will be founded directly on these strata, from Meyerhof equation ($q_0 = 3.3 \cdot N \cdot B$ ($tf/m^2$)), critical bearing capacity will be 16 $tf/m^2$, and allowable bearing capacity is approximately 5 $tf/m^2$ (safety factor 3). In the case the base will be set on the strata of N around 10 directly after excavated, the allowable capacity will be twice. In the case further excavated and founded on the ground of top face of the layer 2, allowable capacity will still more increase up to 20 $tf/m^2$. Even if the penetration (Df) will be carried out, the extra would be very few.

In the case of pile foundation (relying on the data of BP-2, BP-3, and BP-4 locating at the proposed pump house, most important facility of this site), 3-1, 3-3, and 4 layer will relatively be considered suitable for the bearing layer with regard to pile foundation.

a: In the case of bearing plane being 180 m contour level of the top of the layer 3, the critical bearing strength at the end of pile is :

$$Rup = (15 \sim 30) \cdot 30 = 450 \sim 900 \ tf/m^2$$

Then allowable bearing strength is 150 ~ 300 $tf/m^2$.

b: In the case of bearing plane being 165 m contour level of the top of the 3-3 layer, the critical bearing strength at the end of pile is :

$$Rup = (15 \sim 30) \cdot 45 = 675 \sim 1350 \ tf/m^2$$

Then allowable bearing strength is 225 ~ 450 $tf/m^2$.

c: In the case of bearing plane being 160 m contour level of the top of the layer 4, the critical bearing strength at the end of pile is :

$$Rup = (15 \sim 30) \cdot 60 = 900 \sim 1800 \ tf/m^2$$

Then allowable bearing strength is 300 ~ 600 $tf/m^2$.

In any case, the skin frictional bearing strength will be able to add to those end strengths, and those strengths will be decided with relation to allowable vertical loading capacity of pile itself when designing.

iii) Nose Nullah Cross Drainage Site

The site is located just the cross point with proposed canal alignment and Nose Nullah. This location is in subjacent non-gravely piedmont slopes characterized by very gentle (almost flat) plains, surface layer of which is mainly composed of silt, clay and partly fine sand. At the location, the width and depth of nullah is approximately 15~20m and 2.5m respectively.

Ground profile

From the result of BC-1 borehole, the recovered material is almost of identical nature, brown in color and generally composed of sandy silt to clayey silt and partly brownish gray fine sand layers whose thicknesses are ranging from 1 to 2 m.

The soil strata encountered is, up to 6.2 m very loose fine sand and soft silty layers that has N value lower than 10, up to 10.5 m medium to relatively dense silt to fine sand (N values 20 ~ 30), and up to 17 m stiff clayey silt (N values 15 ~25). Downward to these layers, the strata are partly clayey soil and/or partly sandy soil, the N values showing some part high (more than 50) and some part slightly higher than or just 30. The piezometric level is in the stiff clayey silt.

The bearing capacity of the ground

The stratum up to 2 meters is soft clayey soil. It is unsuitable for spreading foundation on this stratum directly because much subsidence would be expected. Onward to the strata up to a little lower than 6 m, N values show 8 ~ 10. If the facility will be founded directly on these strata, from Meyerhof equation ($q_0 = 3.3 \cdot N \cdot B$ ($tf/m^2$)), critical bearing capacity will be 26 $tf/m^2$, and allowable bearing capacity is approximately 8 $tf/m^2$ (safety factor 3).

In the case of pile foundation penetrating up to 8 m depth which is the top of fine sandy layer whose N values are 20 ~ 30, the critical bearing capacity at the end pile is:

$$Rup = (15 \sim 30) \cdot 20 = 300 \sim 600 \ tf/m^2$$

Otherwise in the case penetrating up to 18 m depth whose N values are more than 30, the critical bearing capacity at the end of pile is :

$$Rup = (15 \sim 30) \cdot 30 = 450 \sim 900 \ tf/m^2$$

In any case, the skin friction bearing strength will be able to add to those end strengths. The safety factor when deciding the allowable bearing capacity is 3.

iv) Luni Nullah Cross Drainage Site

The site is located at the cross point with proposed canal alignment and Luni Nullah. This location is on recent non-gravely piedmont slopes mainly formed by eroded and sedimented material from Gumal River, Luni River and Luni Nullah. These are actually the one serial channel having the quite extensive catchment area reaching to Afghanistan going across the border of country and usually flowing perennially. Relatively abundant water runoff is checked by artificial bunds at some places and irrigated to farmland characterized as Rod Kohi irrigation system in this area. Surface layer of these narrow piedmont slopes is mainly composed of silt to fine sand, though other part of area (subrecent piedmont slopes) is basically silt and clay. At the location, the width is approximately 50 m and the height of the river bank is 4 to 5 m.

Ground profile

One borehole (BC-2) was drilled up to 16 m depth at the riverbed.
The top layer up to 3.5 m of the recovered material of this hole is recent river deposits composed of loose fine to silty sand, partly clayey silt showing N value 6 ~ 7 except the dried and hardened surface layer. Just downward to this layer, the medium to relatively dense fine sand layer whose N is ranging from around 20 to 40 is underlying. Groundwater table is in this layer. Onward to this layer up to 12 m is cohesive soil, the uppermost 1 m has low consistency whose N value is 4 to 5 supposed to be influenced by ground-water. Downward to these layers composed of silty to fine sand, the N value is up to the drilled depth showing 30 to 46.

The bearing capacity of the ground

The results obtained indicate that the top few meters are composed of loose silty to fine sand and cohesive soil intercalating partly clayey silt of recent river deposits.
Because of above reason, the spreading foundation is considered impossible from the view point of strength and stability.

In the case of pile foundation, two cases will be considered, namely,

a: the case founding on the fine sand stratum (N values 19 ~ 40) of depth 3.5 ~ 7m.

b: the case founding on the strata of silty to fine sand (N values 30 ~ 46) of depth lower than 12 m.

Case a: Careful consideration will need because the thickness of bearing stratum is relatively thin, loose recent riverbed deposit is overlying, and furthermore the subsidence may be caused why just underlying cohesive stratum is soft.

Case b: The critical bearing strength at the end of pile on the top of this layer is :

$$Rup = (15 \sim 30)\cdot 30 = 450 \sim 900 \text{ tf/m}^2$$

Then allowable bearing strength is 150 ~ 300 $tf/m^2$.

The skin frictional bearing strength will be able to add to those end strengths, and those strengths will be decided with respect to allowable vertical loading capacity of pile itself when designed.

(3) Borrow Material

Fundamentally, the embankment material where canal will be constructed would be diverted from excavated material around that site. The soil mechanics of these soils (OMC, $\rho dmax$ ) are as mentioned before. However, about 15 km from the pumping station consist of loose dune sands which may be low water tightness, low bearing capacity and low stability. That needs borrow material transported from utterly separated area from construction site when constructing open canal along this section. Therefore the borrow material area having enough volume of suitable material for embankment has to be set as near the site as possible. The area showing good topography for excavating, having suitable volume of applicable embankment material is few around study area. The foot slope of Khisor Range locating a little down stream side of Bilot is composed of Talus deposit, and Silt, Clay , Sand layers of Siwalik to Recent age. Though the data of soil mechanical properties of these type of soil are not obtained yet so far, they could be suitable for this purpose. Then as planned borrow material area will be set the area shown in Fig. A.21.

## A.2 Land Conservation

The study area is located in very gentle plains of central part of Subrecent ~ Recent Non-gravely Piedmont Slopes surrounded by Ranges west to northerly and Indus river easterly. The inclination of the stream in this area is ranging approximately 1 in 200 to 1000. Fig. A.22 shows the distribution of Sand dune area, Rod Kohi area (Recent piedmont plain including badlands), and the other piedmont plain area (Subrecent piedmont plain) of D. I. Khan District. Though the major tributaries (Tank Zam, Gumal Zam, and Khora Zam) that drain through D. I. Khan District depress deeply in the mountain range area, they diverse into several streams and infiltrate into the ground after flowing into the piedmont plain and their scale becomes relatively small. The serial streams following above rivers are roughly Nose ~ Takwara Nullah from Tank Zam, Luni ~ Gumal Nullah from Gumal Zam, Gud Toa ~ Lohra Nullah from Khora Zam. While, in the northern area around Khisor, Marwatt

Ranges, the eolian dune sand extends widely, forming undulating gentle slope with inclination around 1 in 200.

The main subjects with regard to Land/Soil conservation in the study area are considered to be the following three, from the geomorphologic matter mentioned above and the characteristic semi-arid climate of this area.

1. Erosion, sedimentation and water logging caused by sheet flow from inundation.
2. Wind erosion in dune sand area.
3. Salinity in the command area.

### A.2.1 Erosion, Sedimentation and Waterlogging

The following matter will be described as main erosion control methods carried out in such study area of this project.

(1) Upstream engineering consists of every means by which run-off can be delayed or redistributed at and near the source, and includes:

1) increasing or improving the plant cover.
2) small scale detention structures, including gully plugging of stream origins, contour ridging, water ponds for livestock.

(2) Downstream engineering consists of all other attempts to confine or redistribute flood water after it has issued from its confined hill catchment onto the plains below, and includes:

1) the canalization of streams to confine them to a definite bed down which detritus will be carried further down-stream.
2) the provision of an afforested belt on both banks which can serve as an overflow for the partial disposal of extra heavy floods.
3) larger engineering structures such as dams, reservoirs, levees, extra flood channels.

Those control methods will be summarized by function as follows.

Summary of Erosion Control Methods Classified by Function

| Function | | Methods |
|---|---|---|
| A. | to improve existing plant *cover* on | |
| (i) | through village organizations | 1. partition of shamlat (common) land.<br>2. co-operative management of grasslands. |
| (ii) | through forest protection and afforestation | 3. better management of existing forests.<br>4. village plantations. |
| B. | to build up *soil fertility* in ploughed land. | 5. manuring and green manuring.<br>6. preserve stubble and crop residues.<br>7. consolidation of holdings. |
| C. | to *reduce the exposure of bare soil* during monsoon. | 8. choice of crops and crop particularly rotations.<br>9. strip cropping.<br>10. reduce bare fallow.<br>11. restrict cultivation of steep slopes. |
| D. | to increase *surface storage and infiltration.* | 12. cover crops and mulching.<br>13. contour ploughing.<br>14. contour ridging.<br>15. bench terraces. |
| E. | to increase infiltration into the *deeper layers.* | 16. subsoiling.<br>17. trenching.<br>18. basin listing. |
| F. | to prevent run-off gaining a *cumulative velocity.* | |
| (i) | by control of *field drainage.* | 19. grassed ditches.<br>20. masonry outlets in field bunds.<br>21. contour bunds set out with a side slope so that water is led off fields quickly.<br>22. live hedges & contoured hedgerows. |
| (ii) | by control of *drainage outside fields* | 23. gully plugging & check dams. |
| G. | to divert *excess water* out of natural channels. | 24. diversion bunds.<br>25. diversion ditches.<br>26. deliberate water-spreading by flooding of overflow meadows.<br>27. water tanks.<br>28. road drainage control & recovery of landslips. |
| H. | to head back *accumulations of water* river bed itself. | 29. small water-holding bunds in the multiple along torrent beds.<br>30. major reservoirs. |
| I. | to confine the torrent or river to a *channel* | 31. canalizing smaller torrents by planned vegetational . control.<br>32. river bank consolidation in major streams |

A to F of above Table are mainly upstream engineering, and G•H•I are downstream engineering. Further description among the upstream engineering, A is waste land management, F(ii)is minor operations in the heads of torrents and from B to F(i) are farm practice.

Judged from the existing data, the probable flood volume up to 2.33 years' doesn't cause the damage to farm, but once the flood more than this probability will be outbroken, farms are substantially damaged by extended waterlogging etc. Assuming Munning's roughness coefficient of straight river 0.03 and of meadow river 0.04, the velocity of Nose Nullah or Luni Nullah may be inferred 1.5 ~ 2.0 m/sec from their scales in the case river flow occurs full of channel. This velocity causes significant erosion from river-bank and simultaneous sedimentation standing in the part of channel may suffer secondary damage. The flow of more than 2.33 years' probability flood may not be confined in the channel resulting sheet-flow and waterlogging.

The variable control methods described above table should be carried out effectively to prevent from erosion, sedimentation and waterlogging in the command area.
The following plans and designs are on consideration in this project as to main canal, distributaries, cross-drainages and on-farms

(a) Main canal is aligned just slightly higher than existing ground height so that the flood may pass directly through such cross drainage structure as culvert-type or super-passage without checking it. Then sedimentation and water-logging may not take place.
(b) Canalization and river-training are on plan to confine the flood in the channel preventing from sheet-flow. Even if sheet-flow will happen, most part will be drained rapidly by irrigation and drainage network in the command area or retained by bund working as wide and shallow reservoir so that it may flow slowly. Therefore erosion seems not become significant problem.
(c) The masonry outlets mentioned item 20 of the table to prevent bund from broken, drain the water smoothly and head back accumulations of water riverbed itself. In that case, to prevent gully erosion, or short retention of water when river flows still fully, the counterwork mentioned in item 29 of the table will be necessary. The matters mentioned in (a) and (b) will be controlled certainly with progress of project, and the matters in (c) except large scale structures are one of the methods of farm practice and should be able to be carried out by farmers' associations.

In a granted that above mentioned counterwork will be carried out sufficiently, the problem of erosion, sedimentation and waterlogging will not be significant so much. However it is necessary for a representative organization of administration to lead that above mentioned small scale erosion control methods should be well known to farmers or farmers' associations and implemented promptly, though large scale ones like river-training will be carried out in project itself.

Erosion and resulted sedimentation in riverbed will be reduced if river bank consolidation (rip rap etc.) and gully plugging etc. will be carried out effectively. Erosion and sedimentation of upstream (mountain range) side of command area is important for facility conservation directly concerning to canal itself rather than erosion control because the sheet-flow will be checked by canal embankment and the runoff are flowing into main drainage system or sheet-flow drainage system. Traditionally-made existing bund system may also make the velocity of sheet-flow less by storage effectiveness of farmland basin so that erosion and sedimentation may not cause significant damage to canal facilities.

The sedimentation transported from mountainous area may be described as follows.

Main tributaries from mountain-range through study area up to Indus river are three (Tank Zam, Gumal River, and Khora River). Their location and annual discharge are shown in Fig. A.23 and Table A.5. The Tank Zam and Khora River drain moderate scale areas of the Bhittanni and Sulaiman Ranges, respectively, but the Gumal River carries the aggregate flow from a system that extends far to the west and south, into eastern Afghanistan and western West Pakistan.

Feasibility Study on Gumal Zam Dam Multipurpose Project reported the sediment concentration over 16 years at Kot Murtaza from 1960 to 1975. It reported the average suspended sediment was 5.25% by weight. Three years in the sample exceed 7%. The linear correlation between concentration and annual runoff is good. Correlation coefficient is r=0.86 for 16 years. Since the final average runoff is 442 $hm^3$/year (358 E3 AF), the final sediment by weight is 5.25 E-2 · 442 E6 = 23.2 E6 metric ton/year and that by volume is approximately 9 million $m^3$/year.

Furthermore from the report on groundwater resource development survey in 1960 to 1964 are available the data of sediment transport in the area on Tank Zam near Jandola, Gumal river at Kot Murtaza and Gumal river at Khajuri Kach. Table A.5 shows the measured discharge of river-flow that enter D. I. Khan District (1960—1963), and suspended concentration of water in Gumal River. Their relationships are shown in Fig. A.24 and Fig. A.25.

The volume of traveling sand transported as the tractable plus the suspended from Kot Murtaza is calculated about 1 million $m^3$/year or a little more inferred from the flowing pattern of Fig. A.24, and that around the crossing point with proposed canal alignment is only $2 \sim 3 \cdot 10^4$ $m^3$/year. In the case of Gumal river, most of the sand transported from maintenance area to piedmont plain will deposit around Kot Murtaza (8 million $m^3$/year), and the rest (around 1 million $m^3$/year) may pass through there and deposit along the area up to the proposed canal. The influence of traveling sand from mountainous area may therefore be very few in the project area and canal. Provided the flow of Rod Kohi is never checked on the way, though the traveling sand around $1000 \sim 2000$ $m^3$/day flowing through command area may happen momentarily, it may be transported until Indus river. As to the other rivers, the matters are considered likely. Then the sedimentation may only be derived from erosion around piedmont plain mentioned before.

### A.2.2 Wind Erosion in the Dune Sand Area

As mentioned before, dune sand area is extended around the footslopes of Khisor, Marwatt ranges located northern side of project area. In the project, the end part of Feeder canal, Pumping station, and the uppermost stream section 10 ~ 15 km of Main canal are proposed and about 700 ha of command area will be included in this dune sand area. Wind erosion in the Dune Sand Area is essential for soil conservation from the standpoint of farmland conservation and above mentioned facility conservation against sedimentation.

When considering the soil conservation in sand dune area, sheet erosion by wind and water action, and desiccation caused of loss of soil water by low retention capacity could be considered well as erosion processes. Especially, dry farming technique is important to improve and carry out effectively to prevent from wind erosion.

With wind erosion control and dry farming technique methods, this could be included the above summary of erosion control method, the next three titles should be coped.

1) fixation of sand dunes.
2) shelterbelts and wind-breaks.
3) improve dry-farming practice.

The sand here is usually derived from the nearest open torrent bed along which sand eroded from neighboring uplands has been dumped. Another source is of course the main river channels which are often miles wide. From both these sources, the sand is whipped up by the hot summer winds and carried considerable distances away from the actual stream-bed.

(1) Fixation of Shifting Sand

For fixation of sandy land, fixation of shifting sand is necessary. The mechanics of sand movement may be considered as:

In the case of both the larger rivers and of the smaller foothill torrents, the coarser sand is the first to be dumped by the stream, while the finer particles are carried farther out into the plains or down further itself. Once a bed of sand is dried and becomes exposed to wind action, however, it starts moving in the direction in the prevailing wind and in its movement it acts as a sandpaper and recruits more sand from the ground it gets blown over. Though the sand whipped up moves some distance by wind and sediments some parts, these are easily moving repeatedly because it is very loose and non-cohesive. Generally soil particles up to around 1 mm diameter making up a field with a smooth dry pulverized fallow, began to move when the wind reached a velocity of 10~15 knots at 1 ft above ground.

For fixation of sand dune and reducing wind erosion, vegetation was in the end the surest defense.

The use of annual leguminous crop plants such as gram is a simple mean of establishing plant growth on dunes, but most of these being winter annuals do not provide a cover when they are most needed, during the hot summer season. It is therefore generally worth while to take some extra trouble over securing some more permanent plant cover by hedging systematically the grass grownable in the very few moistured sandy areas will be necessarily.

For this purpose, cane grasses and anjan grass etc. are very useful. Cane grasses such as Saccharum munja, Saccharum arundinaceum and Saccharum spontaneum (kahi) will serve the purpose, as they all produce a very large bulk of cane, leaves and roots from a minimum of moisture. Recently Vetiver grass, one of the cane grasses, is practically utilizing well at some places. Anjan grass is also capable of surviving long drought periods and can be either cut or grazed.

These hedging serve the following twofold purpose:

i) by covering the fallow land with a mat of vegetation it reduces surface sheet-wash to a minimum.
ii) it provides a mass of vegetable matter which when ploughed under, helps to build up a far better tilth, particularly where sheet-wash has already swept away the top-soil and left only a clay or kankar subsoil exposed.

The potential value of grass is a mean not only of preventing soil erosion but of actively building up a better tilth .

(2) The shelterbelts and wind-breaks.

Where the contour terrace bunds are at right angles to the prevailing wind these should be heavily stocked as wind-breaks. Where the contour terrace system falls parallel to the prevailing wind then a separate series of wind-breaks of grass, trees and bushes must be established, preferably on a system of low bunds at right angles to the wind.

(The Function and Layout of Wind-breaks and Shelter-belts.)

Where the damaging wind is constantly from one fixed direction, there can be no doubt as to how the wind-breaks should be aligned. They must be at right angles to the wind force. The larger the number of replications of parallel lines the better, as repeated lines, even if well spaced out, tend to give a cumulative amount of shelter. Where winds are variable and shifting, secondary wind-breaks may be needed at right angles to the alternative wind or else more frequent wind-breaks in the primary direction may serve the purpose. When the wind is constant, one wind-break should give effective shelter to an area of a width equal to 15 to 20 times the height of its trees, and of a rectangular shape. When the wind comes from two directions, the shape of the area sheltered alters to a triangle and the area is greatly reduced.

The trees themselves should be selected to give a maximum of screening effect, for instance alternate taller tree and lower tree, with the squat shrub-tree filling up the gaps between the taller and more open crowned trees.

Height alone is only of value provided the belt as a whole presents a more or less complete front to the wind, thus a single row of tall trees with bare trunks and wide gaps in the lower part of the windwall will obviously allow a lot of wind through, and the objective should be to build up from the ground, using whatever local species will form a resistant windwall. This of course need not be all in the same row as the tallest trees, and in fact a better windwall is formed by having the ground-level shrubs to wind-ward, the small tree species in the middle, and the tallest species to leeward. For instance, the ideal form of shelter-belt to break the force of the desiccating summer strong wind is probably an outer and lower fringe of low grasses, then cane grass and shrubs leading up to trees in the rear. Well-spaced tree belts with intermediate belts of low dense hedges could be more effective.

(The Situation of and Proposals to the Study area)

The main wind directions brought from monsoon in north-western Pakistan are said to be SW during the summer monsoon season of June to September, and mainly N direction in winter monsoon season of December to March. The wind directions in D. I. Khan, however, are statistically shown in Fig. B.1.4 of ANNEX B. That is to say, the weak winds of their velocity less than 10 knots in kharif (summer monsoon) season deflect from S to NE with E~SE as the central figure, and low frequent strong winds more than 10 knots are from E~NE or W. On the other hand, the ones less than 10 knots in rabi season (October to May) lean to the SE in the case of relatively the weaker and to the NE in the case of the stronger with E as the central figure, and strong ones more than 10 knots deflect from NE or NW with N as the central figure.

Checking the shape of sand-dune and ripple-mark in the field, the typical sand-dunes shape the crescent having gentle slope directing N~NE (partly W) and opposite side much steeper, and the ripple-marks have E-directing gentle slope and W steeper. Judged from the above, the usual winds in this district may be considered from E, and fewer strong winds from N or W.

The shelterbelts and wind-breaks in this area should be proposed to be aligned as main wind direction is N against strong ones and the secondary is E against usual wind shifting sand.

(3) Improve Dry-Farming Practice.

The first consideration in the barani cultivation of crops in sandy area is the storage and effective utilization of water in the soil.

Careful matter is that in areas of exceptionally low rainfall in the pre-monsoon period ploughing or otherwise stirring of the soil may be actually harmful as it is liable to aggravate erosion by wind. The safest way, therefore, would be to open up the land with the first monsoon shower. Furthermore a deep loose fine soil should be overlaid by a dry surface mulch of larger soil crumbs through which stored water cannot be lost through evaporation. Moreover as the most desirable methods, vegetation cover mentioned in (a) for covering the uncropped land will reduce surface soil wash and help to build up a better humus content.

Recommendable cropping methods in sandy area are proposed as following:

i) When possible, green manuring rather than the production of fodder crops is to be advocated, and the production of kharif fodder crops is not advisable. Guara is the best of the orthodox green manure plants, and its use should be widely publicized amongst the cultivators.

In the use of green manure the main essentials are:

(a) quick production of a large bulk of vegetable fiber,

(b) quick rotting of this fiber,

(c) moisture storage,

ii) Such crops as juar, maize and bajra make heavy demands on stores of plant nutrients and transpire more water per unit of dry matter produced that any rabi crop it is possible to grow on barani land in this country.

iii) If fodder crops as must be grown it is better to keep to finer-leafed rabi crops such as gram, oats, barley or wheat and lift the crop before the grain begins to form.

iv) Of the kharif fodder crops the best for soil improving is guara, either pure or mixed with juar.

v) The seed bed should be moist, deep, firm and fine. A layer of about 3 inches of fine earth should be on the top of moist earth underneath. At least three inches mulch is necessary in order to prevent loss of moisture.

The first essentials in dry farming are to have terracing the fields for reducing the loss of surface water, to subsoil and deep plough for moisture conservation in the deeper layers, and to make contour bund and contour hedge for working the surface soil to make and keep it more absorptive and effective water-catching.

Contour hedge etc. is the most useful practice for fixation of shifting sand and retaining water in the soil. The standard technique for hedging has been to raise an artificial dune by planting a line of wooden palisade with a space between each post. Where ploughing is possible and the soil contains some admixture of clay, the technique is to plough fairly deeply to about 6", and then by making a double-turn of the plough to throw up a slight bank every 15 yard or so, which will retain the rainfall and secure good seepage.

(Counterwork in the project)

From the view point of matters mainly protecting such important facilities as canal and pumping station, main point in this project is making shelterbelts and wind-breaks around the important facilities.

The direction of facilities from pumping station to main canal is approximately E-W in dune sand area. As mentioned in section (b), the shelterbelts and wind-breaks in this area should be proposed to be aligned as main wind direction is N against strong ones and the secondary is E against usual wind shifting sand. Fundamentally it is expected afforestation will be carried out along the bank of main canal, shelterbelts and wind-breaks should be aligned that trees and grasses will be planted to the mountain side of bank effectively defending from strong wind. Further it also seems to be better that the secondary will be planted and hedged to east side of pumping station and line's length 50 m and line's interval 50 m to crossing direction to main canal. Various dry farming practice for fixation of shifting sand in the command area should be prevailed to farmers and farmers' associations as the important farming practice by administrative organization.

### A.2.3 Salinity in the Command Area

The water quality of surface water is as followings from the result of water quality investigation in this project.

The water of Indus river intended to be utilized for irrigation in this project and of Paharpur canal fed already from Indus river showing every item relatively low, that is Total Dissolved Salts (TDS) around 120 ppm, EC about 0.20 mS/cm, SAR about 0.3, Na-ion around 0.30 meq/l and pH about 8.5 which indicates those are non-sodium water chemically equilibrium to calcium carbonate is non-saline and non-alkali and have very good quality for irrigation.

That of Gumal River system derived from western mountain, however, shows relatively low salinity as of sampling, that is, TDS among 500 and 700 ppm, EC among 0.9 and 1.2 mS/cm, SAR 4 or 5, but Na-ion shows high including ratio of among 55 and 70 %. That of Khora River system shows better quality than that of Gumal River systems, however, both of them are a little worse quality comparing to that of Indus River.

These qualities from western mountain vary a lot among flood seasons and dry seasons reaching more than 1000 ppm of TDS in dry season.

The water quality of groundwater is as following.

The groundwater around Yarik near abandoned flood plain of Indus River is relatively ordinary type of quality presumably influenced by seepage from Indus River, which shows pH 8.5, EC 0.20 mS/cm, SAR about 7 and TDS 500 ppm.

The groundwater from the other locations are two types having usually higher EC than 4 mS/cm and some of SAR 7 or 8 (saline & non-alkali), others 15 or 16 (saline & alkali). Their TDS are generally very high with almost among 3000 and 6000 ppm so that they may utterly unsuitable for irrigation. Further their Na-ion inclusion and perhaps sulphates are considerably predominant.

Fig. A.8 shows the horizontal distribution of the density of dissolved salts in shallow ground water, and in Fig. A.5 the diagrammatic vertical distributions in 1964 are shown with unconsolidated deposits. From these data it is said that broad areas contain water of good chemical quality, but this water is commonly overlain at shallow depth by water of poor quality.

The dissolved salts in water showing the highest ratio around ground water table may be because of leaching from soil through unsaturated zone and of accumulation around ground water table. Furthermore the process of evapotranspiration also contributes markedly to progressive concentration of dissolved solids in the ground water. In saturated zone, ground water dominantly flows horizontally along layers rather than vertically, then the downstream side has rather higher dissolved salts because of moreover leaching, accumulation and evapotranspiration. In the area along Gumal to Luni River and Indus river, however, dissolved solids become lower because of the infiltration and dilution from these rivers.

The relatively high mineralization in much of the shallow ground water is due not only to the acquisition of soluble mineral matter from the soils but also to the effects of evapotranspiration. As a result of this process, the mineral content of the shallow water becomes concentrated to a level several times greater than that of waters a few feet to a few tens of feet deeper.

Fig. A.6 and Fig. A.7 also show the contour of altitude and depth in feet of groundwater table in 1964 respectively. Fig. A.7 is also shows the depth of ground water measured in Phase 1 of this project in the irrigated area by CRBC Stage I and Paharpur Canal, comparing each other. The result is both are not so different.

The result of soil analysis shows that the soil in this area is generally non-saline ordinal soil as of today indicating pH generally among 8.0 and 8.5 and ECe among 0.1 and 0.7.

However, because it is considered the following two principles as condition creating saline soils, the study area may be exposed to be dangerousness

(a) Evapotranspiration from ground is every time more than precipitation.
(b) Soluble salts exist in soil and groundwater, and will accumulate.

In the case precipitation is very low, leaching in the ground by percolation is strongly suppressed and then most of salt-base is retained in the soil without leached. However, during very limited period in a year, ground is moistured and soluble salts move downward and accumulate around some level.

Soluble salts, main compounds of which are chloride, sulfate and carbonate, exist in the soil separated because their solubility is different from each other. Namely, calcium carbonate with the lowest solubility accumulates in shallower level in the ground and calcium sulfates a little deeper because of its higher solubility. Chloride, e.g. sodium chloride, is very soluble and accumulates further deep-level than calcium sulfate.

As mentioned hitherto, generally plenty of salt-bases are there in the soil of arid climate. As far as the case groundwater table is very deep is concerned (the depth of groundwater table in the study area is usually among 15 ~ 30 m), however, likely as the above investigation result carried out in this project, it is the very rare case that salt-bases accumulate in the surface layer. Therefor it is considered they are not belonging to the category of saline soil in many cases.

However, when this type of soil is salinized, farmland must be often abandoned because desalinization is very difficult.

(Actual salinization of surface soil in arid area)

That plenty of soluble salts is included in the soil of arid area indicates that leaching action doesn't progress well.

Comparing the case that water will be irrigated through canal with the case irrigated by rainfall to the arid soil, the aspect of water situation after infiltrated, especially water and salt balance must show the very big difference.

Namely, the water from rainfall has the feature of not only very low salinity but also low evapotranspiration reflecting the weather condition of rainy season. Then the infiltration of water and the leaching of soluble salt are going downward well.
However, the water from canal will be provided with no relation to surrounding weather condition and the cropping is in general carried out during dry and hot season in arid area aiming to increase the efficiency of photosynthesis. In this season, the direction of soil water predominant to upward rather than downward different much from in the rainy season, salinization may be at least going through the following three processes.

i) Ground surface salinization on due course of groundwater including high ratio of soluble salts going upward by capillary
ii) Irrigating water adds salts to soil
iii) Augmentation of salt including ratio in soil by leaching fraction declining

i) Leaking from canal, stagnation of percolation in the case plenty of water is irrigated at once, forming hardened layer just under the cultivated surface soil compacted by big tractor, momentary groundwater table may be formed at the relatively shallow depth when providing irrigation water. In the case momentary groundwater table formed like this, because its level is very shallow, capillary fringe of this groundwater is easily connect to groundsurface, and with moving upward by suction caused by remarkable evaporation, soluble salts may move to and accumulate around groundsurface. In this case, the most migratory salt is sodium-compound salt which is harmful to crop.

ii) This problem may do not matter so much, because water for irrigation is planned to intake from Indus River having good water quality.

iii) Leaching Fraction, which is the ratio of leaching water volume from rhizosphere to supplying water volume, is the very important problem not only in the case undoubtedly irrigation water has high ratio of dissolved salts, but also in the case like this project the dissolved salts of irrigation water are relatively low. If the leaching fraction is considerably low, salts may accumulate gradually during the long period, and the salts in the soil may not be leached at all. Especially in dry and hot season, it is necessary by all means to secure leaching fraction more than some ratio.

In the study area, the salinity in sand dune area is not significant problem because the sand is very permeable and the salts in the soil are easily leached even by means of very few rainfalls. On the other hand, in the area of clayey soil, especially just after rainfall, some white powdery which seem to be calcium carbonate, calcium sulfate or partly sodium chloride can be found to and fro. This is considered that the salts in the soil accumulated at groundsurface by suction caused by capillary action, because intake rate of the clayey soil is remarkably low and momentary groundwater table was formed at very shallow depth, so that the capillary fringe connected to groundsurface. In the case harmful sodium-compound salt is accumulating relatively in the shallow depth, it indicates the high possibility of easily fluxing to and giving injury around rhizosphere.

(Saline control in the study area)

i) Controlling the use of chemical fertilizer
   Chemical fertilizer should be considered deliberately to use for controlling salinity. It is better to avoid using chemical fertilizer which may cause salinity, and to utilize the droppings of sheep, goat, cattle etc. as much as possible.

ii) Preventing of occurrence the momentary groundwater table.
   For this purpose, the followings are taken up.
   a) Lining of canal
   b) Underdrainage
   c) Laying porous material just under surface soil
   d) Avoiding to form hardened layer
   e) Mulching

a) Lining of canal is to prevent water from leaking, and momentary groundwater table from forming at shallow depth.

b) The purpose of underdrainage is not draining of extra water but eliminating highly soluble sodium-compound salt from surface soil. The interval will be enough to be 50 ~ 100 m to defend against salt accumulation or keep ESP lower than 15%.

c) As laying porous material, cut branches and so on are spread just under surface soil. In this method, it needs attention for over drying and erosion.

d) As one of avoiding methods of forming hardened layer, big tractor is used only for rough cultivation and small tiller for attentive cultivation.

e) The purpose of mulching is to control ascending capillary water from groundwater table, namely to reduce the flux caused by tension difference of subterranean water as much as possible by controlling evaporation from the groundsurface. However it should avoid to make the ground be high temperature.

iii) Controlling the leaching fraction

In irrigation scheme of this project, securing leaching fraction more than some ratio, accumulation of salts to surface soil will be prevented and leaching salt from soil should be accelerated.

vi) Controlling the level of groundwater table

Groundwater in the study area has the high total dissolved salts around groundwater table, so that it is necessarily to keep it low.

In arid area, it is said that the marginal depth against capillary force is 1.2 to 1.5m in sandy soil, and 1.5 to 2m in clayey soil, then ground water level should keep lower than these depths at all times.
The ground water table in the study area in 1964 is generally among 50 to 100 ft shown as Fig. A.7.

To control the groundwater table, actual method is pumping up by well. At that time, the water pumping up from deep layer is better, because of relatively lower TDS, and it is utilisable as domestic water or supplementary irrigation water. Water including high TDS should be disposed.

If water from well includes relatively high ratio of TDS, in the relatively permeable soil, the case soil will be deteriorated by the accumulation of salt is very few. This is because the salt brought to surface soil will easily be leached by relatively few rainfalls on account of the groundwater table keeping lower. If the case the intake rate of the ground surface is low, however, it is apprehensive of happening the case (ii).

If the tubewells will be installed at some locations, around Takwara Nullah where is groundwater table is shallow as shown in Fig. A.7 will be carried out preponderantly.

(Counterwork in this project)

Main canal and distributaries are designed lining by concrete in this project. About leaching fraction, it is necessary to be sufficiently studied in the plan of irrigation and drainage. Installation of underdrainage would be a problem of further discussion because it seems that installation of interval 50 ~ 100 m covering the whole area 100,000 ha is substantially difficult matter. Moreover about the installation of tubewells for lowering the groundwater table, it is better to carry out linked with or only in SCARP which is going on in many places and partly near the study area with the problem of underdrainage. About fertilizer, porous material, hardened layer, and mulching is considered farm practices which farmers or farmers' association will carry out by themselves. The representative administration should take the lead them sufficiently.

## *TABLES*

## Table A.1 The Result of Laboratory Soil Test 1

(Data of WAPDA D.I.Khan C.R.B.I.P. Laboratory)

| Location C.R.B.C. R.D.No. | M.C. in situ (%) | clay ~0.005mm (%) | silt ~0.074mm (%) | sand ~4.76mm (%) | L.L. (%) | P.L. (%) | P.I. (%) | ρ dmax ( lb/ft3) | O.M.C. (%) |
|---|---|---|---|---|---|---|---|---|---|
| 274+000 | | 70 | 28 | 2 | 42 | 25 | 17 | 103.3 | 19.0 |
| -do- | 5.3 | 35 | 60 | 5 | 26 | 20 | 6 | 110.3 | 17.0 |
| 278+000 | | 72 | 27 | 1 | 39 | 24 | 15 | 109.9 | 16.5 |
| 280+000 | | 54 | 36 | 10 | 29 | 21 | 8 | 114.5 | 14.4 |
| -do- | | 40 | 59 | 1 | 39 | 18 | 11 | 111.8 | 16.4 |
| 282+000 | 4.1 | 32 | 61 | 7 | 22 | 19 | 3 | 114.2 | 13.6 |
| -do- | | 32 | 58 | 10 | 25 | 15 | 10 | 117.8 | 13.6 |
| 291+000 | 12.0 | 50 | 47 | 3 | 28 | 23 | 5 | 113.6 | 15.8 |
| 294+000 | | 47 | 46 | 7 | 36 | 20 | 16 | 117.8 | 12.0 |
| -do- | | 71 | 28 | 1 | 45 | 21 | 24 | 108.8 | 16.6 |
| 296+000 | | 59 | 37 | 4 | 32 | 19 | 13 | 108.8 | 18.5 |
| -do- | 7.8 | 58 | 41 | 1 | 29 | 20 | 9 | 110.5 | 17.0 |
| 299+000 | 14.5 | 41 | 54 | 5 | 24 | 18 | 6 | 117.8 | 14.0 |
| -do- | | 73 | 22 | 5 | 42 | 20 | 22 | 110.8 | 17.0 |
| -do- | | 23 | 52 | 25 | 20 | 18 | 2 | 116.8 | 12.6 |
| -do- | 4.6 | 33 | 57 | 10 | 23 | 17 | 6 | 116.2 | 14.2 |
| 303+000 | 7.0 | 50 | 42 | 8 | 30 | 19 | 11 | 112.2 | 16.0 |
| 305+000 | 3.5 | 73 | 22 | 5 | 0 | 0 | 0 | 108.2 | 18.8 |
| 306+000 | 4.0 | 60 | 36 | 4 | 28 | 18 | 10 | 106.4 | 19.4 |
| 306+950 | 7.0 | 74 | 25 | 1 | 41 | 22 | 19 | 106.4 | 19.4 |
| 309+000 | | 66 | 31 | 3 | 39 | 22 | 17 | 106.4 | 20.0 |
| 311+000 | 3.3 | 54 | 44 | 2 | 29 | 22 | 7 | 111.2 | 16.6 |
| 318+000 | | 75 | 19 | 6 | 38 | 21 | 17 | 108.9 | 16.5 |
| 321+000 | 6.8 | 48 | 48 | 4 | 26 | 22 | 4 | 114.4 | 14.8 |
| 324+000 | | 76 | 20 | 4 | 33 | 23 | 10 | 107.8 | 18.5 |
| 325+000 | | 76 | 22 | 2 | 40 | 24 | 16 | 105.5 | 16.2 |
| 343+000 | 9.5 | 58 | 30 | 12 | 27 | 18 | 9 | 115.5 | 14.0 |

## Table A.2 The Result of Laboratory Soil Test 2

(Data of WAPDA D.I.Khan C.R.B.I.P. Laboratory)

| Location C.R.B.C. R.D.No | Sampling Depth (feet) | Gs | Direct Shear Test ϕ (°) | C (P.S.I) | Clay ~0.005mm (%) | Silt ~0.074mm (%) | Sand ~4.76mm (%) | L.L. (%) | P.L. (%) | Œaly (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| 010+000 | 4.5 | – | 18.00 | 2.00 | – | – | – | – | – | – |
| 037+175 | 4.5 | – | 15.50 | 3.20 | – | – | – | – | – | – |
| 053+571 | 4.5 | – | 21.00 | 5.00 | – | – | – | – | – | – |
| 055+771 | 7.5 | – | 19.00 | 3.40 | – | – | – | – | – | – |
| 081+179 | 7.5 | – | 27.00 | 1.60 | – | – | – | – | – | – |
| 084+855 | 6.5 | – | 23.00 | 4.00 | – | – | – | – | – | – |
| 234+436 | 17.0 | – | – | – | 38 | 58 | 4 | 35.4 | 19.6 | 15.8 |
| -do- | 31.0 | – | – | – | 28 | 63 | 9 | 27.9 | 17.8 | 10.1 |
| 257+000 | 11.0 | 2.72 | – | – | 50 | 49 | 1 | 49.0 | 28.0 | 21.0 |
| 264+000 | 4.0 | – | 32.00 | 0.00 | 12 | 87 | 1 | – | – | – |
| 265+100 | 21.5 | – | – | – | 31 | 66 | 3 | 30.8 | 19.3 | 11.5 |
| 266+517 | 4.0 | 2.70 | – | – | 36 | 61 | 3 | 25.3 | 16.2 | 9.1 |
| -do- | 16.0 | 2.72 | – | – | 41 | 59 | 0 | 42.0 | 25.0 | 17.0 |
| 269+120 | 2.5 | – | 28.00 | 0.00 | 12 | 87 | 1 | – | – | – |
| 273+000 | 4.0 | – | 29.00 | 0.00 | 18 | 81 | 1 | – | – | – |
| 277+000 | 6.0 | – | 28.00 | 0.00 | 30 | 63 | 7 | – | – | – |
| 283+000 | 4.0 | – | 30.00 | 0.00 | 16 | 77 | 7 | – | – | – |
| 284+600 | – | – | 19.00 | 6.00 | 88 | 12 | 0 | 70.0 | 26.0 | 44.0 |
| -do- | 5.0 | 2.72 | – | – | 58 | 41 | 1 | 52.0 | 26.0 | 26.0 |
| 289+220 | – | – | 25.00 | 0.50 | 41 | 52 | 7 | 34.0 | 21.0 | 13.0 |
| -do- | 10.0 | 2.72 | 24.00 | 0.00 | 67 | 33 | 0 | 49.0 | 22.7 | 26.3 |
| 303+884 | 23.0 | 2.72 | – | – | 64 | 36 | 0 | 53.0 | 29.9 | 23.1 |
| 308+381 | 5.0 | 2.73 | 25.00 | 0.00 | 77 | 23 | 0 | 49.2 | 22.6 | 26.6 |
| 309+654 | 15.0 | 2.72 | – | – | 69 | 31 | 0 | 51.0 | 24.7 | 26.3 |
| 314+168 | 10.0 | – | 22.00 | 0.00 | – | – | – | – | – | – |
| 324+436 | 5.0 | 2.72 | – | – | 69 | 30 | 1 | 51.8 | 23.2 | 28.6 |
| 342+961 | – | – | 24.50 | 0.50 | 52 | 46 | 2 | 30.0 | 18.0 | 12.0 |
| -do- | – | – | – | – | 4 | 21 | 75 | Non Plastic | | |
| -do- | – | – | – | – | 31 | 50 | 19 | 25.0 | 18.0 | 7.0 |
| -do- | – | – | – | – | 53 | 41 | 6 | 41.5 | 20.9 | 20.6 |
| 349+812 | 20.0 | 2.73 | – | – | 61 | 38 | 1 | 56.0 | 29.0 | 27.0 |
| 353+216 | – | – | – | – | 30 | 55 | 15 | 23.9 | 17.8 | 6.1 |
| -do- | – | – | – | – | 51 | 42 | 7 | 41.5 | 19.8 | 21.7 |
| -do- | – | – | – | – | 10 | 67 | 23 | Non Plastic | | |
| 358+742 | 10.0 | 2.72 | 28.00 | 0.00 | 59 | 41 | 0 | 39.2 | 21.0 | 18.2 |
| 360+212 | – | – | – | – | 43 | 50 | 7 | 40.4 | 23.5 | 16.9 |
| -do- | – | – | – | – | 29 | 64 | 7 | 29.9 | 19.9 | 10.0 |
| -do- | – | – | – | – | 43 | 40 | 17 | 39.2 | 21.0 | 18.2 |
| 376+714 | 5.0 | 2.73 | – | – | 62 | 37 | 1 | 64.0 | 33.0 | 31.0 |

**Table A.3**

**Triaxial Shear Test (Uu Quick) CRBC Stage III**

From R.D.368+380 to R.D.768+660

(Data of WAPDA D.I.Khan C.R.B.I.P. Laboratory)

| R.D.No | Location | Depth (in feet) | Φ (°) | C (P.S.I.) |
|---|---|---|---|---|
| 385+380 | Ghdh Nala | 10'00" | 9 | 22.60 |
| | | 10'00" | 9 | 23.00 |
| | | 10'00" | 12 | 18.30 |
| | | 10'00" | 11 | 19.40 |
| 417+250 | Khud wararuki | 39'06" | 10 | 19.70 |
| | | 37'09" | 8 | 23.60 |
| 419+190 | Valchri Nala | 10'00" | 18 | 6.90 |
| | | 15'00" | 10 | 18.70 |
| | | 20'00" | 8 | 24.80 |
| 439+585 | Gajistan Nala | 10'00" | 13 | 8.20 |
| | | 10'00" | 14 | 9.20 |
| | | 15'00" | 16 | 7.20 |
| 472+330 | Sherana Nala | 10'00" | 10 | 17.30 |
| | | 20'00" | 18 | 5.00 |
| | | 15'00" | 15 | 8.10 |
| | | 20'00" | 21 | 3.40 |
| 449+540 | Ramak Nala | 59'09" | 10 | 16.80 |
| | | 38'09" | 11 | 17.10 |
| 543+345 | Ladle Wala Khud | 57'09" | 16 | 7.80 |
| 754+856 | Dhauri Nala | 22'09" | 14 | 9.70 |
| 764+555 | Sheeran Nala | 19'00" | 15 | 9.40 |

**Table A.4** **The Result of Field Density Test**

(Data of WAPDA D.I.Khan C.R.B.I.P. Laboratory)

| Location (R.D.No.) | Material | Wet Density (lbs/ft3) | Dry Density (lbs/ft3) | Field M.C. (%) |
|---|---|---|---|---|
| 303+884 | Hard Silty Clay | 116.00 | 103.20 | 13.0% |
| 309+654 | Hard Silty Clay | 111.30 | 101.90 | 9.2% |
| 349+000 | Silty Clay | 106.40 | 93.50 | 13.8% |
| 324+436 | Silty Clay | 119.30 | 100.80 | 18.4% |
| 289+220 | Hard Silty Clay | 112.20 | 102.00 | 10.0% |
| 284+600 | Hard Silty Clay | 120.70 | 105.00 | 15.0% |
| 308+381 | Hard Silty Clay | 108.30 | 101.20 | 7.0% |
| 358+742 | Silty Clay | 101.00 | 93.50 | 8.0% |
| 314+168 | Clayey Silt | 99.45 | 88.00 | 13.0% |

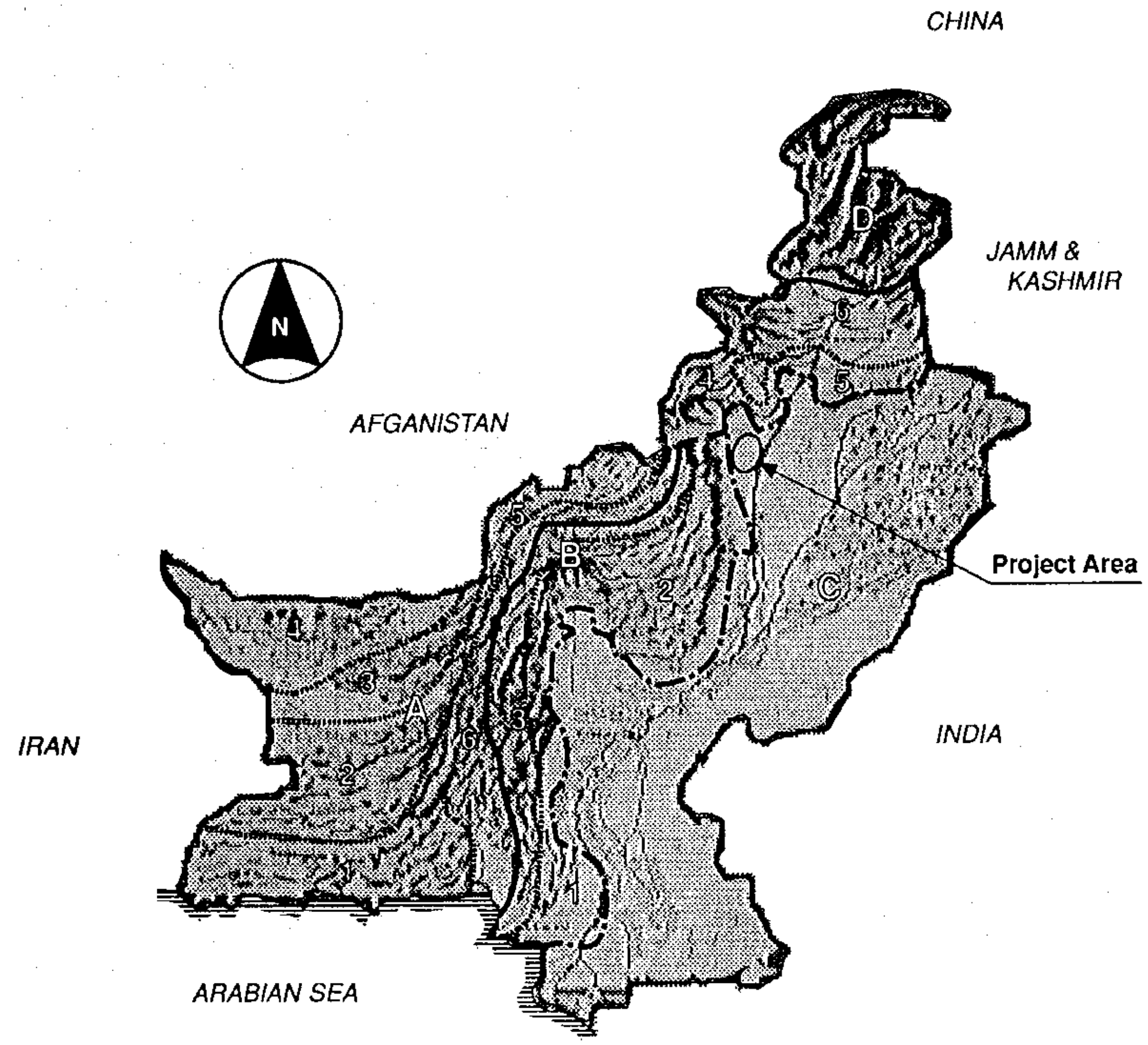
**Table A.5 Measured discharge of three streams that enter D.I.Khan District**

**1962 - 63**

(Data reported by Surface Water Circle, WASID, WAPDA, Lahore)

| Stream | Drainage area (sq. mi.) | Year | Discharge: Million acre-ft | Discharge: Mean cfs | Discharge: Cfs per sq. mi. |
|---|---|---|---|---|---|
| Tank Zam at | | | | | |
| Jandola | 810 | 1961 | 0.156 | 215.0 | 0.256 |
| | | 1962 | 0.115 | 159.0 | 0.189 |
| | | 1963 | 0.170 | 234.0 | 0.279 |
| Gumal River at | | | | | |
| Khajuri Kach | 11,200 | 1962 | 0.337 | 466.0 | 0.042 |
| Gumal River near | | | | | |
| Kot Murtaza | 13,870 | 1960 | 0.385 | 531.0 | 0.038 |
| | | 1961 | 0.418 | 574.0 | 0.041 |
| | | 1962 | 0.289 | 400.0 | 0.029 |
| | | 1963 | 0.391 | 540.0 | 0.039 |
| Daraban (Zam) at | | | | | |
| Zam Tower | 432 | 1961 | 0.032 | 44.6 | 0.105 |

# FIGURES




A. BALUCHISTAN BASIN

1. South Makran belt
2. North Makran belt
3. Ras Koh belt
4. Chagai belt
5. Zhob belt
6. Axial belt

B. INDUS BASIN

1. Kirthar province
2. Sulaiman province
3. Axial belt
4. Waziristan
5. Trans-Indus and Salt Ranges
6. Kohat-Potwar province

C. INDUS PLAIN

D. NORTHERN MONTANE AREA

**Fig.A.1 Geologic Provinces of Pakistan**

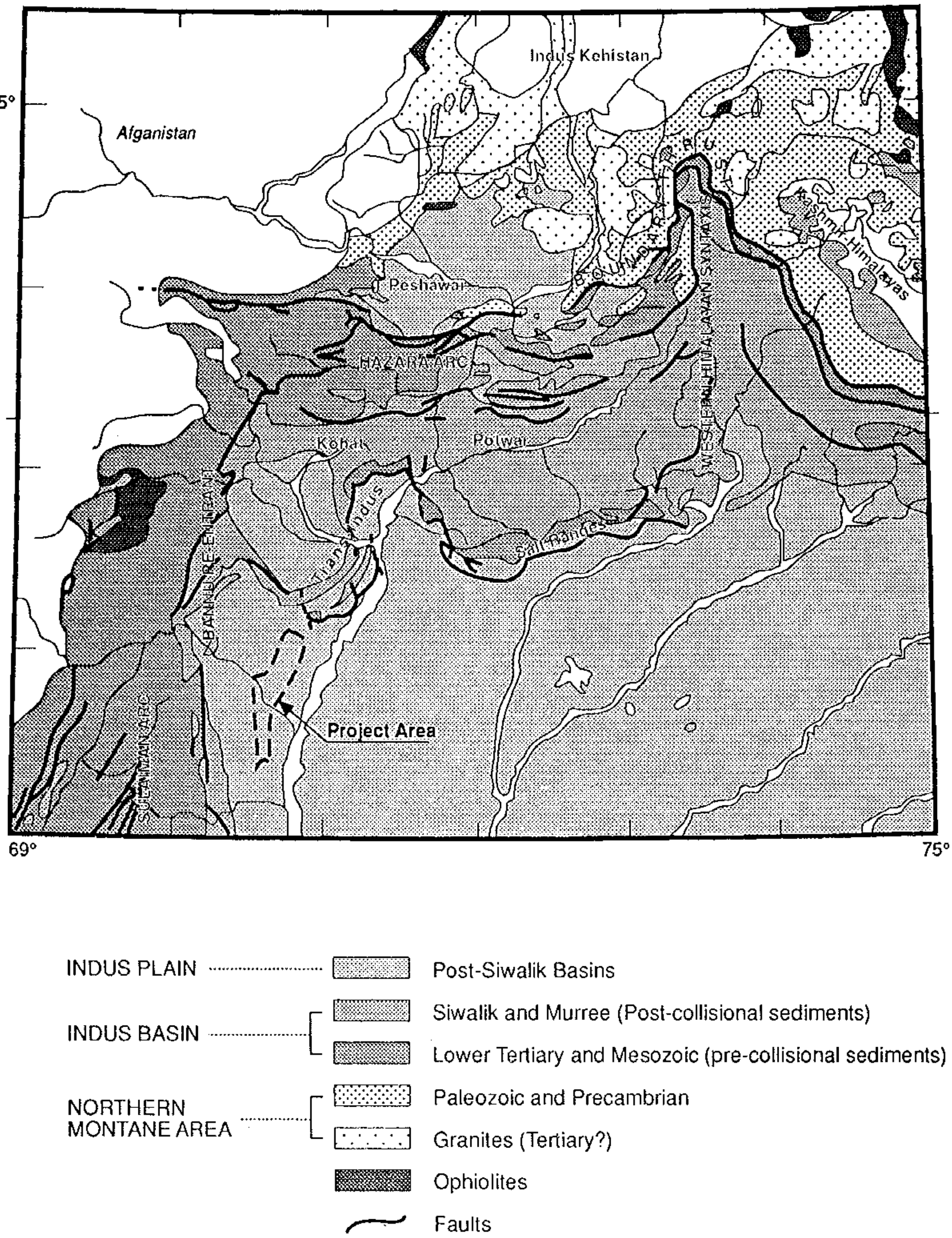



**Fig.A.2 Geology in Northern Pakistan**

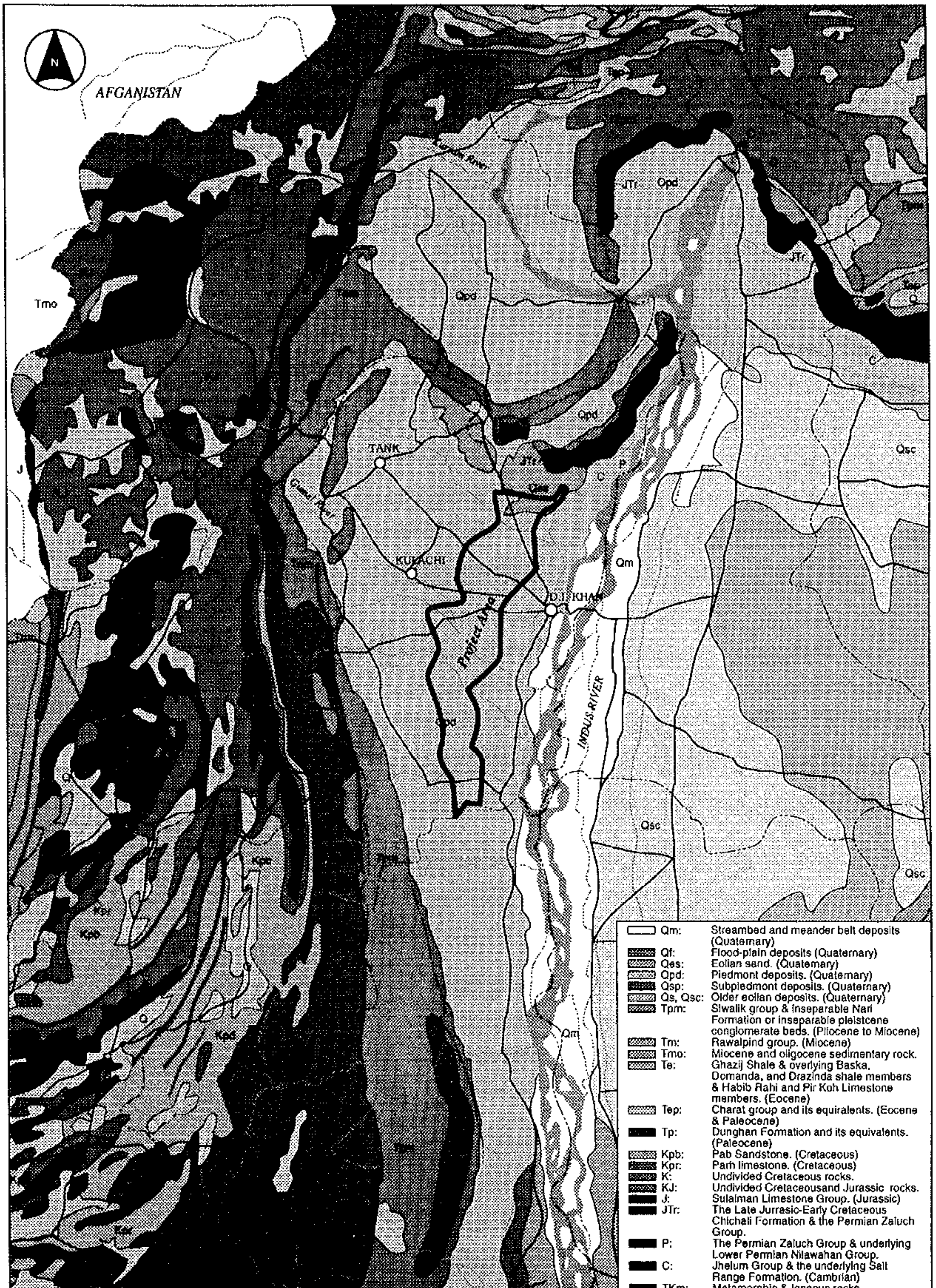



**Fig. A.3(1) Geological Map around Project Area**

## Fig. A.3(2) Explanation

Recent

Qm :Streambed and meander-belt deposit.

Qf :Flood-plain deposit ( Sand deposits ).

Qes :Eolian sand; mostly barchan-type sand dunes ( Piedmont and related deposits ).

Qp :Piedmont deposits; coarse detrital material derived from adjacent high-lands.

Qsp :Subpiedmont deposits; finer detrital material derived from adjacent high-lands ( Deposits of extinct streams ).

Qfx :Flood-plain deposits ( lower terrace ).

Pleistocene and Early Recent ( Older eolian deposits )

Qs :Eolian sand; barchan, surf, or complex dunes; relief less than 100 feet.

Qsc :Eolian sand deposits; deposits of extinct streams, and the Chung formation, undivided.

Pliocene and Miocene sedimentary rocks

Tpm :Siwalik group & inseparable Nari Formation ( Oligocene ); mostly sandstone, conglomerate, and siltstone; also include inseparable Pleistocene conglomerate beds; thicknesses up to 15,000 feet.

Miocene sedimentary rocks

Tm :Rawalpindi group ( Kamlial Formation and Murree Formation ); mostly dark colored shale and sandstone of continental origin.

Eocene sedimentary rocks

Te :Ghazij Shale & overlying Baska, Domanda, and Drazinda shale members & Habib Rahi and Pir Koh limestone members; mostly limestone, some marl and shale.

Eocene and Paleocene sedimentary rocks

Tep :Charat Group ( Kohat Formation, Mamikhel Clay, Chor Galli Formation, and Bhadrar Formation ), Shekhan Limestone, Panoba Shale, Sakesar Limestone, and Nammal Formation, all Eocene in age, and the Patala Formation, Lockhart Limestone, Hangu Formation, and Dhak Pass Formation, all Paleocene in age are included in the Salt Range and Kohat-Potwar province.

Paleocene sedimentary rocks

Tp :Dunghan Formation and its equivalents; blue or gray limestone with some shale and sandstone in the basal portion; mostly Paleocene in age but fossil evidence indicates Late Cretaceous-Early Eocene sedimentation; thicknesses up to 2,500 feet.

Cretaceous and Jurassic sedimentary rocks

Kpb :Pab Sandstone; sandstone with marly limestone near base.

Kpr :Parh limestone; mostly limestone, some marl and shale; include Sember Formation; mostly shale, marl and limestone.

K :Undivided Cretaceous rocks; include Pab Sandstone, Mughal Kot formation, Parh limestone, Goru formation, Lumshiwal Sandstone, and Chichali & Sembar Formation.

KJ :Undivided Cretaceous and Jurassic Groups; thickness about 1,300 feet.

J :Sulaiman Limestone Group ( Takatu(Chiltan) limestone, Anjira formation, Loralai limestone ) and the underlying Spingwar formation

Jurassic and Triassic sedimentary rocks

JTr :The Late Jurassic-Early Cretaceous Chichali Formation and the Permian Zaluch Group in the Salt and Trans-Indus range, ( narrow inseparable outcrops ); mostly limestone and interbedded shale.

Permian sedimentary rocks

P :The Zaluch Group ( Products limestone ); mostly limestone with some shale and sandstone beds in basal and upper portion, underlying Lower Permian Nilawahan Group ( Lavender clay, Speckled sandstone, Olive series, and the basal Tachir boulder bed ).

Cambrian sedimentary rocks

C :The Jhelum Group ( Salt pseudmorph beds, Magnesian sandstone, Neobolus beds, and Purple sandstone ) & the underlying Salt Range Formation ( Punjab saline series ) of questionable Late Precambrian age.

Metamorphics and Igneous rocks

TKm :The Precambrian Metamorphic & Igneous rocks.

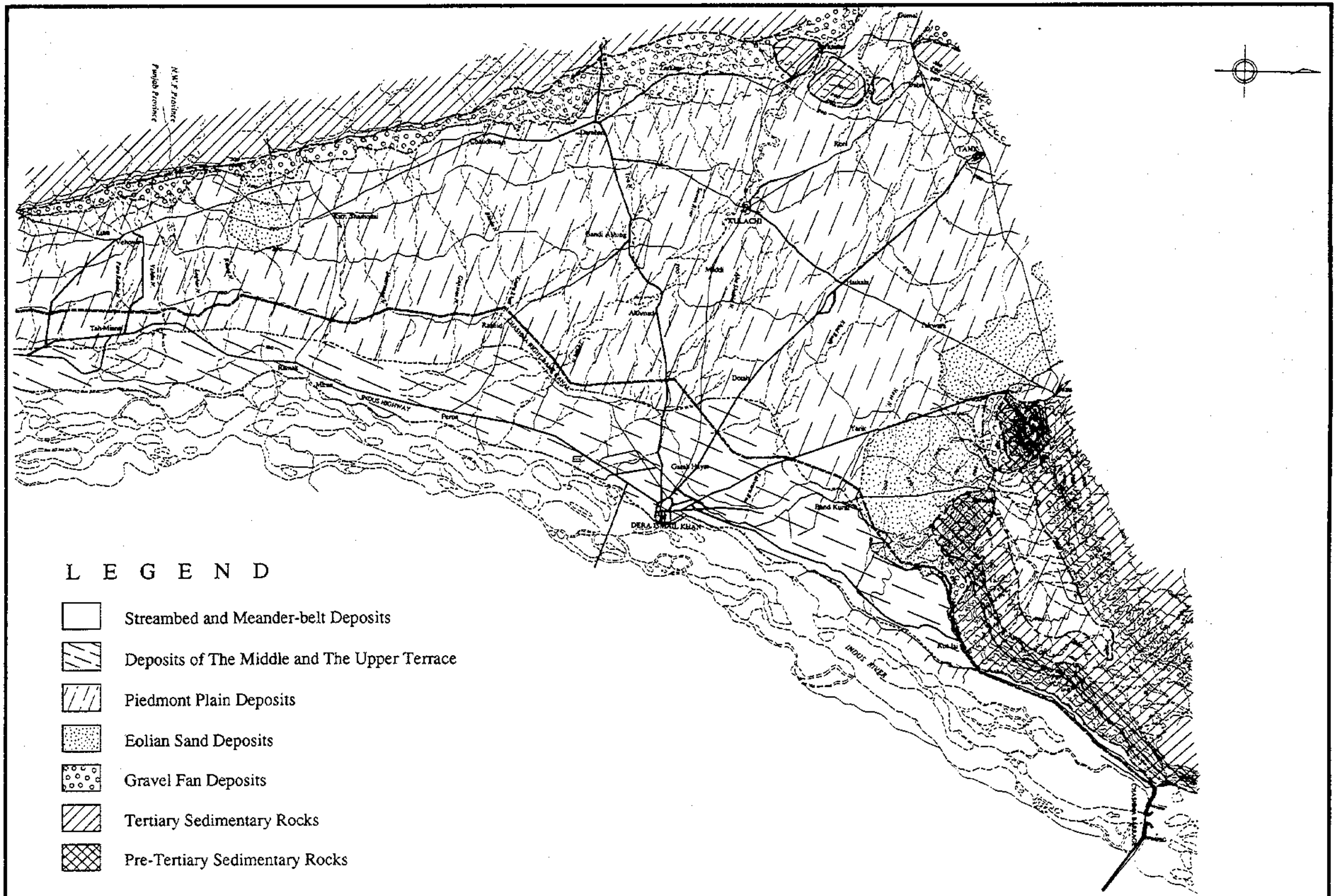



**Fig. A.4 Geological Map of D. I. Khan District**

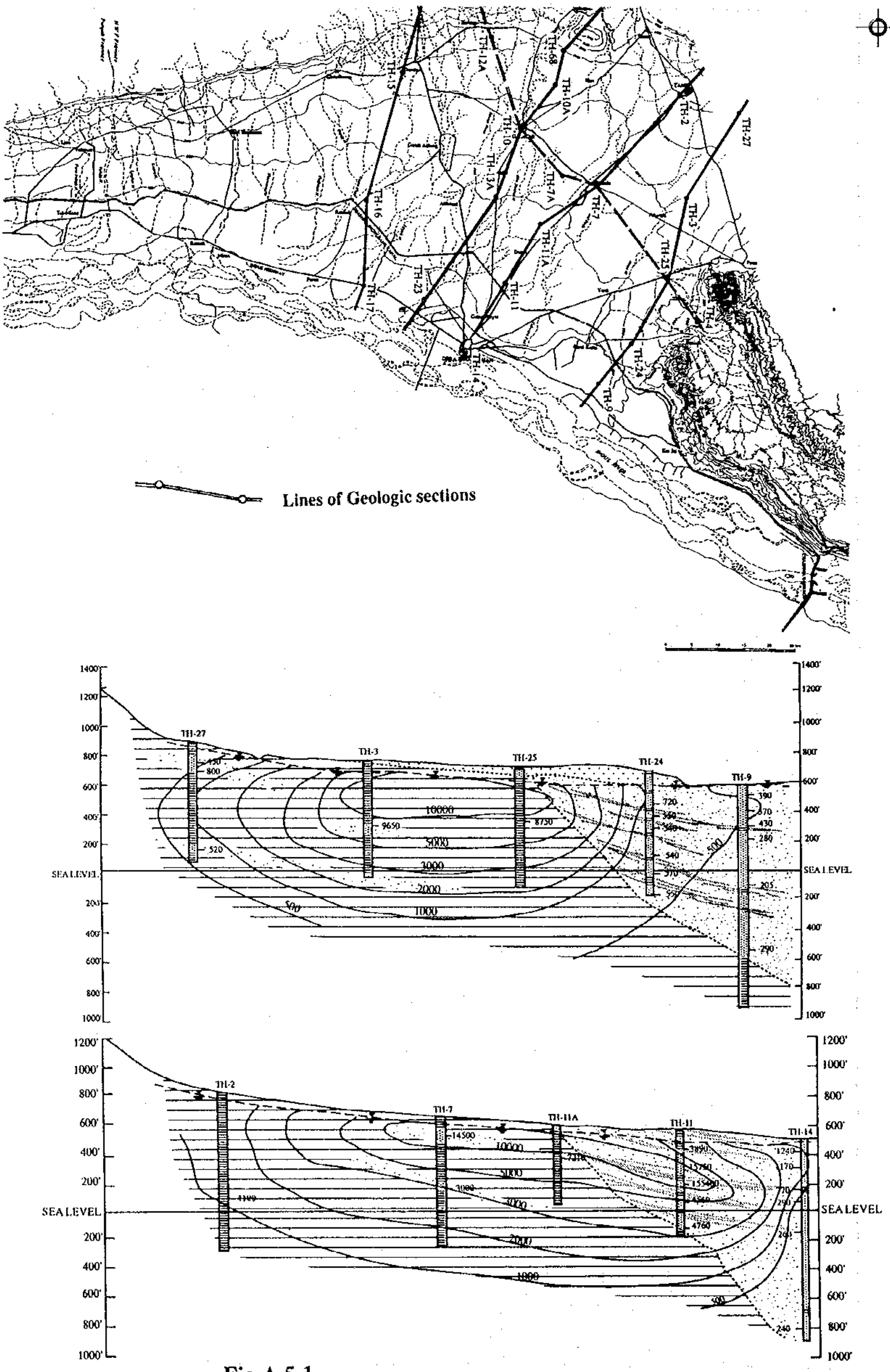



**Fig.A.5-1**
**Diagrammatic Sections of Unconsolidated Deposits and Vertical Distribution of Dissolved Solids**

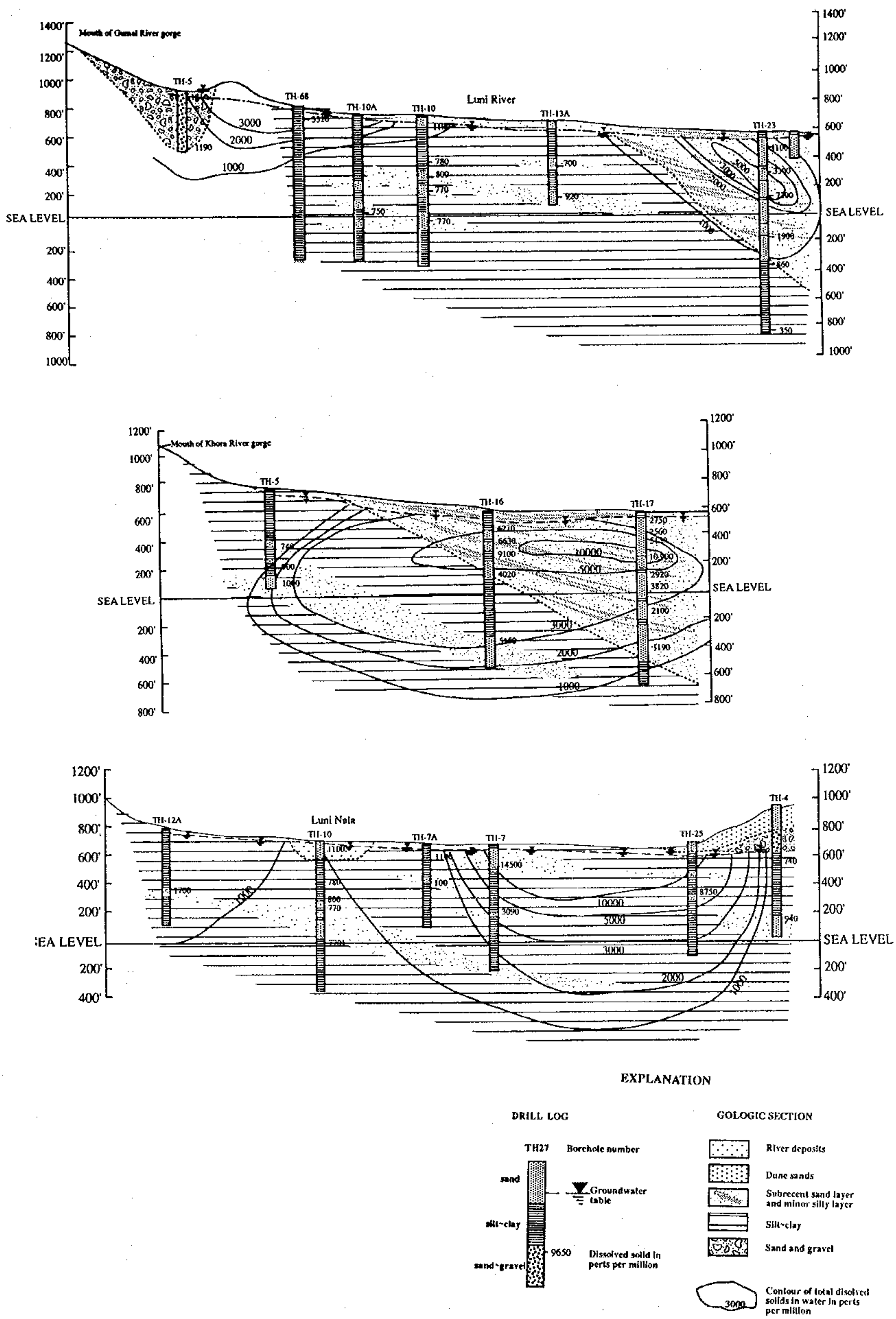



**Fig.A.5-2**
**Diagrammatic Sections of Unconsolidated Deposits and Vertical Distribution of Dissolved Solids**

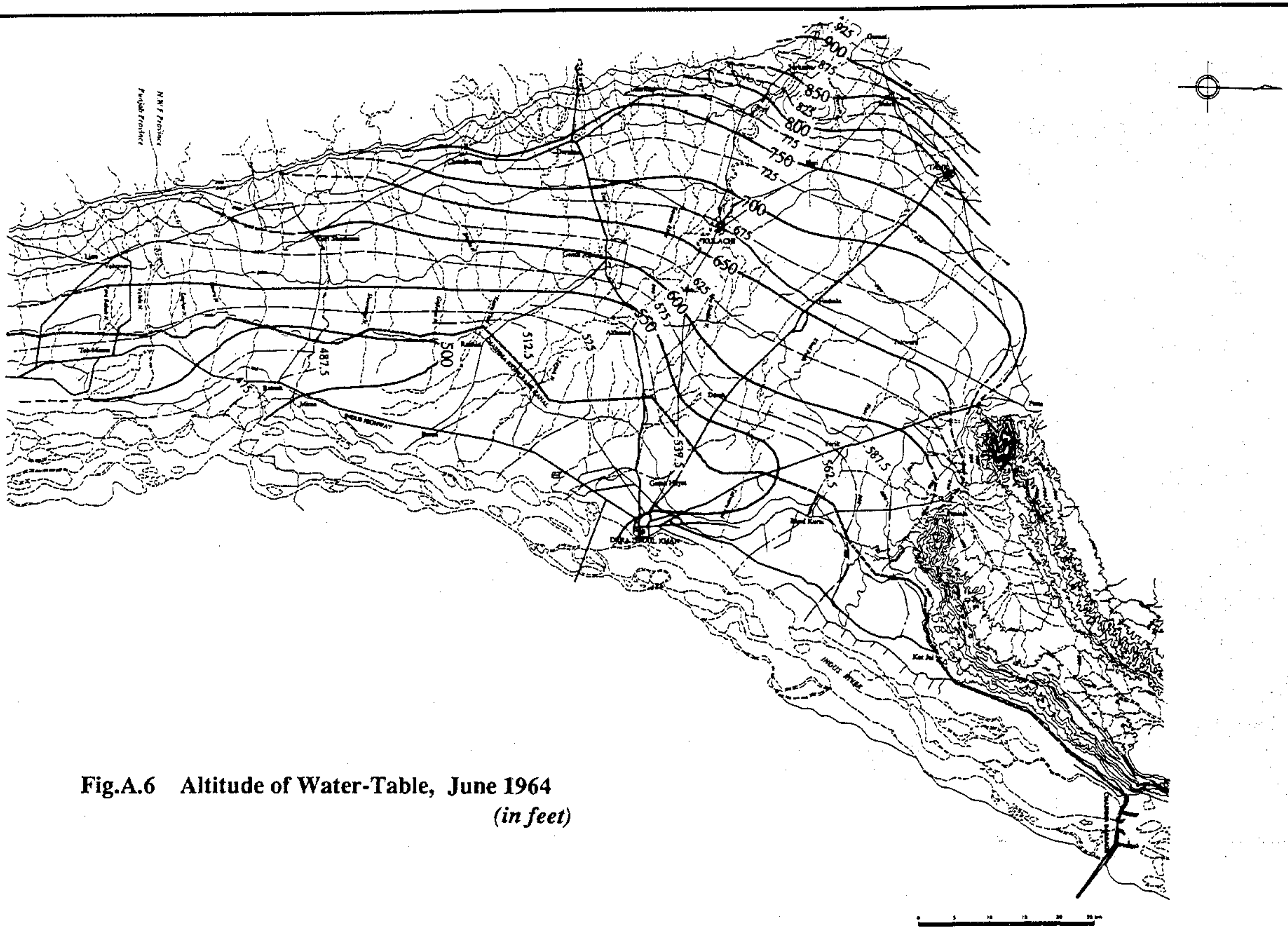



Fig.A.6 Altitude of Water-Table, June 1964
*(in feet)*

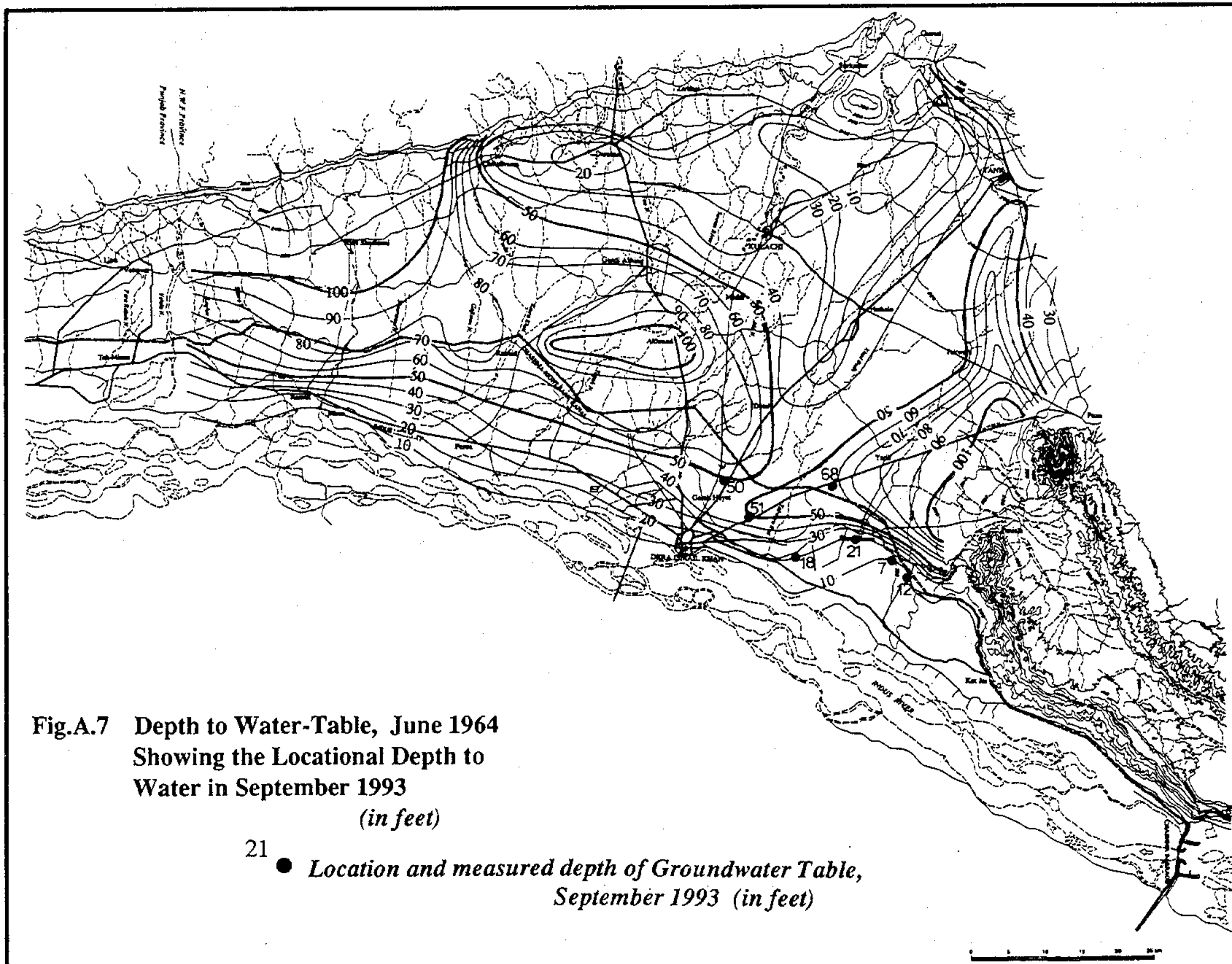
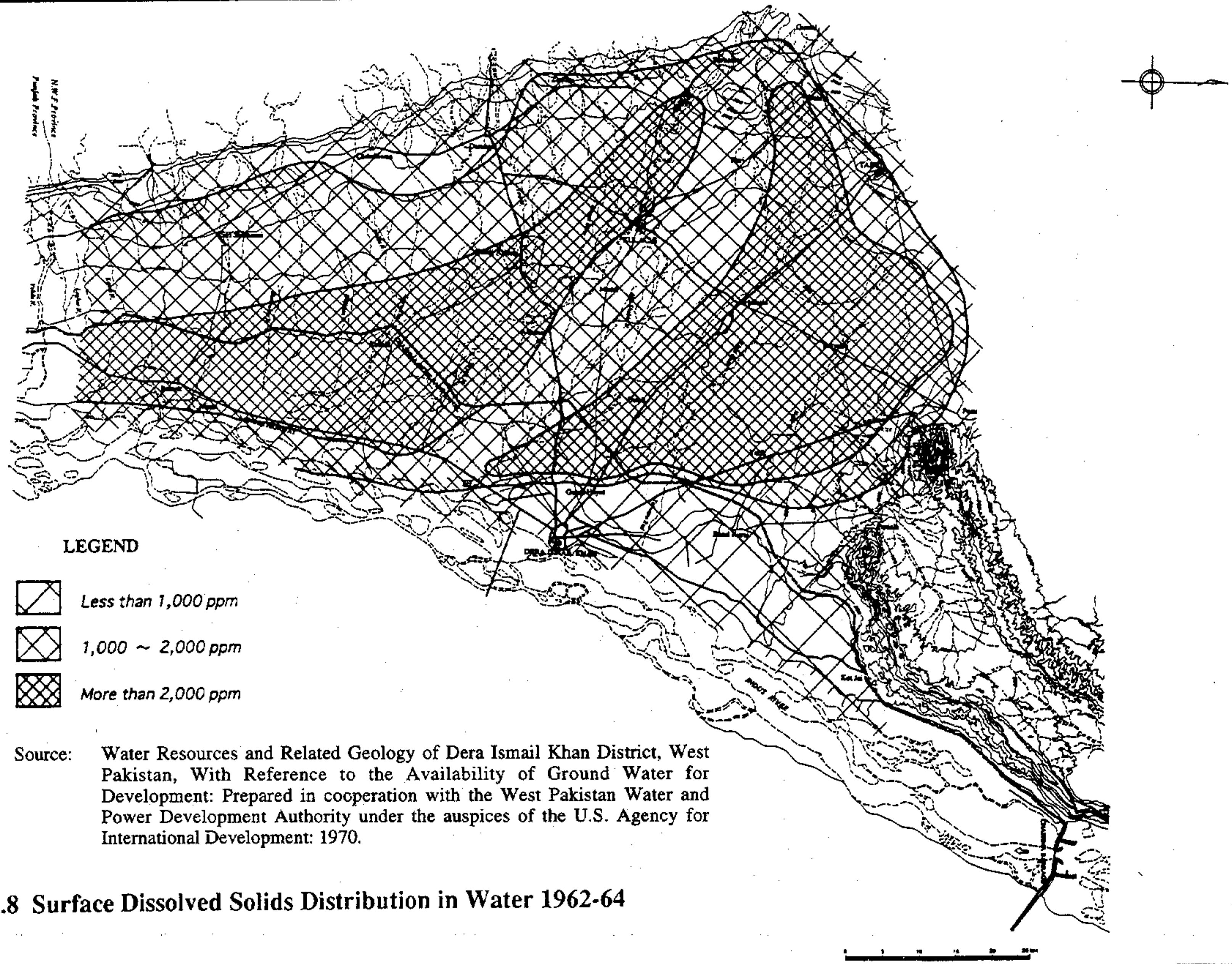


**Fig.A.7 Depth to Water-Table, June 1964 Showing the Locational Depth to Water in September 1993**
*(in feet)*

21 ● *Location and measured depth of Groundwater Table, September 1993 (in feet)*




Source: Water Resources and Related Geology of Dera Ismail Khan District, West Pakistan, With Reference to the Availability of Ground Water for Development: Prepared in cooperation with the West Pakistan Water and Power Development Authority under the auspices of the U.S. Agency for International Development: 1970.

**Fig.A.8 Surface Dissolved Solids Distribution in Water 1962-64**

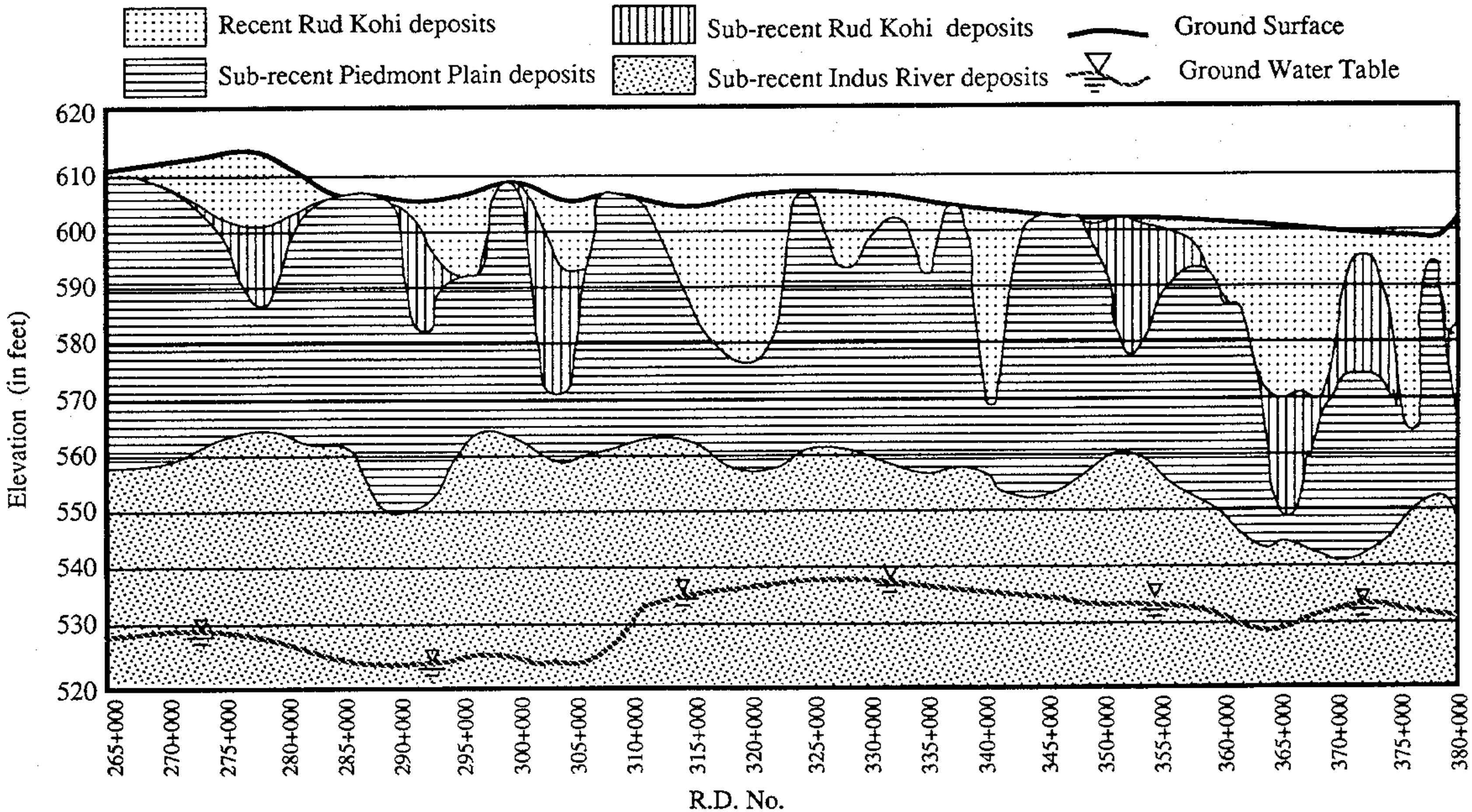



**Fig.A.9 Geologic Profile along CRBC Alignment of Construction Stage II**

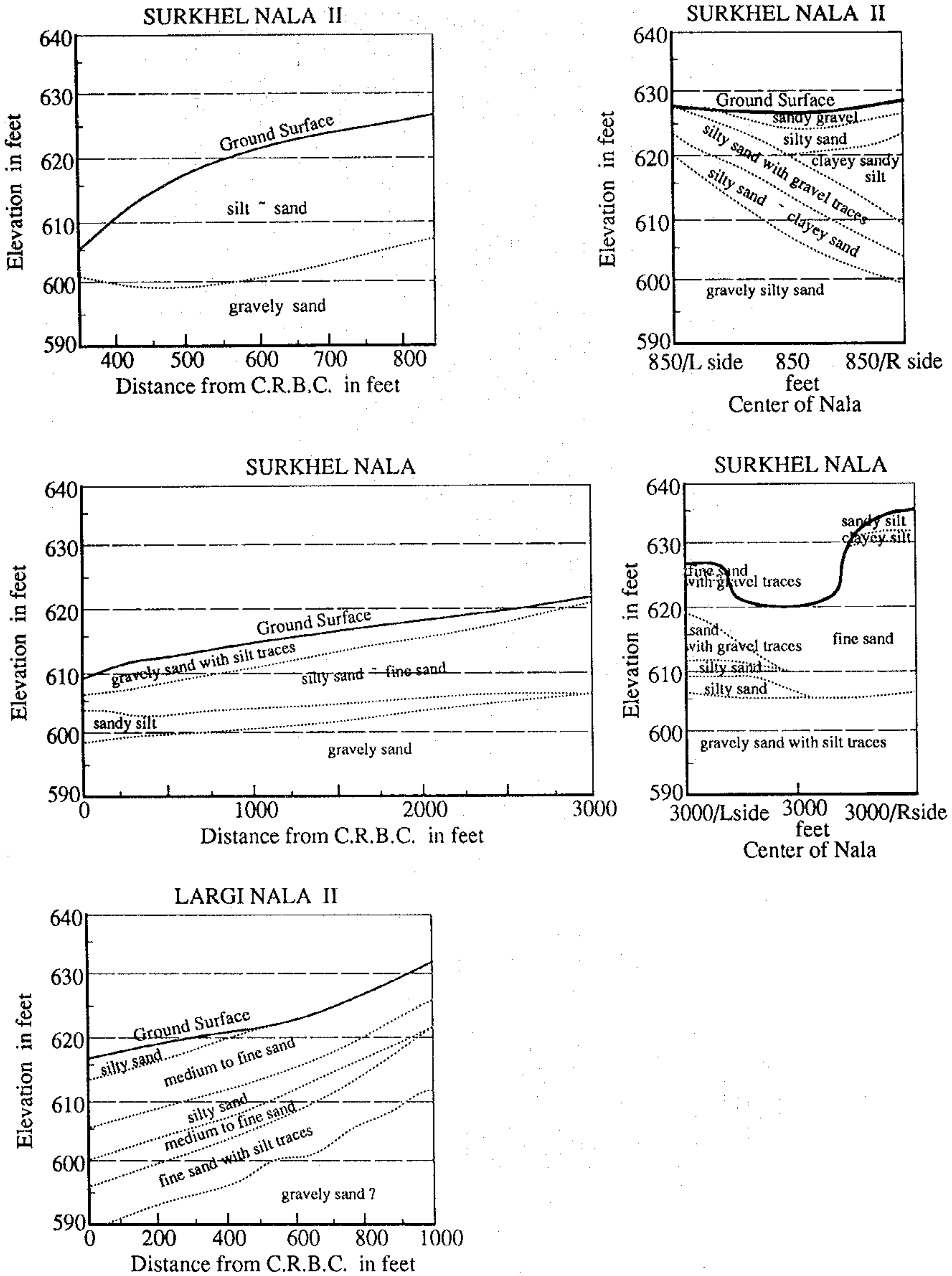



**Fig. A.10 Geologic Section near surface at the foot of Khisor Range**

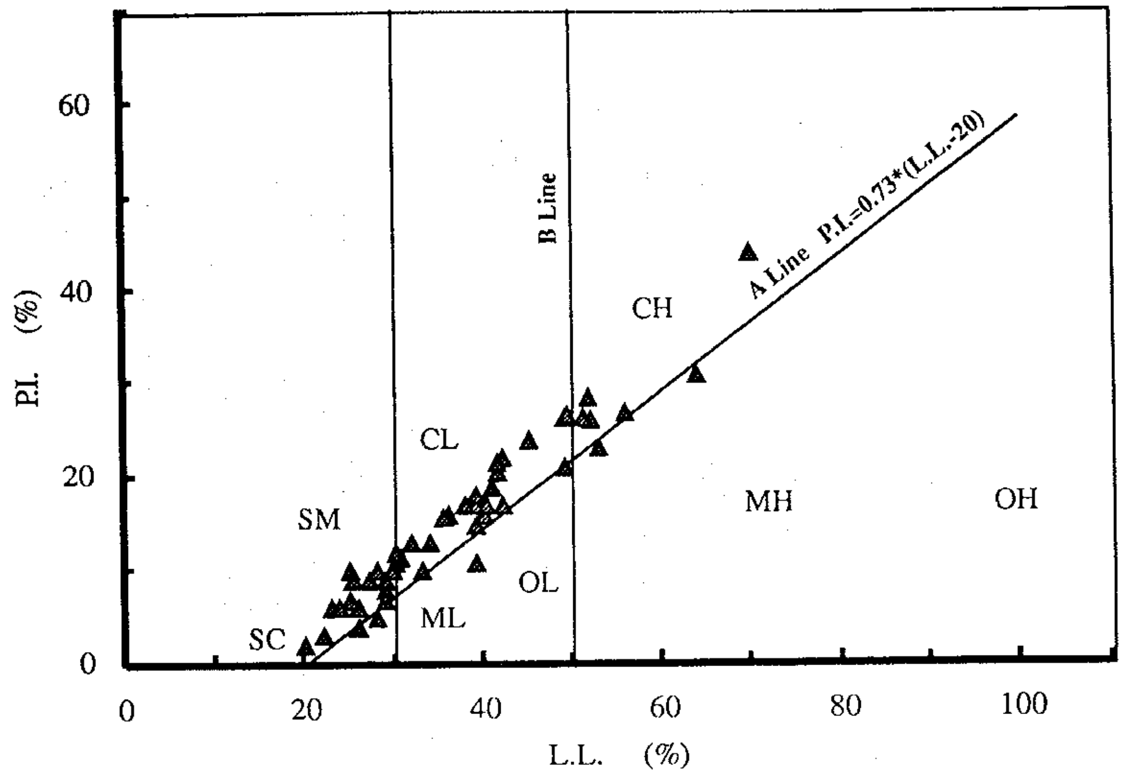



Fig.A.11 L.L./P.I. Relationship

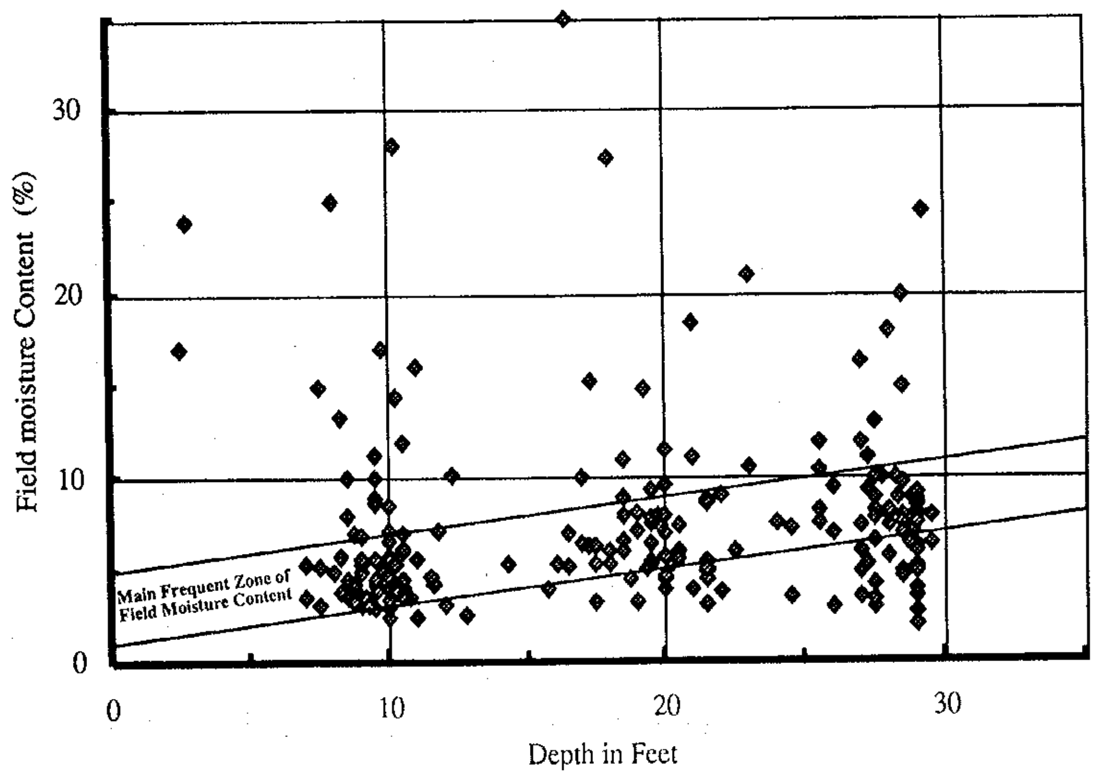



Fig.A.12 Frequency of Field Moisture Content to Depth

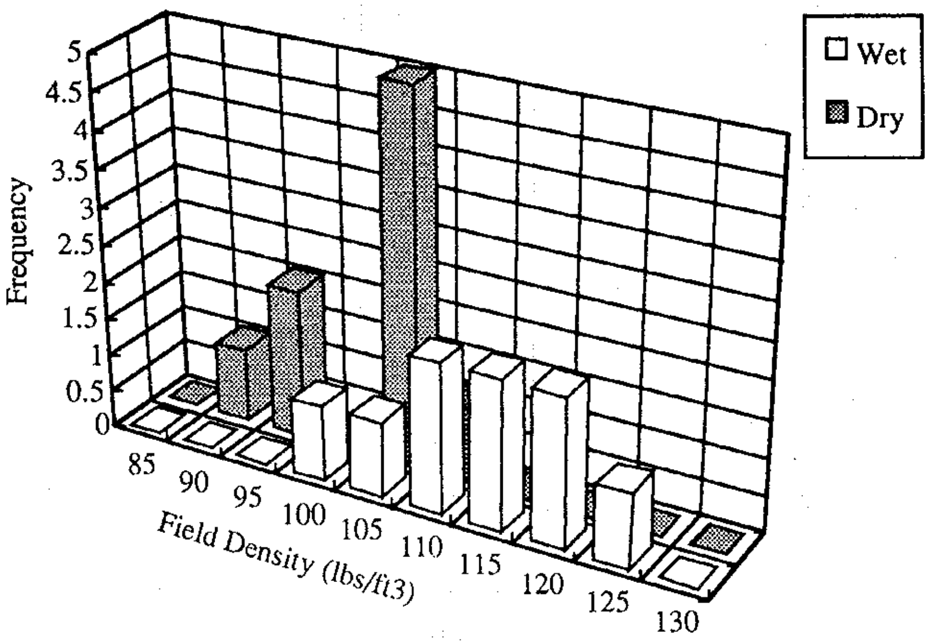



**Fig.A.13 Frequency of Field Density**

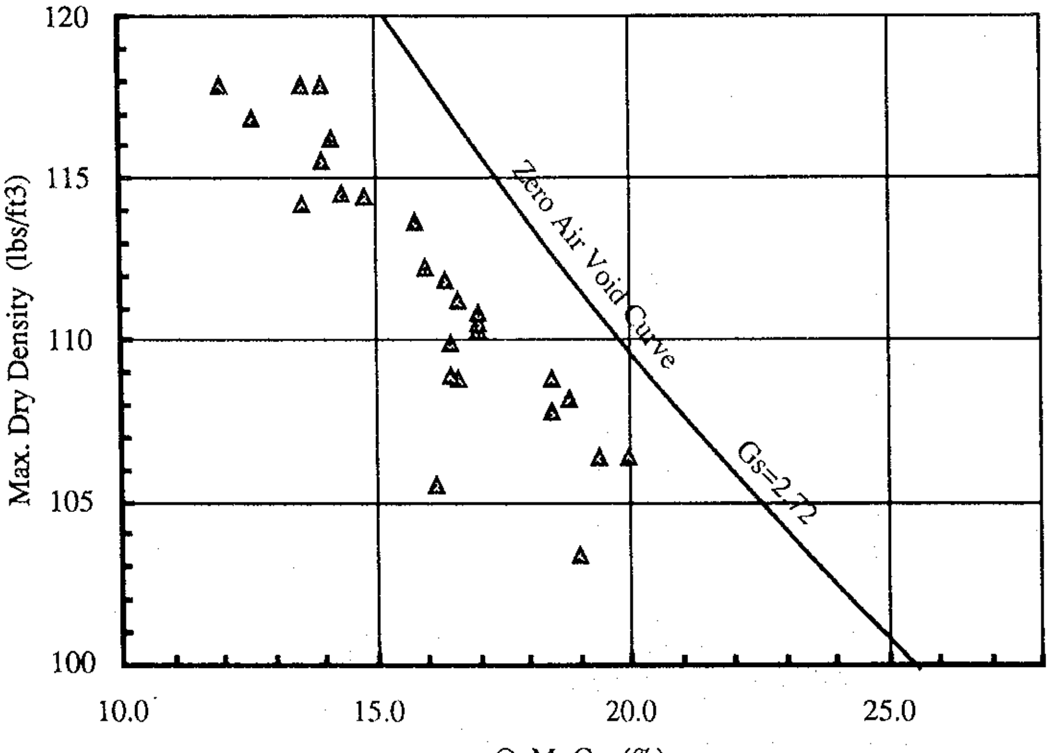



**Fig.A.14 O.M.C. / Max. Dry Density Relationship**

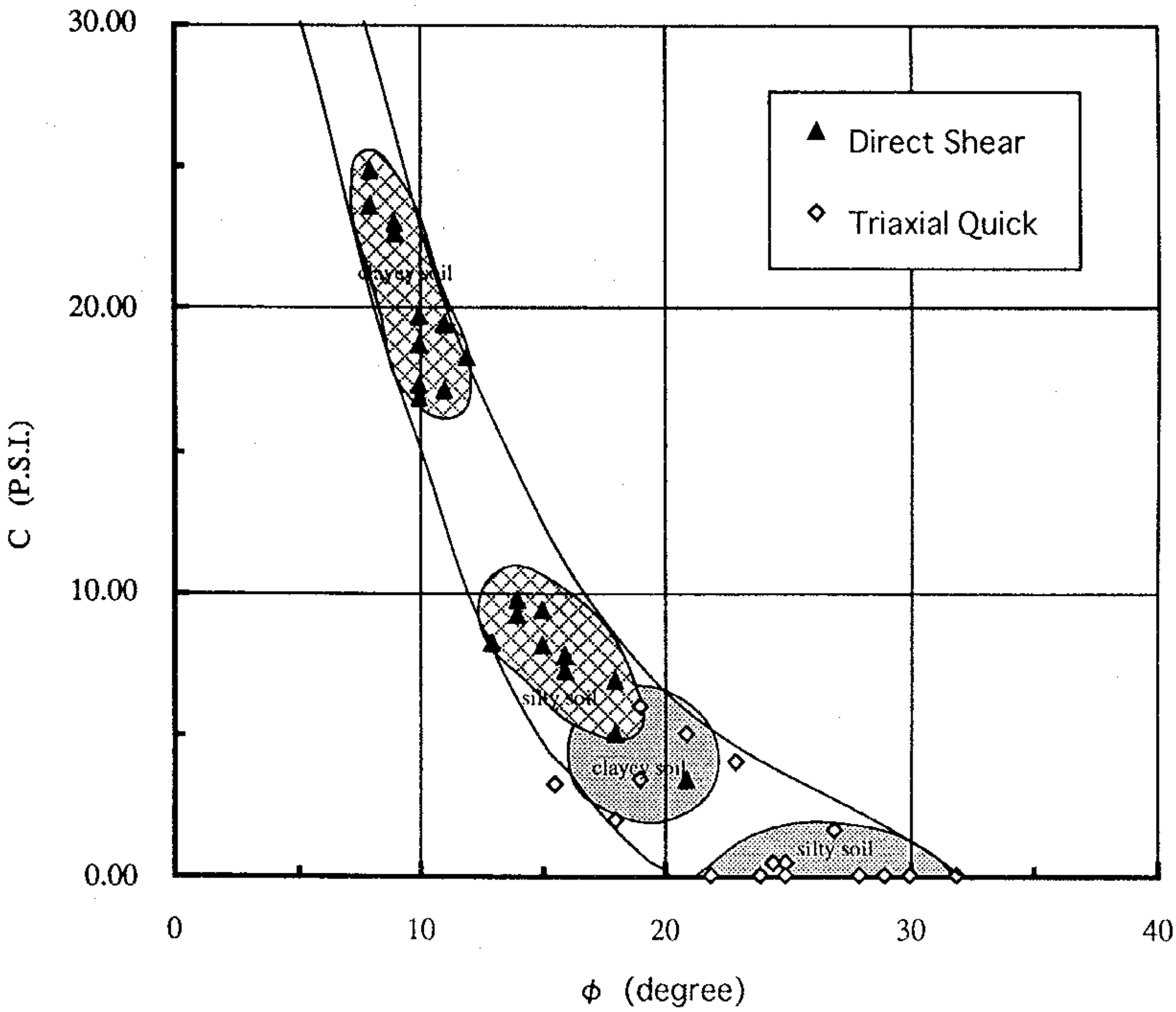



**Fig. A.15 Shearing Strength**

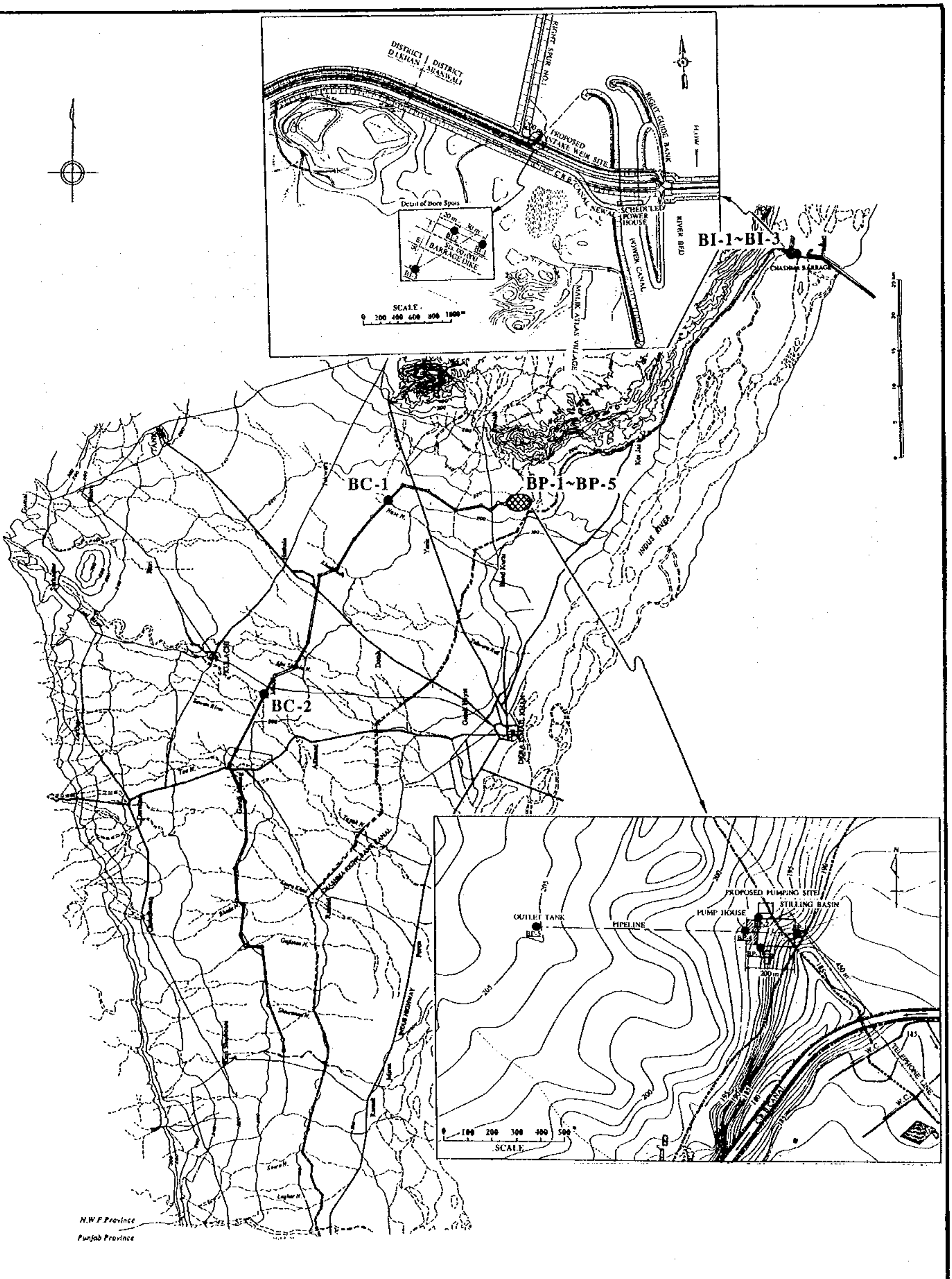



Fig.A.16 Location Map of Geotechnical Investigation Site

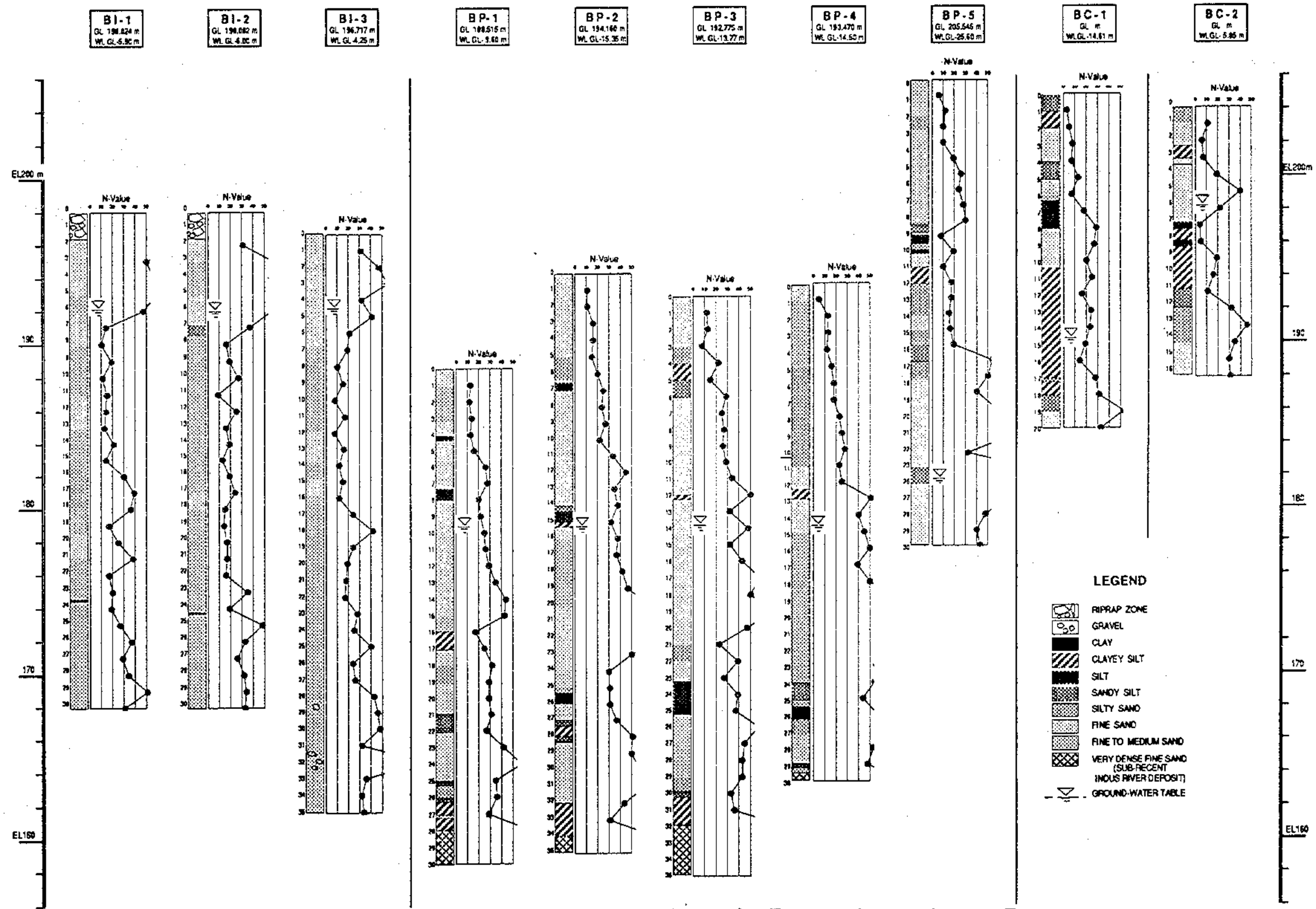
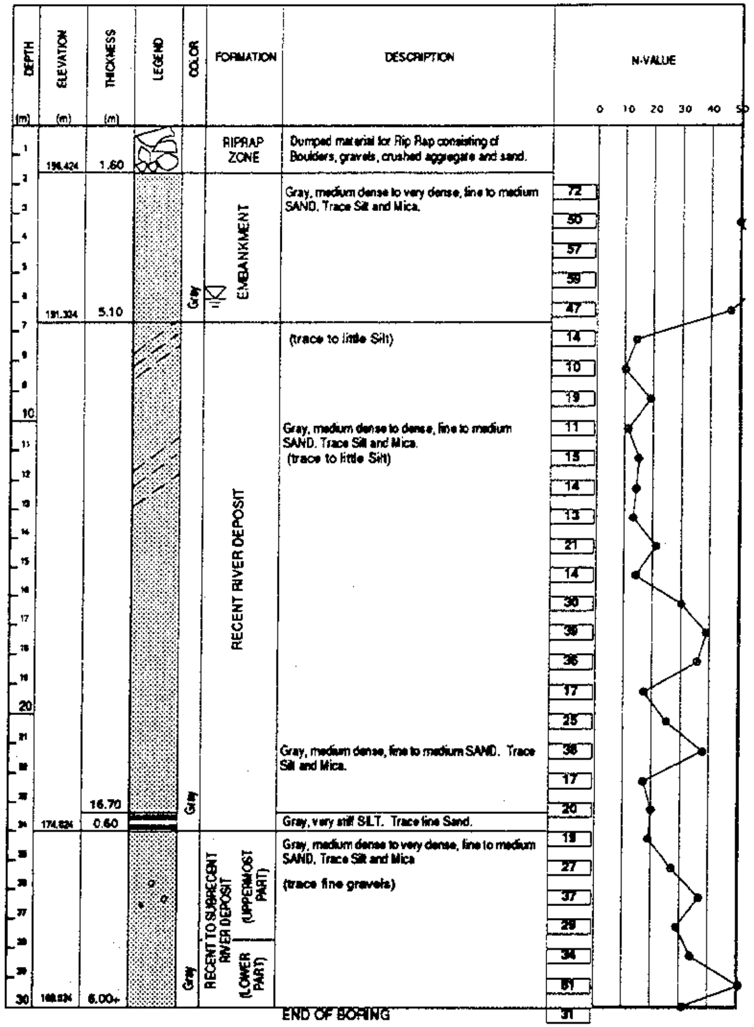



Fig.A.17 A Summary of Drill Hole Logs with Penetration Resistance Data

## Intake Site
## BI-1

GROUND ELEVATION: 198.024m
DEPTH OF WATER TABLE: GL-5.90m




## Intake Site
## BI-2

GROUND ELEVATION: 198.082m
DEPTH OF WATER TABLE: GL-6.00m

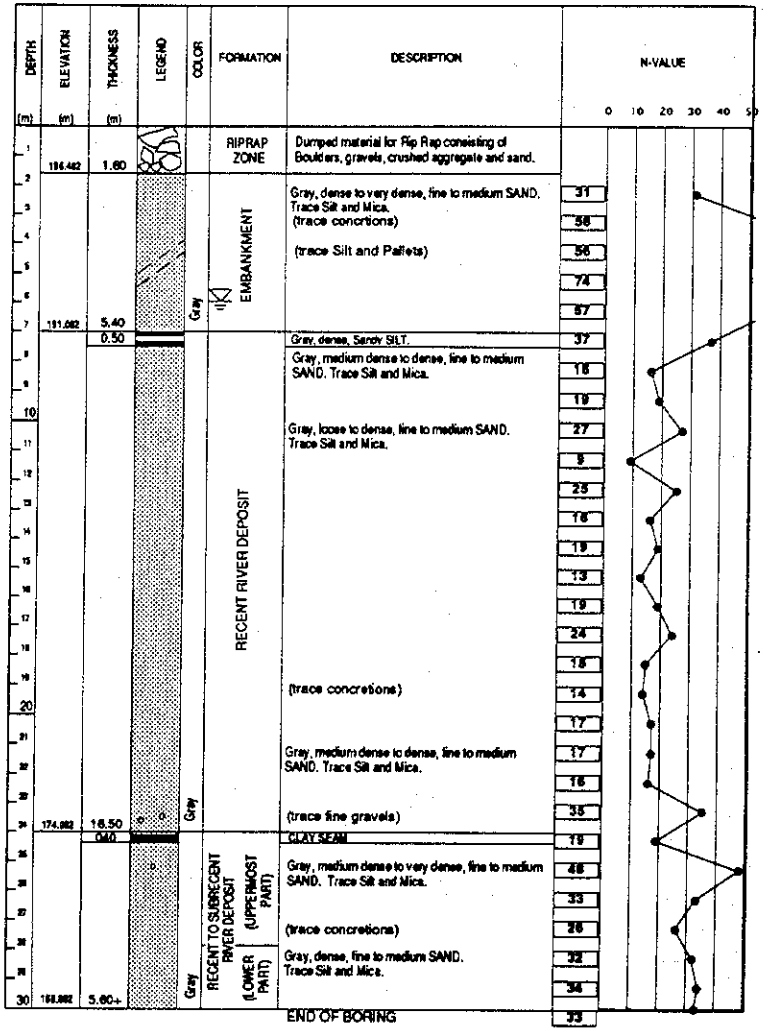
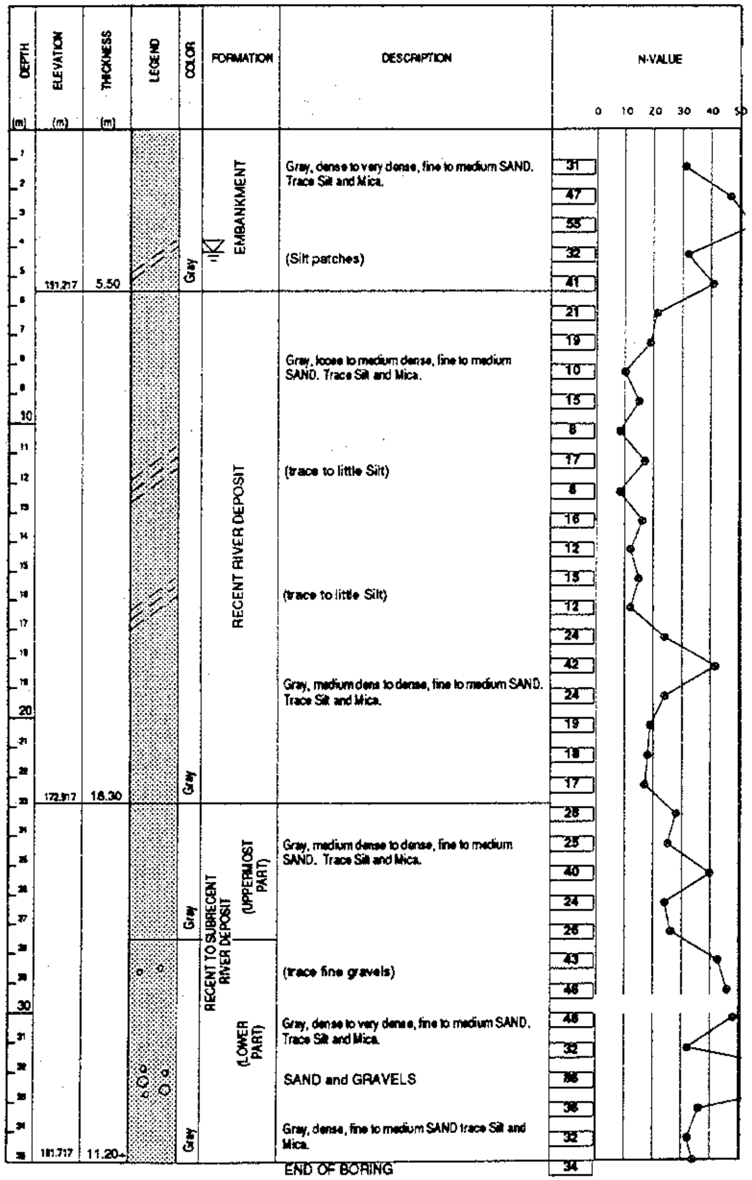



**Fig.A.18 - 1 Result of Drilling Log - 1**

## Intake Site
## BI-3

GROUND ELEVATION: 196.717m
DEPTH OF WATER TABLE: GL-4.25m




## Pumping Site
## BP-1

GROUND ELEVATION: 188.515m
DEPTH OF WATER TABLE: GL-9.60m

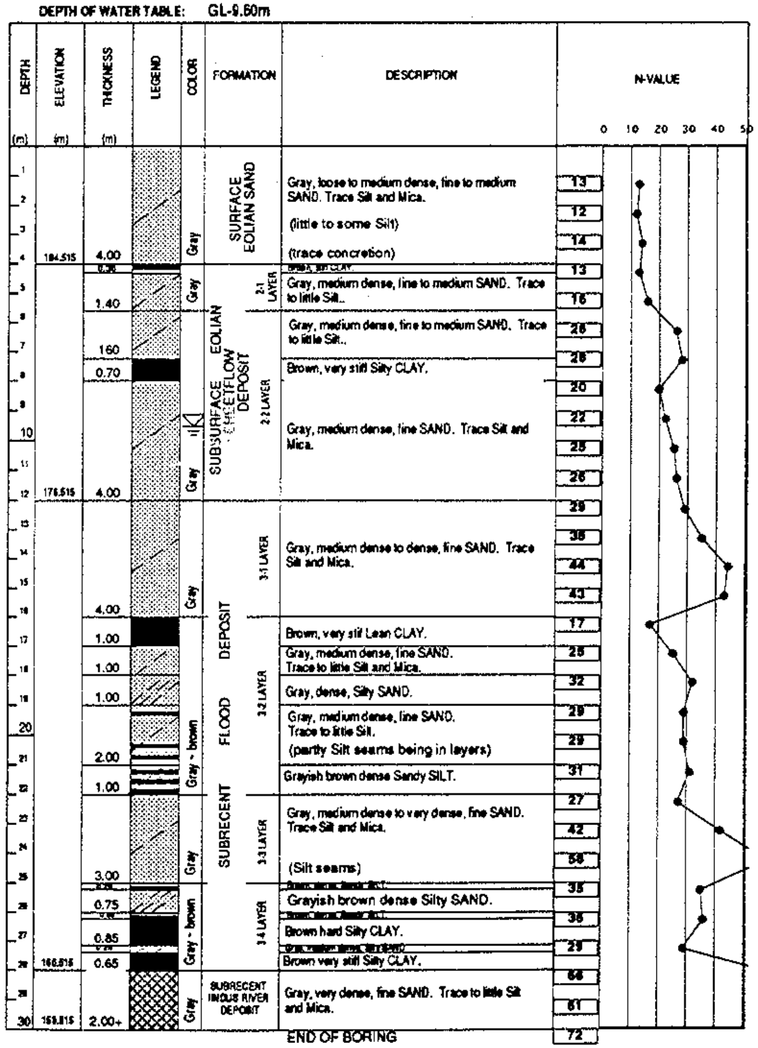
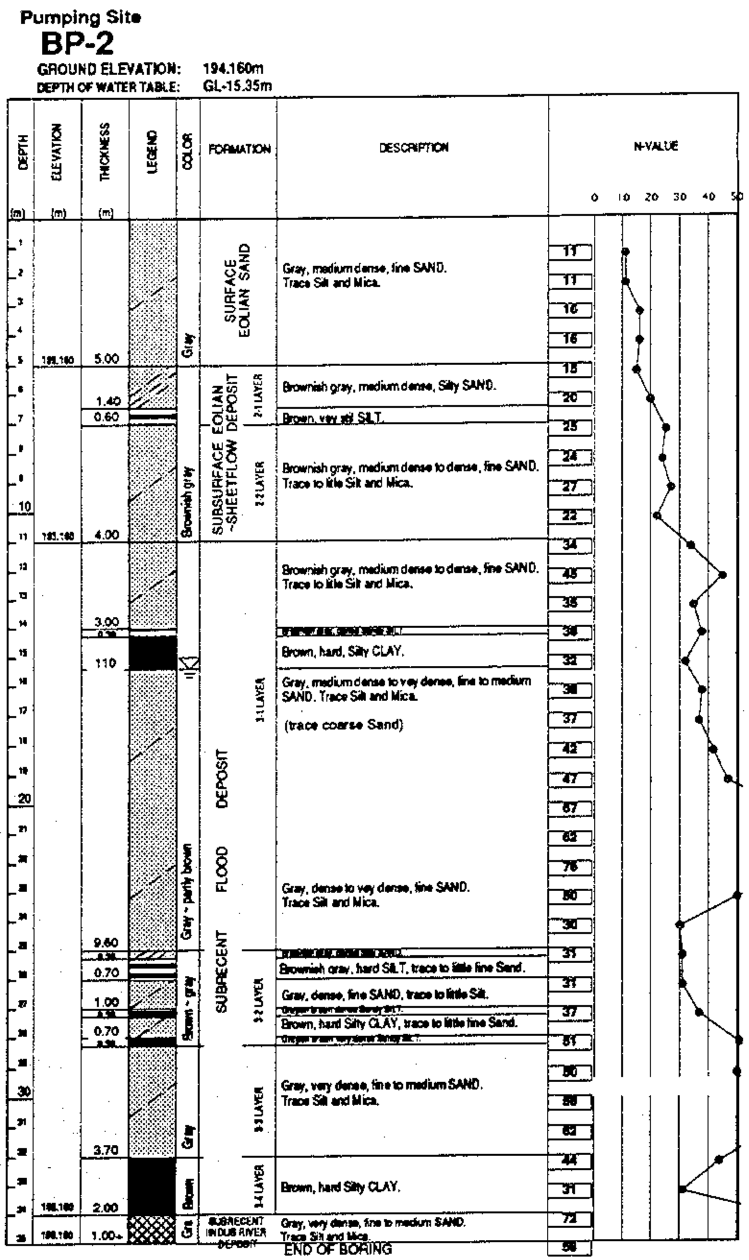



Fig A 18 - 2 Result of Drilling Log - 2



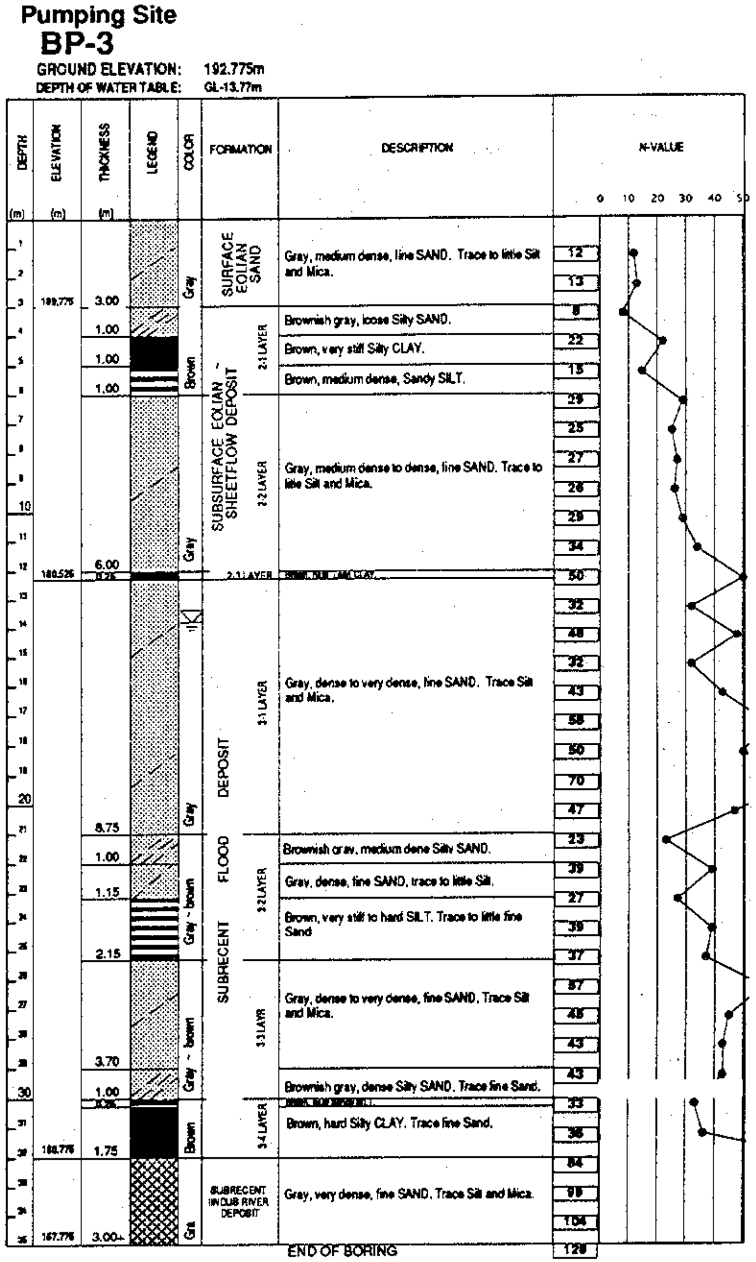
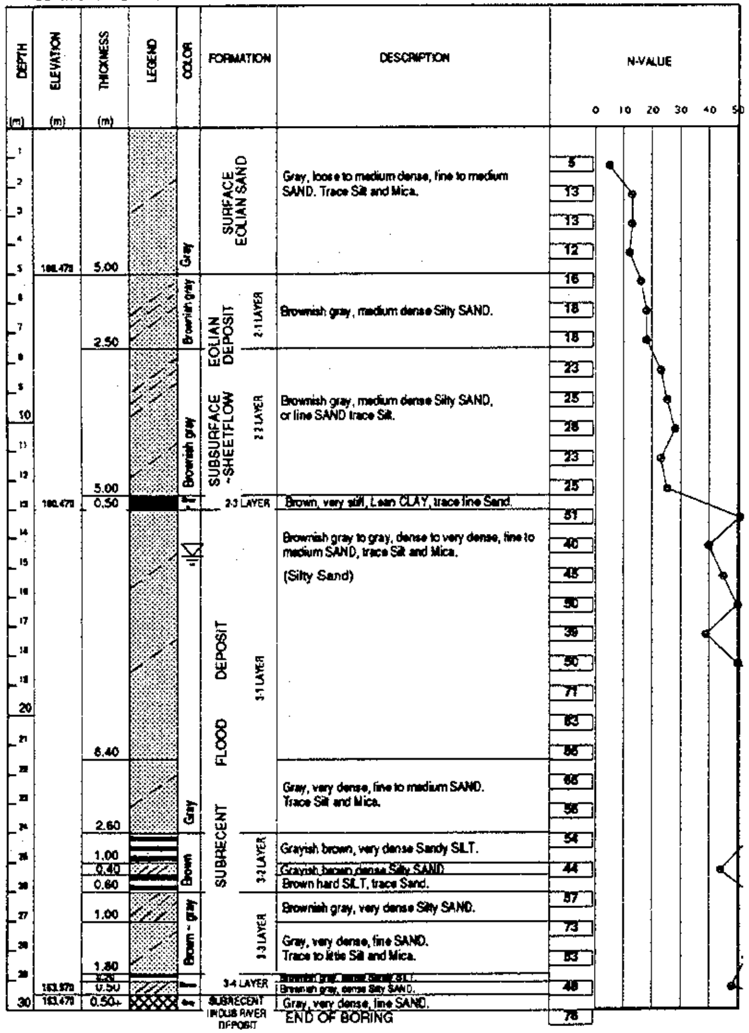




Fig. A.10 - 3 Result of Drilling Log - 3

**Pumping Site**
**BP-4**
GROUND ELEVATION: 193.470m
DEPTH OF WATER TABLE: GL-14.50m




**Pumping Site**
**BP-5**
GROUND ELEVATION: 205.545m
DEPTH OF WATER TABLE: GL-25.60m

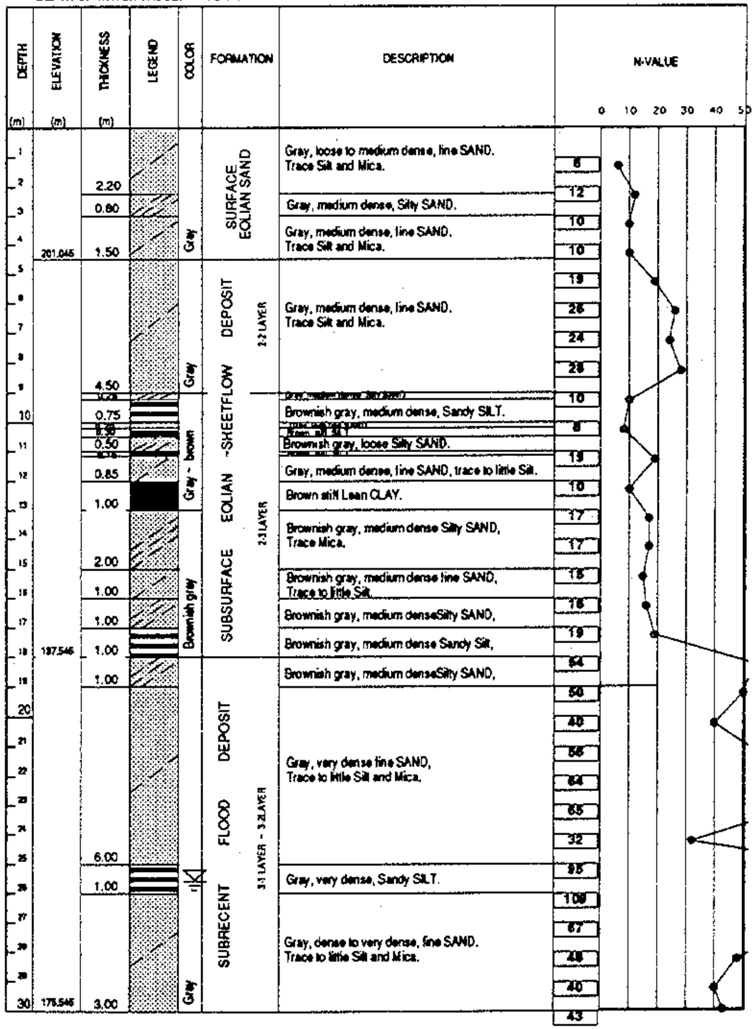
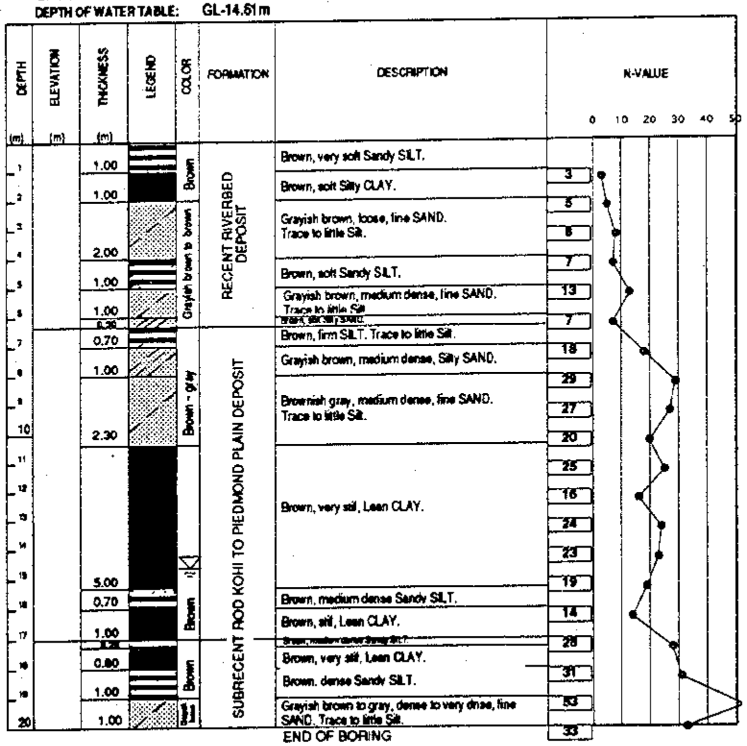



Fig.A.18 - 4 Result of Drilling Log - 4

Nose Nullah Riverbed

**BC-1**

GROUND ELEVATION:
DEPTH OF WATER TABLE: GL-14.61m




Luni Nullah Riverbed

**BC-2**

GROUND ELEVATION:
DEPTH OF WATER TABLE: GL-5.85m

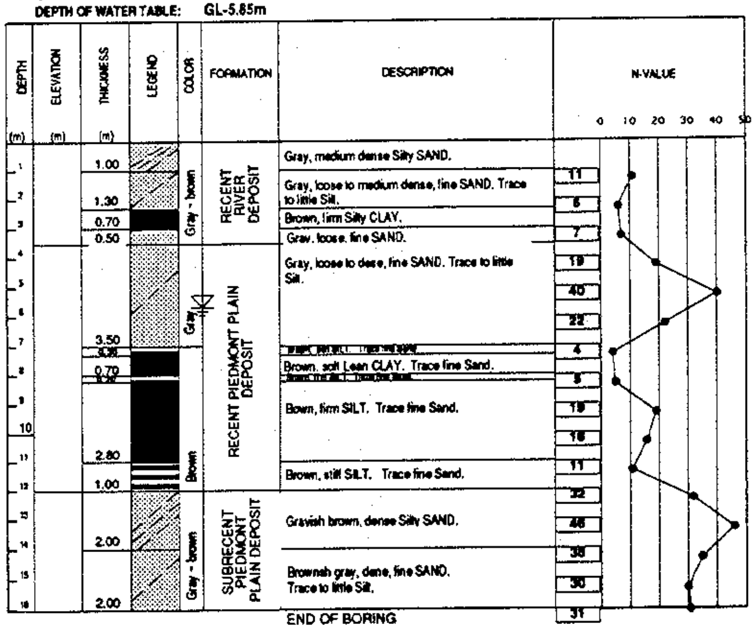



**Fig.A.18 - 5 Result of Drilling Log - 5**

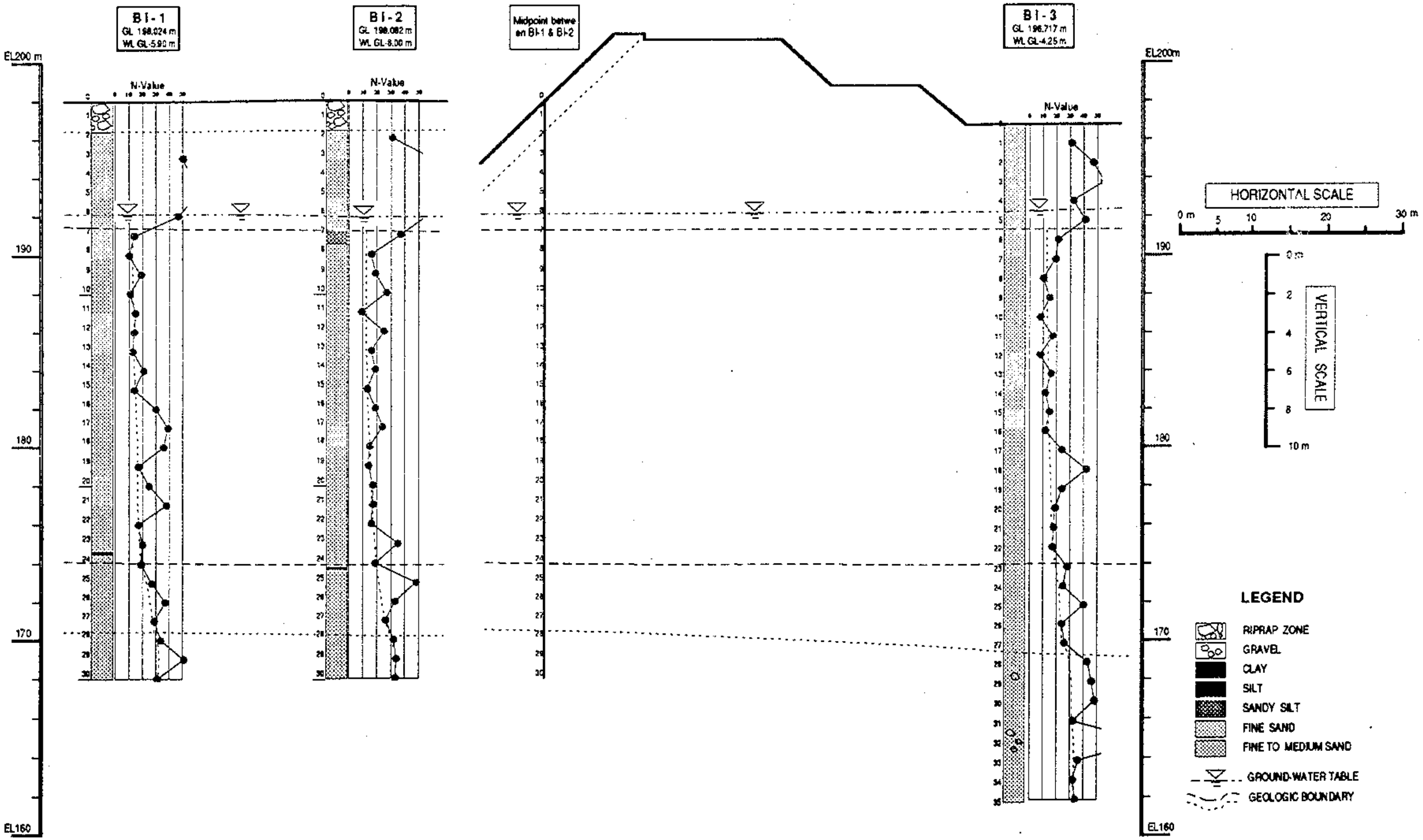



Fig.A.19 Geologic Profile at Proposed Intake Site

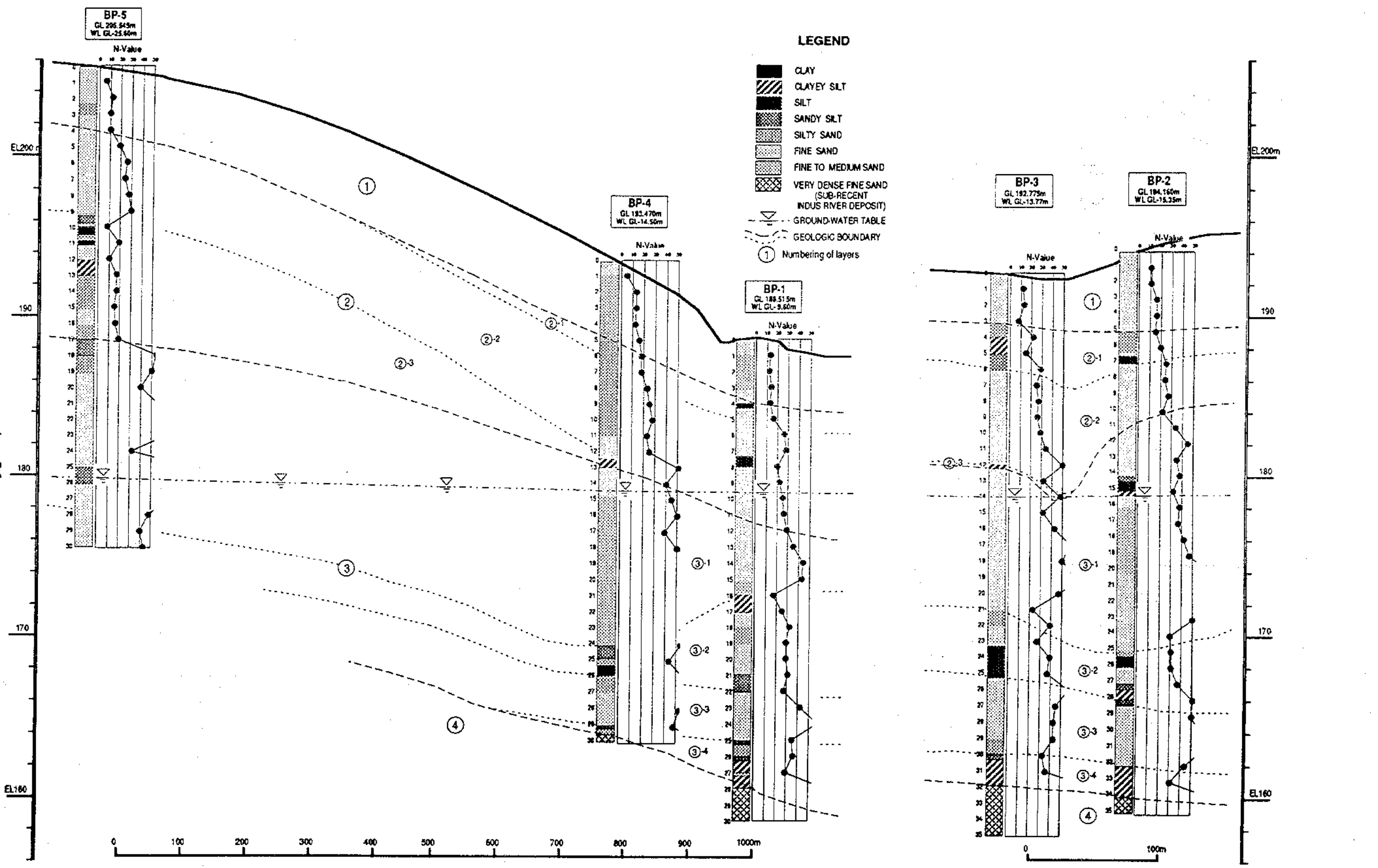



Fig.A.20 Geologic Profile at Proposed Pumping Station Site

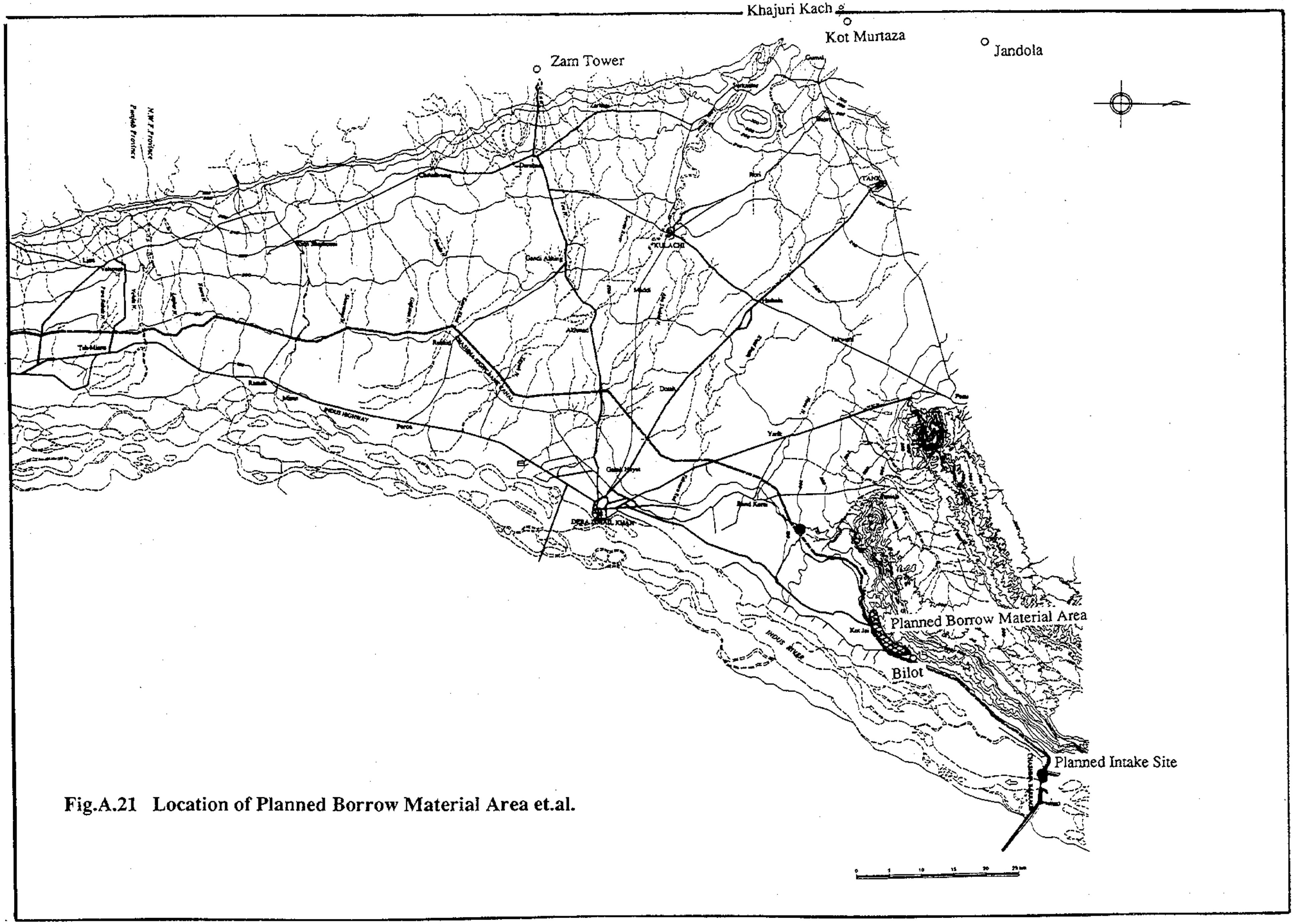



Fig.A.21 Location of Planned Borrow Material Area et.al.

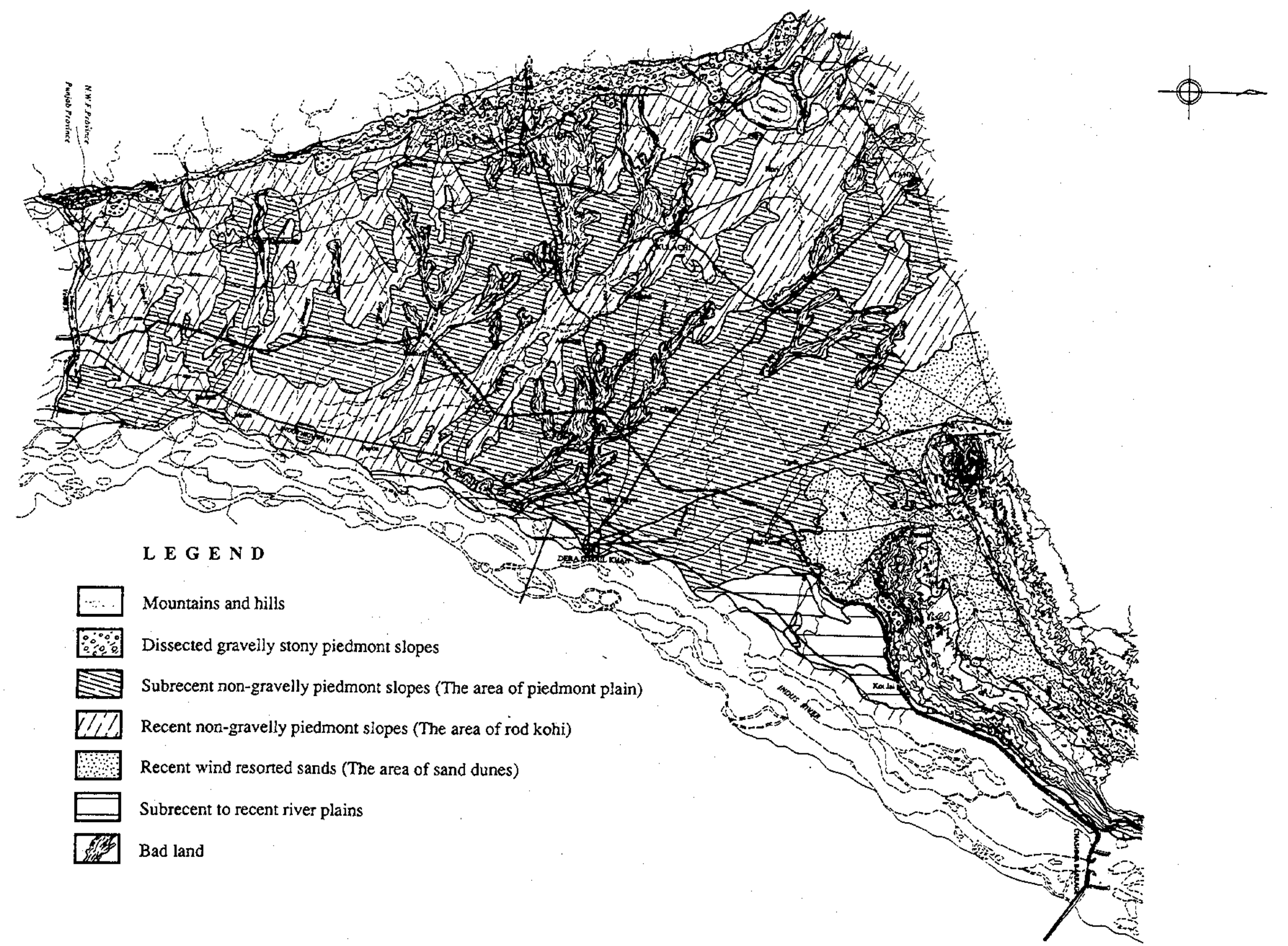



**Fig. A.22 Land System of D. I. Khan District**

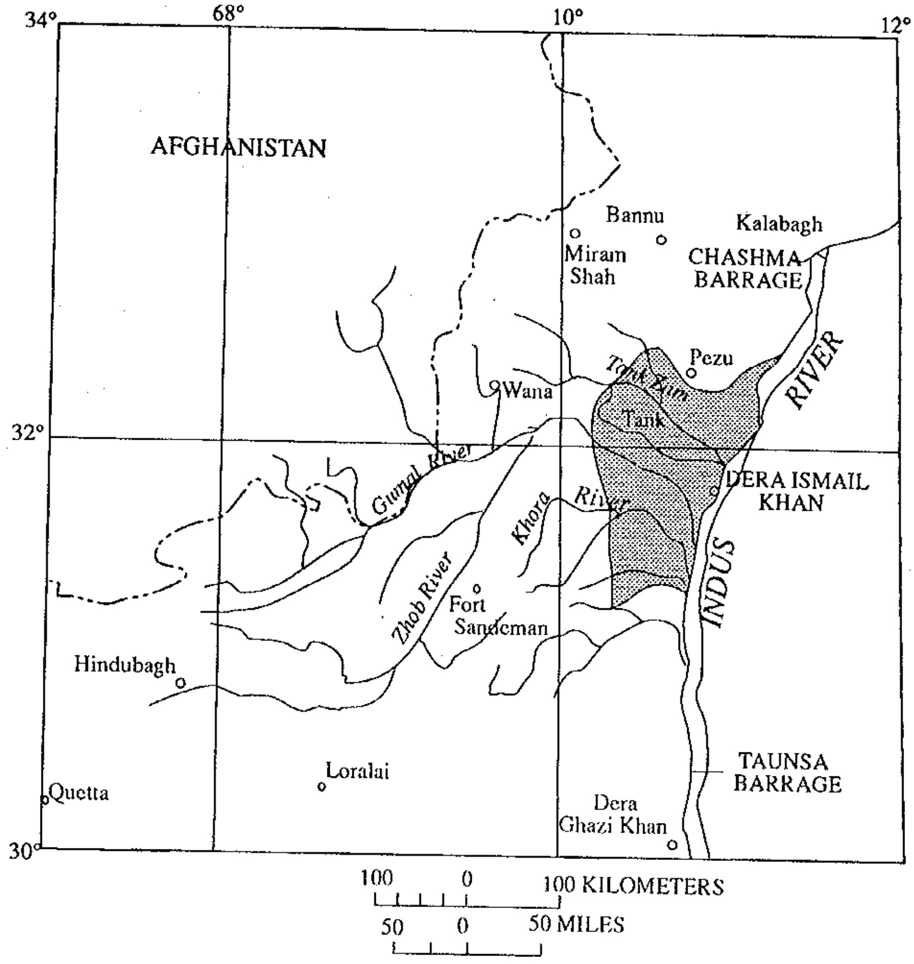



**Fig.A.23** Major tributaried that drain through D.I.Khan District to the Indus River Modified from "Map of Pakistan"(Survey of Pakistan, 1962)

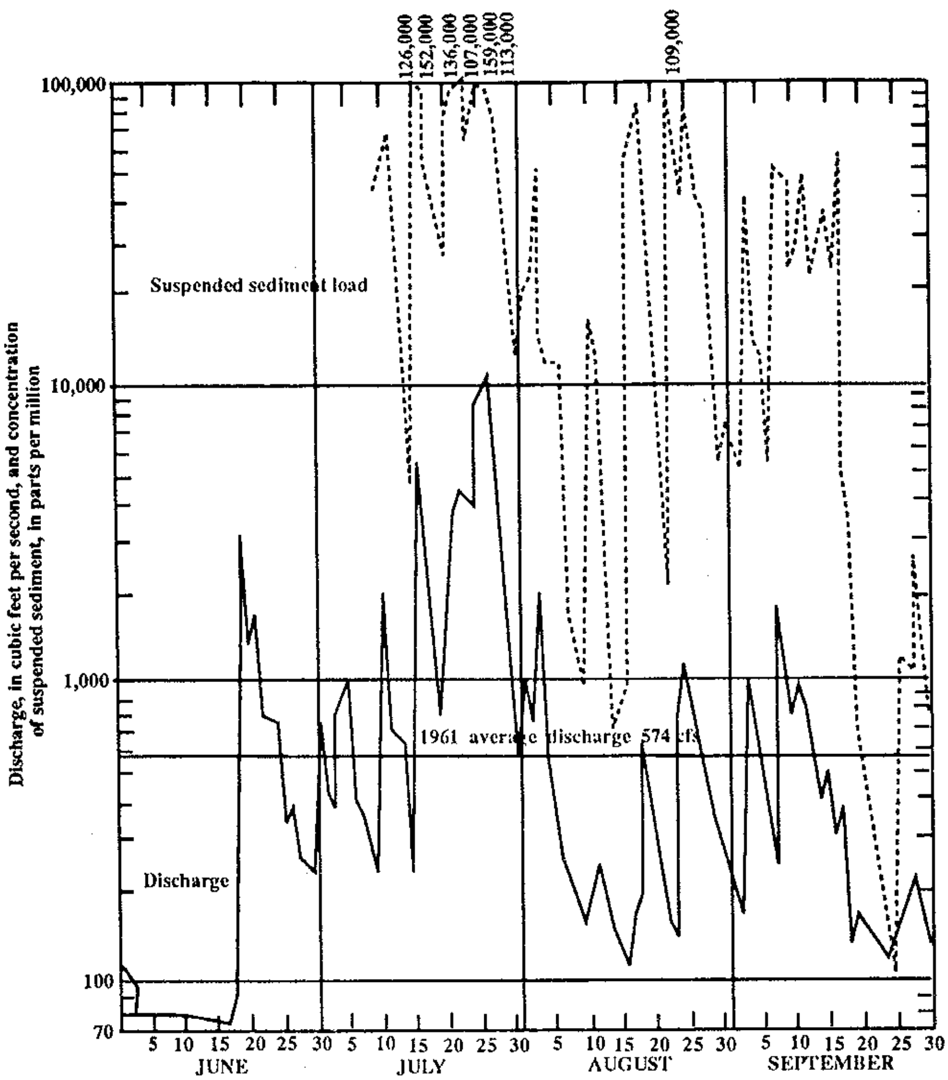



Fig.A.24 Discharge and suspended-sediment concentration of water in Gumal River near Kot Murtaza, June-September 1961.

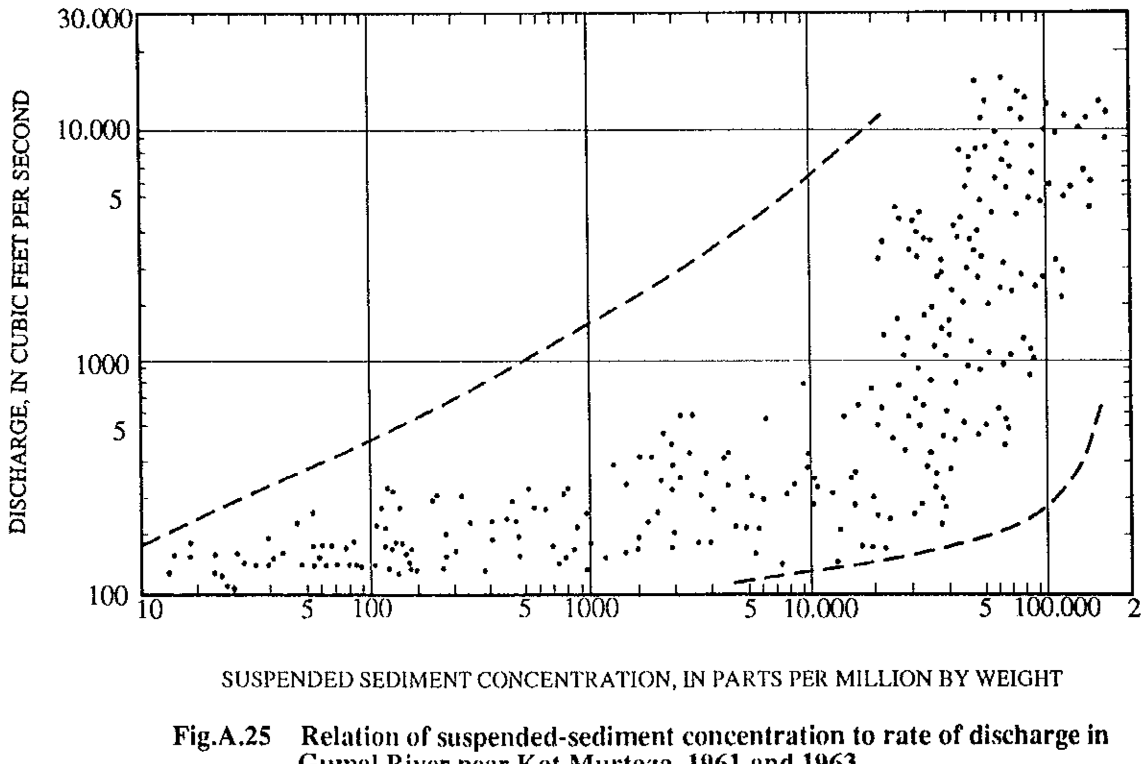



Fig.A.25 Relation of suspended-sediment concentration to rate of discharge in Gumal River near Kot Murtaza, 1961 and 1963

# ANNEX B

# METEOROLOGY AND HYDROLOGY

**ANNEX-B**

**METEOROLOGY AND HYDROLOGY**

**Table of Contents**

## List of Tables



## List of Figures

# ANNEX B METEOROLOGY AND HYDROLOGY

## B.1 Meteorology

### B.1.1 Climate

The climate of the Study Area is semi-arid and is characterized by large seasonal variations of meteorological indicators, such as temperature and rainfall.

Although the annual rainfall is relatively low, high intensity rains of short duration do occur occasionally causing floods in Rod Kohis which extend to upper portion and cross over the Study Area.

Characteristics of climate of the Study Area are summarized in Table B.1.1, showing monthly average data at D. I. Khan station which is a representative meteorological station regarding the Study Area, summer daily temperatures range from 18 - 46 °C, in winter 12 - 34 °C, rainfall ranges from 200 - 400 mm, mean annual evaporation is around 2,550 mm, and relative humidity ranges from 38 (in March) - 65 (in December) percent.

### B.1.2 Meteorological Station

There are several meteorological stations operated by various agencies adjacent to the Study Area. Available stations for the Study are eleven (11) as listed in Table B.1.2, and shown in the location map of respective stations (Fig. B.1.1).

D. I. Khan station operated by Pakistan Meteorological Department is only a station among these observing general meteorological factors for long term. All other stations are observed rainfall only. Tank and Chaudwan stations are recording rainfall by automatic rain gauges (Automatic gauge of D. I. Khan station has not been functioning since 1987).

### B.1.3 Rainfall

(1) Characteristics of rainfall

The Study Area is affected by movement of monsoon depression in summer, and westerly disturbances during winter. Though flood mainly occurs by the summer rain, sometimes winter rain also cause flood problems in and around the Study Area due to flashy flows. The monsoon rains result from a series of tropical depressions formed in the Bay of Bengal affected by confluence of southern air currents from the equatorial regions and westerly crossing the Indian Peninsula from Arabian Sea. These depressions move in a south-westerly direction and cause rainfall in parts of Sindh, Punjab up to D. I. Khan.

The rainfall in the Study Area is generally associated with conventional thunder type storms of high intensity and short duration.

(2) Monthly rainfall

According to the rainfall data regarding the Study Area, substantial two peaks are recognized in summer and winter. Biggest peak occur in summer from July to September, other peak presents in winter from February to April. Monthly rainfall data of meteorological stations concerning of the Study Area, namely, D. I. Khan, Tank, Chaudwan, Lar, Girser, Kotla and Chashma, are shown in Table B.1.3 ~ Table B.1.9.

Annual rainfall is averaged at 274 mm in the D. I. Khan station (1941~1993), which vary between less than 100 mm and more than 400 mm year by year.

(3) Daily rainfall

Daily maximum rainfall has been occasionally observed at more than 100 mm. Daily rainfall amounts of each year frequency are calculated as follows:

Result of Frequency Analysis for Daily Rainfall

| Return period | Probable daily rainfall (mm) | |
|---|---|---|
| | D. I. Khan | Tank |
| 2 year | 48.4 | 46.5 |
| 5 year | 72.9 | 64.8 |
| 10 year | 89.1 | 76.9 |
| 20 year | 104.7 | 88.5 |
| 50 year | 124.8 | 103.5 |
| 100 year | 139.9 | 114.8 |

Duration of rainfall is usually shorter than 24 hours. According to the rainfall data of Tank station observed by automatic gauge, 74 % of amount of one sequential rainfall occurs within one hour. 95 % of the same occurs during 12 hours.

(4) Rainfall intensity

Short duration rainfall data such as hourly rainfall over a period of many years are available at Tank station among stations equipped with rainfall gauge.

On the purpose of formulating design drainage discharge, provable rainfall intensity should be analyzed. Applying short duration rainfall data of Tank Station, provable rainfall intensities in each return period are calculated by Gumbel method as shown on the Table below.

Provable Rainfall Intensity

(mm/hr)

| Return Period | Rainfall duration | | | | |
|---|---|---|---|---|---|
| | 1 hr | 6 hr | 12 hr | 18 hr | 24 hr |
| 2 year | 32.16 | 6.58 | 3.49 | 2.44 | 1.84 |
| 5 year | 48.92 | 9.79 | 4.94 | 3.45 | 2.58 |
| 10 year | 60.02 | 11.91 | 5.90 | 4.12 | 3.08 |
| 20 year | 70.66 | 13.95 | 6.82 | 4.76 | 3.55 |
| 30 year | 76.78 | 15.12 | 7.34 | 5.13 | 3.82 |
| 40 year | 81.10 | 15.95 | 7.72 | 5.39 | 4.01 |
| 50 year | 84.44 | 16.59 | 8.00 | 5.59 | 4.16 |
| 80 year | 91.44 | 17.93 | 8.61 | 6.01 | 4.47 |
| 100 year | 94.76 | 18.56 | 8.90 | 6.21 | 4.62 |

Based upon the provable rainfall intensity calculated above, provable rainfall intensity curves are formed for conveniences for further study as follows:

Provable Rainfall Intensity Curve

| Return Period | Provable rainfall intensity curve |
|---|---|
| 2 year | $R = \frac{32.14}{T^{0.90}}$ |
| 5 year | $R = \frac{62.64}{T+0.28}$ |
| 10 year | $R = \frac{74.67}{T+0.24}$ |
| 20 year | $R = \frac{85.97}{T+0.22}$ |
| 30 year | $R = \frac{92.46}{T+0.20}$ |
| 40 year | $R = \frac{97.03}{T+0.20}$ |
| 50 year | $R = \frac{100.64}{T+0.19}$ |
| 80 year | $R = \frac{108.09}{T+0.18}$ |
| 100 year | $R = \frac{111.71}{T+0.18}$ |

Note: R; rainfall intensity (mm/hr), T; duration time (hr)

(5) Areal rainfall

Characteristic of areal rainfall around the Study Area could be recognized by means of correlating analysis of observed rainfall at several stations. Correlating analysis of daily rainfall between two stations among all available stations shown in Fig. B.1.1. has been conducted. Correlation coefficients on the analysis are summarized as follows:

Correlation Coefficients of Rainfall on Each Station

| Station | D. I. Khan | Tank | Choudwan | Lar | Griser | Kotola | Chashma |
|---|---|---|---|---|---|---|---|
| D. I. khan | 1.000 | | | | | | |
| Tank | 0.359 | 1.000 | | | | | |
| Chowdwan | * | * | 1.000 | | | | |
| Lar | 0.568 | 0.185 | * | 1.000 | | | |
| Griser | 0.217 | 0.278 | * | 0.473 | 1.000 | | |
| Kotola | 0.370 | 0.115 | * | 0.687 | 0.126 | 1.000 | |
| Chashma | 0.103 | 0.117 | * | 0.089 | 0.154 | 0.170 | 1.000 |

* : The analysis including Chowdwan data are incomplete due to lacking data.

Considering the distance between each two stations on the correlating result above, the relation between distance and correlation coefficient of rainfall is summarized in

Fig. B.1.2. Providing that correlation coefficient of more than 0.6 is statistically significant on correlation relation, rainfall zone could be limited within the circle area having radius of less than around 17 km.

The aerial extent in Pakistan has been generally observed less than 800 sq. km. The result of this analysis accord the observation.

### B.1.4 Evapotranspiration

(1) Observation of evaporation

As to observe pan-evaporation in and around the Study Area, class A pan have been installed at four (4) meteorological stations, namely, D. I. Khan, Tank, ARI weather station, and Arid Zone station.

ETpan data are available in Tank and Arid Zone station. Though D. I. Khan station has observed ETpan, only data of ETpan in recent less than one year are accessible. As the Tank and Arid Zone station have observed ETpan since 1970 and 1983, respectively, such data of ETpan in both stations can be availed on identifying of irrigation water requirement of the Study Area ( Table B.1.10, Table B.1.11 ).

(2) Result estimated by Penman Method

Complete data sets of D. I. Khan station are available for estimating ETo by the modified Penman method. Estimated ETo of 1,590.6 mm par year, could be compared with ETpan of Arid Zone station in D. I. Khan as shown in Fig. B.1.3.

Considering circumstance of pan installed in Arid Zone Station, pan coefficient Kp (ETo = Kp x ETpan) in summer, is decided at 0.65 ~ 0.7 consulting with FAO publications. The ETo estimated by modified Penman method seems reliable in comparison with ETpan applying this Kp value.

### B.1.5 Wind

Wind direction and speed of the Study Area vary seasonally. In summer, east/northeast wind is distinguished having average wind velocity of 1.40m/s (2.7 knots/hr). In winter, west/northwest wind blowing from mountainous area occur frequently having average wind veracity of 0.99m/s(1.9 knots/hr) lower than in other season. Fig. B.1.4 show conspicuous direction and speed of wind in each season.

## B.2 Hydrology

### B.2.1 River system

The Study Area is located in the meandering flood plain of the Indus River which extend between the Indus River and the foot hills of Suleiman Range. Floodwater on the flood plain originates from five (5) major and numerous number of small Zams (Zam is a local term for perennial Rod Kohi). The river system schematically is shown in Fig. B.2.1.

These Zams cross the Study Area to the Indus River. Catchment area and network of the Zams are as follows:

Catchment Area and Network of Zams

| Name of Zam | Catchment Area ($km^2$) | Major Distributaries | Minor Distributaries |
|---|---|---|---|
| Tank Zam | 2,310 | Takwara | Hauz Khad |
| | | Sidqi | Mir Sahib Nal. |
| | | Chowa | Paresh Khel |
| | | Pir Kach | |
| | | Lohra | |
| | | Kiryani | |
| Gomal Zam | 35,580 | Gomal | Niskore |
| | | Luni | Crost Weir |
| | | | Luni |
| Shaikh Haider Zam | 450 | Gud Toa | Swan |
| Draban Zam | 1,080 | God Rod | Kauri |
| | | Lohra | |
| | | Gud Toa | |
| Chodhwan Zam | 900 | Gud Rod | Tarkhoba |
| | | | Kindi Attaulla |
| | | | Nahara |
| | | | Sangi |
| | | | Chutewah |
| | | | Jand |
| Other Nullahs | 250 | Ramak | |
| | | Gajistan | |
| | | Poung | |
| | | Zaman | Sheraua |
| | | Narsal/Kaur | |
| | | Suheli | |
| | 40,570 | | |

### B.2.2 Flood damage

In low flows, the flood water of the Rod Kohi is utilized for crop production effectively. However during severe flood, due to lack of proper distribution and cross-drainage facilities of flood flows, the CRBC embankment is often breached and inundation of flood water is also caused in the low lying areas resulting in losses to property, communication system, canals, crops and human lives.

The flood damage on Rod Kohi area in D. I. Khan concerning the Study Area, has been analyzed on the feasibility study for development of Rod Kohi schemes in D. I. Khan. The average annual flood damage is estimated at 3.28 million Rs., in which agricultural damage through standing water share approximately 40 percent of the total value.

In the flood irrigation aspect, farmers seem to be rather fond of flooding in their farm. In comparison with expected amount of agricultural benefit, flood damage in public and private sector are negligible small due to lower population density and taking their consideration for decreasing damage by settling higher portion.

### B.2.3 Stream discharge

(1) Stream gauge station

There are eight (8) stream gauge stations where flow measurements have been carried out or are being observed at present. The list of the stations are shown as follows:

Stream Gauge Station

| Name of station | River | Latitude | Longitude | Period of record |
|---|---|---|---|---|
| Jandola | Tank Zam | 32°21' | 70°06' | 1961~1968<br>1979~1988 |
| Khajuri Kach | Gomal Zam | 32°06' | 69°53' | 1962~1967<br>1980~1988 |
| Kot Murtaza | Gomal Zam | 32°06' | 70°04' | 1960~1988 |
| Zam Tower | Daraban Zam | 31°45' | 70°12' | 1980~1988 |
| Sharik Weir | Zhob River | - | - | 1976~1985 |
| Mir Ali Khel | Zhob River | 31°43' | 69°35' | 1964~1969 |
| Gul Kach | Gomal Zam | 31°51' | 69°31' | 1965~1967 |
| Domanda | Choudhwam Zam | 31°35' | 70°12' | 1982~1985 |

(2) Stream data

Annual maximum historical peak flow data available at four (4) stations among eight (8) stations are considered reliable as attached in Table B.2.1. Frequency analysis by Gumbel method has been carried out and results are as follows:

Result of Frequency Analysis for Stream Data

( in cfs)

| Return Period | (Tank Zam) Zam Post | (Gomal Zam) Tot Murtaza | (Gomal Zam) Khajur Kach | (Daraban Zam) Zam Tower |
|---|---|---|---|---|
| 2 | 12,960 | 16,000 | 18,120 | 3,670 |
| 5 | 20,400 | 33,670 | 23,840 | 6,380 |
| 10 | 25,320 | 49,800 | 27,620 | 8,180 |
| 20 | 30,040 | 68,780 | 31,250 | 9,900 |
| 30 | 32,760 | 81,460 | 33,340 | 10,890 |
| 40 | 34,680 | 91,270 | 34,810 | 11,590 |
| 50 | 36,160 | 99,090 | 35,950 | 12,130 |
| 80 | 39,270 | 117,240 | 38,340 | 13,270 |
| 100 | 40,740 | 126,480 | 39,470 | 13,800 |
| Catchment Area | $2,310km^2$ | $35,580km^2$ | $35,080km^2$ | $1,080km^2$ |
| Specific Discharge17.6 | 3.6 | 1.1 | 12.8 | |

Note: Specific discharge is calculated based upon discharge in 100 year return period per $km^2$.

According to the results of peak discharge tabulated above, specific peak discharge from huge catchment is significantly lower than the same from smaller catchment. The reason of this difference is due to non-uniform areal rainfall distribution on the catchment.

(3) Relation between discharge and rainfall data

Synthetic approach using series of rainfall and stream flow data related to each other is experimentally tried using observed data in Tank. Fig. B.2.2 and Fig. B.2.3 indicate actual data of hourly rainfall and water stage at Kot Murtaza water gauging station simultaneously. Referred rainfall data at Tank station and Choudwan station in the figures seem to have no significant relation with run-off discharge represented by the water stage data. This attempt mean the difficulty for adopting general approach for hydrological analysis. Besides these, following difficulties in this area on the hydrological aspect are recognized.

- Lack of precise hydrological data and incomplete observation system of the flood peak and duration.

- Shifting course of the rivers in the flood flow.
- Artificially modified regime of river flow such as use of flood water for Rod Kohi
- Significant effect of areal and periodical distribution of rainfall. (Uniform rainfall in whole catchment area hardly occur because catchment area of each river are comparably larger than rainfall zone. Moreover, rainfall occurs for shorter duration than concentration time of catchment.)

Considering these hydrological characteristic of the Study area, the results expected from hydrological analysis would be of limited value.

Though general hydrological technique such as rational formula, unit hydrograph can be applicable on the Study on small drainage catchment area, substantial study on major tributaries must be proposed to avail frequency analysis on the basis of observed runoff data.

## B.3 Water Quality

Water quality tests for surface and ground water on the Study Area, have been conducted during the field survey. Location of sampling sites are shown in Fig. B.3.1. Results of testing is shown in Table B.3.1, and classification on sodium absorption ratio (SAR) is indicated in Fig. B.3.2. Referring results of testing for surface water at the Chashma reservoir and CRBC canal are classified $C_1S_1$ (Low salinity, Low sodium), Indus river water seems to be quite suitable for irrigation. On the contrary, other surface water sample at each Nullah indicate $C_2S_1$ (Medium salinity, Low sodium) or $C_3S_1$ (High salinity, Low sodium). These results show that salinity issues will be occurred when the water is used for irrigation.

All samples of groundwater are recognized high salinity hazard. Besides these water quality tests, an analysis for ground water has been conducted so far. The report "Quality of Irrigation Water of some Selected Tube-wells of D. I. Khan District" by ARI. is an investigation covering the Study Area. 17 sites for sampling on the investigation among 179 sites are located within the Study Area mainly along the Bannu road. Water quality of ground water in the Study Area mostly indicates C2S1 (Medium Salinity, Low Sodium) or C3S1 (High Salinity, Low Sodium) in consideration with results of both tests.

Though ground water can be used for irrigation with a little danger of development of harmful levels of exchangeable sodium, special management for salinity control may be required and plants with good salt tolerance should be selected. These grandwater is major source for domestic water supply including drinking purpose. Considering high salinity hazard of grandwater, groundwater may not avail for drinking water supply depend upon class of salinity hazard.

# *TABLES*

## Table B.1.1 Meteorological Data of D. I. Khan Station

| Items | Unit | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PRESSURE | | | | | | | | | | | | | | |
| Station level | mb | 996.5 | 994.4 | 991.3 | 987.0 | 981.9 | 976.6 | 976.5 | 928.7 | 983.5 | 990.0 | 994.8 | 996.9 | 987.4 |
| TEMPERATURE | | | | | | | | | | | | | | |
| Dry bulb | flC | 12.6 | 15.4 | 20.9 | 27.6 | 33.1 | 35.8 | 33.7 | 32.7 | 31.3 | 26.5 | 19.3 | 13.6 | 25.2 |
| Wet bulb | flC | 8.5 | 10.5 | 15.1 | 19.4 | 22.0 | 25.1 | 27.1 | 27.1 | 24.6 | 19.6 | 14.3 | 9.7 | 18.6 |
| Dew point | flC | 3.7 | 5.2 | 10.2 | 13.7 | 15.1 | 19.7 | 24.2 | 24.7 | 21.3 | 15.1 | 10.2 | 5.6 | 14.1 |
| Mean temp. | flC | 12.2 | 14.7 | 19.9 | 26.0 | 30.9 | 34.2 | 32.7 | 31.9 | 30.2 | 25.3 | 19.1 | 13.6 | 24.2 |
| MAXIMUM TEMPERATURE | | | | | | | | | | | | | | |
| Mean daily max | flC | 20.3 | 22.1 | 26.9 | 33.5 | 38.7 | 41.5 | 38.5 | 37.4 | 36.7 | 33.4 | 27.7 | 21.9 | 31.5 |
| Manthly high max | flC | 24.9 | 27.2 | 33.1 | 40.3 | 44.1 | 46.7 | 44.0 | 41.4 | 40.1 | 37.1 | 32.2 | 26.5 | 36.5 |
| Extremes highest | flC | 28.9 | 30.6 | 37.2 | 43.3 | 47.9 | 50.0 | 47.0 | 44.5 | 42.5 | 40.5 | 35.0 | 30.6 | 50.0 |
| MINIMUM TEMPERATURE | | | | | | | | | | | | | | |
| Mean daily min | flC | 4.2 | 7.3 | 12.9 | 18.5 | 23.1 | 26.8 | 26.9 | 26.4 | 23.8 | 17.3 | 10.5 | 5.3 | 16.9 |
| Manthly low min | flC | 0.8 | 2.6 | 7.2 | 13.4 | 18.0 | 22.2 | 22.3 | 22.3 | 19.7 | 12.9 | 5.5 | 1.7 | 12.4 |
| Extremes lowest | flC | -3.0 | -2.0 | 0.0 | 7.0 | 15.0 | 18.0 | 21.0 | 18.0 | 16.0 | 8.0 | 2.0 | -2.0 | -3.0 |
| RELATIVE HUMIDITY | % | 59.5 | 55.5 | 55.5 | 46.0 | 36.5 | 42.0 | 59.5 | 64.5 | 57.5 | 53.0 | 58.0 | 61.5 | 54.0 |
| VAPOUR PRESSURE | mb | 8.3 | 9.2 | 12.8 | 15.9 | 17.5 | 23.3 | 30.1 | 31.1 | 25.4 | 17.5 | 12.7 | 9.4 | 17.8 |
| CLOUD AMOUNT | | | | | | | | | | | | | | |
| All cloud | oktas | 2.3 | 2.8 | 3.2 | 2.8 | 1.8 | 1.5 | 2.6 | 2.4 | 1.0 | 0.6 | 1.1 | 2.2 | 2.0 |
| Low cloud | oktas | 0.7 | 0.9 | 0.9 | 0.9 | 0.5 | 0.3 | 0.9 | 0.8 | 0.4 | 0.1 | 0.2 | 0.6 | 0.6 |
| SUN-SHINE HOURS | hrs | 6.9 | 7.0 | 7.2 | 8.7 | 9.7 | 8.4 | 8.9 | 9.4 | 9.0 | 9.1 | 8.2 | 6.6 | 8.3 |
| PRECIPITATION | | | | | | | | | | | | | | |
| Mean monthly | mm | 8.8 | 17.9 | 37.0 | 23.5 | 16.7 | 14.1 | 61.4 | 55.6 | 19.7 | 5.9 | 2.4 | 9.8 | 272.7 |
| No. of rainy days | days | 1.4 | 2.0 | 3.3 | 2.4 | 1.2 | 1.1 | 3.1 | 2.9 | 0.9 | 0.4 | 0.3 | 0.9 | 19.9 |
| Extremes wettest | mm | 56.3 | 53.8 | 101.7 | 106.5 | 106.8 | 77.9 | 180.6 | 178.6 | 83.6 | 33.1 | 15.8 | 63.8 | 445.3 |
| Extremes driest | mm | 0.0 | 0.0 | 1.8 | 0.0 | 0.0 | 0.0 | 0.0 | 3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 139.5 |
| Heaviest 24hrs | mm | 23.4 | 43.7 | 75.0 | 26.4 | 57.3 | 53.8 | 108.2 | 112.5 | 49.2 | 28.2 | 11.7 | 40.4 | 112.5 |
| WIND | | | | | | | | | | | | | | |
| Mean wind | knots | 2.2 | 2.2 | 2.4 | 2.5 | 2.7 | 3.2 | 3.1 | 2.8 | 2.0 | 1.6 | 1.7 | 1.4 | 2.3 |
| Direction | deg. | 320 NW | 340 N | 38 NE | 51 NE | 67 NE | 105 E | 99 E | 81 E | 105 E | 76 E | 351 N | 320 NW | 60 NE |
| Max wind speed | knots | 28.0 | 23.0 | 16.0 | 16.0 | 40.0 | 32.0 | 35.0 | 35.0 | 35.0 | 20.0 | 10.0 | 35.0 | 40.0 |

Note: D.I.Khan Meteorological Station locats at Lat.31fl49', Long.70fl55'.
Above data calculated based upon the observed data from 1961 to 1990 (Only rainfall is from 1941 to 1992).

## Table B.1.2 List of Meteorological Sation

| Name of Station | Latitude | Longitude | Elevation (m) | Operating Agency* | Period of Record | Items of Observation | Remarks |
|---|---|---|---|---|---|---|---|
| 1 D.I.Khan | 31 39' | 70 55' | 172 | PMD | 1941-1993 | every factors | |
| 2 Tank | 32 13' | 70 32' | 244 | WAPDA | 1960-1993 | every factors | Automatic gaugeing |
| 3 Chaudwan | 31 36' | 70 20' | 229 | WAPDA | 1985-1993 | rainfall | Automatic gaugeing |
| 4 Daraban | 31 44' | 70 20' | | IRR | 1958-1961 | rainfall | |
| 5 Kulachi | 31 56' | 70 28' | 213 | IRR | 1958-1967 | rainfall | |
| 6 Lar | 32 03' | 70 58' | | IRR | 1941-1993 | rainfall | |
| 7 Girser | 31 58' | 70 56' | | IRR | 1941-1993 | rainfall | |
| 8 Kotla | 32 10' | 71 05' | 190 | IRR | 1941-1993 | rainfall | |
| 9 Chashma | 32 27' | 71 20' | | IRR | 1941-1990 | rainfall | 1986 - : unreliable |
| 10 ARI weather st. | 31 40' | 70 56' | | AD | 1991-1993 | every factors | |
| 11 Arid Zone st. | 31 40' | 70 56' | | AD | 1983-1993 | every factors | |

*: PMD ; Pakistan Meteorological Department
WAPDA ; Water & Power Development Authority
IRR ; Irrigation Department of NWFP
AD ; Agriculture Department of NWFP

## Table B.1.3 Rainfall Data of D.I.Khan Station

(in mm)

| Year | Jan. | Feb. | Mar. | April | May | June | July | Aug. | Sep. | Oct. | Nov. | Dec. | Total | Daily max |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1941 | 10.2 | 3.8 | 45.5 | 19.1 | 45.5 | 5.3 | N.D | 63.8 | 0.0 | N.D | N.D | N.D | 312.2 | 48.8 |
| 1942 | 37.8 | 56.4 | 0.0 | 7.6 | 26.4 | 7.1 | N.D | 42.7 | 3.3 | 0.0 | 0.0 | 18.0 | 343.4 | 68.6 |
| 1943 | 8.9 | 0.0 | 19.1 | 7.4 | 9.9 | 16.5 | 83.6 | 1.8 | N.D | N.D | 0.0 | 0.0 | 147.1 | 12.2 |
| 1944 | 13.5 | 45.2 | 17.3 | 21.1 | 1.3 | 6.9 | 11.9 | 0.0 | N.D | N.D | 0.0 | 3.6 | 308.6 | 139.7 |
| 1945 | 29.7 | 0.0 | 3.3 | 33.8 | 2.5 | 6.6 | 1.8 | 18.5 | 5.6 | 0.5 | 0.0 | 0.3 | 102.6 | 18.8 |
| 1946 | 0.5 | 0.0 | 8.9 | 0.0 | 0.0 | 1.5 | 4.6 | 2.8 | 0.0 | 15.0 | 0.0 | 2.5 | 35.8 | 14.5 |
| 1947 | 3.8 | 7.9 | 24.4 | 0.0 | 0.0 | 0.0 | 0.0 | 9.9 | 0.0 | 0.0 | 0.0 | 1.8 | 47.8 | 11.4 |
| 1948 | 2.8 | 22.4 | 0.0 | 11.2 | 0.0 | 0.4 | N.D | 12.2 | 0.0 | 0.0 | 0.0 | 0.0 | 161.4 | 52.1 |
| 1949 | 0.0 | 18.5 | 25.4 | 1.8 | 0.0 | 1.5 | 9.7 | 23.9 | 0.0 | 0.0 | 0.0 | 0.0 | 80.8 | 20.3 |
| 1950 | 36.3 | 13.0 | 17.8 | 35.6 | 0.8 | 0.0 | 24.9 | 22.6 | 8.1 | 0.0 | 0.0 | 0.0 | 159.0 | 24.9 |
| 1951 | 3.8 | 0.0 | 71.4 | 34.5 | 14.7 | 2.5 | 30.0 | 4.6 | 0.0 | 0.0 | 3.0 | 0.0 | 164.6 | 40.6 |
| 1952 | 5.1 | 39.4 | 2.8 | 0.0 | 0.0 | 11.4 | 13.0 | 38.1 | 0.0 | 0.0 | 0.0 | 1.5 | 111.3 | 38.1 |
| 1953 | 3.3 | 9.7 | 0.0 | 21.6 | 0.0 | 40.6 | 39.4 | 77.5 | 0.8 | 0.0 | 0.0 | 0.0 | 192.8 | 74.9 |
| 1954 | 0.0 | 72.6 | 17.3 | 25.1 | 13.2 | 5.1 | 12.2 | 0.3 | 10.7 | 0.0 | 0.0 | 0.0 | 156.5 | 50.8 |
| 1955 | 1.0 | 1.0 | 29.5 | 2.8 | 56.4 | 5.3 | 46.2 | 83.3 | 27.9 | 0.0 | 0.0 | 23.4 | 276.9 | 39.4 |
| 1956 | 2.0 | 13.2 | N.D | 61.0 | 0.0 | 0.0 | N.D | 97.3 | 7.6 | 2.5 | 0.0 | 0.0 | 611.6 | 124.5 |
| 1957 | 47.2 | 1.0 | N.D | 78.0 | 19.6 | 24.4 | 37.1 | 46.2 | 41.9 | 3.3 | 18.8 | 19.6 | 337.1 | 41.9 |
| 1958 | N.D | 0.0 | N.D | 0.0 | 0.0 | 7.4 | N.D | 30.2 | 3.0 | 15.0 | 0.0 | 63.2 | 226.8 | 68.8 |
| 1959 | N.D | 35.1 | 0.0 | 34.5 | 19.6 | 10.2 | N.D | 0.0 | 7.9 | 8.9 | 60.5 | 0.0 | 451.4 | 98.0 |
| 1960 | 1.3 | 0.0 | 32.0 | 18.0 | 0.0 | 0.0 | N.D | 11.4 | 33.3 | 0.0 | 0.0 | 0.0 | 239.0 | 121.9 |
| 1961 | 4.6 | 6.6 | 25.4 | 13.0 | 2.0 | 4.8 | 143.5 | 6.6 | 1.3 | 38.1 | 0.0 | 0.0 | 245.9 | 86.9 |
| 1962 | 1.8 | 29.7 | 27.9 | 0.0 | 17.3 | 2.5 | 20.1 | 105.7 | 18.5 | 29.2 | 0.8 | 11.9 | 265.4 | 81.3 |
| 1963 | 0.0 | 10.4 | 26.9 | 34.8 | 30.0 | 0.0 | 32.8 | 15.7 | 0.5 | 0.0 | 1.0 | 1.0 | 153.1 | 19.3 |
| 1964 | 17.3 | 4.6 | 25.9 | 0.0 | 0.0 | 0.0 | 142.5 | 51.3 | 26.7 | 0.0 | 0.0 | 1.0 | 269.3 | 84.8 |
| 1965 | 1.0 | 4.1 | 18.3 | 66.0 | 20.8 | 12.4 | 34.5 | 8.4 | 0.3 | 0.0 | 0.8 | 0.5 | 167.1 | 22.9 |
| 1966 | 0.0 | 31.0 | 3.0 | 67.8 | 6.9 | 2.5 | 89.7 | 32.5 | 5.3 | 0.0 | 0.3 | 0.0 | 239.0 | 29.2 |
| 1967 | 0.0 | 8.1 | 77.9 | 21.6 | 5.3 | 0.0 | 53.8 | 101.9 | 11.7 | 17.0 | 3.8 | 55.9 | 357.0 | 54.1 |
| 1968 | 20.6 | 38.1 | 37.8 | 1.0 | 19.1 | 26.7 | 20.8 | 24.1 | 0.0 | 2.8 | 0.0 | 3.0 | 194.0 | 26.2 |
| 1969 | 1.0 | 18.3 | 0.8 | 7.9 | 14.0 | 2.8 | 0.0 | 61.2 | 48.3 | 0.0 | 0.0 | 0.0 | 154.3 | 48.3 |
| 1970 | 9.9 | 53.8 | 34.0 | 2.8 | 4.3 | 23.9 | 100.3 | 18.0 | 0.0 | 0.0 | 0.0 | 0.0 | 247.0 | 35.1 |
| 1971 | 0.0 | 1.8 | 12.4 | 0.5 | 54.6 | 4.1 | 17.3 | 26.9 | 33.8 | 0.0 | 1.0 | 0.0 | 152.4 | 46.5 |
| 1972 | 26.2 | 12.4 | 4.3 | 40.9 | 7.4 | 42.2 | 10.9 | 51.8 | 24.9 | 0.0 | 5.1 | 43.2 | 269.3 | 27.9 |
| 1973 | 4.3 | 10.9 | 21.1 | 3.6 | 16.3 | 0.0 | 180.6 | 47.2 | 21.1 | 0.0 | 0.0 | 0.0 | 305.1 | 108.2 |
| 1974 | 6.8 | 34.3 | 21.4 | 27.2 | 5.1 | 59.0 | 109.4 | 81.9 | 2.8 | 0.0 | 0.0 | 10.2 | 358.1 | 38.6 |
| 1975 | 3.3 | 13.7 | 27.7 | 37.6 | 4.3 | 77.9 | 87.1 | 45.3 | 11.9 | 0.0 | 0.0 | 5.7 | 314.5 | 53.8 |
| 1976 | 8.0 | 23.0 | 33.7 | 15.0 | 12.7 | 63.5 | 8.9 | 160.8 | 39.3 | 0.0 | 0.0 | 0.0 | 364.9 | 21.8 |
| 1977 | 20.6 | 0.5 | 1.8 | 30.5 | 2.5 | 17.7 | 45.1 | 86.6 | 11.0 | 0.0 | 7.0 | 0.2 | 223.5 | 67.4 |
| 1978 | 19.4 | 0.6 | 101.7 | 20.1 | 8.0 | 0.0 | 95.3 | 19.6 | 31.8 | 0.0 | 0.0 | 1.3 | 297.8 | 38.0 |
| 1979 | 56.1 | 46.3 | 61.6 | 13.7 | 59.7 | 2.3 | 52.0 | 26.9 | 23.0 | 8.2 | 13.2 | 15.2 | 378.2 | 38.0 |
| 1980 | 23.9 | 23.3 | 68.1 | 8.2 | 1.0 | 20.0 | 26.5 | 14.0 | 44.1 | 2.3 | 5.0 | 1.3 | 237.7 | 44.1 |
| 1981 | 14.2 | 26.0 | 66.2 | 1.3 | 9.8 | 6.0 | 137.7 | 131.7 | 0.0 | 9.3 | 0.0 | 0.0 | 402.2 | 73.2 |
| 1982 | 25.5 | 11.8 | 70.2 | 33.3 | 106.8 | 0.0 | 31.7 | 77.4 | 4.0 | 33.1 | 15.8 | 16.8 | 426.4 | 49.3 |
| 1983 | 0.0 | 14.3 | 0.0 | 106.5 | 11.1 | 16.9 | 55.1 | 178.6 | 42.2 | 0.0 | 0.0 | 0.1 | 424.8 | 56.2 |
| 1984 | 4.3 | 7.6 | 23.8 | 14.7 | 0.0 | 26.0 | 16.5 | 33.5 | 0.0 | 10.2 | 1.0 | 3.2 | 140.8 | 26.0 |
| 1985 | 11.1 | 5.8 | 4.5 | 26.2 | 0.0 | 5.6 | 0.0 | 55.9 | 0.0 | 7.4 | 0.0 | 23.0 | 139.5 | 51.6 |
| 1986 | 0.0 | 20.5 | 56.4 | 32.6 | 64.3 | 0.0 | 85.1 | 56.5 | 0.0 | 12.4 | 5.3 | 1.4 | 334.5 | 57.3 |
| 1987 | 0.0 | 50.0 | 67.0 | 4.6 | 11.2 | 7.4 | 15.4 | 3.2 | 0.0 | 0.0 | 0.0 | 0.0 | 158.8 | 44.0 |
| 1988 | 2.5 | 0.0 | 48.5 | 0.0 | 6.3 | 1.6 | 75.8 | 8.3 | 16.6 | 2.0 | 0.0 | 28.8 | 190.4 | 27.3 |
| 1989 | 4.4 | 0.0 | 46.6 | 0.7 | 3.8 | 15.7 | 73.5 | 132.1 | 0.0 | 0.0 | 1.4 | 51.0 | 329.2 | 112.5 |
| 1990 | 13.1 | 21.2 | 32.2 | 15.3 | 24.7 | 13.2 | 42.6 | 72.7 | 83.6 | 0.0 | 0.0 | 24.9 | 343.5 | 49.2 |
| 1991 | 0.0 | 30.3 | 38.6 | 48.8 | 11.7 | 0.7 | 2.9 | 134.1 | 7.6 | 8.5 | 2.8 | 1.1 | 287.1 | 82.2 |
| 1992 | 31.9 | 46.8 | 52.8 | 53.4 | 10.3 | 0.9 | 55.2 | 30.8 | 128.0 | 0.0 | 7.2 | 3.8 | 421.1 | 65.6 |
| 1993 | 4.4 | 11.6 | 68.1 | 22.3 | 0.7 | 8.5 | 87.8 | 33.6 | 4.3 | 0.6 | 0.0 | 0.0 | 241.9 | 26.2 |
| Mean | 10.2 | 18.7 | 36.6 | 23.4 | 16.7 | 14.1 | 59.1 | 58.6 | 19.5 | 5.5 | 2.2 | 9.2 | 273.8 | |

N.D: no data are available.