No.

JAPAN INTERNATIONAL COOPERATION AGENCY

MINISTRY OF WATER RESOURCES
HIS MAJESTY'S GOVERNMENT OF NEPAL

FEASIBILITY STUDY
ON
RAJKUDWA IRRIGATION PROJECT

ANNEXES

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NIPPON KOEI CO., LTD
in Association with
HOKKAIDO ENGINEERING CONSULTANTS CO., LTD.

FEASIBILITY STUDY

ON

THE RAJIKUDWA IRRIGATION PROJECT

ANNEXES

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ANNEX - A

METEOROLOGY AND HYDROLOGY

ANNEX - A

METEOROLOGY AND HYDROLOGY

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ANNEX - A METEOROLOGY AND HYDROLOGY

A.1 GENERAL

A.1.1 Introduction

This Annex describes the results of meteorological and hydrological studies made during the periods from June 1992 to June 1993. Investigation and studies were carried out on the natural conditions in the study area in order to assess the potential of the surface water resources for the Rajkudwa Irrigation Project. The objectives of the study include the following items:

i) to collect and analyze the meteorological and surface water hydrological data in and around the project area.

ii) to estimate runoff discharge at the intake site as a parameter for the water balance study,

iii) to assess the potentiality and quality of the local rivers in the study area,

iv) to estimate the peak discharge of the probable flood for the related rivers, and

v) to estimate sediment load for the design of irrigation facilities.

A.1.2 Study Area

The study area is located in the northern part of Kapilvastu District of Lumbini Zone in the Western Development Region. The study area lies on the Terai plain which gently slopes from north to south towards the Indo - Nepal border. The ground elevation varies from 90 m to 190 m . The East-West Highway passes through the study area and divides it into northern and southern parts.

The average slope at the northernmost point of the study area, starting from Pattharkot Village (El. 187 m at the cultivated field) to Murmi Village (El. 121 m), is 1 in 130. Similarly, the central region of the study area, from Murmi to the East-West Highway, with an elevation of 115 m to 117 m, has a relatively gentle average slope of 1 in 600. The southernmost region of the study area, extending from the highway to Bishambapur Village (El. 100 m), has a rather flatter slope of 1:800 on the average.

The east and west boundary areas are terraces of the Kondre, Banganga, Gudrung, and Belwagurdwa rivers, with natural forests on them. The study area slopes gradually from the forest areas to the central part where most of the cultivated fields exist. Ghorahi Nala, a natural drain of the study area, runs through the central low lying area and meets the Banganga river at a point downriver.

A.2 AVAILABLE DATA

A.2.1 Meteorological Data

A.2.1.1 Rainfall Data

There are five meteorological service stations in and around the study area operated by the Deperatment of Hydrology and Meteorology, Ministry of Water Resources. Their data records and locations are shown in Table A.2.1 and Fig.A.2.1, respectively. The monthly summary of rainfall data is shown in Table A.2.2.

Since rainfall intensity data was not available for the study area, an automatic rain gauge was installed at the beginning of the study period in Basantapur, which is located in the irrigation area under consideration.

A.2.1.2 Other Meteorological Data

There are five climatological stations at Taulihawa, Bhairahawa, Butwal, and Khanchikot which record daily air temperature, relative humidity, wind speed, and hours of sunshine. The monthly records through 1986 are available in "Climatological Records of Nepal" published by the Department of Meteorology and Hydrology, Ministry of Water Resources.

The data records of the climatological stations are shown in Table A.2.3 and the monthly summary is shown in Table A.2.4.

A.2.2 Runoff Data

No runoff record is available for the related rivers in the study area. The study team installed river gauges at four locations, Ranikudwa site on the Gudrung river, near the confluence of the Rajkudwa river and the Kondre river, at the Kondre river bridge and the Belwagurdwa bridge of the East-West Highway (Fig.A.2.2).

Starting in July 1992, discharge measurement at these four locations has been carried out using current meters, and rating curves were obtained as shown in Fig.A.2.3 to Fig.A.2.6. Together with these measurements, the river water levels were recorded every morning, mainly aiming to find the low flow during the study period. Using these records and rating curves, low flow discharges during the study period were obtained as shown in Table A.2.5.

A.2.3 Sediment Data

Sampling of suspended load sediment and bed load sediment was carried out several times during the study period at the Gudrung river, the Kondre river, and the Belwagurdwa river. Since 1992 was a drought year with an annual rainfall of 1744 mm, sediment sampling during times of flood was quite limited.

In the Phase 2 field study, bed material sampling was conducted at the proposed headworks sites, and particle size was analyzed in order to estimate total sediment load. The relation between sediment flux and discharge at the time of sampling was determined from these data. The results were utilized to determine the dimension of the settling basins.

A.3 METEOROLOGY

A3.1 Climate

The study area is located below 200 m in elevation and has a subtropical climate. Agro-meteorologically, a year is broadly divided into three (3) seasons;

	Season	Period	Characteristics
i)	Rainy season	June - September	high temperature, humid
ii)	Winter season	October - March	low/moderate temperature, dry
iii)	Spring season	April - May	max. temperature nearly 40 °C, dry

According to the records at the Taulihawa Meteorological Observatory, which is the closest to the study area, the mean monthly temperature varies from 15 °C in January to 31 °C in June, while the mean monthly relative humidity fluctuates between 45 % and 85 %. Annual evapotranspiration ranges from 1,200 mm to 1,700 mm.

A.3.2 Rainfall

A.3.2.1 Rainfall Characteristics

The mean annual rainfall for the last 20 years in Pattharkot, which is situated close to the proposed Gudrung headworks ("Gudrung headworks") site is comparatively high 2,236 mm. Only two (2) years, including 1992, received annual rainfall of less than 2,000 mm. The annual rainfall of 80 % dependability, which is generally used for irrigation planning, amounts to 2,100 mm.

About 86 % of the annual rainfall was observed within the four (4) months from June to September. After the rainy season, sporadic rainfall occured in October, but little rainfall was observed in November and December. It is generally dry with only occasional rainfall in January, February, and March . In April and May, occasional storms are brought by the southeast monsoon.

Although, the annual rainfall itself is ample, the concentration of rainfall in the rainy season hampers its year-round effective use for crops. In particular, transplanting date of paddy rice, a predominant summer crop in the rainy season, largely depends on the rainfall in June, which varies greatly. In case the transplanting is delayed, the yield may be reduced due to water shortage in the late growing stage, and winter crop cultivation is sometimes abandoned. Fig.A.3.1 shows the monthly rainfall at Pattharkot for 15 years, and a large yearly fluctuation is evident.

A.3.2.2 Rainfall Probability

For the irrigation and drainage planning of the project area, the rainfall probability was examined. Taking into consideration that records have been kept for 20 years, and it is closest to the project area, Pattharkot station (St. No. 0721) was selected for this analysis.

The probable rainfall of a 5-year return period, i.e., 80 % reliability, is generally used for estimating effective rainfall for irrigation planning. The 80 % reliable annual rainfall amounts to 2100 mm at Pattharkot, which shows high probability of rainfall in a certain year.

The probable maximum daily rainfall was estimated for drainage planning by means of the Iwai, Gumbel and Pearson III method. Since the results by these three methods are similar, the maximum value was adopted for each return period as follows.

Unit: mm

Return Period	Iwai	Gumbel	Pearson III
X=1/ 2	158	159	156
X=1/ 5	214	217	213
X=1/ 10	253	255	254
X=1/ 20	290	292	295
X=1/ 30	312	313	320
X=1/ 50	340	340	352

Note: Underlined values were adopted.

The 3-day maximum rainfall is used for the design of field drains. In the design manual for the irrigation project in Nepal, "PDSP Manual", a procedure to obtain the probable maximum 3-day rainfall from the mean annual rainfall is introduced. Using the mean annual rainfall at Pattharkot, the 3-day probable maximum rainfall was calculated as follows.

Unit: mm

Return Period	24-hour rainfall	3-day rainfall
X=1/ 5	217	352
X=1/10	255	407
X=1/20	295	471
X=1/30	320	506
X=1/50	352	542

A.3.3 Other Meteorological Conditions

A.3.3.1 Air Temperature

The air temperature in the project area is greatly influenced by the southeast and the northwest monsoons prevailing in the rainy and in the dry season, respectively. The monthly mean, monthly mean maximum, monthly mean minimum, and extreme minimum temperatures for Taulihawa are shown below. At this station, where a sub-toropical climate is predominant, the mean air temperature is 25 °C. From March to June is the hot season with a mean maximum air temperature over 30 °C. The highest temperatures occur in May and June, occasionally rises over 40 °C.

unit : °C

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Absolute Max	27.6	31.6	39.6	42.9	43.0	43.6	40.0	38.5	36.6	35.6	33.0	30.8	
Mean Max	22.4	25.1	31.4	36.1	36.8	36.2	33.0	33.3	32.5	32.2	29.0	24.4	31.0
Mean	15.4	17.4	22.7	27.9	29.8	30.7	29.2	29.7	28.4	26.1	21.3	16.9	24.6
Mean Min	8.0	9.7	13.9	19.7	22.7	25.1	25.5	26.0	24.3	20.1	13.7	9.3	18.2
Absolute Min	3.6	3.4	7.3	13.2	15.5	20.3	19.8	23.4	20.5	12.8	7.4	3.2	

A.3.3.2 Relative Humidity

The average of the daily relative humidity recorded at 8:40 and 17:40 were adopted as the daily relative humidity. The monthly mean relative humidity for Taulihawa is shown below. The average relative humidity is about 70 % and varies from about 80 % in the rainy season to about 40 % in the hot season. The lowest humidity occurs in April, while the highest in December and January.

unit : %

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
84	72	52	43	53	66	81	80	81	77	77	82	71

A.3.3.3 Evapotranspiration

No pan evaporation data have been recorded in and around the study area. Monthly open water evaporation (E_0) in Bhairahawa was estimated in the "Design Manuals for Irrigation Projects in Nepal" and is as follows.

unit : mm

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
2.7	3.7	5.6	8.1	8.8	7.6	6.3	6.1	5.3	4.9	3.8	2.7	5.5

The evaporation usually varies day to day due to air temperature, relative humidity, rainfall, and so forth. The maximum evaporation rate is nearly 9 mm in the hot season, and less than 3 mm in winter. Since Bhairahawa is located in the midst of the Terai area, it is assumed that the evaporation rate in the study area is less than the above values.

A.3.3.4 Sunshine Hours

The daily sunshine hour for each month at Bhairahawa is shown below. The mean annual sunshine hours is 7.7 hours per day. The mean daily sunshine hours for each month varies from about 6 hours/day in the rainy season to 9 hours/day in the hot season. The following table shows monthly mean sunshine hours in Bhairahawa.

unit : hours/day

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
7.1	8.1	8.5	8.9	9.4	7.6	5.6	6.4	6.3	8.0	8.5	7.6	7.7

A.3.3.5 Wind Speed

The mean wind speed at 3 m height in Bhairahawa is 4.0 km/hour (1.1 m/sec), varying from 1.8 km/hour (0.5 m/sec) in December to 7.4 km/hour (2.1 m/sec) in May. In the hot season, the daily fluctuation of the air temperature is large, which causes turbulence and strong winds. The monthly mean wind speed in Bhairahawa, the closest wind speed observatory to the study area, is summarized below.

unit : km/hour

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
2.0	2.6	3.7	6.1	7.4	5.9	6.1	4.8	6.3	3.5	2.2	1.8	4.0

A.4 RUNOFF STUDY

A.4.1 Runoff Characteristics of the Area

The study area lies close to the meeting point of the Siwalik Range and the Terai plain. In geographical terms, the study area is composed of piedmont fans in the north and flat plains in the south. The rivers originate from steep and small mountainous watersheds and form fans while flowing to the Terai plains. The flood concentration time is short, and the peak discharge is high because of such basin characteristics. A certain amount of the river water is lost as understream at the top of the fans. Some of the understream water appears as springs at the foot of the fans and/or the terrace scarp, while the rest recharges confined groundwater.

A.4.2 River System

Three rivers are situated adjacent to the study area and are under consideration as irrigation water sources for the area. They are the Gudrung river, the Kondre river, and the Belwagurdwa river.

The Gudrung river is situated in the north and west of the study area and originates in the Siwalik range. The catchment area at the proposed headworks site is 29 km^2 and the length of the river course is about 10 km at the longest reach. The gradient of the catchment is very steep averaging about 7 %. The catchment is round-shaped and small tributaries run in all directions.

The Kondre river runs in the east of the study area with a long and narrow basin in a north-to-south direction. The catchment area at the confluence of the Rajkudwa river is 24 km^2, while those at the considered headworks site and the East-West Highway are 33 km^2 and 43 km^2 , respectively. The average slope of the river course at the considered headworks site is about 4 %.

The Belwagurdwa river flows in the west of the study area with a catchment area of 153 km^2 at the crossing of the East-West Highway. The catchment is longand runs east-to-west in the Siwalik range and flows to the south picking up small tributaries on the plain including the Gudrung river. The longitudinal gradient of the river course is about 0.1 % near the study area.

The location of the rivers is shown in Fig.A2.2.

A.4.3 Actual Runoff

Discharge measurements and river gauge observations were carried out for estimating water availability at the proposed intake sites. Rating curves were prepared for these sites from the relationship between the measured discharge and river water level. This observation has been done since July, 1992. The location of the observation points are shown in Fig.A2.2.

A.4.3.1 Gudrung River

A river gauge of 3 m in length was installed 200 m upstream of the proposed headworks site in August 1993. Since then, water level observation has been done every morning and discharge measurement were also carried out less frequently. These measurements aimed primarily at evaluating low flow for irrigation planning.

The Gudrung riverbed at the proposed headworks site consists of boulders and stones down to the bedrock which is 5 to 6 m below the riverbed. A certain amount of runoff is thought to be flowing below the riverbed level as understream. Based upon engineering geological considerations, an understream of at least 30 l/sec was estimated (Sub-section B1.4.6 "Engineering Geological Problems at Gudrung Headworks Site" in Annex B).

The actual discharge observed at the Gudrung river is summarized below.

unit :l/sec

	1992					1993	
	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Mean discharge	610	540	600	220	160	140	110
Lowest discharge	430	190	260	200	130	130	90

Since 1992 was a drought year, few major floods were observed during the study period. The biggest flood was observed at the site on August 20, 1992 with an estimated discharge of more than 250 m^3/sec. According to an interview of residents near the river, such floods are observed every year.

A.4.3.2 Kondre River

Two river gauges of 4 m in length were installed in the Kondre river in late July, 1992. One was located 500 m downstream of the confluence of the Rajkudwa river and the Kondre river. The other was installed at the crossing point of the East-West Highway. Since then, water level observation has been done every morning and discharge measurement were also carried out less frequently.

The actual mean discharge observed at the Kondre river is summarized below.

unit :l/sec

	1992					1993	
	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Confluence							
Mean discharge	1230	1030	370	90	70	70	80
Lowest discharge	90	210	100	80	70	70	70
Bridge point							
Mean discharge	2140	1630	1720	400	170	160	110
Lowest discharge	70	660	450	160	160	150	90

A.4.3.3 Belwagurdwa River

A river gauge of 4 m in length was installed in the Belwagurdwa river in August, 1992. The location was the crossing point of the East-West Highway. Water level observation was done every morning up to the end of the field study period and discharge measurement was also carried out less frequently.

The actual mean discharge observed at the Belwagurdwa river is summarized below.

unit :l/sec

	1992					1993	
	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Mean discharge	7280	11000	6890	1440	510	290	170
Lowest discharge	500	2200	2000	1000	320	240	170

A.4.4 Runoff Model Simulation

A.4.4.1 General

In this section, the runoff study to determine the irrigation water availability is mentioned. The objectives of the runoff study were to represent the low flows in the dry season and dry periods in the rainy season, which have a great deal of influence on irrigation planning.

The hydrological charcteristics of the study area do not allow a runoff analysis using average monthly values. The rainfall distribution differs year by year, and a runoff simulation for as long a duration as possible was required. With this in mind, the Tank Model Method was adopted to simulate the past runoff on a daily basis.

A.4.4.2 Basic Considerations

Prior to making models, the following conditions were assumed:

(1) Evaporation loss
Since no evaporation record was available for the area, estimated evapotranspiration using the modified Penman method was used considering average climatological conditions of Bhairahawa in the Terai area . Taking into consideration i) the locations of the catchments of the related rivers, which are all adjacent to the hill area, and ii) the catchments are mostly covered by forests, the rate of evaporation loss against the runoff was assumed at 50 % of the estimated evapotranspiration at Bhairahawa. The evaporation loss by month is shown below.

unit : mm/day

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1.1	1.5	2.5	3.5	4.0	3.4	2.7	2.5	2.2	2.0	1.5	1.0	2.2

(2) Runoff Coefficient

Coefficients for the long term runoff were examined as an indicator for the models. According to the values adopted for other basin irrigation projects and/or basin development projects, 60 % was taken as the average runoff coefficient. The tank model parameters were adjusted according to this runoff coefficient.

A.4.4.3 Tank Model

The runoff characteristics of the Gudrung river and the Kondre river were examined by applying a runoff simulation model called Tank Model Method on the basis of daily rainfall for 15 straight years and runoff records during the study period. The runoff discharge at the assumed headworks sites was estimated from rainfall records applying the model with necessary adjustment of model parameters. The developed models are thought to well represent the actual runoff well.

The basic idea of the Tank Model is intelligible. Consider a tank with a hole at the bottom determining infiltration rate to the lower layer and holes at the side representing runoff. The tank model used in this study has four tanks combined vertically. The top tank represents the ground surface and the top soil layer, and its output corresponds to rapid runoff. The second tank represents the subsurface runoff. The third tank and the fourth tank correspond to the base flow from groundwater. In the course of the simulation, daily rainfall depth is put into the top tank and the depth of water released from a hole is calculated by the following equation:

$$I = aH \qquad (1)$$

Where,
- I= runoff (mm/day)
- a= coefficient of a hole
- H= water depth above the hole (mm)

In the simulation process, daily rainfall in mm is put into the top tank and the depth of water released from a hole is calculated by the equation (1). The water from the bottom hole is put into the second tank and the same calculation is repeated down to the fourth tank. The depth of the runoff is given as the sum of the water released from the side holes. The loss due to evapotranspiration in the catchment area is expressed by subtracting the depth of daily evapotranspiration from the storage.

Models for the Gudrung river and the Kondre river were prepared as they were considered the main water source for the study area. The tank parameters were adjusted according to the low flow observed during the study period.

A.4.5 Available Surface Water

A.4.5.1 Gudrung River

The tank model parameters for the Gudrung river at the proposed headworks site are illustrated in Fig.A.4.1. The model is characterized by low percolation loss, i.e., the small percolation hole of the fourth tank. Since the bedrock depth at the headworks site is 5 to 6 m, the percolation loss to downstream is thought to be very low. The results of the simulated runoff from 1978 to 1992 are shown in Table A.4.1, which summarizes the results of daily discharge into a 10-day mean discharge.

A.4.5.2 Kondre River

The parameters for the tank for the Kondre river are shown in Fig.A.4.2. The tank parameters were adjusted according to the observed low flow at the confluence of the Kondre river and the Rajkudwa river. Then the estimated discharge were applied for the considered headworks site. The discharge, in cumec, was obtained from the proportion of the catchment area at the considered headworks site to that at the confluence. The results of the simulated runoff from 1978 to 1992 are shown in Table A.4.1, which summarizes the results of the daily mean discharge into a 10-day mean discharge.

A.5 FLOOD STUDY

A.5.1 General

The purpose of the flood study in this Chapter was to estimate the probable flood discharge for the design of major facilities on and around the water source rivers. Since no reservoir which may be used for flood control is planned upstream of the study area, the peak discharge of probable floods was analyzed.

Since no discharge records or previous study reports exist for the related rivers, the flood study was done based upon daily rainfall data for 20 years at Pattarkot, which is located closest to the catchments of the rivers. The rainstorm and flood with an occurance probability of 1 in 50 years were adopted for the design of the major facilities.

A.5.2 Design Rainstorm

Based upon the estimated probable flood described in Sub-Section A.3.2.2, the design rainstorm was detremined. For the design of the headworks, a return period of 1 in 50 years was adopted, namely 352 mm/day, which was obtained by Log Pearson type III Method.

Since no rainfall data for a fixed time was available, it was calculated by the Sharman's equation as shown below:

$$R_t = R_{24} \times \sqrt{\frac{t}{24}} \qquad \text{-------------------------------} \quad (A5.1)$$

Where,	t	=	Duration of rainfall (hour)
	R_t	=	Rainfall for t hours
	R_{24}	=	Rainfall for 24 hours of certain return period

A.5.3 Design Flood

A.5.3.1 Peak Discharge

A design flood of 1 in 50 years was estimated for the proposed Gudrung headworks site. The design flood was estimated using the rational method as shown below:

$$Q = \frac{1}{3.6} \times f \times r \times A \qquad \text{---------------------------} \quad (A5.2)$$

Where,	Q	=	Peak discharge (cumec)
	f	=	Runoff coefficient
	r	=	Rainfall intensity within the time of concentration (mm/hour)
	A	=	Catchment area (km^2)

In this study, a runoff coefficient (f) of 0.75 was adopted for the small and mountainous catchments.

A.5.3.2 Time of Concentration

The time of concentration of the flood (t_g) was calculated by the Kraven's method. The Kraven's method provides the speed of the flood water according to the gradient of the catchment as follows:

H / L	more than 1/100	1/100 to 1/200	less than 1/200
W (m/s)	3.5	3.0	2.1

Where,
W = velosity of flood water (m/s)
H = Elevation gap in the catchment (m)
L = Horizontal length of the longest river course

A.5.3.3 Design Flood for the Gudrung Headworks

Based upon the above-mentioned methods, the design flood for the proposed headworks of the Gudrung river was calculated. The parameters for the calculation are shown below.

Catchment area	(A)	:	29	km^2
Elevation gap	(H)	:	704	m
Length of river course	(L)	:	9500	m
Runoff coefficient	(f)	:	0.75	

The gradient of the catchment is more than 1/100 and the flood speed becomes 3.5 m/sec. As a result, the time of concentration is calculated to be 0.754 hour.

Based upon the Shraman's equation with an 1 in 50 years probable 24 hour rainstorm (352 mm), the rainfall of this storm within the time of concentration (0.754 hr) was found to be 62 mm, with a rainfall intensity of 82 mm/hour.

Finally, a peak discharge of 497 m^3/sec was obtained, using Equation A5.2. Thus a design flood discharge of 500 m^3/sec is to be adopted for the headworks site.

A.5.3.4 Flood Hydrograph for the Gudrung Headworks Site

Besides the regular river gauge observation, flood observations were carried out during the study period. Floods occur frequently from night to early morning and the flood period is very short, thus it was difficult to observe the entire flood. At the Gudrung headworks site, seven actual flood hydrographs were recorded, of which five included the flood peak. Rainfall recorded by the automatic rain gauge at Basantapur, which is situated 6 km south of Pattharkot, and the actual flood hydrographs are shown in Fig.A.5.1.

Taking into account the actual flood hydrographs and the design flood discharge obtained from the rational method, a model hydrograph was prepared using a tank model for flood runoff. Since the flood runoff consists mostly of surface runoff, a model of two vertical tanks was used. The tank parameters and the estimated runoff for the design flood are shown in Fig.F.4.1 in Annex F and Table A.5.1.

A.6 SEDIMENT STUDY

A.6.1 General

Sediment intrusion into the irrigation canal brings about serious problems, not only for the crop growth but also for the maintenance of the irrigation facilities. Sediment in the irrigation water reduces the cross-sectional area of the canals, which results in a shortage of the irrigation water and a low crop yield. Once irrigation facilities have malfunctioned due to sediment, enormous efforts are required to restore the original capacities. In this regard, sediment control is inevitable for irrigation planning. In this study, sediment analysis was carried out for the assumed water source rivers to determine the particle size of the sediment and the type of transport, i.e., suspended load transport or bed load transport.

A.6.2 Assumed Sediments

The minimum particle size of sediment which must not enter the irrigation facilities, depends on the particle size of intruding materials, the existence of sediment in the canals, etc., but is generally considered to be about 0.3 mm. A desilting basin will be designed to collect deposits of this size.

A.6.3 Field Sampling

Suspended load sampling was carried out during the study period for the assumed water sources in the study area. The observation points were i) the proposed headworks site of the Gudrung river, ii) the Kondre river 500 m downstream of the confluence of the Kondre river and the Rajkudwa river, iii) the Kondre river at the crossing of the East West Highway, and iv) the Belwagurdwa river at the crossing of the East West Highway. The results are shown in Fig.A.6.1.

The suspended load content of the Kondre river varies from 16 mg/l to 7,480 mg/l, while that of the Gudrung river ranges from 4 mg/l to 96 mg/l. The suspended load content of the Kondre river was more than six times as much as that of the Gudrung river for the same discharge.

Several bed load collections were carried out during the study period, using bed load collectors. The collected materials were sent to the laboratory and analyzed regarding particle size and specific gravity.

River bed materials were collected as supplemental data for the bed load analysis. The same laboratory tests were conducted as those on the collected bed load materials.

A.6.4 Sediment Load Analysis

The sediment load is governed by the bed materials and tractive force. Many sediment volume calculation formulas for generally describing the relation between them have been proposed. Based upon field observations involving bed materials sampling, river characteristics, and conditions, the sediment load by discharge was estimated.

A.6.4.1 Bed Load

For estimating bed load, it is recommended to make a dimensionless indication of sediment vlolume and tractive force on a graph using the mean grain size from the observed data. That is,

$$\frac{q_B}{u_* d} = f\left\{\frac{u_*^2}{\left(\frac{\sigma}{\rho}-1\right)gd}\right\} \qquad \text{(A6.1)}$$

Where,

q_B	=	Sediment load per unit width and time (m^3/sec/m)
d	=	particle size of bed load (m)
u_*	=	friction speed
σ	=	density of sands
ρ	=	density of water
g	=	gravitational acceleration (m/sec)

This formula was developed by Kalinske and Brown. The result of the particle size analysis for the samples collected at the site is shown in Fig.A.6.2 and Table A.6.1. In this analysis, a particle size of over 40 mm was not taken into account because the intake screen spaces are 40 mm in width.

Using the relationship shown in Fig.A.6.3, the bed load by discharge was estimated as shown in Table A.6.1.

A.6.4.2 Suspended Load

Suspended load was estimated based on field observations and the Lane-Kalinske formula as shown below.

$$q_s = \int_a^h u \cdot C \cdot d_z = qC_a P \exp\left(\frac{15aw_0}{hu_*}\right) \qquad \text{(A6.2)}$$

Where,

q_s	=	suspended load per flow of unit width (g/cm)
a	=	height of the beginning point of calculation
h	=	depth of water
u	=	flow speed
C	=	density of suspended load
q	=	flow of unit width (cm^2/sec)
w_0	=	rate of sedimentation

$$w_0 = \frac{1}{18} \cdot \left(\frac{\rho'}{\rho} - 1 \right) \cdot \frac{g}{\nu} \cdot d^2 \quad \text{-----------------------} \quad (A6.3)$$

where,
- ρ' = density of particles
- ρ = density of water
- g = gravitational acceleration
- ν = coefficient of kinematic viscosity of water
- d = diameter of particles

u_* = speed of friction

P = value derived from Fig.A.6.4 with parameters of $n/h^{1/6}$ (the unit of n, roughness number, is in MKS unit and that of h is in FPS unit), and w_0 / u_*.

The C_a means the density of the suspended solids at a height of "a". When this "a" is "0" in equation A6.2, the suspended load for the unit width of flow is calculated by the following equation:

$$q_s = qC_0P \times 10^{-6} \text{ (g/cm)} \quad \text{--------------------------------------} \quad (A6.4)$$

In this equation, C_0 represents the density of the suspended load near the river bed, which is calculated by the following equation:

$$\frac{C_0}{\Delta F(w_0)} = 5.55 \times \left[\frac{1}{2} \frac{u_*}{w_0} \exp\left(-\frac{w_0^2}{u_*} \right) \right]^{1.61} \quad \text{-----------------------} \quad (A6.5)$$

where, $\Delta F(w_0)$ = Proportion (%) of particles of which rate of sedimentation is w_0

Calculation using the above-mentioned procedure is shown in Table A.6.3 where the suspended load by particle size and discharge are given.

A.6.4.3 Total Sediment Load

The estimated curves of the suspended load and the bed load by dischareg are illustrated in Fig.A.6.5 with observed suspended loads. The curves represent the observed values well and are considered applicable for estimation of sediment load.

The estimated sediment load by discharge up to 20 m^3/sec is shown in Table A.6.4.

TABLES

Table A.2.1 List of Rainfall Gauging Stations

No.	Station Name	Latitude	Longitude	Altitude (m)	Established Data	Remarks
0723	Bhagwanpur	N27°41'	E82°48'	80	Jan '75	
0707	Bhairahawa (AGRIC)	N27°32'	E83°28'	120	Jan '68	
0705	Bhairahawa Airport	N27°31'	E83°26'	110	Sep '66	
0703	Butwal	N27°42'	E83°28'	205	Jul '56	
0715	Khanchikot	N27°44'	E83°09'	1760	Nov '70	
0727	Lumbini	N27°28'	E83°17'	95	Oct '80	
0721	Patharko West	N27°46'	E83°03'	200	Mar '73	
0716	Taulihawa	N27°33'	E83°04'	94	Nov '70	

Source : Climatological Records of Nepal

Table A2.2 (1/8) Monthly Rainfall

Station : 0723 Bhagwanpur unit : mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1976	7	20	0	18	45	163	489	373	197	44	0	0	1356
1977	32	0	17	26	31	76	870	530	78	74	0	14	1748
1978	14	19	58	28	23	377	1038	244	142	28	2	14	1987
1979	16	26	0	27	75	132	611	359	111	27	3	30	1417
1980	2	0	0	0	54	317	837	491	268				1969
1981	26	9	36	21	193	234	627	406	620	0	22	8	2202
1982	30	8	64	11	35	103	405	160	392	37	13	7	1265
1983	22	0	3	4	77	62	304	255	529	209	0	37	1502
1984	41	4	5	8	54	434	519	412	343	40	0	24	1884
1985	20	9	0	14	53	310	1032	351	509	132	0	24	2454
1986	0	31	0	55	109	305	512	291	354	23	22	68	1770
Mean	19	11	17	19	68	228	659	352	322	61	6	23	1786

Remarks: Blank means "not available"

Table A2.2 (2/8) Monthly Rainfall

Station : 0707 Bhairahawa (AGRC) unit : mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1968	48	0	6	0	12	190	247	209	195	25		4	
1969			0	34				366	179				
1970		13	14			437	284	318	282			0	
1971	24	24	0			340	256	365	143	139	0	0	
1972	0	34	1	0	0	115	389		174				
1973	23	1	48	8	116	344	316	287	550	199	0	0	1892
1974	5	3	25	12	37	136	556	461	172		0	5	
1975	16	18	16	8	28	126	486	337	350	62	0	0	145
1976	6	29	0	3	65	288	436	537	245	12	0	0	1621
1977	3	10	0	24	130	83	698	314	60	76	0	15	1412
1978	10	23	57	3	12	348	623	115	404	13	5	8	1620
1979	8	5	1	11	7	165	643	311	181	107	5	45	1487
1980	1	5	9	2	154	480	386	343	344	28	0	1	1753
1981	76	3	19	58	65	450	768	375	529		34	0	
1982	14	7	58	37	31	238	554	305	484	31	10	10	1778
1983	25	0	11	27					279	178	0	27	
1984	15	5	1	5	43	1035	606	200	356	60	0	26	2352
1985	12	9	0	22	59	158	537	298	402	174	0	30	1700
1986	2	26	0	68	88	271	383	317	448	113	21	61	1797
1987	4	8	5	74	19	78	579	408	264	117	0	10	1564
1988	0	9	20	84	49	201	941	694	150	7	6	56	2217
1989	35	19	50	0	66	265	983	162	394	2	2	16	1992
1990	0	52	20	11	188	264	778	400	171	190	0	4	2077
mean	16	14	16	23	61	286	545	339	294	85	4	15	1698

Remarks: Blank means "not available"

Table A2.2 (3/8) Monthly Rainfall

Station : 0705 Bhairahawa Airport unit : mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1971	15	7	9	33	75	299	332	306	87	35	0	0	1198
1972	0	2	0	0	0	80	505	44	50	10	10	0	701
1973	60	39	27	8	105	342	153	321	625	242	0	0	1922
1974	5	1	29	6	38	157	828	566	153	14	0	4	1801
1975	16	17	27	1	28	73	684	485	371	99	0	0	1801
1976	6	3	0	4	72	285	439	523	299	11	0	0	1642
1977	4	10	0	19	110	52	629	476	64	90	0	6	1460
1978	9	14	46	5	16	318	574	193	329	29	3	8	1544
1979	6	11	1	4	7	84	774	293	107	54	4	51	1396
1980	2	5	7	0	106	480	514	286	318	5	0	2	1725
1981	83	2	18	58	51	446	891	417	457	0	45	0	2468
1982	12	4	61	17	31	184	581	398	357	16	8	4	1673
1983	21	0	11	33	126	78	558	278	230	149	0	30	1514
1984	5	2	2	6	65	941	610	255	314	39	0	1	2240
1985	12	5	0	14	51	148	389	234	468	182	0	37	1540
1986	1	21	0	87	53	309	416	323	419	131	27	62	1849
mean	16	9	15	18	58	267	555	337	291	69	6	13	1655

Remarks: Blank means "not available"

Table A.2.2 (4/8) Monthly Rainfall

Station : 0703 Butwal unit : mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1958	0	12	3	32	14	150	769	825	341	189	0	0	2334
1959	40	0	12	14	114	323	536	486	548	257	0	0	2329
1960	0	0	58	0	42	470	771	586	414	51	0	0	2392
1961	10	39	0	0	55	483	371	717	195	81	0	17	1966
1962	76	46	58	61	43	758	537	912	286	12	0	1	2792
1963	5	0	20	31	95	508	661	474	350	25	69	1	2239
1964	0	0	0	27	95	274	1185	577	464	105	0	7	2734
1965	10	13	9	23	21	214	743	1079	211	38	14	0	2375
1966	3	21	0	2	39	407	591	1661	174	58	0	8	2963
1967	0	0	32	40	38	465	541	563	454	0	0	5	2140
1968	48	0	13	7	25	403	612	428	400	204	0	36	2176
1969	7	0	2	73	108	295	550	495	356	10	0	0	1896
1970	26	16	21	35	62	971	1188	622	675	77	0	0	3693
1971	11	5	23	88	167	692	481	994	293	392	100	0	3245
1972	0	45	23	4	15	157	987	245	552	73	5	0	2104
1973	70	24	7	24	135	564	614	381	985	320	8	0	3129
1974	0	1	6	0	117	183	1137	938	324	98	0	5	2808
1975	24	8	30	20	78	287	1051	703	721	319	0	0	3241
1976	19	14	0	1	155	551	713	470	326	49	0	0	2296
1977	7	8	1	117	94	127	494	704	181	143	0	31	1906
1978	7	33	24	3	36	586	125	313	290	130	6	5	1555
1979	4	18	0	10	10	340	643	573	209	160	12	35	2013
1980	0	9	6	0	52	353	691	399	243	100	0	0	1852
1981	40	1	26	35	110	266	631	547	320	0	33	0	2009
1982	16		83	19	62	549	684	464	627				
1983	14	0	5	24	229	105	663	405	522	190	0	64	2220
1984	0	4	6	4	16	695	1170	516	473	55	0	3	2941
1985	4	6	2	9	198	286	699	271	635	163	0	53	2321
1986	0	44	1	24	89	577	580	381	418	192	10	58	2372
1987	0	5	11	44	73	225	964	590	622	88	0	10	2631
1988	0	12	13	52	135	252	1262	790	343	22	2	38	2921
1989	24	7	41	0	114	425	1225	762	361	37	2	10	3007
1990	0	41	71	42	233	324	746	663	407	334	0	9	2868
Mean	14	13	18	26	87	402	746	622	416	124	8	12	2489

Remarks: Blank means "not available"

Table A2.2 (5/8) Monthly Rainfall

Station : 0715 Khanchikot unit : mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1976	14	23	2	1	112	262	326	302	234	11	0	0	1287
1977	5	6	11	50	156	235	430	617	73	36	0	49	1668
1978	20	43	52	39	82	476	736	308	321	55	4	24	2160
1979	14	73	3	20	37	254	562	389	52	6	20	98	1528
1980	2	29	25	6	145	379	710	423	729	4	0	0	2452
1981	63	10	33	48	111	264	514	537	823	0	66	0	2469
1982	79	22	94	15	74	186	425	436	413	24	19	4	1791
1983	27	5	27	18	313	198	343	239	857	269	0	53	2349
1984	43	11	4	16	64	443	626	208	433	44	0	22	1914
1985	10	3	1	21	171	188	803	277	449	146	3	80	2152
1986	1	58	7	24	82	575	382	203	426	70	22	88	1938
Mean	25	26	24	23	122	315	532	358	437	60	12	38	1973

Remarks: Blank means "not available"

Table A2.2 (6/8) Monthly Rainfall

Station : 0727 Lumbini unit : mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1981	56	2	20	39	178	356	842	362	476	0	28	0	2359
1982	23	6	34	26	26	208	626	360	565	21	9	2	1906
1983	21	0	7	28	50	94	755	205	307	155	0	25	1647
1984	25	17	3	2	54	853	539	135	450	35	0	25	2138
1985	21	0	0	33	63	277	724	401	510	130	1	21	2181
1986	5	18	0	70	79	215	318	221	405	34	0	30	1395
Mean	25	7	11	33	75	334	634	281	452	63	6	17	1938

Remarks: Blank means "not available"

Table A2.2 (7/8) Monthly Rainfall

Station : 0721 Patharkot West unit : mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1973				8	90	712	300	442	638	249			
1974					34	8	1067	1182	909	4	89	13	
1975	19	22	16	10	34	273	822	535	413	78	0	0	2222
1976	20	10	0	0	120	495				24			
1977		0	0	24	51	159	491	481	122	190	0	30	
1978	13	44	28	43	33	408	962	341	390	34	3	10	2309
1979	17	34	1	5	9	423	517	439	314	107	7	46	1915
1980	0	5	14	10	172	569	652	672	331	46	0	0	2472
1981	62	8	55	45	100	267	893	665	561	0	58	4	2716
1982	15	8	7	18	64	283	627	543	432	23	39	6	2064
1983	25	3	0	25	109	81	465	608	679	255	0	78	2328
1984	30	4	5	4	36	655	765	306	344	129	0	24	2302
1985	6	10	0	23	190	185	757	506	445	179	0	34	2335
1986	0	24	3	36	84	266	572	625	490	70	82	62	2314
1987	0	2	14	40	10	88	900	732	405	71	0	6	2269
1988	0	13	16	52	40	430	649	678	273	3	0	6	2161
1989	49	15	28	0	104	268	815	382	683	7	13	9	2372
1990	0	63	15	37	176	255	659	353	314	266	0	33	2169
1991	13	1	3	7	70	422	418	855	392	0	0	79	2259
1992	7	11	0	0	35	361	424	450	200	223	33	0	1744
Mean	13	15	8	22	85	301	642	560	423	120	13	33	2236

Remarks: Blank means "not available"

Table A.2.2 (8/8) Monthly Rainfall

Station : 0716 Taulihawa unit : mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1971	32	37	8	108	105	366	463	491	299	102	0	0	2010
1972	0	34	1	0	0	131	431	46	235	36	10	0	926
1973	99	21	24	10	89	416	307	224	225	220	0		
1974	7	7			35	151	1082	628	188	118	0	4	
1975	22	0	40	0	48	216	762	447	410				
1976				10	36	181	312	534	206	12			
1977		10	0	32	67	68	360	353	126	75	0	6	
1978	8	40	40	8	21	250	680	204	195	17	2	7	1471
1979	12	18	1	2	39	265	572	184	102	26	10	27	1259
1980	1	18	16	0	104	418	511	518	353	1	0	0	1939
1981	62	14	37	39	136	437	511	328	416	0	28	2	1952
1982	31	9	85	42	41	220	454	335	398	65	13	4	1884
1983	23	0	16	30	35	61	641	190	377	124	0	15	1339
1984	12	4	0		30	390	468	130	292	30	0	16	
1985	13	7	0	18	91	142	680	334	442	213	0	21	2121
1986	3	20	0	98	83	230	841	148	315	65	13	60	1689
1987	0	5	0	32	32	15	656	366	230	78	0	8	1341
1988	0	5	43	85	58	197	576	442	137	11	0	40	1489
1989	29	9	14	0	76	280	471	333	336	1	5	14	2201
1990	0	47	33	30	77	155	1106	263	83	0	0	10	1578
Mean	20	16	20	30	60	229	594	325	268	63	4	14	1643

Remarks: Blank means "not available"

Table A.2.3 List of Climatological Stations

No.	Station Name	Latitude	Longitude	Altitude (m)	Established Data	Remarks
0707	Bhairahawa (AGRIC)	N27°32'	E83°28'	120	Jan '68	
0705	Bhairahawa Airport	N27°31'	E83°26'	110	Sep '66	
0703	Butwal	N27°42'	E83°28'	205	Jul '56	
0715	Khanchikot	N27°44'	E83°09'	1760	Nov '70	
0716	Taulihawa	N27°33'	E83°04'	94	Nov '70	

Source : Climatological Records of Nepal

Table A.2.4 (1/2) Summary of Meteorological Condition

Mean Maximum Temperature (unit : °C)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
0707 Bhairahawa (AGRIC)	22.2	24.9	31.3	35.5	35.7	34.9	32.5	33.1	32.1	31.6	28.6	24.2	30.6
0705 Bhairahawa Airport	22.2	25.2	31.6	36.0	36.1	35.3	32.7	33.3	32.3	31.6	28.6	24.2	30.8
0703 Butwal	21.7	24.7	30.5	35.6	35.5	34.6	32.3	32.9	31.5	31.1	28.2	24.0	30.2
0715 Khanchikot	12.7	14.3	18.7	22.3	23.0	23.5	22.6	23.3	22.0	20.7	17.3	13.9	19.5
0716 Taulihawa	22.4	25.1	31.4	36.1	36.8	36.2	33.0	33.3	32.5	32.2	29.0	24.4	31.0

Mean Temperature (unit : °C)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
0707 Bhairahawa (AGRIC)	15.5	17.3	22.4	27.4	29.5	30.1	29.2	29.6	28.4	25.9	21.7	17.4	24.5
0705 Bhairahawa Airport	15.4	17.8	23.1	28.1	30.0	30.5	29.2	29.7	28.5	26.1	21.8	17.2	24.8
0703 Butwal	16.6	18.9	24.2	29.1	29.8	30.1	28.7	29.1	27.4	26.3	22.9	18.6	25.1
0715 Khanchikot	8.8	10.3	14.6	18.2	19.0	20.2	19.9	20.3	18.9	16.8	13.4	10.1	15.9
0716 Taulihawa	15.4	17.4	22.7	27.9	29.8	30.7	29.2	29.7	28.4	26.1	21.3	16.9	24.6

Mean Minimum Temperature (unit : °C)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
0707 Bhairahawa (AGRIC)	8.7	9.8	13.6	19.4	23.3	25.4	25.9	25.9	24.7	20.1	14.8	10.5	18.5
0705 Bhairahawa Airport	8.7	10.3	14.5	20.1	24.0	25.6	25.8	26.1	24.6	20.6	15.0	10.3	18.8
0703 Butwal	11.4	13.1	17.8	22.6	24.1	25.5	25.1	25.3	23.2	21.2	17.0	13.2	20.0
0715 Khanchikot	4.7	6.2	10.4	14.0	15.0	16.9	17.2	17.2	15.8	13.0	9.4	6.2	12.2
0716 Taulihawa	8.0	9.7	13.9	19.7	22.7	25.1	25.5	26.0	24.3	20.1	13.7	9.3	18.2

Extreme Minimum Temperature (unit : °C)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
0707 Bhairahawa (AGRIC)	5.3	6.1	8.6	13.8	18.7	20.9	22.8	23.5	21.6	15.2	11.5	7.5	5.3
0705 Bhairahawa Airport	5.6	6.6	9.6	14.5	19.0	21.0	23.5	24.0	21.8	16.7	11.2	7.4	5.6
0703 Butwal	6.6	8.6	11.8	18.5	17.4	22.4	22.4	21.5	21.2	18.1	13.3	8.3	6.6
0715 Khanchikot	1.9	2.2	5.8	9.1	10.5	13.3	15.9	15.8	13.8	10.5	6.4	2.5	1.9
0716 Taulihawa	5.1	5.9	9.5	14.2	18.8	20.9	22.7	23.9	21.5	15.5	10.2	6.4	5.1

Relative Humidity (unit : %)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
0707 Bhairahawa (AGRIC)	84	78	62	52	60	69	82	82	84	81	78	83	75
0705 Bhairahawa Airport	78	67	47	38	49	63	78	78	79	74	72	78	67
0703 Butwal	72	64	47	40	51	69	81	81	82	73	64	69	66
0715 Khanchikot	71	69	55	53	66	81	92	90	87	75	75	70	74
0716 Taulihawa	84	72	52	43	53	66	81	80	81	77	77	82	71

Table A.2.4 (2/2) Summary of Meteorological Condition

Sunshine Hours — unit : hours

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
0707 Bhairahawa (AGRIC)	7.1	8.1	8.5	8.9	9.4	7.6	5.6	6.4	6.3	8.0	8.5	7.6	7.7
0705 Bhairahawa Airport													
0703 Butwal													
0715 Khanchikot	6.3	7.9	9.8	10.0	9.2	7.6	7.0	6.4	7.5	7.8	7.3	7.6	7.9
0716 Taulihawa													

Wind Speed — unit : km/hour

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
0707 Bhairahawa (AGRIC)	2.0	2.6	3.7	6.1	7.4	5.9	6.1	4.8	3.5	2.2	1.8	1.8	4.0
0705 Bhairahawa Airport													
0703 Butwal													
0715 Khanchikot	7.6	8.5	10.7	11.5	10.1	9.3	8.1	6.9	7.9	7.2	7.2	7.9	8.6
0716 Taulihawa													

Rainfall — unit : mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
0707 Bhairahawa (AGRIC)	16	11	14	24	65	351	564	311	339	72	7	20	1794
0705 Bhairahawa Airport	15	7	13	22	63	302	580	334	306	64	8	18	1732
0703 Butwal	9	14	14	22	95	403	639	461	387	119	6	25	2194
0715 Khanchikot	26	26	26	26	124	320	553	364	458	65	13	42	2043
0716 Taulihawa	18	14	20	28	62	236	561	301	293	57	7	16	1613

Table A.2.5 Observed Discharge (1/4)

Gudrung Headworks Site unit : m3/sec

	1992					1993				
Date	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1		0.58	0.33	0.29	0.19	0.13	0.11	0.10	0.10	0.09
2		0.20	0.31	0.28	0.19	0.14	0.11	0.11	0.11	0.09
3		0.19	0.29	0.27	0.19	0.13	0.13	0.10	0.11	0.08
4		0.29	0.26	0.26	0.19	0.13	0.11	0.10	0.10	0.08
5		0.22	0.54	0.26	0.19	0.13	0.11	0.10	0.10	0.08
6		0.52	0.82	0.26	0.19	0.13	0.11	0.09	0.10	0.08
7	Start	0.26	0.70	0.23	0.19	0.14	0.11	0.09	0.11	0.08
8	0.59	0.26	0.60	0.26	0.19	0.14	0.11	0.09	0.11	0.08
9	0.50	0.23	0.48	0.23	0.18	0.14	0.11	0.09	0.10	0.09
10	0.48	0.54	0.48	0.23	0.17	0.14	0.11	0.09	0.10	0.09
10 day mean	0.52	0.33	0.48	0.26	0.19	0.14	0.11	0.10	0.10	0.08
11	0.45	0.33	0.41	0.23	0.17	0.14	0.11	0.09	0.10	0.09
12	0.44	0.46	1.70	0.21	0.17	0.14	0.11	0.08	0.09	0.09
13	0.43	3.50	2.90	0.21	0.17	0.14	0.11	0.09	0.09	0.09
14	0.43	1.20	1.20	0.21	0.17	0.14	0.11	0.10	0.09	0.09
15	0.45	0.96	0.76	0.21	0.17	0.13	0.11	0.10	0.09	0.09
16	0.44	0.56	0.66	0.21	0.17	0.14	0.11	0.09	0.09	0.13
17	0.89	0.44	0.60	0.21	0.16	0.13	0.11	0.09	0.09	0.12
18	0.44	0.38	0.52	0.21	0.16	0.13	0.11	0.09	0.09	0.11
19	0.45	0.46	0.48	0.20	0.15	0.13	0.11	0.09	0.09	0.10
20	0.47	0.45	0.45	0.20	0.15	0.13	0.11	0.09	0.09	0.10
10 day mean	0.49	0.87	0.97	0.21	0.16	0.14	0.11	0.09	0.09	0.10
21	0.75	0.35	0.44	0.20	0.15	0.13	0.11	0.09	0.09	0.09
22	0.55	0.30	0.41	0.20	0.15	0.13	0.11	0.09	0.09	0.09
23	0.58	0.28	0.38	0.21	0.15	0.13	0.11	0.09	0.09	0.08
24	1.77	0.26	0.38	0.21	0.14	0.13	0.11	0.08	0.09	0.08
25	0.67	0.23	0.35	0.21	0.14	0.13	0.11	0.10	0.09	0.17
26	1.07	0.29	0.34	0.21	0.14	0.13	0.11		0.09	0.08
27	0.63	1.30	0.32	0.20	0.13	0.13	0.11	0.28	0.09	0.52
28	0.87	0.26	0.32	0.20	0.13	0.13	0.11	0.14	0.09	0.13
29	0.83	0.56	0.32	0.20	0.13	0.13	0.09	0.12	0.09	0.11
30	0.61	0.33	0.30	0.20	0.14	0.13		0.11	0.09	0.10
31	0.55		0.29		0.14	0.13		0.11		0.09
10 day mean	0.81	0.42	0.35	0.20	0.14	0.13	0.11	0.12	0.09	0.14
Monthly mean	0.61	0.54	0.60	0.22	0.16	0.14	0.11	0.10	0.09	0.11

Note: Discharge derived from the rating curve with river gauge records read in the morning.

Table A.2.5 Observed Discharge (2/4)

Kondre Upstream Site										unit : m3/sec
	1992					1993				
Date	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1	16.00	3.30	0.37	0.10	0.08	0.07	0.08	0.07	0.10	0.06
2	0.28	0.29		0.10	0.08	0.07	0.08	0.07	0.10	0.06
3	0.20	0.29	0.29	0.10	0.08	0.07	0.08	0.07	0.10	0.06
4	0.12	0.40	2.25	0.10	0.07	0.07	0.08	0.06	0.09	0.06
5	0.15	0.35		0.09	0.07	0.07	0.08	0.06	0.09	0.06
6	0.09	0.34	0.32	0.09	0.07	0.07	0.08	0.06	0.09	0.06
7	9.94	0.30	0.24	0.09	0.07	0.07	0.08	0.06	0.09	0.06
8	0.34	0.29	0.17	0.09	0.07	0.07	0.08	0.06	0.09	0.06
9	0.18	0.21	0.15	0.09	0.07	0.07	0.08	0.06	0.08	0.06
10	0.22	1.10	0.14	0.09	0.07	0.07	0.08	0.06	0.08	0.06
10 day mean	2.75	0.69	0.49	0.09	0.07	0.07	0.08	0.06	0.09	0.06
11	0.10	0.35	0.13	0.09	0.07	0.07	0.08	0.06	0.08	0.06
12	0.09	0.46	1.15	0.09	0.07	0.07	0.08	0.06	0.08	0.06
13	0.08	10.00	1.95	0.09	0.07	0.07	0.08	0.06	0.08	0.06
14	0.07	0.86	0.41	0.09	0.07	0.07	0.08	0.06	0.08	0.06
15	0.48	0.76	0.29	0.09	0.07	0.07	0.08	0.06	0.08	0.06
16	0.13	0.50	0.25	0.08	0.07	0.07	0.07	0.07	0.08	0.30
17	0.10	0.40	0.31	0.08	0.07	0.07	0.07	0.07	0.08	0.07
18	0.11	0.43	0.19	0.08	0.07	0.07	0.07	0.08	0.08	0.06
19	0.24	0.60	0.18	0.08	0.07	0.07	0.07	0.08	0.08	0.06
20	0.18	0.64	0.16	0.08	0.07	0.07	0.07	0.08	0.07	0.06
10 day mean	0.16	1.50	0.50	0.09	0.07	0.07	0.08	0.07	0.08	0.09
21	0.33	0.35	0.15	0.08	0.07	0.07	0.07	0.09	0.07	0.06
22	0.14	0.32	0.14	0.08	0.07	0.07	0.07	0.09	0.07	0.05
23	0.17	0.35	0.13	0.08	0.07	0.07	0.07	0.09	0.06	0.05
24	0.31	0.30	0.12	0.23	0.07	0.07	0.07	0.09	0.06	0.05
25	0.44	0.29	0.12	0.10	0.07	0.07	0.07	0.12	0.06	0.25
26	4.34	3.30	0.12	0.09	0.07	0.07	0.07	0.16	0.06	0.12
27	0.82	2.40	0.11	0.09	0.07	0.07	0.07	0.16	0.06	0.07
28	0.64	0.35	0.11	0.08	0.07	0.07	0.07	0.19	0.06	0.32
29	0.76	0.80	0.11	0.08	0.07	0.07		0.12	0.06	0.15
30	0.29	0.40	0.11	0.08	0.07	0.07		0.11	0.06	0.15
31	0.33		0.10		0.07	0.08		0.10		0.12
10 day mean	0.78	0.89	0.12	0.10	0.07	0.07	0.07	0.12	0.06	0.13
Monthly mean	1.23	1.03	0.37	0.09	0.07	0.07	0.08	0.08	0.08	0.09

Note: Discharge derived from the rating curve with river gauge records read in the morning.

Table A.2.5 Observed Discharge (3/4)

Kondre River Downstream Site — unit : m3/sec

	1992					1993				
Date	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1	3.60	5.60	1.00	0.45	0.20	0.17	0.15	0.08		
2	0.90	0.80	21.00	0.64	0.20	0.17	0.15	0.08		
3	0.24	1.70	1.10	0.62	0.20	0.17	0.15	0.07		
4	0.10	1.20	1.70	0.62	0.18	0.17	0.15	0.07		
5	0.21	0.90	1.80	0.47	0.18	0.17	0.15	0.07		
6	0.07	0.76	0.98	0.47	0.18	0.18	0.13	0.07		
7	10.00	0.68	0.80	0.43	0.18	0.18	0.13	0.07		
8	1.40	0.66	0.72	0.38	0.18	0.18	0.12	0.07		
9	0.90	2.23	0.72	0.38	0.18	0.17	0.12	0.06		
10	0.32	3.80	0.64	0.38	0.18	0.17	0.11	0.06		
10 day mean	1.77	1.83	3.05	0.48	0.19	0.17	0.14	0.07		
11	0.24	0.82	0.62	0.16	0.17	0.17	0.11	0.06		
12	0.16	1.00	0.86	0.32	0.17	0.17	0.11	0.06		
13	0.12	7.20	4.60	0.30	0.17	0.17	0.11	0.05		
14	0.10	1.40	1.10	0.25	0.17	0.16	0.11	0.05		
15	10.00	1.30	0.92	0.24	0.17	0.16	0.11	0.05		
16	0.34	0.84	0.82	0.25	0.17	0.16	0.11	0.05		
17	0.16	0.74	4.20	0.25	0.17	0.16	0.11	0.05		
18	0.16	0.94	0.80	0.25	0.16	0.16	0.11	0.05		
19	1.20	2.20	0.74	0.25	0.16	0.16	0.11	0.05		
20	0.11	2.10	0.72	0.25	0.16	0.16	0.09	0.06		
10 day mean	1.26	1.85	1.54	0.25	0.17	0.16	0.11	0.05		
21	1.20	0.80	0.68	0.25	0.16	0.16	0.09	0.07		
22	0.16	0.76	0.66	0.24	0.16	0.16	0.09	0.09		
23	0.32	0.70	0.66	0.30	0.16	0.16	0.09	0.12		
24	12.00	0.66	0.64	1.10	0.16	0.16	0.09	0.10		
25	1.70	0.66	0.62	0.94	0.16	0.16	0.09	0.10		
26	15.00	0.66	0.62	0.66	0.16	0.16	0.09	0.07		
27	1.80	2.20	0.60	0.38	0.16	0.15	0.09	0.03		
28	1.70	0.90	0.52	0.31	0.16	0.15	0.09	0.21		
29	2.10	3.70	0.47	0.25	0.16	0.15	0.09	0.12		
30	0.50	0.98	0.47	0.24	0.16	0.15		0.06		
31	0.90		0.45		0.16	0.15		0.21		
10 day mean	3.40	1.20	0.58	0.47	0.16	0.16	0.09	0.11		
Monthly mean	2.14	1.63	1.72	0.40	0.17	0.16	0.11	0.08		

Note: Discharge derived from the rating curve with river gauge records read in the morning.

Table A.2.5 Observed Discharge (4/4)

Belwagurduwa River unit : m3/sec

	1992					1993				
Date	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1		2.60	9.20	1.80	1.00	0.32	0.24	0.17		
2		2.60	16.00	1.80	0.60	0.32	0.17	0.17		
3		2.20	11.50	1.80	0.60	0.32	0.17	0.17		
4		9.20	8.40	1.80	0.60	0.32	0.17	0.17		
5		5.00	9.20	1.80	0.60	0.32	0.17	0.17		
6		3.50	11.50	1.80	0.60	0.32	0.17	0.17		
7	Start	2.80	8.40	1.80	0.60	0.32	0.17	0.17		
8	8.00	2.60	8.40	1.80	0.60	0.32	0.17	0.17		
9	4.60	2.20	8.40	1.80	0.60	0.32	0.17	0.11		
10	4.20	25.00	7.60	1.80	0.60	0.32	0.17	0.11		
10 day mean	5.60	5.77	9.86	1.80	0.64	0.32	0.18	0.16		
11	7.00	5.00	7.60	1.60	0.60	0.32	0.17	0.11		
12	4.90	7.60	8.40	1.40	0.56	0.32	0.17	0.11		
13	2.80	52.00	25.00	1.40	0.50	0.32	0.17	0.11		
14	1.60	14.00	11.50	1.30	0.50	0.32	0.17	0.11		
15	11.50	12.00	7.60	1.30	0.50	0.32	0.17	0.11		
16	7.20	7.80	6.20	1.30	0.50	0.32	0.17	0.11		
17	4.20	5.60	4.50	1.30	0.50	0.32	0.17	0.11		
18	5.50	8.40	4.50	1.30	0.50	0.32	0.17	0.11		
19	6.80	12.00	4.00	1.30	0.50	0.32	0.17	0.11		
20	2.80	9.80	4.00	1.30	0.50	0.32	0.17	0.11		
10 day mean	5.43	13.42	8.33	1.35	0.52	0.32	0.17	0.11		
21	9.20	7.00	3.50	1.30	0.41	0.24	0.17			
22	5.00	6.20	3.00	1.30	0.41	0.24	0.17			
23	0.50	5.80	2.60	1.30	0.41	0.24	0.17			
24	5.00	5.80	2.60	1.30	0.41	0.24	0.17			
25	9.20	5.00	2.60	1.10	0.41	0.24	0.17			
26	40.00	38.00	2.30	1.10	0.41	0.24	0.17			
27	14.00	36.00	2.20	1.10	0.32	0.24	0.17			
28	15.00	10.00	2.20	1.10	0.32	0.24	0.17			
29	13.00	16.00	2.20	1.10	0.32	0.24				
30	4.50	8.40	2.20	1.00	0.32	0.24				
31	3.50		2.00		0.32	0.24				
10 day mean	10.81	13.82	2.49	1.17	0.37	0.24	0.17			
Monthly mean	7.28	11.00	6.89	1.44	0.51	0.29	0.17	0.14		

Note: Discharge derived from the rating curve with river gauge records read in the morning.

Table A.4.1 Estimated Discharge of the Related Rivers

Gudrung River

Catchment area = 29 sq.km — unit : cumec

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Jan.	0.234	0.246	0.245	0.388	0.242	0.262	0.294	0.206	0.202	0.215	0.188	0.341	0.189	0.302	0.204
Feb.	0.331	0.296	0.182	0.214	0.212	0.188	0.184	0.204	0.279	0.205	0.195	0.209	0.355	0.197	0.201
Mar.	0.235	0.189	0.185	0.269	0.193	0.172	0.179	0.172	0.185	0.211	0.181	0.235	0.195	0.184	0.171
Apr.	0.281	0.173	0.166	0.342	0.190	0.194	0.157	0.180	0.222	0.216	0.241	0.146	0.205	0.171	0.152
May	0.205	0.157	0.473	0.339	0.339	0.348	0.190	0.562	0.287	0.158	0.189	0.290	0.549	0.270	0.170
Jun.	1.525	1.678	3.677	1.175	1.079	0.242	4.144	0.553	1.012	0.294	2.159	0.850	1.038	1.851	1.829
Jul.	7.240	3.330	4.113	6.174	3.803	1.845	4.727	5.373	3.702	5.898	4.213	4.849	3.468	2.395	2.110
Aug.	2.604	2.803	4.731	5.083	3.724	4.368	1.691	2.658	3.876	5.094	4.528	2.873	2.704	6.463	2.492
Sep.	2.123	1.940	1.966	4.722	3.217	5.627	2.575	3.568	3.437	3.175	2.709	4.483	1.551	3.038	1.054
Oct.	0.498	0.724	0.478	0.248	0.278	1.728	0.742	0.943	0.677	0.450	0.204	0.647	1.947	0.214	1.648
Nov.	0.227	0.211	0.221	0.362	0.281	0.204	0.209	0.218	0.474	0.206	0.191	0.236	0.221	0.202	0.286
Dec.	0.242	0.290	0.211	0.244	0.244	0.457	0.257	0.313	0.436	0.209	0.229	0.221	0.264	0.460	0.182
Mean	1.312	1.003	1.387	1.630	1.150	1.303	1.279	1.246	1.232	1.361	1.269	1.282	1.057	1.312	0.875

unit : cumec

	Minimum	Maximum	Mean
Jan.	0.188	0.388	0.251
Feb.	0.182	0.355	0.230
Mar.	0.171	0.269	0.197
Apr.	0.146	0.342	0.203
May	0.157	0.562	0.302
Jun.	0.242	4.144	1.540
Jul.	1.845	7.240	4.216
Aug.	1.691	6.463	3.713
Sep.	1.054	5.627	3.012
Oct.	0.204	1.947	0.762
Nov.	0.191	0.474	0.250
Dec.	0.182	0.460	0.284
			1.247

Kondre River

Catchment area = 33 sq.km — unit : cumec

	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
Jan.	0.246	0.257	0.247	0.403	0.250	0.270	0.301	0.212	0.206	0.219	0.194	0.355	0.197	0.305	0.212
Feb.	0.346	0.306	0.188	0.221	0.218	0.192	0.188	0.210	0.285	0.208	0.202	0.218	0.371	0.202	0.208
Mar.	0.248	0.196	0.192	0.284	0.198	0.176	0.182	0.176	0.187	0.215	0.188	0.246	0.204	0.188	0.177
Apr.	0.296	0.180	0.173	0.350	0.197	0.201	0.160	0.187	0.229	0.223	0.252	0.153	0.217	0.176	0.158
May	0.224	0.165	0.507	0.356	0.354	0.365	0.198	0.591	0.300	0.162	0.198	0.307	0.545	0.283	0.180
Jun.	1.568	1.765	3.916	1.302	1.089	0.255	4.362	0.575	1.053	0.310	2.260	0.889	1.080	1.973	1.971
Jul.	7.677	3.364	4.173	6.504	3.976	1.913	4.884	5.668	3.752	6.240	4.300	5.042	3.578	2.312	2.093
Aug.	2.517	2.737	4.822	5.203	3.737	4.461	1.613	2.719	3.954	5.273	4.628	2.817	2.594	6.799	2.470
Scp.	2.075	1.921	1.909	4.878	3.250	5.854	2.550	3.536	3.388	3.136	2.665	4.612	1.534	2.983	1.027
Oct.	0.373	0.712	0.435	0.254	0.289	1.718	0.773	0.878	0.612	0.466	0.215	0.572	1.896	0.224	1.642
Nov.	0.238	0.221	0.230	0.381	0.296	0.211	0.216	0.224	0.491	0.214	0.201	0.249	0.229	0.211	0.297
Dec.	0.253	0.307	0.219	0.247	0.248	0.470	0.266	0.321	0.446	0.216	0.272	0.232	0.277	0.475	0.188
Mean	1.338	1.011	1.418	1.699	1.175	1.340	1.308	1.275	1.242	1.407	1.298	1.308	1.060	1.344	0.885

unit : cumec

	Minimum	Maximum	Mean
Jan.	0.194	0.403	0.258
Feb.	0.188	0.371	0.237
Mar.	0.176	0.284	0.204
Apr.	0.153	0.350	0.210
May	0.162	0.591	0.316
Jun.	0.255	4.362	1.624
Jul.	1.913	7.677	4.365
Aug.	1.613	6.799	3.756
Sep.	1.027	5.854	3.021
Oct.	0.215	1.896	0.737
Nov.	0.201	0.491	0.261
Dec.	0.188	0.475	0.296
			1.274

Note: Results of the Tank Model Method

Table A.5.1 Runoff for the Probable Rainstorm of 1 in 50 year (1/2)

Calculation interval	0.1 hour	HA1=	22	HB1=	4
Catchment area	29.0 km2	HA2=	0	CB1=	0.015
Rainfall intensity	46.5 mm	CA1=	0.8	CB0=	0.0005
Runoff coefficient	0.75	CA2=	0.1		
Flood concentration	0.75 hour	CA0=	0.02		
Total rainfall	62.2 mm				

Time (hour)	Rain (mm)	H1 (mm)	QA1 (mm)	QA2 (mm)	QA0 (mm)	H2 (mm)	QB1 (mm)	QB0 (mm)	Qt (mm)	Qt (m3/sec)
0	0.0	0.0	0.0	0.000	0.0	0.0	0.000	0.000	0.0	0.000
0.1	5.8	5.8	0.0	0.581	0.1	0.1	0.000	0.000	0.6	46.823
0.2	5.8	10.9	0.0	1.093	0.2	0.3	0.000	0.000	1.1	88.027
0.3	5.8	15.4	0.0	1.543	0.3	0.6	0.000	0.000	1.5	124.287
0.4	5.8	19.4	0.0	1.939	0.4	1.0	0.000	0.001	1.9	156.195
0.5	5.8	22.9	0.7	2.288	0.5	1.5	0.000	0.001	3.0	240.695
0.6	5.8	25.2	2.6	2.524	0.5	2.0	0.000	0.001	5.1	412.306
0.7	5.8	25.4	2.7	2.543	0.5	2.5	0.000	0.001	5.3	426.035
0.8	5.8	25.4	2.8	2.545	0.5	3.0	0.000	0.002	5.3	427.134
0.9		19.6	0.0	1.964	0.4	3.4	0.000	0.002	2.0	158.177
1.0		17.3	0.0	1.728	0.3	3.7	0.000	0.002	1.7	139.196
1.1		15.2	0.0	1.521	0.3	4.0	0.001	0.002	1.5	122.546
1.2		13.4	0.0	1.338	0.3	4.3	0.005	0.002	1.3	108.167
1.3		11.8	0.0	1.178	0.2	4.5	0.008	0.002	1.2	95.508
1.4		10.4	0.0	1.036	0.2	4.7	0.011	0.002	1.0	84.363
1.5		9.1	0.0	0.912	0.2	4.9	0.014	0.002	0.9	74.550
1.6		8.0	0.0	0.802	0.2	5.0	0.016	0.003	0.8	65.910
1.7		7.1	0.0	0.706	0.1	5.2	0.018	0.003	0.7	58.301
1.8		6.2	0.0	0.621	0.1	5.3	0.019	0.003	0.6	51.601
1.9		5.5	0.0	0.547	0.1	5.4	0.020	0.003	0.6	45.700
2.0		4.8	0.0	0.481	0.1	5.4	0.022	0.003	0.5	40.502
2.1		4.2	0.0	0.423	0.1	5.5	0.022	0.003	0.4	35.923
2.2		3.7	0.0	0.373	0.1	5.5	0.023	0.003	0.4	31.889
2.3		3.3	0.0	0.328	0.1	5.6	0.024	0.003	0.4	28.334
2.4		2.9	0.0	0.289	0.1	5.6	0.024	0.003	0.3	25.202
2.5		2.5	0.0	0.254	0.1	5.6	0.025	0.003	0.3	22.440
2.6		2.2	0.0	0.223	0.0	5.7	0.025	0.003	0.2	20.006
2.7		2.0	0.0	0.197	0.0	5.7	0.025	0.003	0.2	17.860
2.8		1.7	0.0	0.173	0.0	5.7	0.025	0.003	0.2	15.967
2.9		1.5	0.0	0.152	0.0	5.7	0.025	0.003	0.2	14.297
3.0		1.3	0.0	0.134	0.0	5.7	0.025	0.003	0.2	12.823
3.1		1.2	0.0	0.118	0.0	5.7	0.025	0.003	0.1	11.522
3.2		1.0	0.0	0.104	0.0	5.7	0.025	0.003	0.1	10.374
3.3		0.9	0.0	0.091	0.0	5.7	0.025	0.003	0.1	9.359
3.4		0.8	0.0	0.080	0.0	5.6	0.025	0.003	0.1	8.462
3.5		0.7	0.0	0.071	0.0	5.6	0.024	0.003	0.1	7.669
3.6		0.6	0.0	0.062	0.0	5.6	0.024	0.003	0.1	6.967
3.7		0.5	0.0	0.055	0.0	5.6	0.024	0.003	0.1	6.346
3.8		0.5	0.0	0.048	0.0	5.6	0.024	0.003	0.1	5.796
3.9		0.4	0.0	0.042	0.0	5.6	0.023	0.003	0.1	5.308

Table A.5.1 Runoff for the Probable Rainstorm of 1 in 50 year (2/2)

Calculation interval	0.1 hour	HA1=	22	HB1=	4
Catchment area	29.0 km2	HA2=	0	CB1=	0.015
Rainfall intensity	46.5 mm	CA1=	0.8	CB0=	0.0005
Runoff coefficient	0.75	CA2=	0.1		
Flood concentration	0.75 hour	CA0=	0.02		
Total rainfall	62.2 mm				

Time (hour)	Rain (mm)	H1 (mm)	QA1 (mm)	QA2 (mm)	QA0 (mm)	H2 (mm)	QB1 (mm)	QB0 (mm)	Qt (mm)	Qt (m3/sec)
4.0		0.4	0.0	0.037	0.0	5.5	0.023	0.003	0.1	4.875
4.1		0.3	0.0	0.033	0.0	5.5	0.023	0.003	0.1	4.491
4.2		0.3	0.0	0.029	0.0	5.5	0.023	0.003	0.1	4.150
4.3		0.3	0.0	0.025	0.0	5.5	0.022	0.003	0.0	3.846
4.4		0.2	0.0	0.022	0.0	5.5	0.022	0.003	0.0	3.575
4.5		0.2	0.0	0.020	0.0	5.4	0.022	0.003	0.0	3.333
4.6		0.2	0.0	0.017	0.0	5.4	0.021	0.003	0.0	3.118
4.7		0.2	0.0	0.015	0.0	5.4	0.021	0.003	0.0	2.925
4.8		0.1	0.0	0.013	0.0	5.4	0.021	0.003	0.0	2.752
4.9		0.1	0.0	0.012	0.0	5.4	0.020	0.003	0.0	2.597
5.0		0.1	0.0	0.010	0.0	5.3	0.020	0.003	0.0	2.457
5.1		0.1	0.0	0.009	0.0	5.3	0.020	0.003	0.0	2.331
5.2		0.1	0.0	0.008	0.0	5.3	0.019	0.003	0.0	2.218
5.3		0.1	0.0	0.007	0.0	5.3	0.019	0.003	0.0	2.115
5.4		0.1	0.0	0.006	0.0	5.3	0.019	0.003	0.0	2.021
5.5		0.1	0.0	0.005	0.0	5.2	0.019	0.003	0.0	1.937
5.6		0.0	0.0	0.005	0.0	5.2	0.018	0.003	0.0	1.859
5.7		0.0	0.0	0.004	0.0	5.2	0.018	0.003	0.0	1.788
5.8		0.0	0.0	0.004	0.0	5.2	0.018	0.003	0.0	1.723
5.9		0.0	0.0	0.003	0.0	5.2	0.017	0.003	0.0	1.663
6.0		0.0	0.0	0.003	0.0	5.1	0.017	0.003	0.0	1.608
6.1		0.0	0.0	0.003	0.0	5.1	0.017	0.003	0.0	1.557
6.2		0.0	0.0	0.002	0.0	5.1	0.016	0.003	0.0	1.510
6.3		0.0	0.0	0.002	0.0	5.1	0.016	0.003	0.0	1.465
6.4		0.0	0.0	0.002	0.0	5.1	0.016	0.003	0.0	1.424
6.5		0.0	0.0	0.002	0.0	5.0	0.016	0.003	0.0	1.385
6.6		0.0	0.0	0.001	0.0	5.0	0.015	0.003	0.0	1.349
6.7		0.0	0.0	0.001	0.0	5.0	0.015	0.003	0.0	1.315
6.8		0.0	0.0	0.001	0.0	5.0	0.015	0.002	0.0	1.282
6.9		0.0	0.0	0.001	0.0	5.0	0.015	0.002	0.0	1.251
7.0		0.0	0.0	0.001	0.0	5.0	0.014	0.002	0.0	1.222
7.1		0.0	0.0	0.001	0.0	4.9	0.014	0.002	0.0	1.194
7.2		0.0	0.0	0.001	0.0	4.9	0.014	0.002	0.0	1.167
7.3		0.0	0.0	0.001	0.0	4.9	0.014	0.002	0.0	1.142
7.4		0.0	0.0	0.000	0.0	4.9	0.013	0.002	0.0	1.117
7.5		0.0	0.0	0.000	0.0	4.9	0.013	0.002	0.0	1.093
7.6		0.0	0.0	0.000	0.0	4.9	0.013	0.002	0.0	1.070
7.7		0.0	0.0	0.000	0.0	4.8	0.013	0.002	0.0	1.048
7.8		0.0	0.0	0.000	0.0	4.8	0.012	0.002	0.0	1.027
7.9		0.0	0.0	0.000	0.0	4.8	0.012	0.002	0.0	1.006

Table A.6.1 Particle Size of River Bed Material

Gudrung River Headworks Site

Particle Size (mm)	Sieves (mm)	Weight of Particles Passed (g)	Cummulative Weight Passed (g)	Cummulative Percentage of Particles passed (%)	Passing (%)
	40	0	0	0.00	100.00
40-25	25	638	638	1.09	98.91
25-20	20	404	1042	1.78	98.22
20-16	16	364	1406	2.40	97.60
16-12	12	384	1790	3.06	96.94
12-10	10	144	1934	3.31	96.69
10-8	8	234	2168	3.71	96.29
8-5	4.75	374	2542	4.35	95.65
5-4	3.36	500	3042	5.20	94.80
4-2	1.18	429	3471	5.93	94.07
2-0.6	0.6	204	3675	6.28	93.72
0.6-0.43	0.425	89	3764	6.43	93.57
0.43-0.3	0.3	25	3789	6.48	93.52
0.3-0.15	0.15	27	3816	6.52	93.48
0.15-0.075	0.075	20	3836	6.56	93.44
0.075-0.05	0.05	21866	25702	43.93	56.07
0.05-0.03	0.03	20663	46365	79.26	20.74
0.03-0.02	0.02	9102	55466	94.81	5.19
0.02-0.01	0.01	2791	58257	99.59	0.41
0.01>	0.01>	243	58500	100.00	0.00

Table A.6.2 Bed Load Calculation Sheet (1/5)

River Discharge (m3/sec)	1.0	Discharge per width (m3/s/m)	0.025
Depth (m)	0.062	Hydraulic Gradient	0.0081
Bed slope	0.0083	Friction speed (m/s)	0.0711

(mm)	d (cm)	i	u*d (m2/s)	$u_*^2/((\sigma/\rho)-1)gd$	f	qB (m3/s/m)	qBi (m3/s/m)	QB (m3/s)	QB (kg/s)
40-25	3.30	0.0109	0.00235	0.0104	-	-	-	-	-
25-20	2.30	0.0069	0.00164	0.0150	-	-	-	-	-
20-16	1.80	0.0062	0.00128	0.0191	-	-	-	-	-
16-12	1.40	0.0066	0.00100	0.0246	-	-	-	-	-
12-10	1.10	0.0025	0.00078	0.0313	-	-	-	-	-
10-8	0.90	0.0040	0.00064	0.0383	-	-	-	-	-
8-5	0.65	0.0064	0.00046	0.0530	0.01	4.62E-06	2.96E-08	0.0000012	0.003
5-4	0.45	0.0085	0.00032	0.0765	0.07	2.24E-05	1.90E-07	0.0000076	0.019
4-2	0.30	0.0073	0.00021	0.1148	0.15	3.20E-05	2.34E-07	0.0000093	0.023
2-0.6	0.13	0.0035	0.00009	0.2649	0.81	7.49E-05	2.62E-07	0.0000105	0.026
0.6-0.43	0.05	0.0015	0.00004	0.6886	1.5	5.34E-05	8.00E-08	0.0000032	0.008
0.43-0.3	0.04	0.0004	0.00003	0.8608	1.6	4.55E-05	1.82E-08	0.0000007	0.002
0.3-0.15	0.02	0.0005	0.00001	1.7215	1.9	2.70E-05	1.35E-08	0.0000005	0.001
0.15-0.075	0.01	0.0003	0.00001	3.4431	2.1	1.49E-05	4.48E-09	0.0000002	0.000
	Total	0.0655					8.32E-07	0.0000333	0.083

Table A.6.2 Bed Load Calculation Sheet (2/5)

River Discharge (m3/sec)	2.0	Discharge per width (m3/s/m)	0.0500
Depth (m)	0.093	Hydraulic Gradient	0.0084
Bed slope	0.0083	Friction speed (m/s)	0.0871

(mm)	d (cm)	i	u*d (m2/s)	$u*^2/((\sigma/\rho)-1)gd$	f	qB (m3/s/m)	qBi (m3/s/m)	QB (m3/s)	QB (kg/s)
40-25	3.30	0.0109	0.00288	0.0157	-	-	-	-	-
25-20	2.30	0.0069	0.00200	0.0225	-	-	-	-	-
20-16	1.80	0.0062	0.00157	0.0287	-	-	-	-	-
16-12	1.40	0.0066	0.00122	0.0369	-	-	-	-	-
12-10	1.10	0.0025	0.00096	0.0470	-	-	-	-	-
10-8	0.90	0.0040	0.00078	0.0574	0.008	6.27E-06	2.51E-08	0.0000010	0.003
8-5	0.65	0.0064	0.00057	0.0795	0.08	4.53E-05	2.90E-07	0.0000116	0.029
5-4	0.45	0.0085	0.00039	0.1148	0.19	7.45E-05	6.33E-07	0.0000253	0.063
4-2	0.30	0.0073	0.00026	0.1722	0.5	1.31E-04	9.54E-07	0.0000382	0.095
2-0.6	0.13	0.0035	0.00011	0.3973	1.2	1.36E-04	4.76E-07	0.0000190	0.048
0.6-0.43	0.05	0.0015	0.00004	1.0329	1.6	6.97E-05	1.05E-07	0.0000042	0.010
0.43-0.3	0.04	0.0004	0.00003	1.2912	1.8	6.27E-05	2.51E-08	0.0000010	0.003
0.3-0.15	0.02	0.0005	0.00002	2.5823	2	3.49E-05	1.74E-08	0.0000007	0.002
0.15-0.075	0.01	0.0003	0.00001	5.1646	2.2	1.92E-05	5.75E-09	0.0000002	0.001
	Total	0.0655					2.53E-06	0.0001012	0.253

River Discharge (m3/sec)	3.0	Discharge per width (m3/s/m)	0.075
Depth (m)	0.119	Hydraulic Gradient	0.0083
Bed slope	0.0083	Friction speed (m/s)	0.0986

(mm)	d (cm)	i	u*d (m2/s)	$u*^2/((\sigma/\rho)-1)gd$	f	qB (m3/s/m)	qBi (m3/s/m)	QB (m3/s)	QB (kg/s)
40-25	3.30	0.0109	0.00325	0.0200	-	-	-	-	-
25-20	2.30	0.0069	0.00227	0.0287	-	-	-	-	-
20-16	1.80	0.0062	0.00177	0.0367	-	-	-	-	-
16-12	1.40	0.0066	0.00138	0.0472	-	-	-	-	-
12-10	1.10	0.0025	0.00108	0.0601	0.02	2.17E-05	5.42E-08	0.0000022	0.005
10-8	0.90	0.0040	0.00089	0.0734	0.04	3.55E-05	1.42E-07	0.0000057	0.014
8-5	0.65	0.0064	0.00064	0.1017	0.14	8.97E-05	5.74E-07	0.0000230	0.057
5-4	0.45	0.0085	0.00044	0.1469	0.4	1.77E-04	1.51E-06	0.0000603	0.151
4-2	0.30	0.0073	0.00030	0.2203	0.77	2.28E-04	1.66E-06	0.0000665	0.166
2-0.6	0.13	0.0035	0.00013	0.5083	1.3	1.67E-04	5.83E-07	0.0000233	0.058
0.6-0.43	0.05	0.0015	0.00005	1.3217	1.8	8.87E-05	1.33E-07	0.0000053	0.013
0.43-0.3	0.04	0.0004	0.00004	1.6521	1.8	7.10E-05	2.84E-08	0.0000011	0.003
0.3-0.15	0.02	0.0005	0.00002	3.3042	2.1	4.14E-05	2.07E-08	0.0000008	0.002
0.15-0.075	0.01	0.0003	0.00001	6.6085	2.2	2.17E-05	6.51E-09	0.0000003	0.001
	Total	0.0655					4.71E-06	0.0001885	0.471

Table A.6.2 Bed Load Calculation Sheet (3/5)

River Discharge (m3/sec)	4.0	Discharge per width (m3/s/m)	0.100
Depth (m)	0.142	Hydraulic Gradient	0.0082
Bed slope	0.0083	Friction speed (m/s)	0.1077

(mm)	d (cm)	i	u*d (m2/s)	u*2/((σ/ρ)-1)gd	f	qB (m3/s/m)	qBi (m3/s/m)	QB (m3/s)	QB (kg/s)
40-25	3.30	0.0109	0.00355	0.0239	-	-	-	-	-
25-20	2.30	0.0069	0.00248	0.0343	-	-	-	-	-
20-16	1.80	0.0062	0.00194	0.0438	-	-	-	-	-
16-12	1.40	0.0066	0.00151	0.0563	0.004	6.03E-06	3.98E-08	0.0000016	0.004
12-10	1.10	0.0025	0.00118	0.0717	0.04	4.74E-05	1.18E-07	0.0000047	0.012
10-8	0.90	0.0040	0.00097	0.0876	0.1	9.69E-05	3.88E-07	0.0000155	0.039
8-5	0.65	0.0064	0.00070	0.1213	0.2	1.40E-04	8.96E-07	0.0000358	0.090
5-4	0.45	0.0085	0.00048	0.1752	0.5	2.42E-04	2.06E-06	0.0000824	0.206
4-2	0.30	0.0073	0.00032	0.2629	0.8	2.58E-04	1.89E-06	0.0000755	0.189
2-0.6	0.13	0.0035	0.00014	0.6066	1.5	2.10E-04	7.35E-07	0.0000294	0.073
0.6-0.43	0.05	0.0015	0.00005	1.5771	1.8	9.69E-05	1.45E-07	0.0000058	0.015
0.43-0.3	0.04	0.0004	0.00004	1.9714	1.9	8.18E-05	3.27E-08	0.0000013	0.003
0.3-0.15	0.02	0.0005	0.00002	3.9429	2.1	4.52E-05	2.26E-08	0.0000009	0.002
0.15-0.075	0.01	0.0003	0.00001	7.8857	2.2	2.37E-05	7.11E-09	0.0000003	0.001
	Total	0.0655					6.33E-06	0.0002532	0.633

River Discharge (m3/sec)	5.0	Discharge per width (m3/s/m)	0.125
Depth (m)	0.162	Hydraulic Gradient	0.0083
Bed slope	0.0083	Friction speed (m/s)	0.1150

(mm)	d (cm)	i	u*d (m2/s)	u*2/((σ/ρ)-1)gd	f	qB (m3/s/m)	qBi (m3/s/m)	QB (m3/s)	QB (kg/s)
40-25	3.30	0.0109	0.00379	0.0273	-	-	-	-	-
25-20	2.30	0.0069	0.00264	0.0391	-	-	-	-	-
20-16	1.80	0.0062	0.00207	0.0500	0.002	4.14E-06	2.57E-08	0.0000010	0.003
16-12	1.40	0.0066	0.00161	0.0643	0.02	3.22E-05	2.13E-07	0.0000085	0.021
12-10	1.10	0.0025	0.00126	0.0818	0.08	1.01E-04	2.53E-07	0.0000101	0.025
10-8	0.90	0.0040	0.00103	0.1000	0.14	1.45E-04	5.80E-07	0.0000232	0.058
8-5	0.65	0.0064	0.00075	0.1384	0.3	2.24E-04	1.44E-06	0.0000574	0.144
5-4	0.45	0.0085	0.00052	0.1999	0.6	3.10E-04	2.64E-06	0.0001056	0.264
4-2	0.30	0.0073	0.00034	0.2999	1	3.45E-04	2.52E-06	0.0001007	0.252
2-0.6	0.13	0.0035	0.00015	0.6920	1.5	2.24E-04	7.85E-07	0.0000314	0.078
0.6-0.43	0.05	0.0015	0.00006	1.7993	1.8	1.03E-04	1.55E-07	0.0000062	0.016
0.43-0.3	0.04	0.0004	0.00005	2.2491	2	9.20E-05	3.68E-08	0.0000015	0.004
0.3-0.15	0.02	0.0005	0.00002	4.4982	2.1	4.83E-05	2.41E-08	0.0000010	0.002
0.15-0.075	0.01	0.0003	0.00001	8.9964	2.3	2.64E-05	7.93E-09	0.0000003	0.001
	Total	0.0655					8.67E-06	0.0003469	0.867

Table A.6.2 Bed Load Calculation Sheet (4/5)

River Discharge (m3/sec)	10.0	Discharge per width (m3/s/m)	0.25
Depth (m)	0.245	Hydraulic Gradient	0.0083
Bed slope	0.0083	Friction speed (m/s)	0.1414

	d	i	u*d	u*2/((σ/ρ)-1)gd	f	qB	qBi	QB	QB
(mm)	(cm)		(m2/s)			(m3/s/m)	(m3/s/m)	(m3/s)	(kg/s)
40-25	3.30	0.0109	0.00467	0.0412	-	-	-	-	-
25-20	2.30	0.0069	0.00325	0.0592	0.02	6.51E-05	4.49E-07	0.0000180	0.045
20-16	1.80	0.0062	0.00255	0.0756	0.08	2.04E-04	1.26E-06	0.0000505	0.126
16-12	1.40	0.0066	0.00198	0.0972	0.14	2.77E-04	1.83E-06	0.0000732	0.183
12-10	1.10	0.0025	0.00156	0.1237	0.2	3.11E-04	7.78E-07	0.0000311	0.078
10-8	0.90	0.0040	0.00127	0.1512	0.4	5.09E-04	2.04E-06	0.0000815	0.204
8-5	0.65	0.0064	0.00092	0.2093	0.76	6.99E-04	4.47E-06	0.0001788	0.447
5-4	0.45	0.0085	0.00064	0.3023	1	6.36E-04	5.41E-06	0.0002164	0.541
4-2	0.30	0.0073	0.00042	0.4535	1.3	5.52E-04	4.03E-06	0.0001611	0.403
2-0.6	0.13	0.0035	0.00018	1.0466	1.7	3.13E-04	1.09E-06	0.0000438	0.109
0.6-0.43	0.05	0.0015	0.00007	2.7211	2	1.41E-04	2.12E-07	0.0000085	0.021
0.43-0.3	0.04	0.0004	0.00006	3.4014	2.1	1.19E-04	4.75E-08	0.0000019	0.005
0.3-0.15	0.02	0.0005	0.00003	6.8028	2.2	6.22E-05	3.11E-08	0.0000012	0.003
0.15-0.075	0.01	0.0003	0.00001	13.6057	2.4	3.39E-05	1.02E-08	0.0000004	0.001
	Total	0.0655					2.17E-05	0.0008663	2.166

River Discharge (m3/sec)	15.0	Discharge per width (m3/s/m)	0.375
Depth (m)	0.313	Hydraulic Gradient	0.0083
Bed slope	0.0083	Friction speed (m/s)	0.1598

	d	i	u*d	u*2/((σ/ρ)-1)gd	f	qB	qBi	QB	QB
(mm)	(cm)		(m2/s)			(m3/s/m)	(m3/s/m)	(m3/s)	(kg/s)
40-25	3.30	0.0109	0.00527	0.0527	0.002	1.05E-05	1.15E-07	0.0000046	0.011
25-20	2.30	0.0069	0.00368	0.0756	0.05	1.84E-04	1.27E-06	0.0000507	0.127
20-16	1.80	0.0062	0.00288	0.0966	0.14	4.03E-04	2.50E-06	0.0000999	0.250
16-12	1.40	0.0066	0.00224	0.1242	0.2	4.48E-04	2.95E-06	0.0001182	0.295
12-10	1.10	0.0025	0.00176	0.1580	0.5	8.79E-04	2.20E-06	0.0000879	0.220
10-8	0.90	0.0040	0.00144	0.1931	0.6	8.63E-04	3.45E-06	0.0001381	0.345
8-5	0.65	0.0064	0.00104	0.2674	0.8	8.31E-04	5.32E-06	0.0002128	0.532
5-4	0.45	0.0085	0.00072	0.3863	1.2	8.63E-04	7.34E-06	0.0002935	0.734
4-2	0.30	0.0073	0.00048	0.5794	1.4	6.71E-04	4.90E-06	0.0001960	0.490
2-0.6	0.13	0.0035	0.00021	1.3371	1.8	3.74E-04	1.31E-06	0.0000524	0.131
0.6-0.43	0.05	0.0015	0.00008	3.4764	2.1	1.68E-04	2.52E-07	0.0000101	0.025
0.43-0.3	0.04	0.0004	0.00006	4.3455	2.1	1.34E-04	5.37E-08	0.0000021	0.005
0.3-0.15	0.02	0.0005	0.00003	8.6910	2.3	7.35E-05	3.68E-08	0.0000015	0.004
0.15-0.075	0.01	0.0003	0.00002	17.3819	2.4	3.84E-05	1.15E-08	0.0000005	0.001
	Total	0.0655					3.17E-05	0.0012682	3.171

Table A.6.2 Bed Load Calculation Sheet (5/5)

River Discharge (m3/sec)	20.0	Discharge per width (m3/s/m)	0.50
Depth (m)	0.373	Hydraulic Gradient	0.0082
Bed slope	0.0083	Friction speed (m/s)	0.1745

(mm)	d (cm)	i	u*d (m2/s)	u*2/((σ/ρ)-1)gd	f	qB (m3/s/m)	qBi (m3/s/m)	QB (m3/s)	QB (kg/s)
40-25	3.30	0.0109	0.00576	0.0628	0.02	1.15E-04	1.26E-06	0.0000502	0.126
25-20	2.30	0.0069	0.00401	0.0901	0.1	4.01E-04	2.77E-06	0.0001108	0.277
20-16	1.80	0.0062	0.00314	0.1151	0.19	5.97E-04	3.70E-06	0.0001480	0.370
16-12	1.40	0.0066	0.00244	0.1480	0.4	9.77E-04	6.45E-06	0.0002580	0.645
12-10	1.10	0.0025	0.00192	0.1883	0.6	1.15E-03	2.88E-06	0.0001152	0.288
10-8	0.90	0.0040	0.00157	0.2302	0.78	1.22E-03	4.90E-06	0.0001960	0.490
8-5	0.65	0.0064	0.00113	0.3187	1	1.13E-03	7.26E-06	0.0002904	0.726
5-4	0.45	0.0085	0.00079	0.4603	1.5	1.18E-03	1.00E-05	0.0004005	1.001
4-2	0.30	0.0073	0.00052	0.6905	1.6	8.38E-04	6.11E-06	0.0002446	0.611
2-0.6	0.13	0.0035	0.00023	1.5934	1.8	4.08E-04	1.43E-06	0.0000572	0.143
0.6-0.43	0.05	0.0015	0.00009	4.1428	2.1	1.83E-04	2.75E-07	0.0000110	0.027
0.43-0.3	0.04	0.0004	0.00007	5.1785	2.1	1.47E-04	5.86E-08	0.0000023	0.006
0.3-0.15	0.02	0.0005	0.00003	10.3570	2.4	8.38E-05	4.19E-08	0.0000017	0.004
0.15-0.075	0.01	0.0003	0.00002	20.7139	2.4	4.19E-05	1.26E-08	0.0000005	0.001
	Total	0.0655					4.72E-05	0.0018862	4.716

Table A.6.3 Suspended Load Calculation Sheet (1/2)

River Discharge(m3/s)= 1.0 Bed Slope = 0.0083

Depth (m) = 0.062 Discharge per width 250.0 cm2/s

(mm)	d (cm)	Wo (cm/s)	u* (cm/s)	Wo/u*	(Wo/u*)^2	P	exp(-(Wo/u*)^2) =A	((0.5u*/Wo)*A)^1.61	ΔF(Wo) (%)	Co Total(ppm)	Co Observed value(ppm)	qs (g/s/cm)	Qs (g/s)	Qs (m3/s)
0.075>	0.0075	0.7	7.114	0.098	0.010	0.47	0.990	13.486	93.44	6994	10	1.18E-03	4.7	1.86E-06
0.15-0.075	0.01	0.8	7.114	0.112	0.013	0.45	0.987	10.826	0.03	2	10	1.13E-03	4.5	1.80E-06
0.3-0.15	0.02	2.3	7.114	0.323	0.105	0.16	0.901	1.705	0.05	0	10	4.00E-04	1.6	6.40E-07
0.43-0.3	0.04	6.0	7.114	0.843	0.711	4.10	0.491	0.137	0.04	0	10	1.03E-02	41.0	1.64E-05
0.6-0.43	0.05	8.0	7.114	1.124	-	-								
2.0-0.6	0.13	20.0	7.114	2.811	-	-								
4.0-2.0	0.3	40.0	7.114	5.622	-	-								
5.0-4.0	0.45	50.0	7.114	7.028	-	-								
Total												1.30E-02	51.8	2.07E-05

River Discharge(m3/s)= 2.0 Bed Slope = 0.0083

Depth (m) = 0.093 Discharge per width 500.0 cm2/s

(mm)	d (cm)	Wo (cm/s)	u* (cm/s)	Wo/u*	(Wo/u*)^2	P	exp(-(Wo/u*)^2) =A	((0.5u*/Wo)*A)^1.61	ΔF(Wo) (%)	Co Total(ppm)	Co Observed value(ppm)	qs (g/s/cm)	Qs (g/s)	Qs (m3/s)
0.075>	0.0075	0.7	8.713	0.080	0.006	0.55	0.994	18.789	93.44	9744	25	6.88E-03	27.5	1.10E-05
0.15-0.075	0.01	0.8	8.713	0.092	0.008	0.51	0.992	15.106	0.03	3	25	6.38E-03	25.5	1.02E-05
0.3-0.15	0.02	2.3	8.713	0.264	0.070	0.20	0.933	2.500	0.05	1	25	2.50E-03	10.0	4.00E-06
0.43-0.3	0.04	6.0	8.713	0.689	0.474	0.06	0.622	0.278	0.04	0	25	6.88E-04	2.8	1.10E-06
0.6-0.43	0.05	8.0	8.713	0.918	0.843	0.04	0.430	0.097	0.15	0	25	4.63E-04	1.9	7.40E-07
2.0-0.6	0.13	20.0	8.713	2.295	-	-								
4.0-2.0	0.3	40.0	8.713	4.591	-	-								
5.0-4.0	0.45	50.0	8.713	5.738	-	-								
Total												1.64E-02	65.8	2.63E-05

River Discharge(m3/s)= 3.0 Bed Slope = 0.0083

Depth (m) = 0.119 Discharge per width 750.0 cm2/s

(mm)	d (cm)	Wo (cm/s)	u* (cm/s)	Wo/u*	(Wo/u*)^2	P	exp(-(Wo/u*)^2) =A	((0.5u*/Wo)*A)^1.61	ΔF(Wo) (%)	Co Total(ppm)	Co Observed value(ppm)	qs (g/s/cm)	Qs (g/s)	Qs (m3/s)
0.075>	0.0075	0.7	9.856	0.071	0.005	0.59	0.995	22.966	93.44	11910	35	1.55E-02	62.0	2.48E-05
0.15-0.075	0.01	0.8	9.856	0.081	0.007	0.55	0.993	18.477	0.03	3	35	1.44E-02	57.8	2.31E-05
0.3-0.15	0.02	2.3	9.856	0.233	0.054	0.23	0.947	3.124	0.05	1	35	6.04E-03	24.2	9.66E-06
0.43-0.3	0.04	6.0	9.856	0.609	0.371	0.07	0.690	0.401	0.04	0	35	1.79E-03	7.1	2.86E-06
0.6-0.43	0.05	8.0	9.856	0.812	0.659	0.05	0.517	0.159	0.15	0	35	1.18E-03	4.7	1.89E-06
2.0-0.6	0.13	20.0	9.856	2.029	-	-								
4.0-2.0	0.3	40.0	9.856	4.058	-	-								
5.0-4.0	0.45	50.0	9.856	5.073	-	-								
Total												3.77E-02	151.0	6.04E-05

River Discharge(m3/s)= 4.0 Bed Slope = 0.0

Depth (m) = 0.142 Discharge per width 1000.0 cm2/s

(mm)	d (cm)	Wo (cm/s)	u* (cm/s)	Wo/u*	(Wo/u*)^2	P	exp(-(Wo/u*)^2) =A	((0.5u*/Wo)*A)^1.61	ΔF(Wo) (%)	Co Total(ppm)	Co Observed value(ppm)	qs (g/s/cm)	Qs (g/s)	Qs (m3/s)
0.075>	0.0075	0.7	10.767	0.065	0.004	0.60	0.996	26.511	93.44	13748	50	3.00E-02	120.0	4.80E-05
0.15-0.075	0.01	0.8	10.767	0.074	0.006	0.58	0.994	21.338	0.03	4	50	2.90E-02	116.0	4.64E-05
0.3-0.15	0.02	2.3	10.767	0.214	0.046	0.25	0.955	3.653	0.05	1	50	1.25E-02	50.0	2.00E-05
0.43-0.3	0.04	6.0	10.767	0.557	0.311	0.08	0.733	0.509	0.04	0	50	3.75E-03	15.0	6.00E-06
0.6-0.43	0.05	8.0	10.767	0.743	0.552	0.05	0.576	0.217	0.15	0	50	2.50E-03	10.0	4.00E-06
2.0-0.6	0.13	20.0	10.767	1.858	-	-								
4.0-2.0	0.3	40.0	10.767	3.715	-	-								
5.0-4.0	0.45	50.0	10.767	4.644	-	-								
Total												7.53E-02	301.0	1.20E-04

River Discharge(m3/s)= 5.0 Bed Slope = 0.0083

Depth (m) = 0.162 Discharge per width 1250.0 cm2/s

(mm)	d (cm)	Wo (cm/s)	u* (cm/s)	Wo/u*	(Wo/u*)^2	P	exp(-(Wo/u*)^2) =A	((0.5u*/Wo)*A)^1.61	ΔF(Wo) (%)	Co Total(ppm)	Co Observed value(ppm)	qs (g/s/cm)	Qs (g/s)	Qs (m3/s)
0.075>	0.0075	0.7	11.500	0.061	0.004	0.63	0.996	29.503	93.44	15300	60	4.73E-02	189.0	7.56E-05
0.15-0.075	0.01	0.8	11.500	0.070	0.005	0.59	0.995	23.752	0.03	4	60	4.43E-02	177.0	7.08E-05
0.3-0.15	0.02	2.3	11.500	0.200	0.040	0.26	0.961	4.099	0.05	1	60	1.95E-02	78.0	3.12E-05
0.43-0.3	0.04	6.0	11.500	0.522	0.272	0.09	0.762	0.602	0.04	0	60	6.38E-03	25.5	1.02E-05
0.6-0.43	0.05	8.0	11.500	0.696	0.484	0.05	0.616	0.270	0.15	0	60	4.05E-03	16.2	6.48E-06
2.0-0.6	0.13	20.0	11.500	1.739	-	-								
4.0-2.0	0.3	40.0	11.500	3.478	-	-								
5.0-4.0	0.45	50.0	11.500	4.348	-	-								
Total												1.17E-01	469.5	1.88E-04

Table A.6.3 Suspended Load Calculation Sheet (2/2)

River Discharge(m3/s)= 10.0 Bed Slope = 0.0083

Depth (m) = 0.245 Discharge per width 2500.0 cm2/s

d (mm)	d (cm)	Wo (cm/s)	u* (cm/s)	Wo/u*	(Wo/u*)^2	P	exp(-(Wo/u*)^2) =A	((0.5u*/Wo)*A)^1.61	ΔF(Wo) (%)	Co Total(ppm)	Co Observed value(ppm)	qs (g/s/cm)	Qs (g/s)	Qs (m3/s)
0.075>	0.0075	0.7	14.142	0.049	0.002	0.68	0.998	41.244	93.44	21389	140	2.38E-01	952.0	3.81E-04
0.15-0.075	0.01	0.8	14.142	0.057	0.003	0.65	0.997	33.225	0.03	6	140	2.28E-01	910.0	3.64E-04
0.3-0.15	0.02	2.3	14.142	0.163	0.026	0.32	0.974	5.845	0.05	2	140	1.12E-01	448.0	1.79E-04
0.43-0.3	0.04	6.0	14.142	0.424	0.180	0.11	0.835	0.975	0.04	0	140	3.85E-02	154.0	6.16E-05
0.6-0.43	0.05	8.0	14.142	0.566	0.320	0.08	0.726	0.490	0.15	0	140	2.63E-02	105.0	4.20E-05
2.0-0.6	0.13	20.0	14.142	1.414	-	-								
4.0-2.0	0.3	40.0	14.142	2.828	-	-								
5.0-4.0	0.45	50.0	14.142	3.536	-	-								
Total												6.16E-01	2464.0	9.86E-04

River Discharge(m3/s)= 15.0 Bed Slope = 0.0083

Depth (m) = 0.313 Discharge per width 3750.0 cm2/s

d (mm)	d (cm)	Wo (cm/s)	u* (cm/s)	Wo/u*	(Wo/u*)^2	P	exp(-(Wo/u*)^2) =A	((0.5u*/Wo)*A)^1.61	ΔF(Wo) (%)	Co Total(ppm)	Co Observed value(ppm)	qs (g/s/cm)	Qs (g/s)	Qs (m3/s)
0.075>	0.0075	0.7	15.985	0.044	0.002	0.70	0.998	50.276	93.44	26073	200	5.25E-01	2100.0	8.40E-04
0.15-0.075	0.01	0.8	15.985	0.050	0.003	0.69	0.997	40.512	0.03	7	200	5.18E-01	2070.0	8.28E-04
0.3-0.15	0.02	2.3	15.985	0.144	0.021	0.35	0.980	7.185	0.05	2	200	2.63E-01	1050.0	4.20E-04
0.43-0.3	0.04	6.0	15.985	0.375	0.141	0.13	0.869	1.265	0.04	0	200	9.75E-02	390.0	1.56E-04
0.6-0.43	0.05	8.0	15.985	0.500	0.250	0.08	0.778	0.667	0.15	1	200	6.23E-02	249.0	9.96E-05
2.0-0.6	0.13	20.0	15.985	1.251	-	-								
4.0-2.0	0.3	40.0	15.985	2.502	-	-								
5.0-4.0	0.45	50.0	15.985	3.128	-	-								
Total												1.40E+00	5610.0	2.24E-03

River Discharge(m3/s)= 20.0 Bed Slope = 0.0083

Depth (m) = 0.373 Discharge per width 5000.0 cm2/s

d (mm)	d (cm)	Wo (cm/s)	u* (cm/s)	Wo/u*	(Wo/u*)^2	P	exp(-(Wo/u*)^2) =A	((0.5u*/Wo)*A)^1.61	ΔF(Wo) (%)	Co Total(ppm)	Co Observed value(ppm)	qs (g/s/cm)	Qs (g/s)	Qs (m3/s)
0.075>	0.0075	0.7	17.450	0.040	0.002	0.72	0.998	57.928	93.44	30041	300	1.08E+00	4320.0	1.73E-03
0.15-0.075	0.01	0.8	17.450	0.046	0.002	0.70	0.998	46.685	0.03	8	300	1.05E+00	4200.0	1.68E-03
0.3-0.15	0.02	2.3	17.450	0.132	0.017	0.04	0.983	8.319	0.05	2	300	6.00E-02	240.0	9.60E-05
0.43-0.3	0.04	6.0	17.450	0.344	0.118	0.14	0.888	1.511	0.04	0	300	2.10E-01	840.0	3.36E-04
0.6-0.43	0.05	8.0	17.450	0.458	0.210	0.10	0.810	0.820	0.15	1	300	1.47E-01	588.0	2.35E-04
2.0-0.6	0.13	20.0	17.450	1.146	-	-								
4.0-2.0	0.3	40.0	17.450	2.292	-	-								
5.0-4.0	0.45	50.0	17.450	2.865	-	-								
Total												2.40E+00	9600.0	3.84E-03

Note:
- d = particle size.
- W_o = rate of sedimentation.
- u* = friction speed.
- P = function of roughness number and depth (derived from Fig. A.6.4).
- $\Delta F(W_o)$ = Proportion (%) of particles of which rate of sedimentation is Wo.
- Co = density of suspended load near the river bed.
- q_s = suspended load per unit width.
- Q_s = suspended load.

Table A.6.4 Summary of Sediment Load

Location: Gudrung Headworks Site

Q	Suspended Load		Bed Load		Total	
(m3/sec)	(kg/s)	(m3/sec)	(kg/s)	(m3/sec)	(kg/s)	(m3/sec)
1	0.083	3.330E-05	0.052	2.072E-05	0.135	5.402E-05
2	0.253	1.012E-04	0.066	2.630E-05	0.319	1.275E-04
3	0.471	1.885E-04	0.151	6.040E-05	0.622	2.489E-04
4	0.633	2.532E-04	0.301	1.204E-04	0.934	3.736E-04
5	0.867	3.469E-04	0.470	1.878E-04	1.337	5.347E-04
6	1.133	4.533E-04	0.669	2.675E-04	1.802	7.208E-04
7	1.360	5.440E-04	1.013	4.052E-04	2.373	9.492E-04
8	1.580	6.318E-04	1.341	5.363E-04	2.921	1.168E-03
9	1.749	6.995E-04	1.827	7.309E-04	3.576	1.430E-03
10	2.166	8.663E-04	2.464	9.856E-04	4.630	1.852E-03
15	3.171	1.268E-03	5.610	2.244E-03	8.781	3.512E-03
20	4.716	1.886E-03	9.600	3.840E-03	14.316	5.726E-03

Note : Specific gravity is 2.5

FIGURES

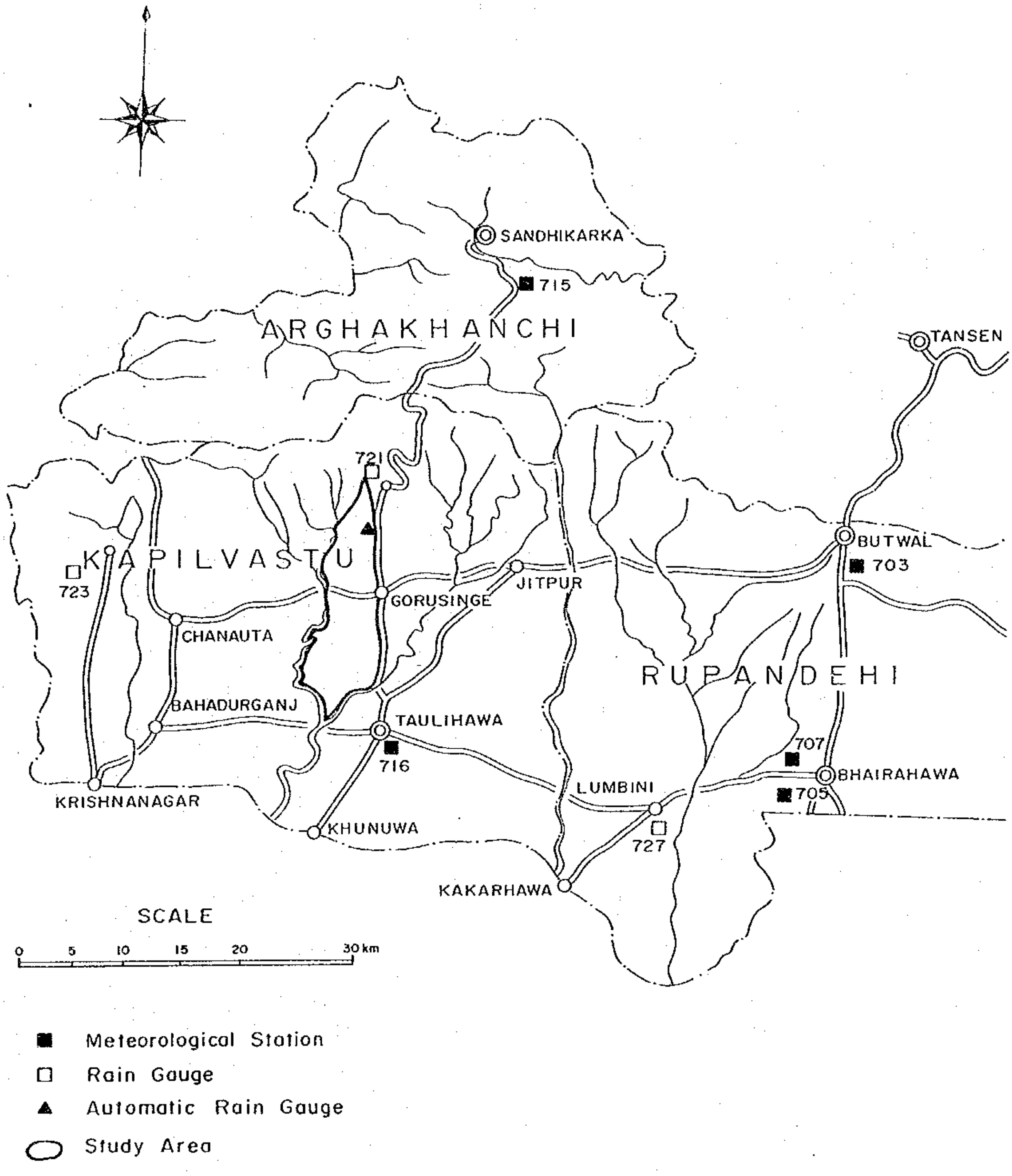

Fig. A.2.1 Location of Meteorological Observatories

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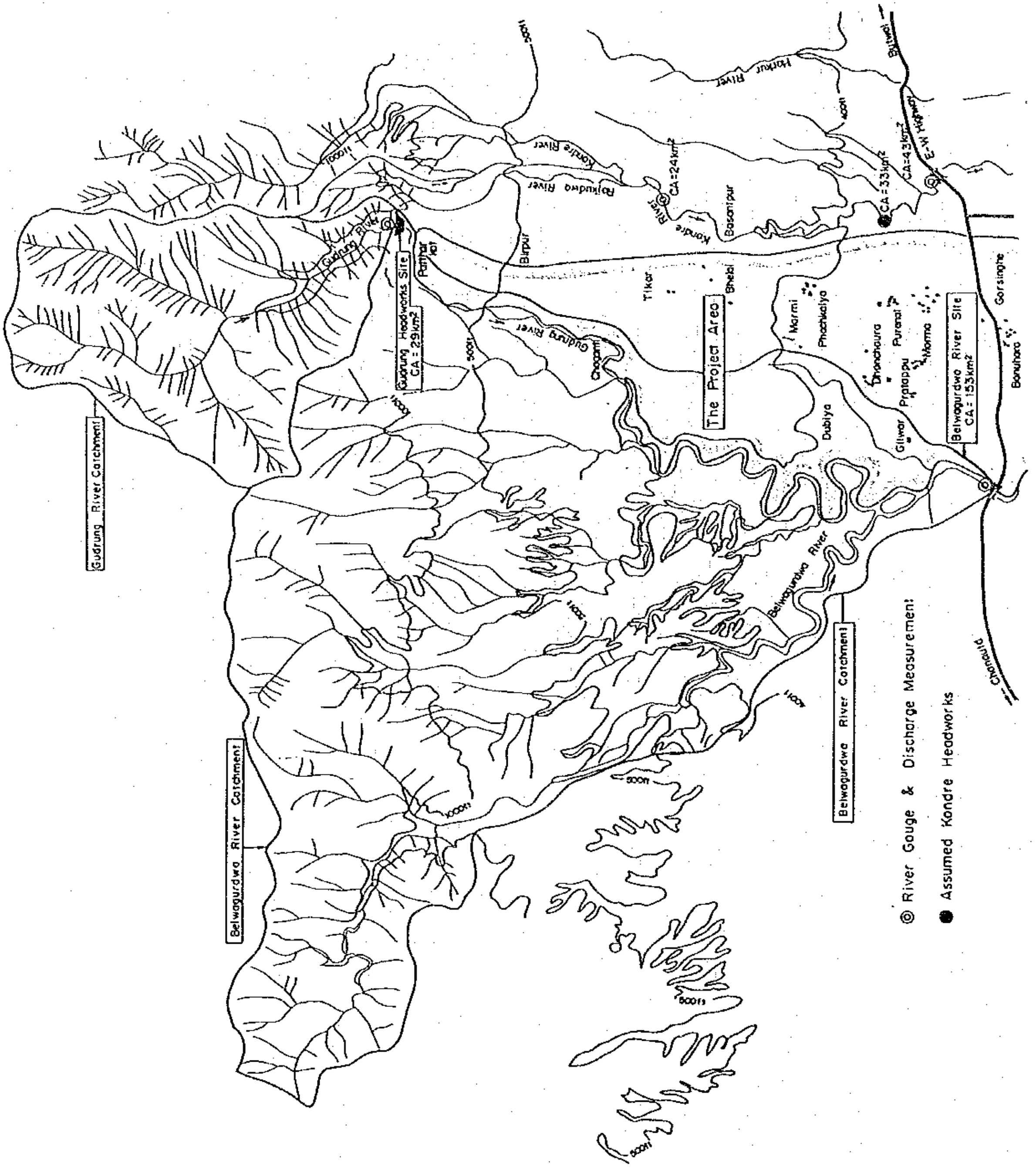

Fig. A.2.2 Location of Related Rivers and Rivergauges

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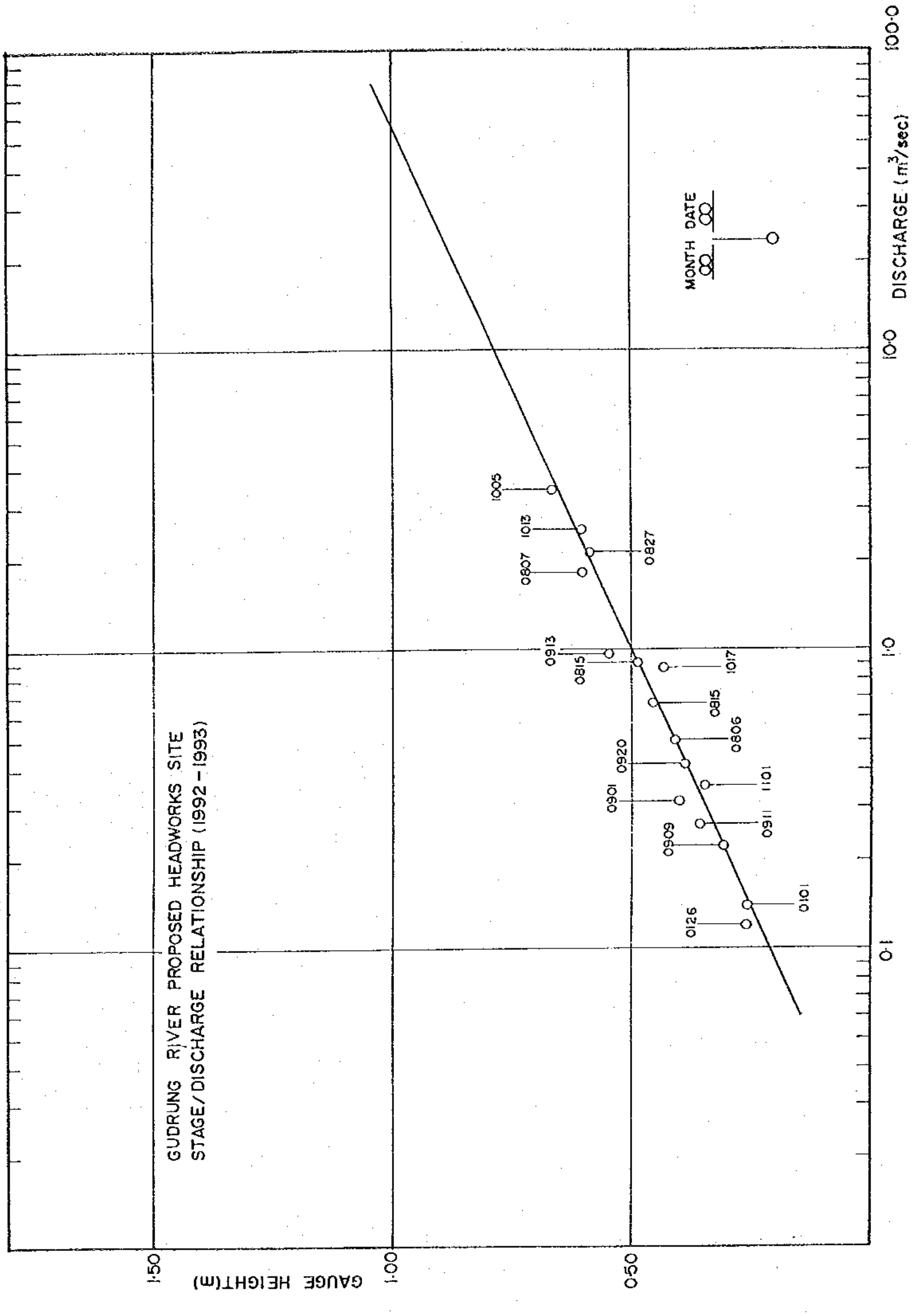

Fig. A.2.3 Rating Curve for the Gudrung River Headworks Site

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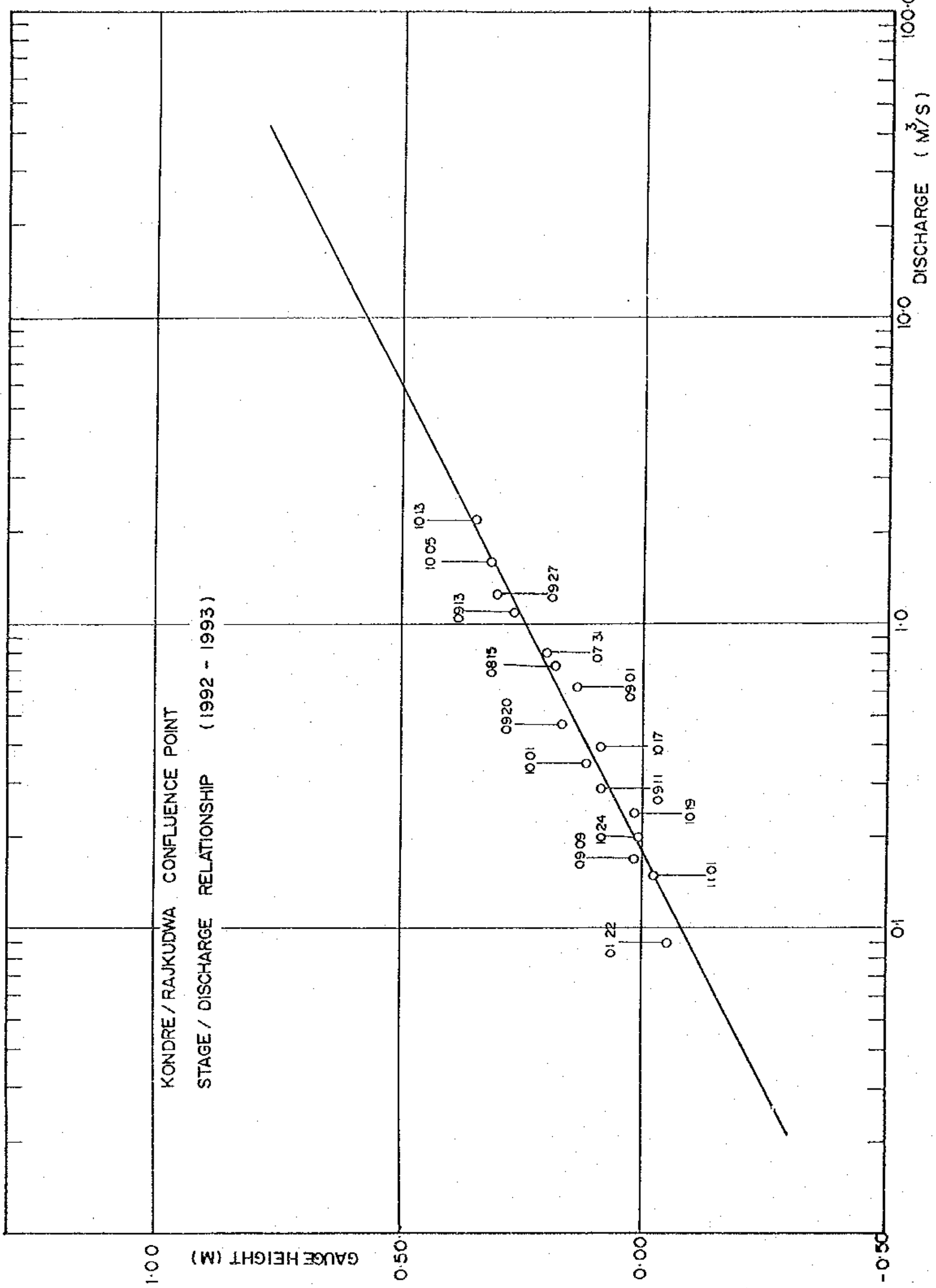

Fig. A.2.4 Rating Curve for the Kondre River Upstream Site

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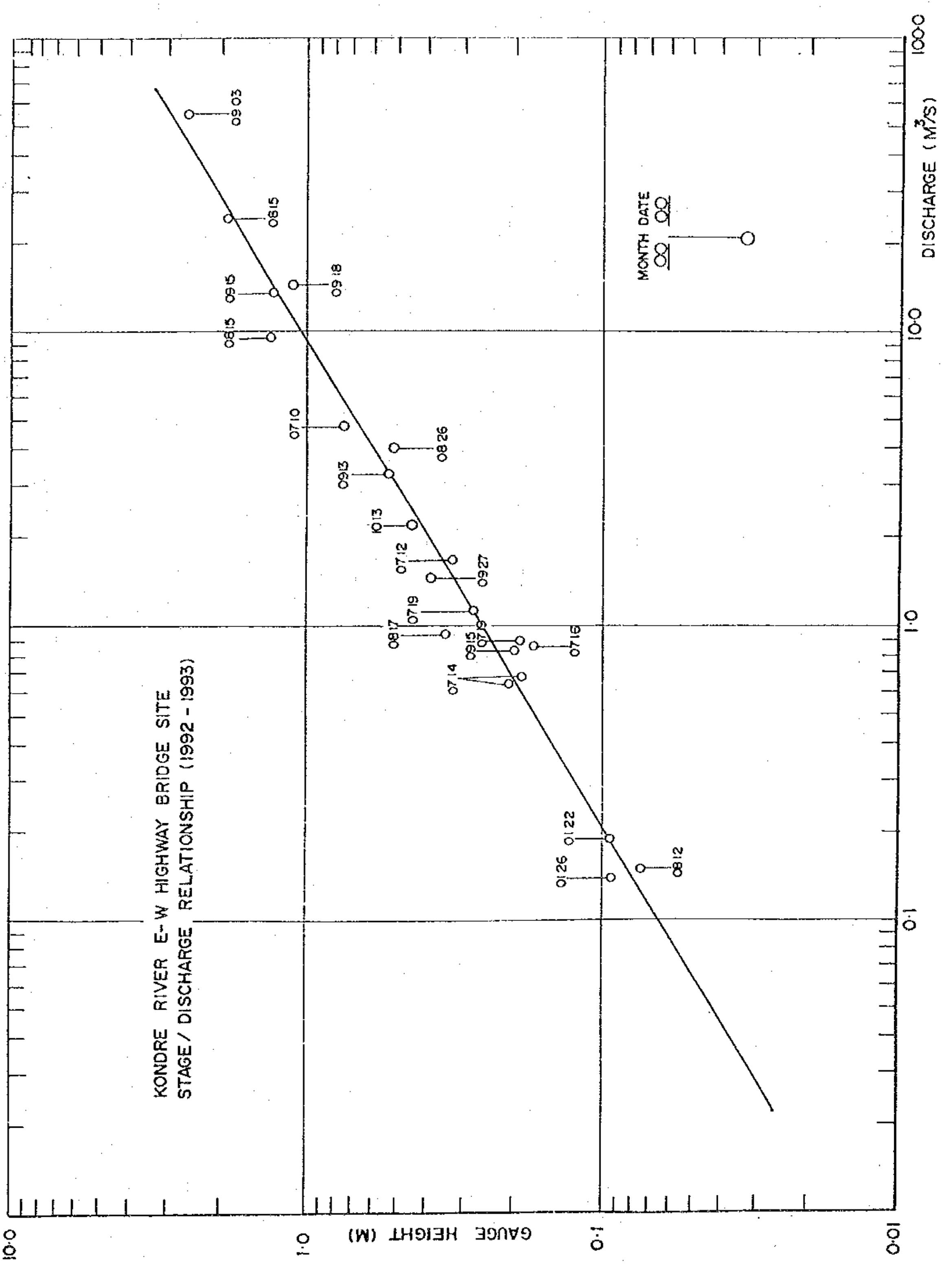

Fig. A.2.5 Rating Curve for the Kondre River Downstream Site

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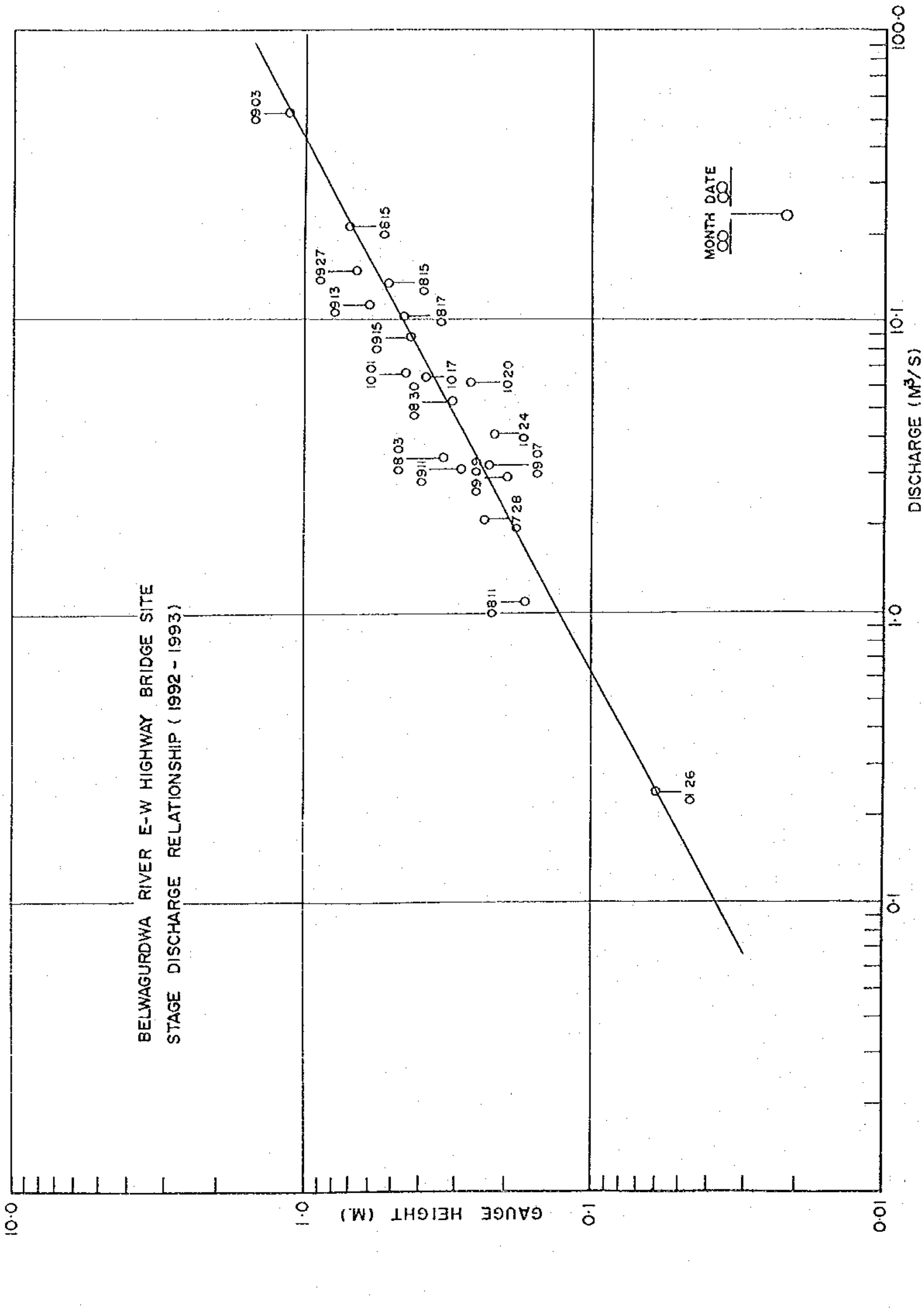

Fig. A.2.6 Rating Curve for the Belwagurdwa River at the East-West Highway Bridge

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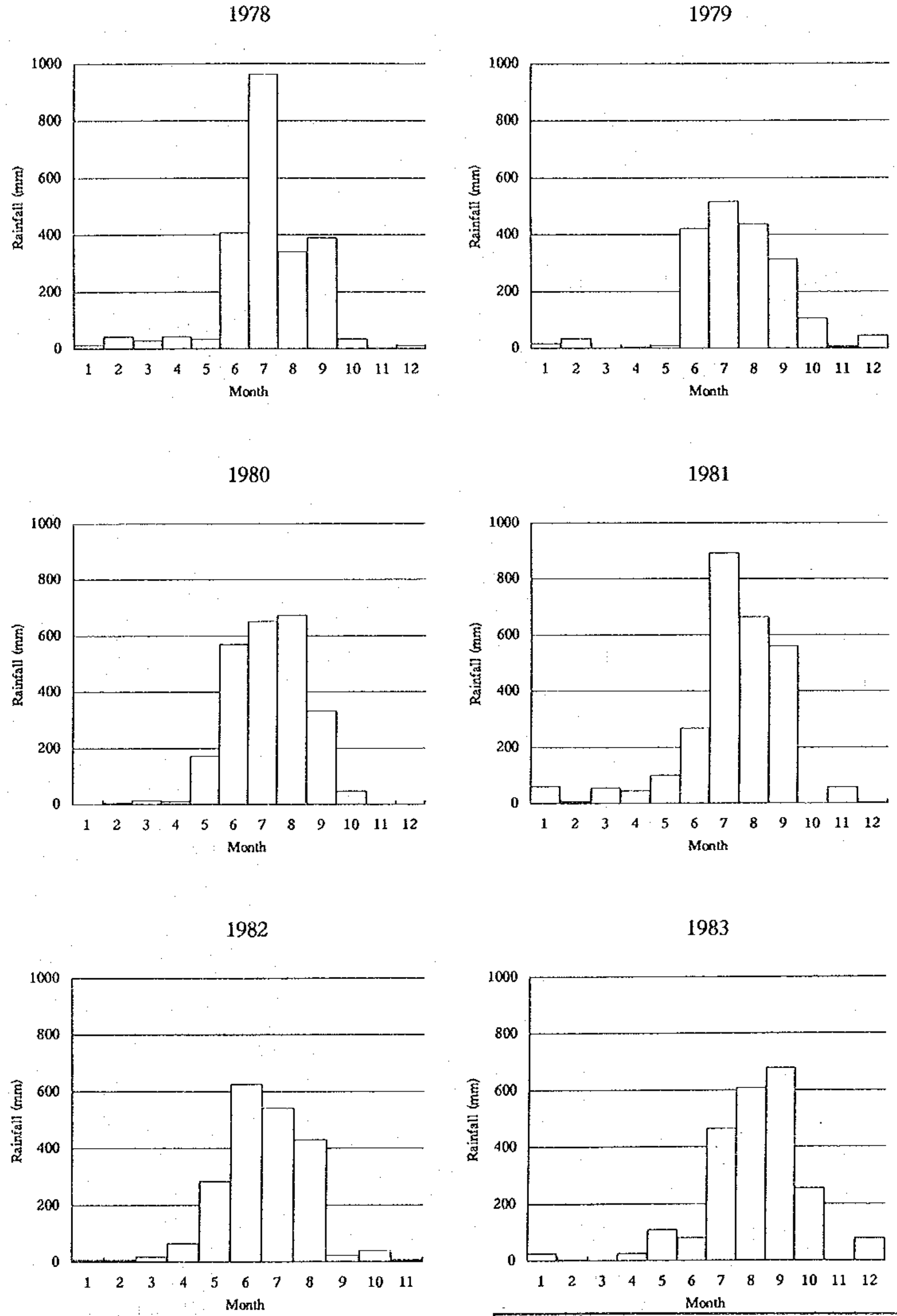

Fig. A.3.1 Monthly Rainfall in Pattharkot (1/3)
(Year 1978-1983)

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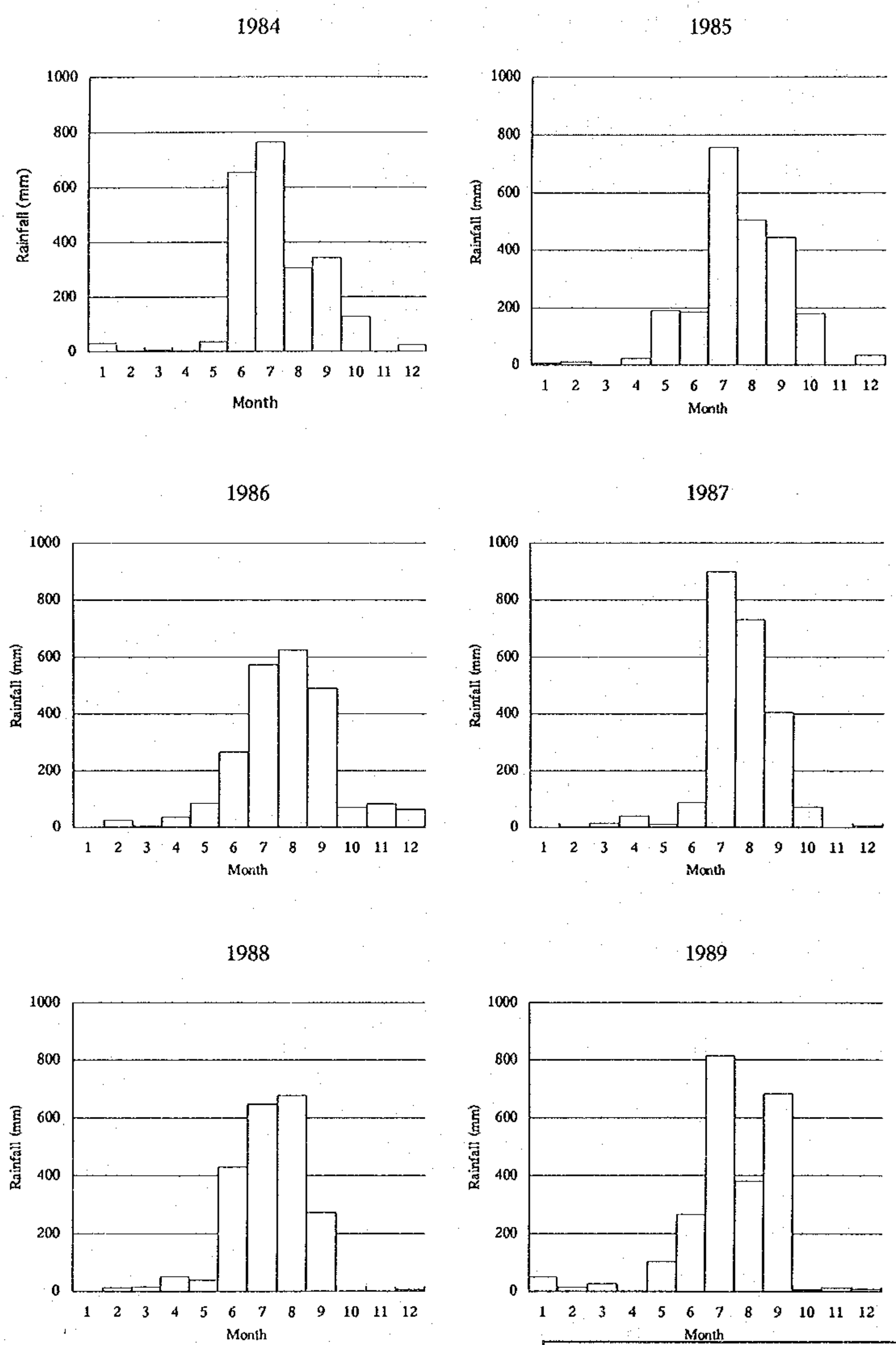

Fig. A.3. 1 Monthly Rainfall in Pattharkot (2/3) (Year 1984-1989)

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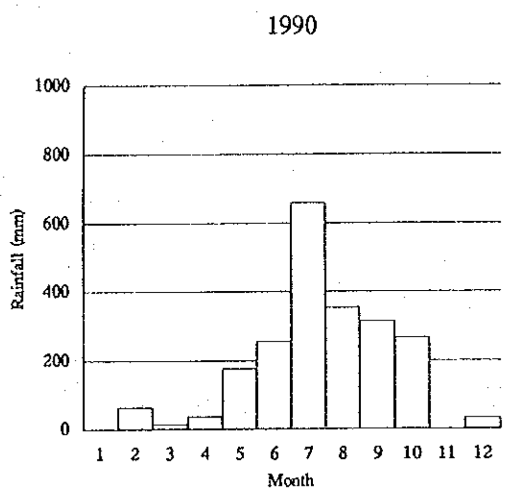

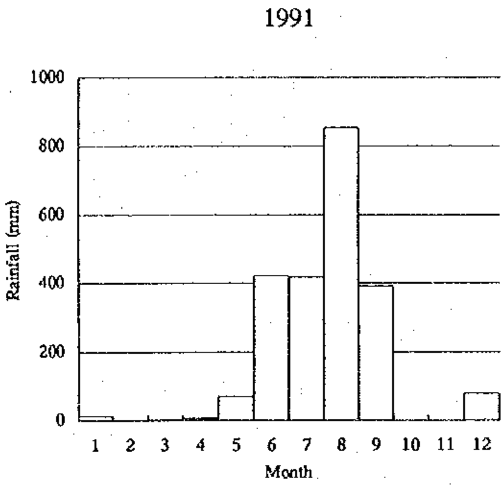

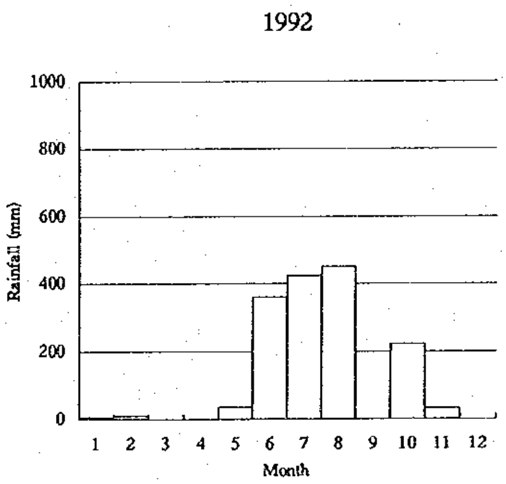

Fig. A.3. 1 Monthly Rainfall in Pattharkot (3/3)
(Year 1990-1992)

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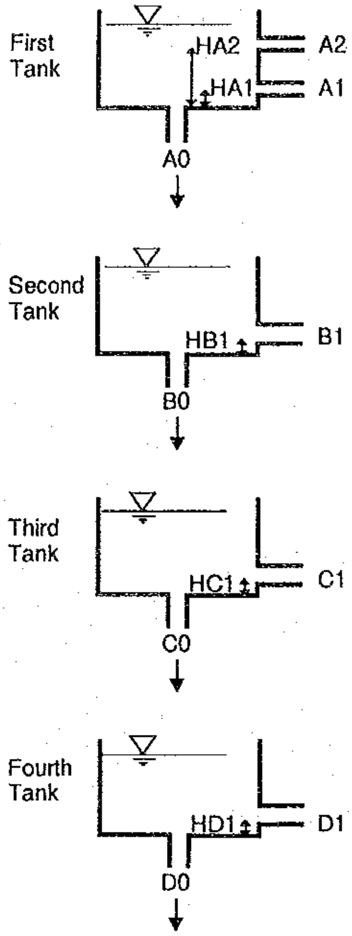

First Tank

HA1= 80.00 A0=0.250
HA2= 0.00 A1=0.400
A2=0.150

Second Tank

HB1= 60.00 B0= 0.200
B1= 0.250

Third Tank

HC1= 40.00 C0= 0.080
C1= 0.100

Fourth Tank

HD1= 20.00 D0= 0.0001
D1= 0.0005

Evaporation

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
(1) Estimated Evapo-transpiration in Bhairahawa (mm/day)	2.1	3.0	4.9	7.0	8.0	6.8	5.3	5.0	4.3	3.9	3.0	2.0
(2) Adopted Basin Evaporation 50% of (1) (mm/day)	1.1	1.5	2.5	3.5	4.0	3.4	2.7	2.5	2.2	2.0	1.5	1.0

Fig. A.4.1 Tank Model for the Gudrung River at Proposed Headworks Site

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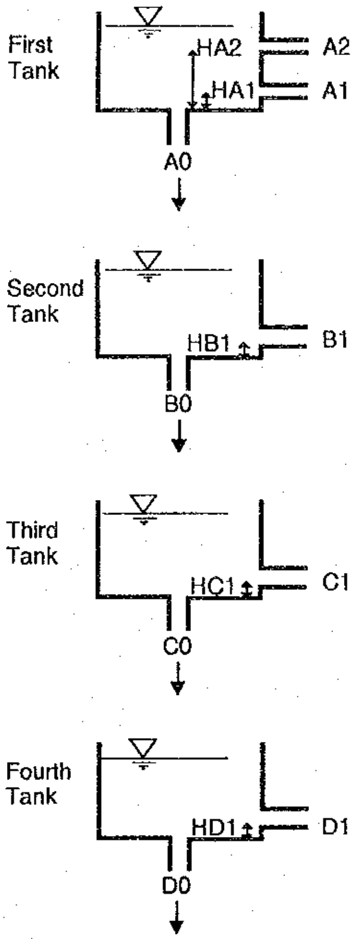

First Tank

HA1= 80.00 A0=0.300
HA2= 0.00 A1=0.400
A2=0.150

Second Tank

HB1= 60.00 B0= 0.220
B1= 0.250

Third Tank

HC1= 40.00 C0= 0.100
C1= 0.100

Fourth Tank

HD1= 20.00 D0= 0.0004
D1= 0.0004

Evaporation

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
(1) Estimated Evapo-transpiration in Bhairahawa (mm/day)	2.1	3.0	4.9	7.0	8.0	6.8	5.3	5.0	4.3	3.9	3.0	2.0
(2) Adopted Basin Evaporation 50% of (1) (mm/day)	1.1	1.5	2.5	3.5	4.0	3.4	2.7	2.5	2.2	2.0	1.5	1.0

Fig. A.4.2 Tank Model for the Kondre River at Considered Headworks Site

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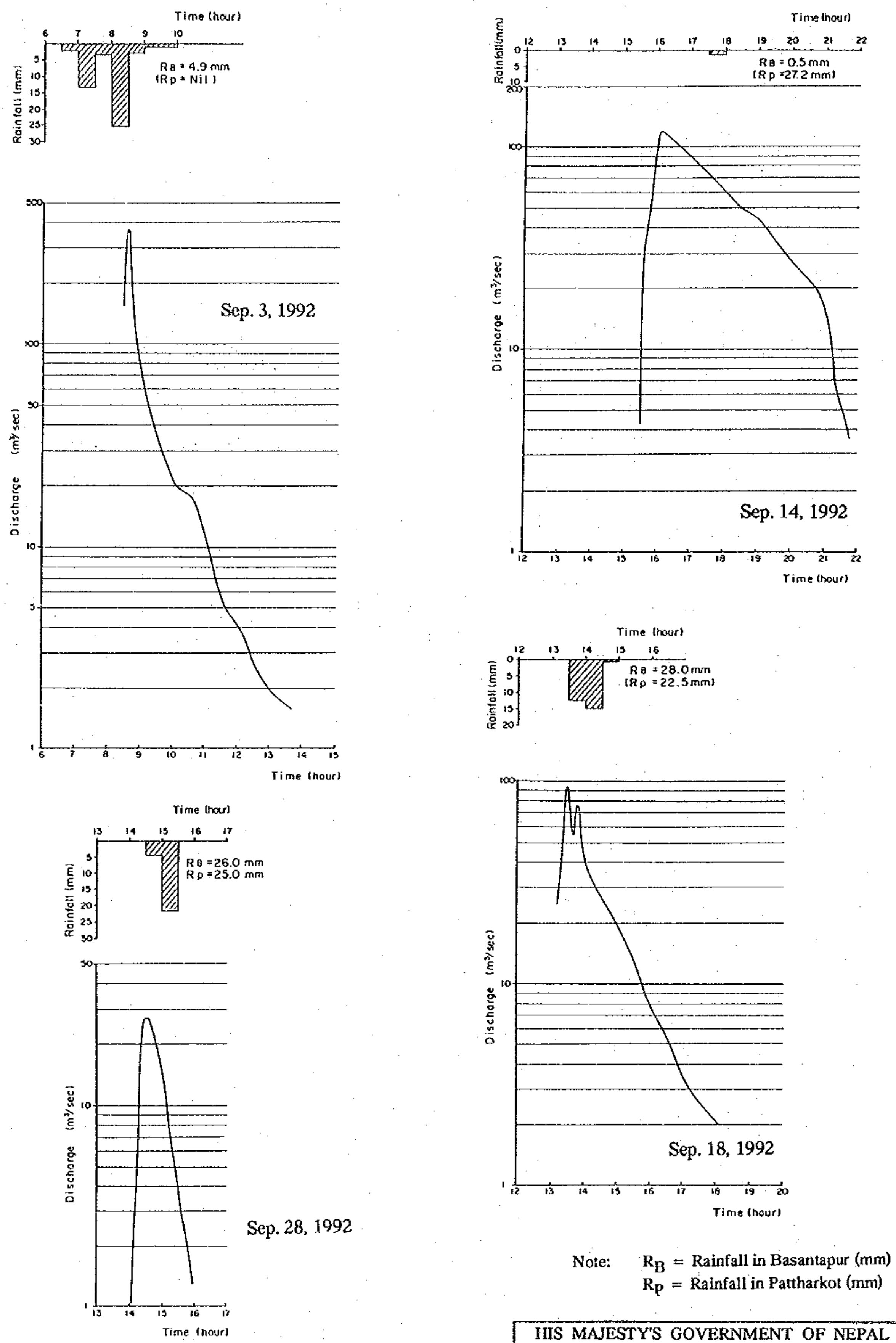

Note: R_B = Rainfall in Basantapur (mm)
R_P = Rainfall in Pattharkot (mm)

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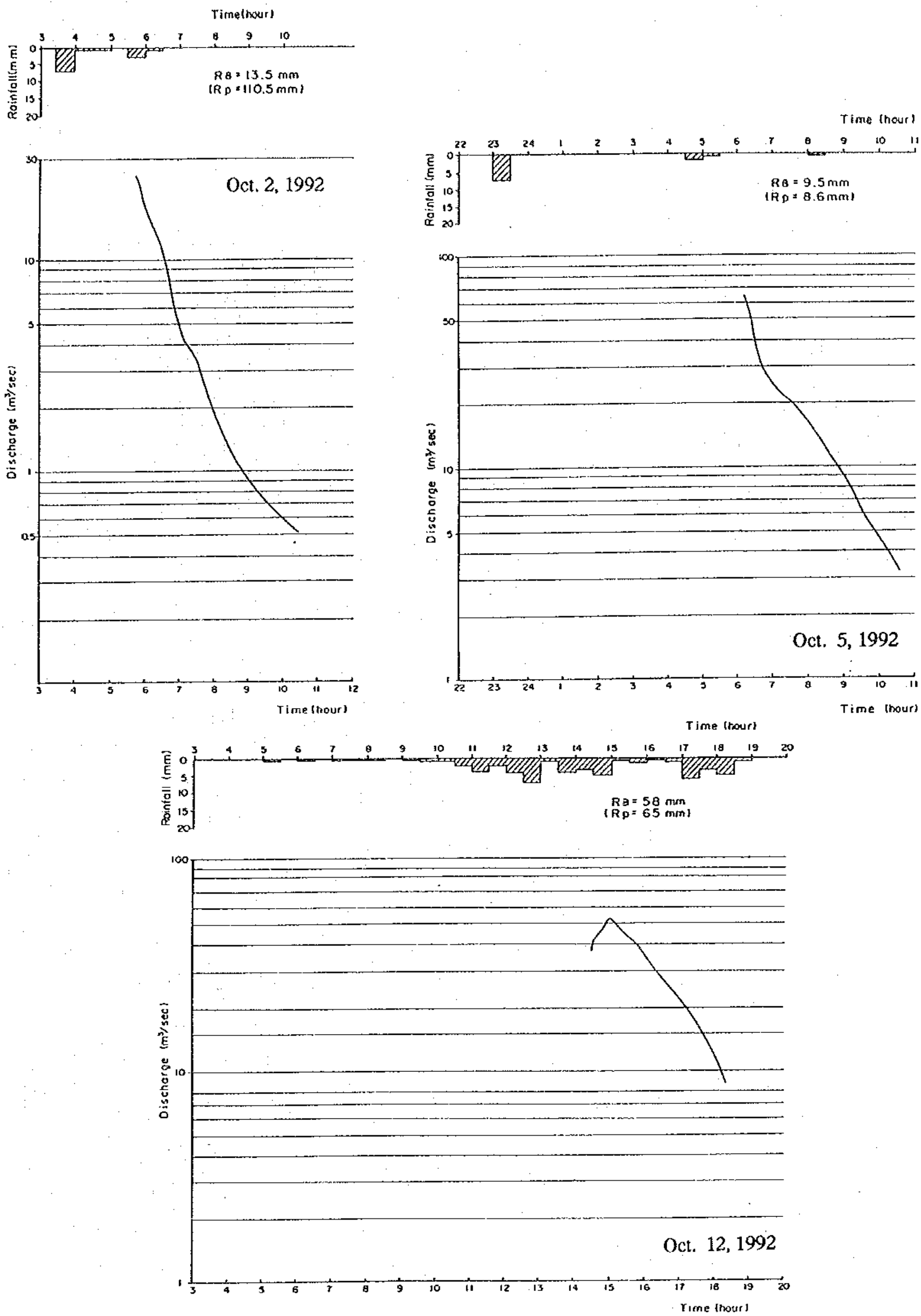
Fig. A.5.1 Observed Hydrographs at Gudrung Headworks Site (1/2)



Note: R_B = Rainfall in Basantapur (mm)
R_P = Rainfall in Pattharkot (mm)

Fig. A.5.1 Observed Hydrographs at Gudrung Headworks Site (2/2)

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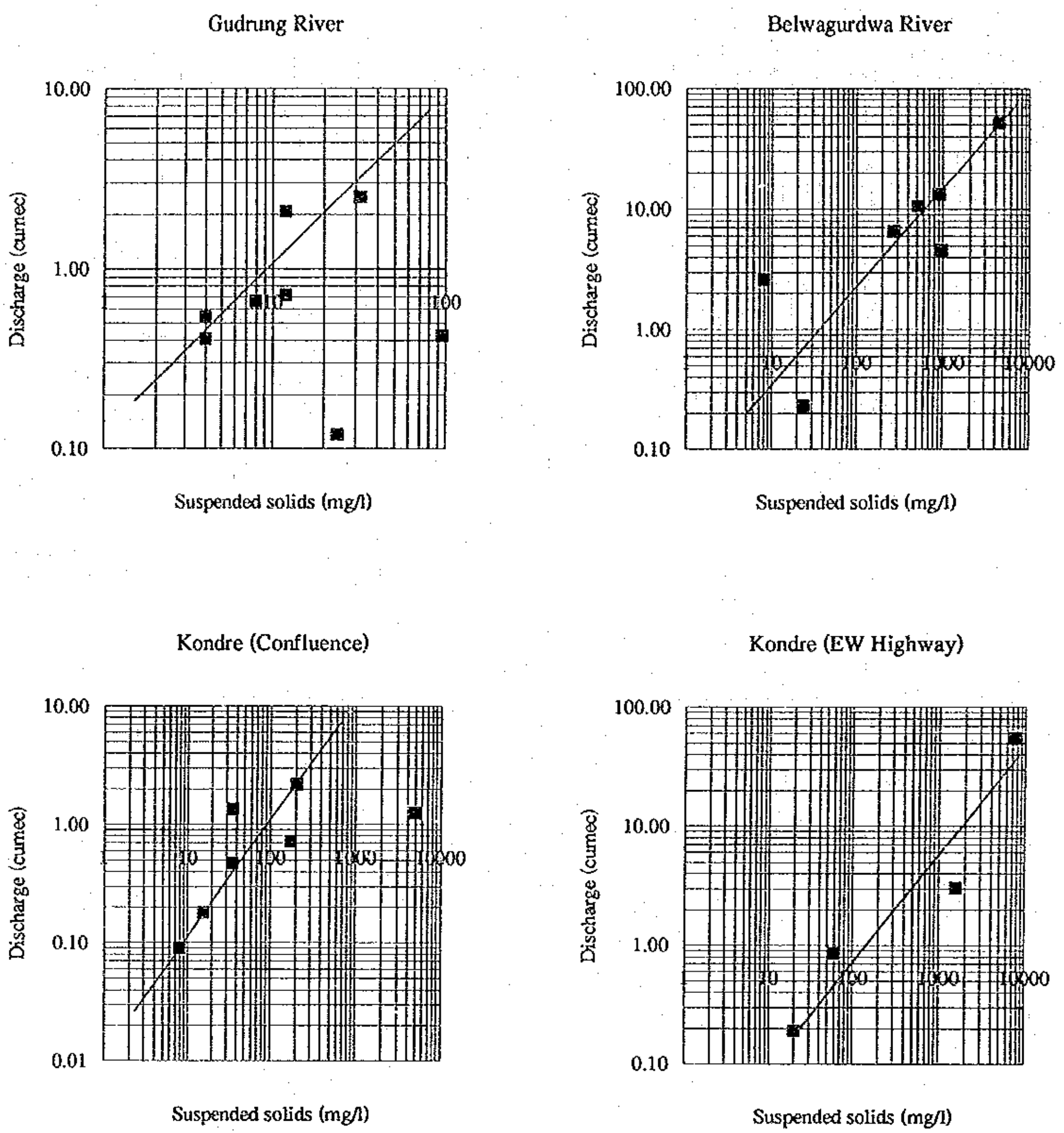

Fig. A.6.1 Relationship between Suspended Solid and Discharge Observed at Site

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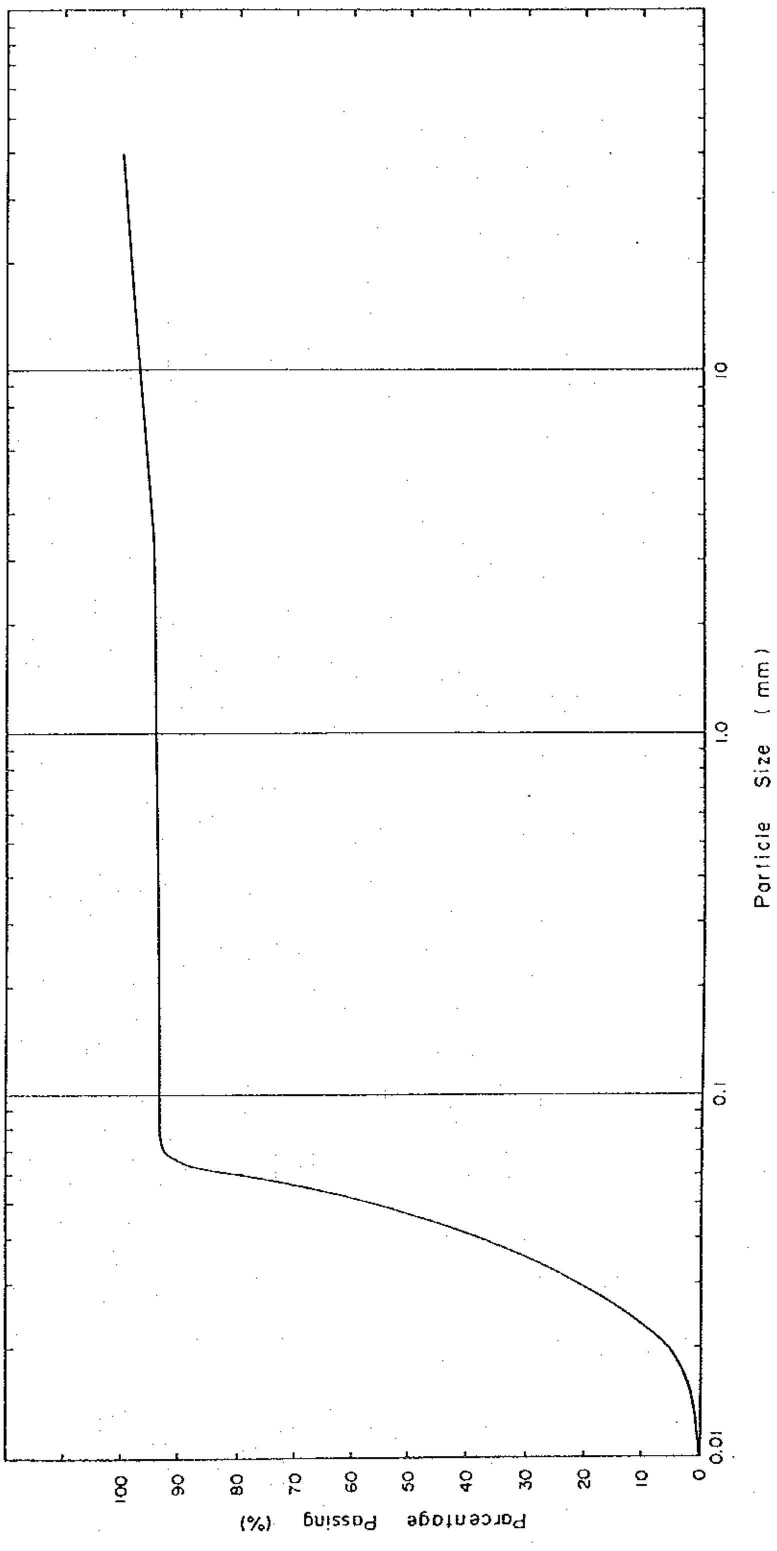

Fig. A.6.2 Particle Size of Collected Bed Material at Gudrung Headworks Site

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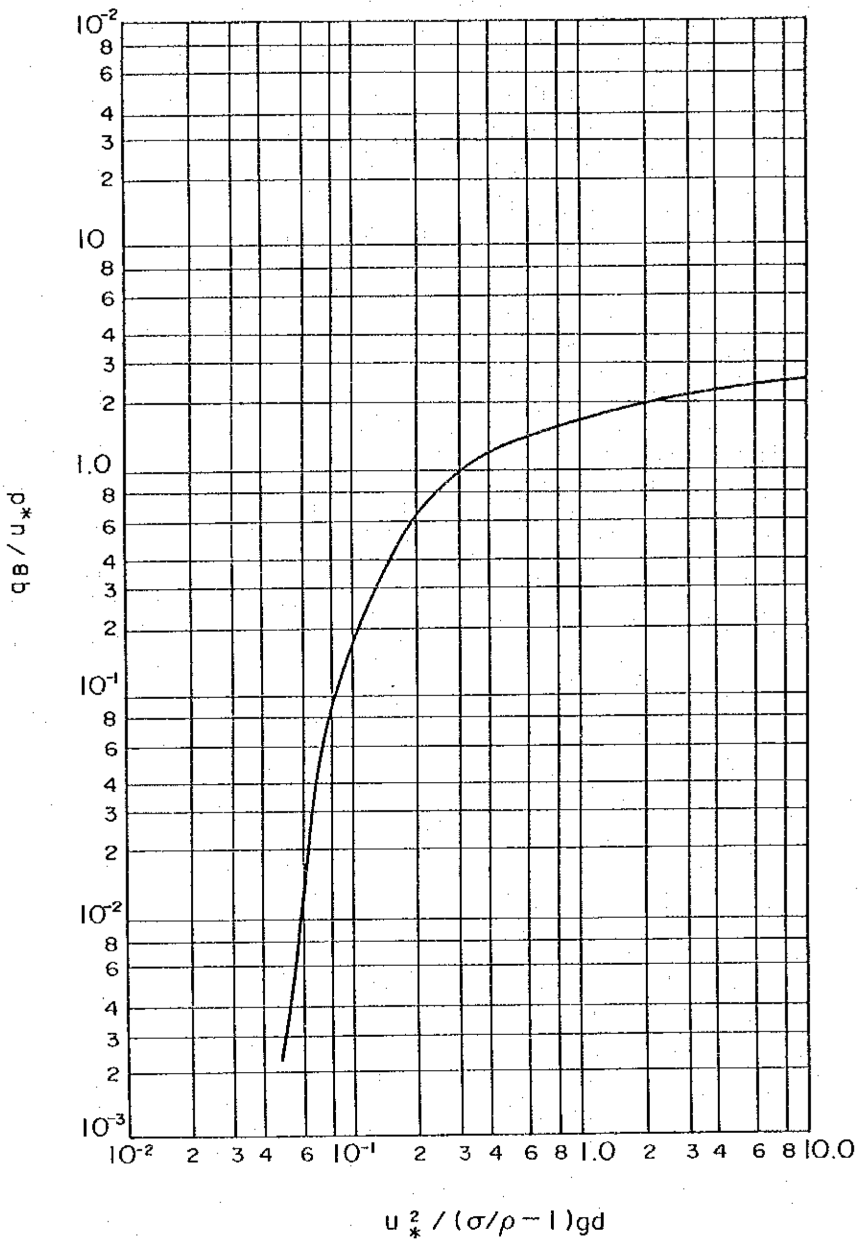

Fig. A.6.3 Relationship for the Kalinske-Brown Equation (Bed Load)

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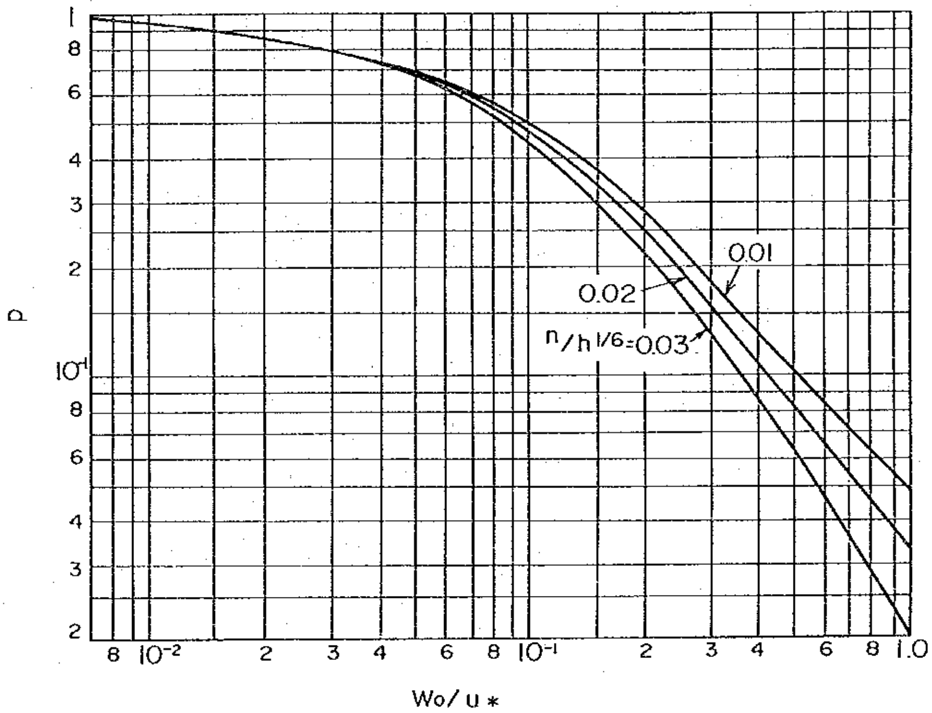

Fig. A.6.4 P-Value for the Lane-Kalinske Equation

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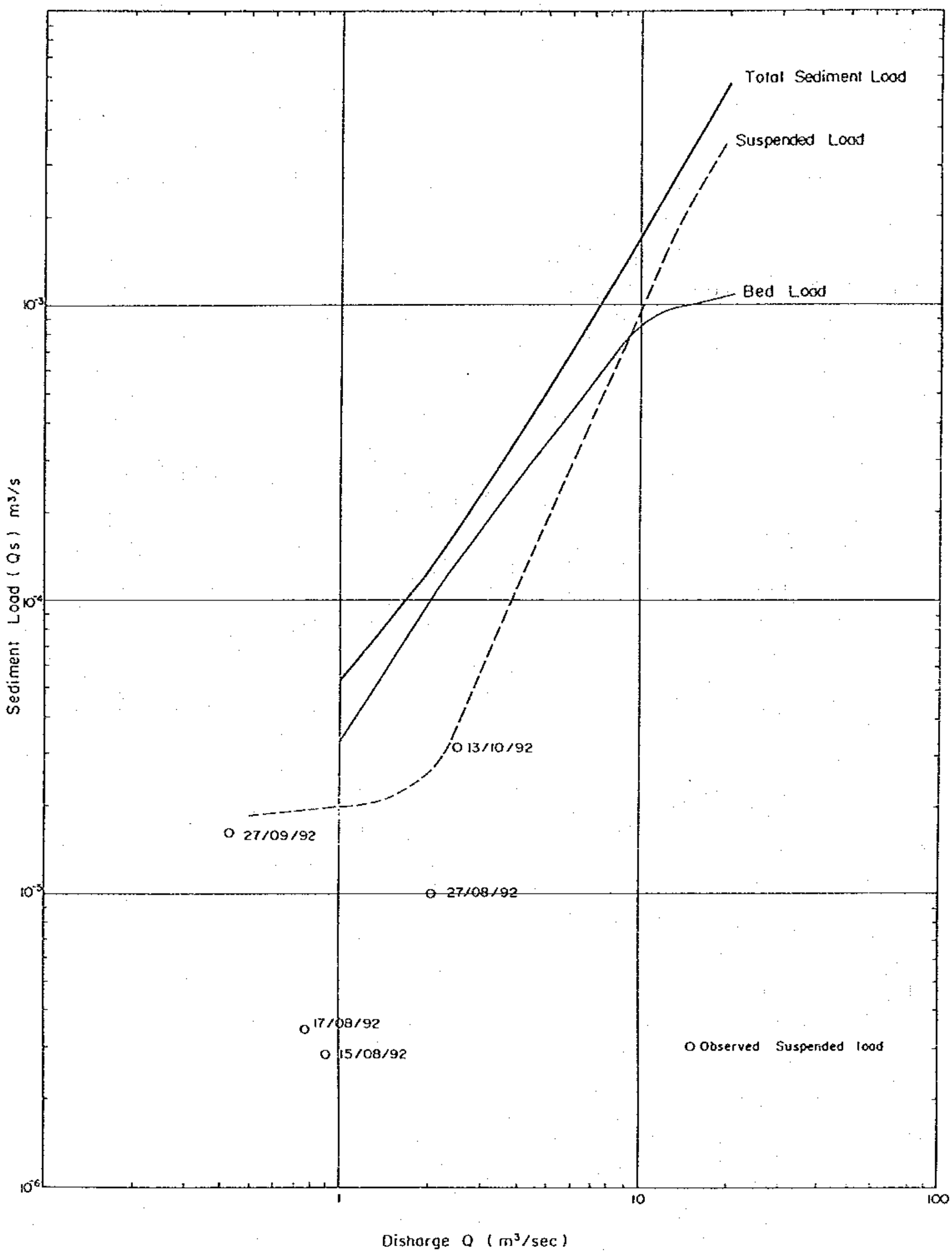

Fig. A.6.5 Total Sediment Load Estimated

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ANNEX - B

GEOLOGY AND HYDROGEOLOGY

ANNEX - B

GEOLOGY AND HYDROGEOLOGY

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ANNEX - B GEOLOGY AND HYDROGEOLOGY

B.1 Geology

B.1.1 Introduction

The study area is located in the vicinity where the Siwalik range and the Terai plain meet. The Siwalik range is mountains of about 600 to 1200 m in height running east to west. The geological investigation of the headworks site of the Rajkudwa Irrigation Project, comprising core boring together with standard penetration tests, electrical logging, and borehole permeability tests, was performed for the purpose of obtaining geotechnical data for the sound engineering design of the structures and examining the possibility of driving sheetpile cutoffs or constructing a concrete cutoff for the proposed headworks site at the Gudrung River near Pattharkot.

In addition, a geologic reconnaissance survey of the area was carried out in order to investigate the geological structure of the study area, especially around the Gudrung Headworks site.

The headworks site is characterized by bouldery and gravely layers, which are abundant in unconfined groundwater, and are underlain by the Siwalik Group bedrock.

B.1.2 Investigation

B.1.2.1 Reconnaissance Survey in the Rainy Season

A geologic reconnaissance survey was conducted at the proposed Gudrung River headworks site. Since the site is covered with a bouldery layer, the feasibility of a boring survey during the dry season was investigated, and a geotechnical survey during the dry season, including core boring, was planned. In addition, some samples of the reddish part of the basement rock were sent to Japan for an X-ray analysis to determine the rock type.

B.1.2.2 Detailed Geological Investigation in the Dry Season

A geological investigation of the Gudrung headworks site was carried out in order to study geological formation of the headworks site was to ensure the sound engineering design of the structures. The investigation work comprised of drilling six boreholes, four of which were drilled across the Gudrung river and the remaining two along the center line of the river.

Standard penetration tests (SPT), borehole permeability tests and electrical logging were conducted in order to study the geotechnical features as described in B.1.4.3 to B.1.4.5. Each of the field activities are summarized in the following table.

BNo.	Depth (m)	Dia. of Borehole (mm)	Drilling Rig*, Maker, and Characteristics	Number of SPT	Number of Permeability Test	Length of Electrical Logging
1	10.0	66	Koken Boring, Japan OP-1	5	2	10.0
2	10.0	76,66	Koken Boring, Japan OP-1	5	2	9.0
3	11.0	76,66	Boyles Bros, U.K. BBS - 10 DH	5	2	10.0
4	14.0	76,66	Boyles Bros, U.K.	8	3	13.0
5	10.0	250	Percussion boring KTK-300, Japan	5	2	9.0
6	15.0	250	Percussion boring KTK-300, Japan	8	3	14.0
Total	70.0			36	14	65.0

* Impregnated type diamond bits (made in USA) were used.

In addition, a field survey was conducted to draw geological maps of both the study area and the Gudrung headworks site.

The location map of the geological investigation is shown in Fig. B.2.2.

B.1.3 Geology

B.1.3.1 Regional Geology

The basement rock in the area is composed mainly of the Siwalik Group sandstone of the Neogene Tertiary. The Siwalik Group is the molasse derived from the Himalayas and consists of sedimentary rock of the Miocene to the Pleistocene.

The Siwalik Group consists of indurated fine sandstone interbedded with variegated clay in the lower part, sandier in the middle part, and pebbly in the upper part. The rock dips at most places towards north and becomes vertical near the Main Boundary Fault. The rock is hard and good in some places, and poorly cemented and weak in other places. The dip joints split the rock and block failure is common, and as the bedding plane is sometimes weak, it acts as a failure plane. Old fossil slides are very common in the Siwalik range.

The deposits in the Terai area are divided into two types, namely the Pleistocene deposits (1b) and the Holocene deposits (1a). The distribution area of the former constitutes the upland which nearly corresponds to the forest area. The latter is formed by the erosion of the former, and is being deposited on it. A large part of the distribution area of the latter corresponds to the flood areas seen during the monsoon seasons. The latter forms typical fans at the entrance points where the Banganga and the Tinau flow into the Terai area from the Siwaliks. (see Fig. B.2.1)

Most of the study area is located on the terrace of the Pleistocene, and is overlain by unconsolidated material such as sand, silt, and clay. The southern part of the study area is located on the alluvial plain.

B.1.3.2 Geology of the Gudrung Headworks Site

The geology of the Gudrung headworks site is shown in Figures B.1.1 to B.1.3, and it is summarized as follows. The stratigraphy is given in the legend in Figures B.1.1 and B.1.2.

The Siwalik Group consists of alternation of coarce to medium sandstone and calcareous fine sandstone to siltstone. The coarse to medium sandstone is grayish, somewhat calcareous and hard. The calcareous fine sandstone to siltstone varies shade of red to brown, and somewhat hard to soft. X-ray analysis (Fig. B.1.5) shows that type of rocks are very calcareous. The general geological structure of the Siwalik Group in the area is the bed strikes N30° and dips 30° to 60°NE. A fault extends parallel to the Gudrung river.

The Siwalik Group basement is overlain by terrace deposits, talus deposits, and alluvial deposits of the Pleistocene to the Holocene, the Quaternary. The terrace deposits are classified into three members depending on the relative height difference above the Gudrung river bed. Fan deposits are divide by age into two groups : new deposits and old deposits.

B.1.3.3 Geology of the Kondre River, 3 km Upstream from the East-West Highway

The geology of the Kondre River, 3 km upstream from the East-West Highway consists of sand, silt, and clay of the Pleistocene. The mean particle size is fine sand. The soils seem to be easily subject to piping.

B.1.4 Engineering Geology

B.1.4.1 General

The results of boring are shown in Fig. B.1.2 (geological profiles) and Fig. B.1.3 (log of boreholes), together with those of standard penetration tests, borehole permeability tests, and electrical logging, and the results are summarized as follows.

The geological boundaries and conditions were successfully found by the methods described above. Basically, the geology of the headworks site at the Gudrung river can be divided into three categories. The upper formation of the headworks site is composed of alluvial deposits comprised of boulders, cobbles, and gravel nearly 5.0 m deep in boreholes 2, 3, 5, and 6. In borehole 4, a gravelly layer of lower terrace deposits goes down to 9.0 m deep from the existing ground level. The lower formation is composed of basement rock of the Siwalik Group. In borehole 1, this formation starts right at ground level. However, the rock in BNo. 1 was found to be unstable and permeable up to 4.1 m from GL.

B.1.4.2 Drilling

Drilling in boreholes BNo. 1 to BNo. 4 was carried out using a core boring system. Double tube core barrels with diamond bits were used for drilling through gravel, boulders, and bedrock formations. Koken (Japan) and Boyles Bros (U.K) drilling rigs were used simultaneously to speed up the work. Drilling in BNo. 5 and BNo. 6 was carried out with a percussion boring system using bailer and chisel. Bentonite slurry was used for BNo. 5 and 6 to prevent the collapse of the hole due to side failure. Soil and rock samples recovered from the core barrels were properly described and preserved in the core boxes. The samples obtained from the percussion boring system bailers were inspected and preserved.

After completion of the drilling work, PVC pipes were installed in the borehole to maintain the hole for future inspection.

B.1.4.3 Standard Penetration Test (SPT)

Standard penetration tests were carried out in the boreholes, approximately at 2.0 m intervals. Split spoon barrels of 50 mm OD were used in the soft formations with the split barrel being replaced by a solid 60° cone of 50 mm diameter. The number of blows to achieve a 30 cm penetration is counted and used as the N-value for the geotechnical designs. In the case where the N-value exceeds 50, the amount of penetration in 50 blows is measured.

B.1.4.4 Borehole Permeability Test

Borehole Permeability tests were carried out in the borehole at 5 m intervals using the falling head method. The boreholes were fully cased to the bottom and the holes were filled with water. The water level in the casing pipe was measured at intervals of 20 seconds for up to five minutes and at 1 minute intervals after 5 minutes up to 20 minutes or more. The water level was measured until it stabilized except in the case of highly porous media.

The permeability of soil was calculated using the following formula (Variable head test) :

$$K = A / (Ft)$$

or $$K = A \cdot \log e (H_1 / H_2) / \{F (t_2 - t_1)\}$$

where, K = the permeability of soil,
T = time lag from plot head ratio (H/H0) and time (T)
A = the cross sectional area of borehole, casing or standpipe as appropriate ;
H_1 = the variable head measured at time t_1 after commencement of test ;
H_2 = the variable head measured at time t_2 after commencement of test ;
F = the intake factor
$F = 2.0D$ for soil flush with bottom at impervious boundary, where D = diameter of borehole.
$F = 2.75D$ for soil flash with bottom in uniform soil.

The results of permeability tests in different geological formations are summarized below : The detailed calculations are given in Table B.1.3.

Geological Formation	K (*cm/sec*)	Average K (*cm/sec*)*
Alluvium	$4.6 \times 10^{-3} \sim 3.2 \times 10^{-2}$	1.2×10^{-2} Lower Terrace
Deposits	5.2×10^{-3}	5.2×10^{-3}
Siwalik Group	$7.0 \times 10^{-6} \sim 1.7 \times 10^{-3}$	4.8×10^{-5}
Siwalik Group (Cracky Zone)	$1.8 \times 10^{-3} \sim 4.8 \times 10^{-3}$	2.9×10^{-3}

* a geometric mean

In the above table, the following must be noted. Since the injection method was used, the permeability for highly permeable layers such as alluvium or lower terrace deposits may be lower than the real values. The real values might be one or two orders higher than the values obtained.

B.1.4.5 Electrical Logging

Electrical logging was carried out in the borehole at 25 cm intervals in order to investigate the geological boundaries and conditions.

The electrical resistivity of a material is the resistance offered by a volume of that material to the flow of electrical current between two opposite faces. Most common rock-forming minerals are insulators, with the exception of metalliferous minerals, which are usually good conductors. In general, therefore, rocks and soils conduct electricity through the water contained in their pores, fissures, or joints. It follows that the conductivity of rocks and soils is largely dependent upon the porosity, the degree of saturation, the degree of concentration and the fracture state.

The resistivities changed dramatically at the deposits-basement boundaries.

B.1.4.6 Engineering Geological Problems at the Gudrung Headworks Site

Geological surveys show that both the Siwalik Group basement rock, including the fault found in BNo.4 (below 9.0 m deep), and the deposits are sound and stable for the construction of the proposed headworks at the Gudrung river, as far as bearing capacity is concerned. The N-values of the headworks site obtained from the standard penetration tests (SPT) were found to be greater than or equal to 50, except in BNo.5, where N-values vary from 43 to 48 up to 4m deep, and in BNo.3, where the N-value is 41 at 4 m deep.

However, the following engineering geological problems must be taken into consideration.

(1) The abutment on the right bank of the headworks site is on a sharp ridge. The sandstone which forms the edge of the ridge has many open cracks caused by weathering and erosion. The maximum gap in the rock is around 50 cm wide. The rock in BNo.1 bored in the sandstone was found to be unstable and permeable up to 4.1 m from GL, hence it will be advisable to remove this rock while maintaining the stability of the slope above BNo.1 (see Fig. B.1.5).

(2) In the vicinity of the above-mentioned abutment and slope, collapse landform was observed. In rainy seasons, surface landslide of the slope could occur. Although it is small-scale mass wasting near the ridge, some preventative measures such as gabions upstream and downstream on the right bank of the headworks should be constructed.

(3) The permeability of the alluvial deposits and lower terrace deposits are much higher than those of the Siwalik Group bedrock. Hence, effort should be made to rest the

foundation of the headworks on the basement rock in order to reduce seepage as much as economically feasible. The alternative of sheetpiling is impossible due to the bouldery layer and the high N-values.

Therefore, in order to decrease the amount of seepage, a concrete cutoff is better than sheetpile cutoffs. The relationships between the horizontal length of a cutoff and the amount of seepage are shown in Table B.1.1. The results are as follows :

- the cutoff should be connected to the foundation.
- the length should be more than 7 m from the boundary of the alluvium and lower terrace in the direction of the left bank.

(4) Talus deposits are distributed on the left bank downstream of the headworks site. In rainy seasons, falling rocks and landslides would occur at some places to a limited extent. The headworks would not be damaged since it is 50 to 100 m from the deposits. However, preventative measures for the proposed canals connected to the headworks have to be considered during planning and construction.

B.1.4.7 Engineering Geological Problems at the Kondre River, 3 km Upstream from the East-West Highway

The geology at the Kondre river, 3 km upstream from the East-West Highway, consists of sand, silt, and clay of the Pleistocene. Table B.1.2 shows the results of particle size analysis. The mean particle size is fine sand. The soils seem to be easily subject to piping. Soil tests (see Table B.1.2) show that the critical hydraulic gradient is 0.657 and 0.961 for the right and left banks, respectively.

Existing laboratory tests show that even when the safety factor is 2.7, sandy soil can be piped. Therefore, some authors, such as Jumikis, Matsuo, and the Japanese society of soil mechanics and foundation engineering recommend that a safety factor of 3 to 4, or greater, should be taken. If a safety factor 4 is applied, the hydraulic gradient must be reduced to less than 0.164 (=0.657/4) in order to prevent piping of the soil.

B.2 HYDROGEOLOGY

B.2.1 Introduction

A hydrogeological investigation was carried out in order to study the possibility of groundwater exploitation for irrigation. The investigation was performed in three stages : field work in the rainy and dry seasons in Nepal and the follow-up work in Japan. During the field work, after inspecting the existing tubewells, pumping tests were conducted, and maximum discharge rates were estimated. The investigation is described in detail in B.2.2. The location map of the hydrogeological study is shown in Fig. B.2.2.

B.2.2 Investigation

B.2.2.1 Hydrogeological Survey in the Rainy Season

(1) References

The hydrogiological reports and data used as references in the study were mainly found at Kapilvastu Tubewell Project Office and at Bhairahawa Lumbini Groundwater Project Office. Some of the references are as follows :

- Groundwater Resource Investigation in Lumbini Zone, Western Terai, Nepal.
- USAID / NEPAL, July 1973.
- Reports and data conducted by Kapilvastu Tubewell Project.
- Master Plan Study on IRDP in Lumbini Zone, JICA, 1990.

In addition, geological maps and books on the study area were found in Kathmandu. Some of them are :

- Geological map by HMGN under the Canadian Assistance Program.
- Groundwater Resources of Nepal, Sharma C.K. (1974).
- Geology of Nepal Himalaya and the Adjacent Countries, Sharma C.K. (1990).
- Engineering Challenges in Nepal Himalaya, Sharma C.K. (1990).

(2) Field Investigation in the Rainy Season

i) A field inspection was carried out to check the condition of the existing tube-wells listed below.
- Three deep tube wells bored by USAID in the 1970's (10/4, 10/5, 10/6),
- Three shallow tube wells bored by DOI in the 1980's (STW-10, 13, 14),
- Three deep tube wells bored by DOI in the 1980's (K-23, 24, 25*, 29),
- Deep tubewell bored by JICA in 1980 (PW-1, OW-1*),
* indicates observation wells.

ii) Pumping tests were conducted on those existing tubewells on which pumps were able to be set. those tests were done in order to estimate the feasibility of groundwater exploitation for irrigation (Gorusinge (STW-14) and Dewari (K-

23)). The pumping tests consisted of preliminary tests, step drawing tests and continuous pumping tests.

B.2.2.2 Hydrogeological Survey in the Dry Season

i) Pumping tests were conducted at Sitapur (PW-1, OW-1). The contents of the tests were the same as in the rainy season, and they are summarized in B.2.4.1.

ii) Groundwater table measurements were carried out to study the groundwater balance of the phreatic aquifer in the study area. The measurement points were Gorusinge, Birpur, and Pattharkot.

iii) Spring discharge measurements at Pattharkot fan were conducted in order to estimate the amount of phreatic groundwater. The phreatic groundwater of Pattharkot fan, in the northern part of the study area, wells up at the southern border of the fan as the East Birpur springs, east of the Gorusinge - Pattharkot road, and the West Birpur springs on the terrace cliff, near the left bank of the Gudrung river. Four measurements were taken, one point at the East Birpur springs and three points at the West Birpur springs.

B.2.3 Hydrogeology of the Study Area

B.2.3.1 General

(1) Hydrogeology of the Terai Plain

The Terai is hydrogeologically divided into three parts :

i) Bhabar Zone ii) Marshy Midland iii) Southern Terai

i) Bhabar Zone : Bhabar zone is at the foot of the Siwalik range and is considered a piedmont fan zone. It consists of boulder, pebble, and sand debris dumped by rivers coming from the higher part of the country. The zone is porous and acts as an excellent groundwater recharge area in the Terai. The thickness of this zone varies from place to place and may average 50 m. At Butwal, it is about 100 m deep, and the bouldery layer is more than 40 m deep. The width of this zone is about 8 to 16 km, averaging 12 km, and its gradient rises sharply near the foothills. The Bhabar is well developed in large and medium-sized rivers originating either in the Mahabharat range or in the north, whereas it is poorly developed in rivers from the Siwalik range. This is due to the fact that the catchment area of the former is larger.

ii) Marshy Midland : South of the Bhabar zone is the Marshy Midland consisting of silt, coarse to medium sand, pebble, and gravel. The area has excellent aquifers and artesian conditions in a few places. These artesian conditions may be found in Lumbini Zone from Bhairahawa to Lumbini. The artesian pressure varies from 5 to 10 m above ground level with a discharge of 4 cusecs. Since this area is located at the end of the Bhabar zone or piedmont fans, a spring line is found which creates a phreatic groundwater discharge zone. The soil of Marshy Midland is waterlogged and heavy. There are numerous oxbow lakes in this area indicating the presence of ancient river channels.

iii) Southern Terai : Southern Terai is located near the India-Nepal border and consists of fine sand and clay beds. The aquifer coming from Marshy midland becomes poor due to an increase of clay. The zone is poor in groundwater resources but it has very fertile soil.

(2) Hydrogeology of the Study Area

The width of Bhabar is more than 12 km in eastern Nepal, and the Tinau and the Banganga river fans, which are close to the study area, are 8 km wide. However,the Gudrung river fan (the Pattharkot fan) is only a few km wide. Most of the study area is located on the Pleistocene terraces and is overlain by impermeable layers such as fine sand, silt, and clay. Therefore, it is hard for rainfall to infiltrate. Fig. B.2.1 shows the hydrogeological map.

B.2.3.2 Present Conditions of Existing Tubewells

In the rainy season, a field reconnaissance survey was conducted in order to check the present condition of the existing tubewells in the study area. The following table shows a summary of the survey, and the details are shown in Table B.2.1. There were only two tubewells used : One was a deep tubewell 200 m in depth in Sitapur (JICA well : artesian), and the other was a shallow tubewell about 70 m deep in Gorusinge. In most cases, dug wells around 10 m deep are used for domestic use or drinking water.

Well No.	Location	Organization	Conditions	Maximum Discharge Rate(1/s)
10/4	Janakpur	USAID deep	abandoned	
10/5	Gorusinge	tubewell	abandoned	
10/6	Bhelai	(1970's)	abandoned	
STW-10	Mahuwa	DOI shallow	unused	2.2 (existing data)
STW-13	Birpur	tubewell	abandoned	
STW-14	Gorusinge	(1980's)	in use (hand pump)	2.0 (present survey)
K-23	Dewari	DOI(aided by	unused	2.1(present survey)
K-24,25	Bichwapur	UNDP) deep tube-	unused	5.7 (existing data)
K-29	Dhakeri	well (1988's)	unused	2.2 (existing data)
PW-1	Sitapur	JICA deep tube-	in use	3.9(present survey)
OW-1		well (1988)	(artesian)	3.9 (present survey)

B.2.4 Possibility of Groundwater Exploitation

B.2.4.1 Pumping Test

Pumping tests were conducted on existing wells as shown in the following table in order to estimate the amount of groundwater available.

Well No. Location	Date	Preliminary Test	Step Drawdown Test Stage		Discharge Q (m^3/d)	Dynamic W.L.(m)	Drawdown (m)	Specific Capacity Q/s ($m^3/d/m$)	Continuous Test	Equipment Used
K-23	July 18 to 24, 1992	6h	1st	2h	91.44 (1.06 l/s)	10.64	7.66	11.93	12h	PumpType : Turbine (made in Japan)
(Dewari)	(rainy season)		2nd	2h	115.2 (1.33 l/s)	15.32	12.34	9.33	Q=2.08 l/s	Max. Head : 40.0m
			3rd	2h	151.2 (1.75 l/s)	19.44	16.46	9.18	s=23.87 m	Max. discharge : 12 l/sec
			4th	2h	178.56 (2.07 l/s)	26.72	23.74	7.52	Q/s=7.52 $m^3/d/m$	
			recovery	2h						
STW-14	July 16 to 22, 1992	6h	1st	2h	53.28 (0.62 l/s)	5.05	1.65	32.29	6h	Pump : Suction Type (made in india)
(Gorusinge)	(rainy season)		2nd	2h	87.84 (1.02 l/s)	5.85	2.45	35.85	Q=1.92 l/s	Max. Suction : 8.0 m
			3rd	2h	135.36 (1.57 l/s)	6.69	3.29	41.12	s=3.83 m	Max. discharge : 18 l/sec
			4th	2h	175.68 (2.03 l/s)	7.36	3.96	44.36	Q/s=43.2 $m^3/d/m$	Power : 7.5 H.P.
			recovery	2h						
PW-1 (Sitapur)	Jan. 27 to 31,1993 (dry season)	6h	1st	2h	86.4 (1.00 l/s)	9.90	8.69	9.94	24h	
			2nd	2h	163.7 (1.90 l/s)	16.65	15.44	7.36	Q=3.90 l/s	
			3rd	2h	255.6 (2.96 l/s)	23.75	22.54	7.87	s=35.21 m	
			4th	2h	336.8 (3.90 l/s)	35.54	34.33	6.81	Q/s=6.64 $m^3/d/m$	Compressor
			recovery	2h					+recovery 24h	Type GPS-370
OW-1 (Sitapur)	Feb. 1 to 3,1993 (dry season)	6h	1st	24h	167 (1.93 l/s)	0.80		(208.75)	24h Q=1.93 l/s s=0.80 m Q/s=(208.9) $m^3/d/m$ + recovery 24h	Denyo, Japan 7 kg/cm^2 Capacity 10.5 m^3/min

B.2.4.2 Aquifer Constants

Aquifer constants were calculated using non-equilibrium formulas such as Theiss', Jacob's and a recovery formula. The results are shown in Table B.2.2, and they are summarized as follows.

	Well No.	Location	Transmissivity T (cm^2/s)	Permeability K (cm/s)	Storage Coefficient S	Max. Discharge (l/s)
present study	STW-14*	Gorusinge	4.80	3.20×10^{-3}	4.93×10^{-4}	2.03 (176 m^3/d)
	K-23*	Dewari	0.366	1.22×10^{-4}	2.72×10^{-4}	2.07 (179 m^3/d)
	PW-1	Sitapur	2.56	5.39×10^{-4}	1.34×10^{-4}	3.90 (337 m^3/d)
	OW-1	Sitapur	4.58	1.02×10^{-3}	2.83×10^{-3}	3.90 (337 m^3/d)
reanalysis of existing data	K-23	Dewari	0.790	2.63×10^{-4}	—	0.85 (73.3 m^3/d)
	K-24,25	Bichwapur	8.78	2.93×10^{-3}	6.55×10^{-3}	5.72 (494 m^3/d)
	K-29	Dhakeri	0.878	2.93×10^{-4}	—	2.22 (192 m^3/d)
	STW-10	Mahuwa	3.82	7.64×10^{-3}	—	2.22 (192 m^3/d)
	STW-13	Gorusinge	5.32	3.55×10^{-3}	—	4.00 (346 m^3/d)

* shows study in the rainy season. Others are conducted in dry seasons.

The permeabilities shown are low values on the order of 10^{-3} to 10^{-4} cm/s, which is close to those of sand. Together with the fact that the pumped confined groundwater contained sand and silt,the low permeabilities suggest that pores in the confined aquifers are filled with sand and silt.

B.2.4.3 Possibility of Confined Groundwater Exploitation for Irrigation

The groundwater resources for exploitation in the study area can be classified into two types : confined and phreatic groundwater.

Judging from pumping tests, the estimated maximum discharge rate of the confined groundwater for deep tubewells from 100 to 130 m in depth is as follows. In major parts of the study area from Sitapur to Pattharkot, the discharge rate is around 4 l/s. For example, in Bhelai, 4 km north of Gorusinge, the rate was estimated using the following data : well depth = 100 m, aquifer thickness = 9.8 m (UNDP data, well No. 10/6), K = 3.2 x 10^{-3} cm/s, S = 4.9 x 10^{-4}, (Gorusinge STW-14 data), pumping time = 1 day, and drawdown s= 15 m. Hence, the pumping rate for a 100 m deep tubewell in Bhelai was estimated at 3.74 *l/s* (323 m3/d) by using the Theiss method. The pumping rate increases southwestward. In Bichwapur, it is 6 *l/s*. However, it is unlikely that the rate exceeds 10 l/s anywhere except in the vicinity of the confluence of the Banganga and the Belwagrudwa rivers.

These rates are insufficient for irrigation, though they are sufficient for domestic use and drinking water. For irrigation wells, the following pumping rates are generally required for efficiency : 10 *l/s* for shallow tubewells around 30 m deep and 25 *l/s* for deep tubewells from 100 to 130 m in depth. The possibility of phreatic groundwater is discussed in B.2.4.5.

B.2.4.4 Reasons for the Low Possibility of Groundwater Exploitation

The low possibility of groundwater exploitation are caused by the following reasons.

i) Small Groundwater Recharge Area

The catchment area of the Pattharkot fan (the Gudrung river) is smaller than that of the Tinau river fan and that of the Banganga river fan, the largest and the second largest fans in Lumbini Zone, respectively. Moreover, in the study area, the Bhabar zone area, which is the groundwater recharge area, is much smaller than those of the Tinau river fan and the Banganga river fan. This means that groundwater is poorly recharged in the study area. (see the following table)

River	Observation Station	Catchment Area (km^2)	Mean Annual Discharge(m^3/s)
Tinau	Butwal	554*	22.2*
Banganga	Banganhia	347*	16.5*
Gudrung	Pattharkot	29	1.1

* Source) River Systems of Nepal

ii) Small Discharge of the Gudrung River

In the Terai piedmont fans, river water infiltrates into the aquifers mainly through the Bhabar zone. The annual mean discharge of the Tinau river and the Banganga river, which are the main rivers in Lumbini Zone, are 22.2 m^3/s and 16.5 m^3/s , respectively. On the other hand, that of the Gudrung river is only 1.1 m^3/s. It means that infiltration is low in the study area.

iii) Low Permeability of the Aquifers

Because pores in the confined aquifers are filled with silty soil and sand, the aquifers show low permeability on the order of 10^{-3} to 10^{-4} *cm/s*, which is close to that of sand.

iv) Poor Well Construction and Development

In addition, well construction (screen, gravel packing, etc.) and development of the existing wells is poor except for the JICA well. If the well development is ideally done, the maximum discharge rate would increase, at least, up to that of the JICA well, 4 *l/s*.

B.2.4.5 Spring Discharge of Birpur Springs

Phreatic groundwater of the Pattharkot fan, in the northern part of the study area, wells up at the southern border of the fan as the east Birpur springs, East of the Gorusinge-Pattarkot road, or the West Birpur springs on the terrace cliff, on the left bank of the Gudrung River. The spring water could be utilized for irrigation. Recharge measurements were carried out at four points from Feb. 10 to 24, and the following results were obtained. (see Table B.2.3)

i) The discharge of the East Birpur springs in February, 1993 was 26 *l/s* initially and 22 *l/s* finally, and it decreased over the observation period exponentially according to the formula,
$Q = 25.2\ e^{-0.116t}$ (the initial day was Feb. 10, t is expressed in days).

ii) The discharge of the West Birpur springs in February, 1993 was 11 *l/s* initially and 10 *l/s* finally, and it decreased over the observation period exponentially according to the formula, $Q = 11.3\ e^{-0.0080t}$. Of this discharge, about 8.5 to 7.2 *l/s* could be utilized for irrigation.

iii) There is a posibility that the groundwater recharge to the spring would decrease due to the construction of the Gudrung headworks and concrete placed on the main canals. If a safety factor of 0.8 is applied, the discharge which could be utilized for irrigation (based on data for February) would be as follows :
the East Birpur springs : 21 to 18 *l/s*, the West Birpur springs : 7 to 6 *l/s*

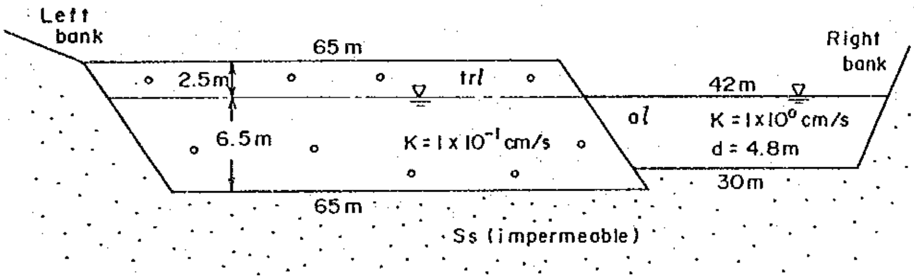
TABLES

Table B.1.1 Relationships Between Horizontal Length of a Cutoff and the Amount of Seepage

Amount of Seepage Q(*l/s*)

	Case			Hydraulic Gradient	Lower Terrace Deposits (trl)	Alluvium (al)	Total
1	Present Conditions			0.0143	6.0	24.7	30.7
2	↑	No Cutoff		0.143	69.6	246.9	316.5
3		↑	al	0.143	69.6	0.0	69.6
4	From case 2 to 8, reservoir		al + trl (up to 2 m from al-trl boundary*)	0.120	53.8	0.0	53.8
5	is filled with water.	From case 3 to 8, cutoff is	al + trl (up to 3 m from al-trl boundary*)	0.103	45.3	0.0	45.3
6		driven into :	al + trl (up to 5 m from al-trl boundary*)	0.079	33.3	0.0	33.3
7			al + trl (up to 10 m from al-trl boundary*)	0.045	16.9	0.0	16.9
8	↓	↓	al + trl (up to 15 m from al-trl boundary*)	0.032	10.6	0.0	10.6

Note : Maximum amount of seepage was estimated by using Darcy's law (Q = KiA).
*) In the left bank direction



Calculation Model
[Initial hydraulic gradient i = 0.0143
Permeability K is assumed.]

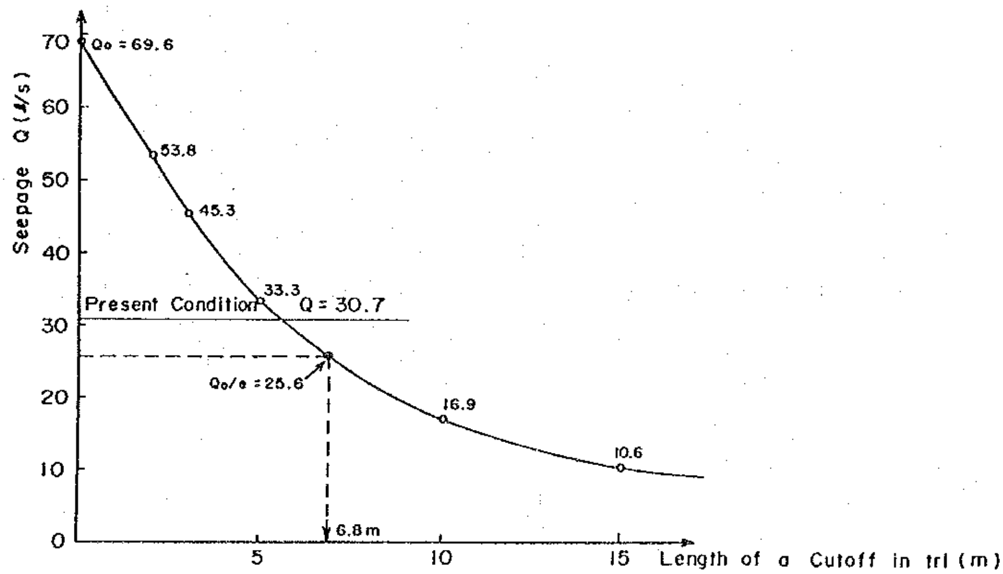
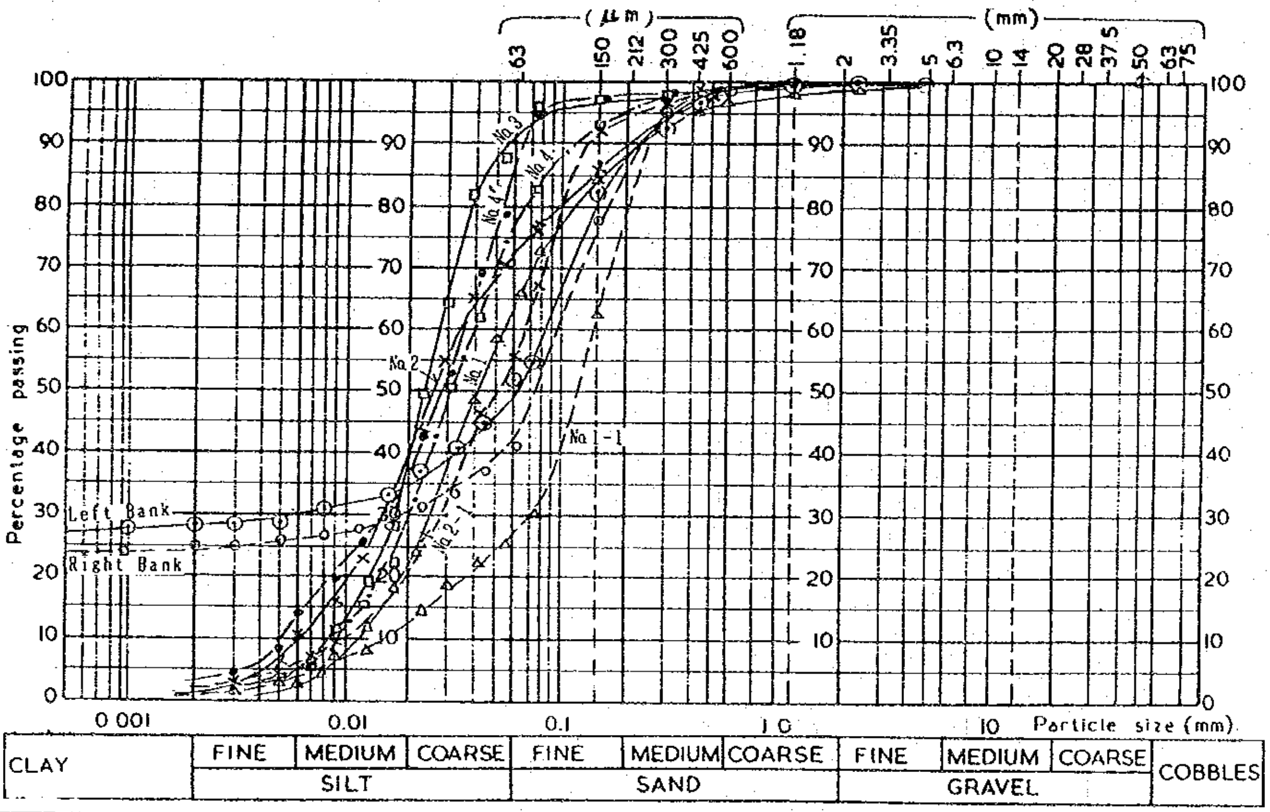


Table B.1.2 **Results of Laboratory Soil Tests at the Kondre River, 3 km Upstream from the East-West Highway.**

Right Bank	Specific Gravity of Water	Gw=0.9978
	Specific Gravity of Soil	Gs=2.654
Left Bank	Specific Gravity of Water	Gw=0.9978
	Specific Gravity of Soil	Gs=2.655

S. No.	Sample No.	Volume of Water Vw(cu.cm.)	Volume of Soil Vs(cu.cm.)	Void Ratio e	Porosity =e/(1+e) (%)	Critical Hydraulic Gradient ic*
1	Right Bank	29.77	19.33	1.540	60.63	0.651
2	Right Bank	30.57	20.20	1.513	60.21	0.658
3	Right Bank	29.67	19.86	1.494	59.90	0.663
	Right Bank Average			1.516	60.25	0.657
4	Left Bank	17.04	23.39	0.729	42.16	0.957
5	Left Bank	14.93	20.98	0.712	41.59	0.967
6	Left Bank	17.04	23.47	0.726	42.06	0.959
	Left Bank Average			0.722	41.94	0.961

*ic = (Gs-1) / (1+e)



Location	Sample	Depth(m)	Description of soils	D_{50}	D_{10}	$u(D_{60}/D_{10})$
Pattharkot	No 1	0.0-0.4	Coarse silt	0.054	0.011	4.91
Pattharkot	No 1-1	0.6-0.7	Fine sand	0.145	0.0152	9.54
Birpur	No 2	0.4-1.0 (Mainly0.6±)	Coarse silt	0.033	0.0061	5.41
Birpur	No 2-1	0.7-1.0	Coarse silt	0.065	0.010	6.50
Bhelai	No 3	0.2-0.6 (0.5±)	Coarse silt	0.027	0.0086	3.14
Murmy	No 4	0.0-0.3	Coarse silt	0.0395	0.0092	4.29
Murmy	No 4'	0.6-1.2 (0.9±)	Coarse silt	0.035	0.00525	6.67
Kondre River	Left Bank		Fine sand	0.085	—	—
Kondre River	Right Bank		Fine sand	0.090	—	—

Table B.1.3 Detailed Calculation Table of Borehole Permeability Tests

Borehole	Depth, m.	Dia of hole casing cm.	X-section Area Sq.cm.	F	(T2-T1) sec.	H1	H2	Log e H1/H2	K cm/sec.	Remarks
1	4.00	6.600	34.2120	16.50	80	4.16	3.46	0.1842	4.77E-03	Crack of 0.75m deep
1	4.00	6.600	34.2120	16.50	1200	3.46	1.23	1.0343	1.79E-03	Crack of 4.0m deep
1	10.00	6.600	34.2120	13.20	1080	10.34	10.31	0.0320	7.68E-05	
2	5.00	7.600	45.3647	16.50	100	5.30	4.49	0.1659	4.56E-03	
2	10.00	6.600	34.2120	16.50	1200	10.72	10.63	0.0084	1.45E-05	
3	4.00	7.600	45.3647	20.90	20	4.20	3.58	0.1597	1.73E-02	
3	10.00	6.600	34.2120	16.50	180	10.25	8.85	0.1469	1.69E-03	
4	5.00	7.600	45.3647	20.90	150	5.35	3.73	0.3607	5.22E-03	
4	10.00	6.600	34.2120	13.20	960	10.25	10.21	0.0036	9.72E-06	
4	14.00	6.600	34.2120	13.20	1080	14.50	14.46	0.0029	6.96E-06	
5	5.00	25.000	490.8750	50.00	200	5.58	4.70	0.1716	8.42E-03	
5	10.00	25.000	490.8750	50.00	360	10.50	10.07	0.0418	1.14E-03	
6	5.00	25.000	490.8750	50.00	60	5.50	4.52	0.1962	3.21E-02	
6	10.00	25.000	490.8750	50.00	960	10.50	10.45	0.0052	5.32E-05	
6	15.00	25.000	490.8750	50.00	960	15.50	15.46	0.0029	2.97E-05	

Table B.2.1 Present Conditions of Existing tubewells

Well No.	Location	Well Depth (m)	Well Diameter (inches)	Static WaterLevel (m)	Discharge (l/s) Free Flow	Pumping	Drowdown (m)	Screen Zone (m)	Condition
USAID									
10/4	Janakpur	uncased	—	—	—	—	—		abandoned
10/5	Gorusinge	66.5	3"	+	0.32	—	—	59.74 - 63.40	abandoned
10/6	Bhelai	44.20	3"	+	0.12	—	—	36.88 - 40.54	abandoned
DOI	Dewari	106	10"/6"	-4.04	—	0.85 ($73.3m^3/d$)	9.30		
K-23				-2.98		2.08 ($124.6m^3/d$)	23.87	36 - 47, 54 - 65, 79 - 84.5, 98.5 - 104	unused
K-24,25	Bichwapur	117	10"/6",4"	-2,60	—	5.72 ($494.2m^3/d$)	16.92	52.5 - 69, 91.5 - 97, 106 - 117	unused
K-29	Dhakeri	114	10"/6"	+	1	2.2	16.42	41 - 52, 73.5 - 79, 95.5 - 112	unused
UNDP									
STW-10	mahuwa	48	4"	-4.0	—	2.2	2.19	41 - 46.5	unused
STW-13	Birpur	33	4"	-13.36	—	—	—	24 - 29.5	abandoned
STW-14	Gorusinge	63	4"	-1.36	—	4.00 ($345.6m^3/d$)	4.08	32.5 - 38, 41 - 46.5, 55 - 60.5	in use
JICA									
PW-1	Sitapur	203.5	8"	1.06	—	3.90 (3368)	35.21	55 - 202, totally 51 m	in use (artesian)
OW-1	Sitapur	203.5	3"	+	—	3.90 (336.8)	2.82	58 - 202, totally 54 m	in use (artesian)

Table B.2.2 Summary of Aquifer Constants and the Maximum Groundwater Discharge Rates

Well No.	Date	Observation Well	Effective Screen Length M (cm)	Formula	Transmissivity T (cm^2/s)	Permeability K (cm/s)	Storage Coefficient S	Maximum Discharge Rate (l/s)
STW-14	July 17.1992	STW-14	1500	Theiss	4.62	3.09×10^{-3}	4.93×10^{-4}	
(Gorusinge)	July 16, 1992			Jacob	5.02	3.35×10^{-3}	(4.37×10^{-7})	
				recovery	4.77	3.18×10^{-3}	—	
	(rainy season)			(average*)	4.80	3.20×10^{-3}	4.93×10^{-4}	2.03 (175.68 m^3/d)
K-23	July 25 to 26,	K-23	3000	Theiss	3.39×10^{-1}	1.13×10^{-4}	(4.89×10^{-2})	
(Dewari)	1992			Jacob	5.60×10^{-1}	1.87×10^{-4}	2.72×10^{-4}	
	July 24, 1992			recovery	2.59×10^{-1}	8.63×10^{-5}	—	
	(dry season)			(average*)	3.66×10^{-1}	1.22×10^{-4}	2.72×10^{-4}	2.08 (179.42 m^3/d)
PW-1	Jan. 29 to 30, 1993	OW-1	4750	Theiss	2.50	5.26×10^{-4}	1.96×10^{-5}	
				Jacob	3.57	7.52×10^{-4}	8.73×10^{-4}	
				recovery	1.881.88	3.96×10^{-4}	—	
(Sitapur)	(dry season)	PW-1		Theiss	(9.13×10^{-1})	(1.92×10^{-4})	1.41×10^{-4}	
				Jacob	(9.52×10^{-1})	(2.00×10^{-4})	(1.80×10^{-8})	
				recovery	(1.14)	(2.40×10^{-4})	—	
				(average*)	2.56	5.39×10^{-4}	1.34×10^{-4}	3.90 (336.8 m^3/d)
OW-1	Feb. 2 to 3, 1993	PW-1	4500	Theiss	11.4	2.53×10^{-3}	2.25×10^{-3}	
				Jacob	9.47	2.10×10^{-3}	3.55×10^{-3}	
				recovery	9.70	2.16×10^{-3}	—	
		OW-1		Theiss	2.22	4.93×10^{-4}	—	
				Jacob	2.09	4.64×10^{-4}	(0.441)	
				recovery	1.89	4.20×10^{-4}	—	
				(average*)	4.58	1.02×10^{-3}	2.83×10^{-3}	3.90 (336.8 m^3/d)
K-23	1970's	K-23	3000	Jacob	1.01	3.35 x 10-4	—	0.85 (73.3 m^3/d)
(Dewari	(dry season)			recovery	0.618	2.06×10^{-4}		
				(average*)	0.790	2.63×10^{-4}		
K-24,25	1980's	K-25	3000	Jacob	4.46	1.49×10^{-3}	6.54×10^{-3}	5.72 (494.2 m^3/d)
(Bichwapur)	(dry season)			recovery	13.1	4.37×10^{-3}	—	
				(average*)	8.78	2.93×10^{-3}	6.54×10^{-3}	
K-29	1980's	K-29	3000	Jacob	8.78×10^{-1}	2.93×10^{-4}	(0.174)	2.22 (192.0 m^3/d)
(Dhakeri)	(dry season)			recovery	(3.26 x 10-1)	(1.09×10^{-4})	—	
				(average*)	8.78×10^{-1}	2.93×10^{-4}	—	
STW-10	1980's	STW-10	500	Jacob	3.82	7.64 x 10-3	—	2.22 (191.8 m^3/d)
(Mahuwa)	(dry seasons)							
STW-14	1980's	STW-14	1500	Jacob	5.32	3.55×10^{-3}	—	4.00 (345.6 m^3/d)
(gorusinge)	(dry season)							

Note : Numbers in the parenthesis are not very reliable. They are omitted from the calculation of the average. * A geometric mean

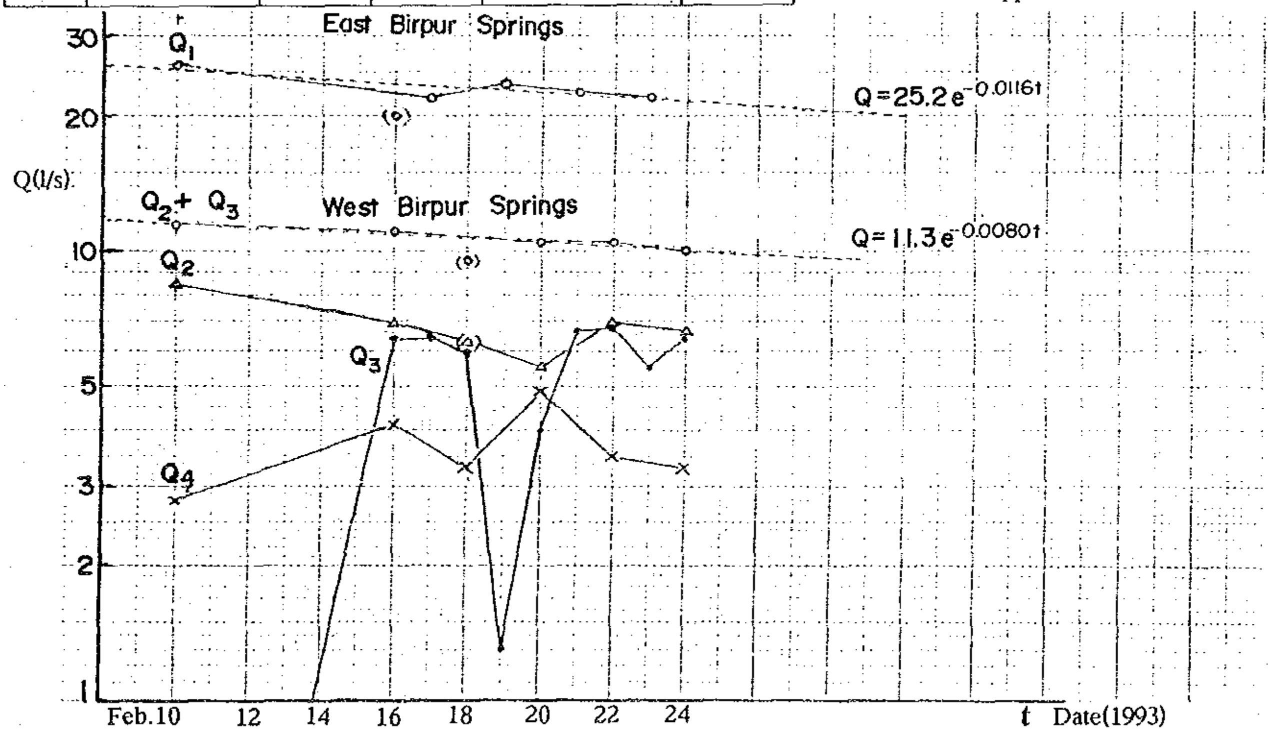
Table B.2.3 Spring Discharge of the Birpur Springs (By means of a V notch)

No.	Date(1993)	Time	L(cm)	H=(L/2)(cm)	Q(l/s)
Q1	Feb.10	13:35	40.8	20.4	25.9
	Feb.16	15:00	(36.6)	(18.3)	(19.8)
	Feb.17	14:53	38.0	19.0	21.7
	Feb.19	17:09	39.1	19.6	23.5
	Feb.21	11:15	38.5	19.3	22.6
	Feb.23	11:30	38.1	19.1	22.0
Q2	Feb.10	16:00	25.9	13.0	8.48
	Feb.16	17:40	24.0	12.0	6.95
	Feb.20	13:50	22.0	11.0	5.60
	Feb.22	14:20	23.9	12.0	6.95
	Feb.24	15:20	23.5	11.8	6.67
Q3	Feb.10	16:50	0.0	0.0	0.00*
	Feb.16	14:20	23.2	11.6	6.39
	Feb.18	9:50	22.6	11.3	5.99
	Feb.19	16:36	12.1	6.1	1.30*
	Feb.20	10:26	18.9	9.5	3.99
	Feb.21	10:30	23.6	11.8	6.67
	Feb.22	11:53	23.7	11.9	6.81
	Feb.23	10:45	21.8	10.9	5.48
	Feb.24	13:55	23.2	11.6	6.39
Q4	Feb.10	17:40	16.6	8.3	2.79
	Feb.16	14:30	19.4	9.7	4.11
	Feb.18	11:45	17.7	8.9	3.32
	Feb.20	11:15	20.8	10.4	4.88
	Feb.22	12:13	18.2	9.1	3.51
	Feb.24	15:55	17.7	8.9	3.32

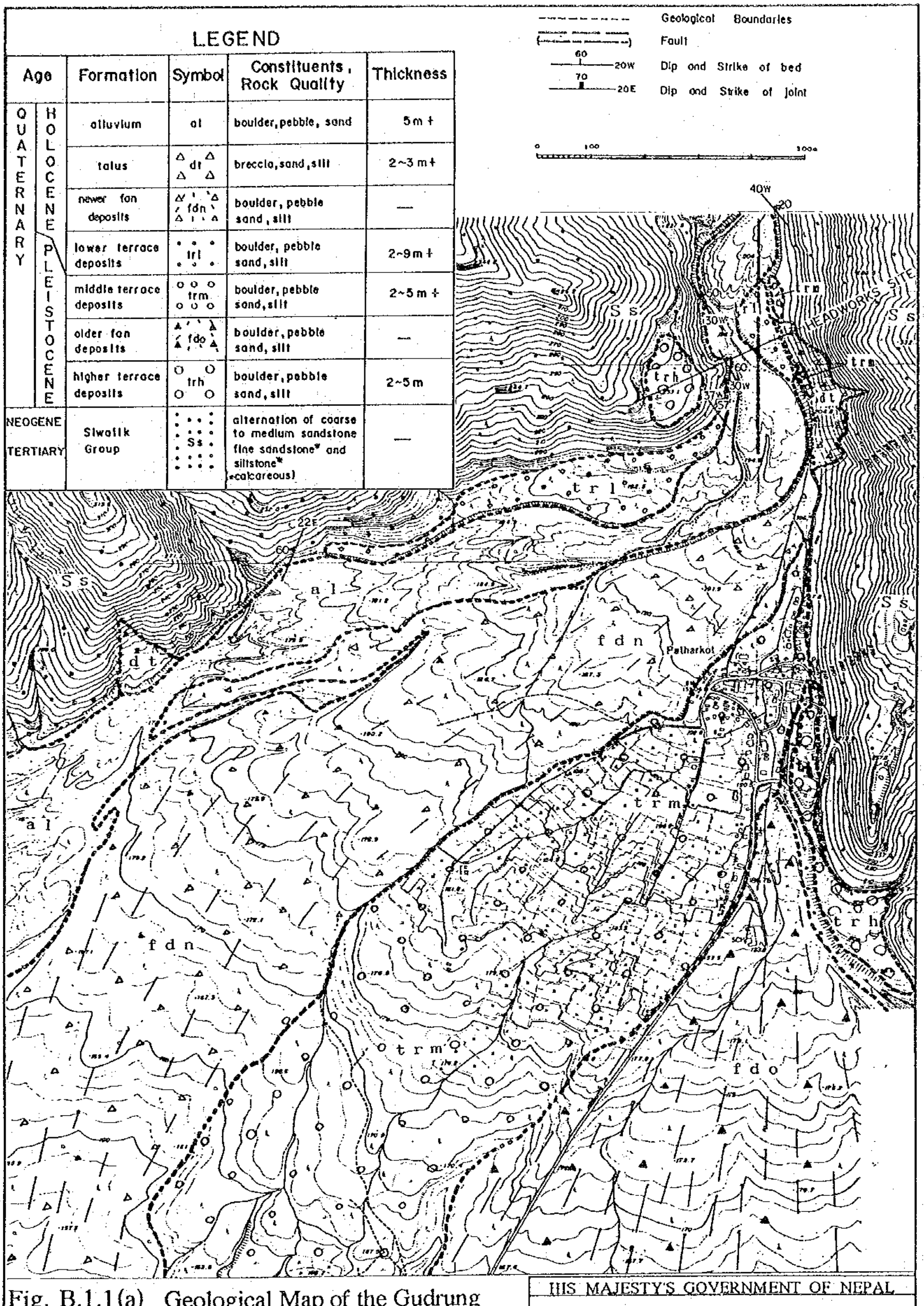
No.	Date	Q(l/s)
Q2 + Q4 (=total discharge from West Birpur Springs)	Feb.10	11.27
	Feb.16	11.06
	Feb.18	(9.58)
	Feb.20	10.48
	Feb.22	10.46
	Feb.24	9.99

Q2 -Q3 (=leakage from the cannal between Q2 and Q3)	Feb.10	(8.48)
	Feb.16	0.56
	Feb.18	0.27
	Feb.22	0.41
	Feb.24	0.28
average	—	0.57

Note)
Q1 : East Birpur Springs
Q2 to Q4 : West Birpur Springs
Q2 : the end of springs (on the canal)
Q3 : 550 m downstream from Q2 (on the canal)
Q4 : former stream from the springs, tributary of the Gudrung river
Numbers with parenthesis shows that the discharges are unstable.
*) Fishermen stopped the stream.



FIGURES



LEGEND

Age		Formation	Symbol	Constituents, Rock Quality	Thickness
QUATERNARY	HOLOCENE	alluvium	al	boulder, pebble, sand	5m +
		talus	dt	breccia, sand, silt	2~3 m+
		newer fan deposits	fdn	boulder, pebble sand, silt	—
	PLEISTOCENE	lower terrace deposits	trl	boulder, pebble sand, silt	2~9m +
		middle terrace deposits	trm	boulder, pebble sand, silt	2~5 m +
		older fan deposits	fdo	boulder, pebble sand, silt	—
		higher terrace deposits	trh	boulder, pebble sand, silt	2~5m
NEOGENE TERTIARY		Siwalik Group	Ss	alternation of coarse to medium sandstone fine sandstone* and siltstone* (*calcareous)	—

Fig. B.1.1(a) Geological Map of the Gudrung Headworks Site (Regional Map)

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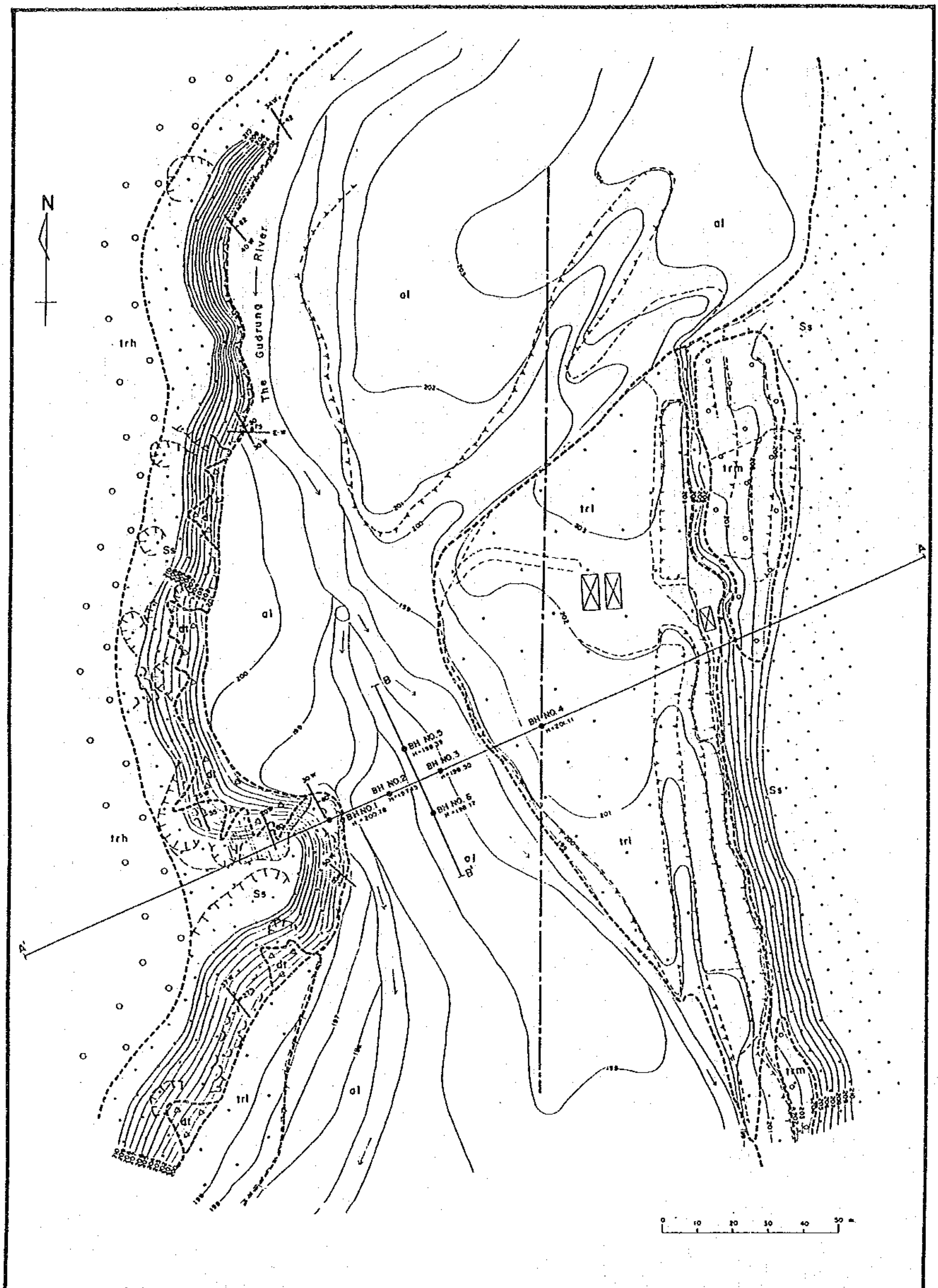

Fig. B.1.1(b) Geological Map of the Gudrung Headworks Site (Detailed Map)

The legend is shown in Fig.B.1.2.

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