MSc THESIS IN HYDROPOWER DEVELOPMENT

HYDROLOGICAL ANALYSIS

FOR

BHERI-BABAI HYDROPOWER PROJECT NEPAL

Shyam Kishor Yadav

JUNE 2002

D1-2002-17

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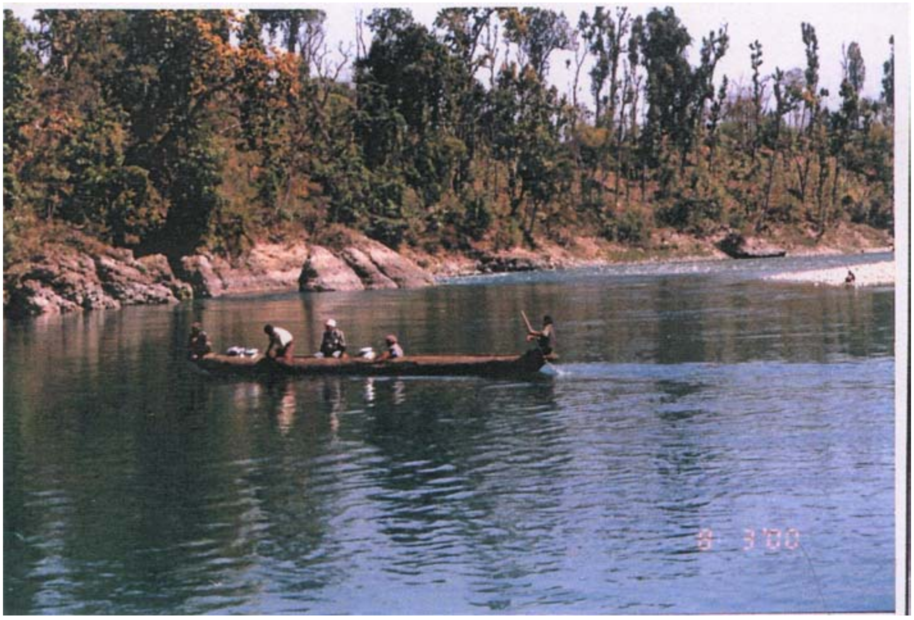

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Summary

The main objective of the study was to investigate the effect of flow regimes and river water temperature regime on aquatic ecology downstream from the intake site in Bheri river and downstream from the outlet in Babai river after diversion of 40 m^3/s of discharge from Bheri to Babai river. The key issues include attaining environmentally acceptable increased water depth in Babai river (less than 30 cm in shallow section), maintaining minimum water depth/flow in Bheri river (at least 30 cm in shallow section) and minimizing decreased water temperature in Babai river. The study has been carried out as per the project requirements and it would be useful for the further detailed analysis.

The Bheri River, which is one of the main tributaries of the Karnali River originates in the glacier of the Himalayas and flows westwards and joins the Karnali river about 15 Km upstream from Chisapani. It is about 400 Km long and its catchment area is 13870 Km^2 at the confluence of the Karnali River and 11255 Km^2 at dam site, the latter is located about 65 km upstream from its confluence with Karnali river. The bed slope is 1/30, 1/70 and 1/400 at the upper, middle and lower reaches of Bheri river respectively. Annual average discharge at intake site is 396 m^3/s with maximum and minimum monthly discharges being 3132 m^3/s and 44 m^3/s respectively.

The Babai river is also a tributary of the Karnali River and it joins the Karnali river about 50 Km downstream from Nepal-India border. It originates from a low mountain in Siwalik and flows northwestward parallel with Bheri river then southward passing through Royal Bardia National Park. The Babai Irrigation weir is located at about 45 km downstream from the proposed outlet site. The catchment area at outlet is 2602 Km^2.Annual average discharge at outlet site is 71 m^3/s with maximum and minimum monthly discharges being 588 m^3/s and 4 m^3/s respectively.

There are 17 rainfall-gauging stations in the Bheri and Babai river basins. Daily rainfall data from these stations were collected from Department of Hydrology and Meteorology. Precipitation gradient was plotted for these basins and gradient curve showed that the least rainfall occurs at the Dunai Station (312), which is located at upper reach in the Bheri river basin while the highest annual rainfall takes place at Nayabasti station (507), which is located in the Babai river basin. The estimated mean annual rainfalls for the Bheri and Babai river basins are 964 mm and 1156 mm respectively.

Run-off data from gauging stations were used as input data to develop flow regimes in Bheri and Babai river basins. Run off at the Jamu station is slow to respond to rainfall in Bheri river basin during rainy season because of the large catchment area and long time lag between tributaries and mainstream for rainfall and run off. On the other hand, run off at Bargadha station has sensitive response because the catchment area is one fourth of the Bheri river basin.

In climatic research it is important to have access to reliable data, which are free from artificial trends or changes. One way of checking the reliability of a climate series is to compare it with surrounding stations. This is the idea behind all tests of the relative homogeneity. As non-homogeneous climate data are a poor source of information for climate research, hydrologists have often preferred to use double mass analysis to obtain information on the relative homogeneity of precipitation series. This technique is purely qualitative. Here the accumulated sums of the total annual precipitation are plotted against each other for the traditional mass curve. Double mass analysis technique was employed to check the quality of these data. The analysis showed inconsistency in stations 312 and 406 of Bheri river basin in 1963 and 1968 respectively. A change in slope of the line reveals to an inconsistency and adjustment was suggested on the basis of the ratio of original slope to that of the inconsistent slope.

Quality control of hydrometric data is usually based on the use of comparative data in one form or another. Data will either be compared to earlier values from the same series; with the corresponding data from the nearby stations. To check the consistency of the data , double mass curve analysis was performed for both Jamu (Bheri) and Bargadha (Babai) stations with near by Chisapani and Jalkundi stations. The analysis showed that Bheri river data has good consistency and for Babai river basin the analysis showed that data of Bargadha station is also homogeneous although correlation is poor.

There will be a decrease in discharge/depth in downstream area after 40 m^3/s water will be diverted from Bheri river at the intake. After thorough monthly analysis of all the available 33 years data, it was found that the project fulfils mandatory compensation flow and required depth to support the downstream aquatic life.

On the other hand, there would be significant flow in Babai river after diversion and mean monthly flows will be in the range of 44-86 m^3/s based on all available 21 years monthly flow analysis. Babai river is virtually dry between January and May in Babai valley where the river is braided becoming wider from 65 m at outlet up to 250 m between Shivpur in Guthi areas. With the increased flows of 40 m^3/s, the expected water depth would increase about 30 cm in the driest months at Chepang (Outlet) and would spread over gravel bar and sand of river width in range between 150 m and 250 m in the flood plains giving a much lower increase in water depth of 15-20 cm in dry season between November and June, between Shivpur and Guthi areas. Therefore an increase of 15 to 20 cm in water depth of Babai River fulfils the project requirement.

One of the big issues has been the change in water temperature of Babai river due to diversion. Bheri river originates from glacier and flows through high mountain regions and Siwalik (area between 200-1000m elevation) where as Babai originates at mid hill and flows through Swalik. Therefore Bheri river water temperature is lower (2°C-6.8°C) compared to Babai river. But there is seasonal temperature difference between these two rivers, the maximum being in the months of July, August and September because of melting of snow in Bheri river.

Water temperature determination for Babai River after mixing was based on water temperature data recorded in Bheri-2 at intake site and Babai-1 outlet site and their respective discharges. Temperature differences of mixed water from outlet and Babai River range from 0.9 °C in July to 3.2 °C in May. The highest temperature difference is in the months of April, May and June (2.2 –3.2 °C) because these are the months when the river has low flows (9-46 m^3/s). The temperature of mixed water at Chepang (outlet) during this period would range between 22.2 °C and 26.1 °C, which is within the range of temperature tolerance to aquatic flora and fauna found growing in this subtropical riverine environment when we compare mixed water temperature with the existing water temperature.

The temperature difference after mixing of Bheri River with Babai would gradually decrease with distance. In order to establish a temperature regime, relationship between air-water temperature differences and discharge was developed so that water temperature at any point downstream can be calculated based on known discharge and known air temperature. In Babai river, correlation was found poor because of lower discharge range while the correlation was found better in Bheri river basin. The nature of curve was found similar in both river basins, air-water temperature difference being small at lower discharges and vice-versa. Since the climatic condition is similar in both the river basins, it was decided to use the trend line equation of Bheri river to Babai river basin and the water temperature at Babai 2 was calculated. The calculated water temperature was compared with the observed water temperature. The analysis showed that in first six months the calculated temperature was higher than the observed one while for the next six months, the scenario was opposite and the difference between calculated and measured water temperature was found up to 5.59°C. Also the temperature calculated downstream at Babai 2 after mixing by using trend line equation was found higher in months March to June than the observed one before mixing, which cannot be because the river has more colder water after mixing and the temperature should be less than before. Therefore it was decided to use the river temperature data of both Babai 1 and Babai 2 stations to develop temperature regime downstream after mixing. The result showed that Babai River after mixing has lower water temperature than the observed one before mixing at Babai 2, which was not true in case of calculation based on trend line. The temperature difference after mixing was found decreasing with distance and less than 2 °C in almost all the months, 22 Km downstream from the outlet point thus fulfilling the project requirement to ensure adequate protection of aquatic life. The increased discharge in Babai river after diversion would spread over larger width downstream giving rise to depth of only 15 – 20 cm, the linear assumption i.e. the rate of heating of water before and after diversion was found to be reasonable.

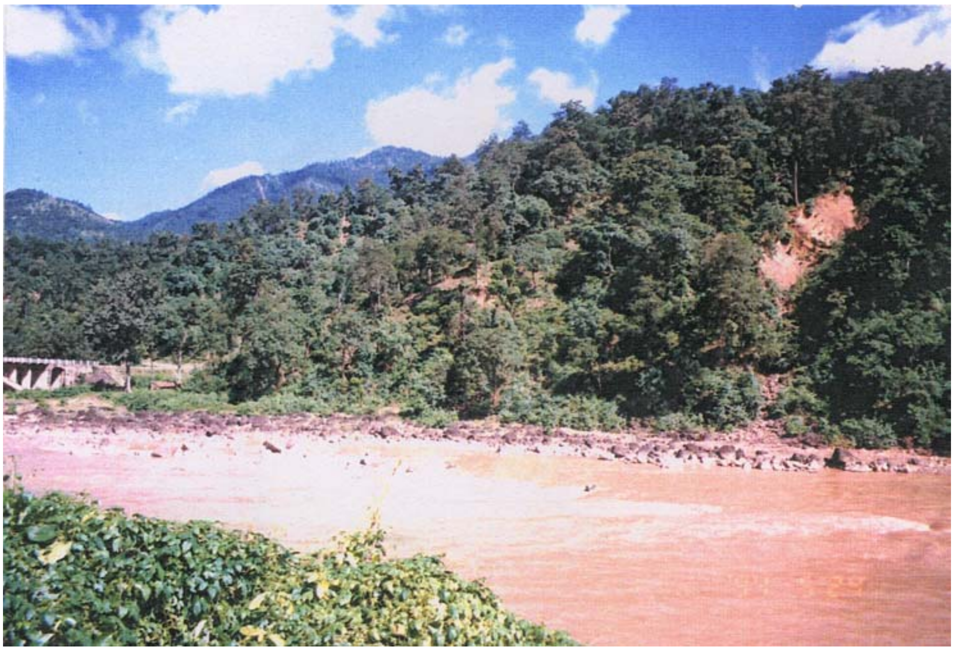
Generally river water temperature increases as it travels downstream like in Babai River. But it was found to be opposite in case of Bheri river after looking in to the data of two stations. The catchment areas of tributaries between these two stations were analysed for the drainage discharge and it was found that tributaries having catchment areas of 425 km^2 that are originating from 2000m elevation contributed (based on specific discharge in Bheri river) average annual discharge of 15 m^3/s. This discharge is only 3.5 % of mean annual discharge of Bheri river. This additional small discharge of 15 m^3/s, which is not of glacier origin, should not lower the water temperature at the downstream station. Therefore there might be error in river temperature data observation.

This is first part of the study and the next one is the study on sedimentation.

Sediment rating curve of Bheri River was plotted based on available one year data and the rating curve clearly showed the random behaviour of sediment and poor correlation with the discharge. Water flow is therefore not a reliable parameter to determine the sediment concentration in the river .The estimated mean annual sediment loads by different methods were calculated and found some variations. As the sediment concentration varies largely with time, and major bulk of the annual sediment load may be transported within a few days, a large quantity of the sediment load may easily pass a sediment gauging station unmeasured if the sampling frequency is poor. Also the estimated sediment load in Bheri river is based on only one-year data, the expected sediment load may be even higher or may be less in other years. Therefore to account for the unmeasured load and its random characteristics, the expected annual sediment load was estimated to be 50 million tonnes (approximately 1.6 times than that of load estimated based on observation of Bheri river data). The sediment concentration based on this expected load was estimated.

Photographs

The proposed Dam Site and Desanding Basin of Bheri River



Outlet Site at Upstream of Babai Bridge at Chepang

Fish at the backwater portion of Babai River at Guthi

Babai Irrigation Weir

Foreword

The present study ‘‘Hydrological Analysis for the Bheri-Babai Hydropower Project, Nepal’’ is a thesis submitted to the Norwegian University of Science and Technology, Department of Hydraulic and Environmental Engineering, in partial fulfilment of the requirements for Master of Science Degree in Hydropower Development.

The work presented in this thesis is my own and all significant outside inputs have been identified and acknowledged to the best of my knowledge. It is intended that this study will be updated when more data becomes available.

A CD is included in the thesis so that the reader can have an access to the detailed analysis, computation and the results.

Shyam Kishor Yadav

June 2002

Acknowledgement

I would like to thank all the people and organisations that have made this thesis possible. Firstly, I would like to thank Prof. Ånund Killingtveit and Prof. Haakon Støle for their timely guidance and suggestions throughout the thesis period.

I would like to thank Department of Hydrology and Meteorology for providing the necessary data for the study. I would also like to thank the personnel of Department of Electricity Development and Multi-Tech Engineering Consultancy for their kind cooperation during my fieldwork.

I would like to express my sincere gratitude to Hilbjorg Sandvik who contributed in providing all the necessary materials in time.

My thanks to Norwegian Agency for International Development (NORAD) for the financial support throughout my study period.

Special thanks to Lalitha, who contributed a lot to my thesis even in difficult situation. More thanks to Naresh for editing my thesis.

My sincere thanks go to all the fellow students in the department for their cooperation.

Shyam Kishor Yadav
June 2002

NTNU, IVB Trondheim
Norway

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List of Abbreviations

Institutions and Organisations

HMG/N	His Majesty's Government of Nepal
WMO	World Meteorological Organisation
ICOLD	International Committee on Large Dams
DHM	Department of Hydrology and Meteorology
NEA	Nepal Electricity Authority
CIWEC	Canadian International Water and Energy Commission
JICA	Japan International Cooperation Agency

Symbols of Parameters and Units

MW	Megawatt
km^2	Square Kilometer
m^3/s	Cubic meter per second
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
Q	Discharge
H	Head
L	Length
M	Manning's Coefficient
A	Area
R	Hydraulic Radius
S	Bed Slope
d/s	Downstream

NTNU
THE NORWEGIAN UNIVERSITY FOR SCIENCE AND TECHNOLOGY
Department of Hydraulic and Environmental Engineering

Master Thesis
In
Hydropower Development (Hydrology)

Canditate: **SHYAM KISHOR YADAV**

Topic: **Hydrological analysis for the Bheri-Babai hydropower project, Nepal**

1. Background

The Bheri-Babai hydropower project is located in mid-western part of Nepal of Surkhet district. The project is planned to produce about 48 MW of electric power by diverting water from Bheri to Babai River through a tunnel of about 12.7 km. The planning of the project depends on hydrological data, and the quality of these data always needs attention. In this study the basic hydrological data needs for the project will be re-evaluated, partly based on new data, partly on new methodology. The results will be compared to previous investigations during the studies performed by JICA.

2. Main questions for the thesis

The thesis shall cover, though not necessarily be limited to, the following main questions:

a) Collect data and establish main characteristics of the flow regime of rivers in the region

b) Analyze the quality of hydrological and meteorological data, and develop methods for filling in or extending data records based on correlation with other nearby stations. As a final result a quality-controlled time-series of river flows at the diversion site should be produced.

c) Perform flood frequency analysis and compute Probable Maximum Flood (PMF) at the intake site. Use the results to decide necessary flood release capacity in intake dam and location of power-house at the outlet site.

d) Investigate the effect on flow regimes and river temperature regime downstream from the intake site in Bheri river and downstream from the outlet in Babai river.

e) Estimate sediment load at the intake site in Bheri river, based on river flow data and calibrated equations for sediment load vs flow at nearby sites. If possible, compare the results with measurements.

3. Supervision, data and information input

Professor Ånund Killingtveit will supervise the thesis work and will make relevant computer models and facilities available. The candidate will be responsible for data collection, quality control and corrections.

4. Report format

Professional structuring of the report is important. Assume professional senior engineers as the main target group.

The report shall include a summary, offering the reader the background, the objective of the study and the main results.

The thesis report shall be in format A4. It shall be typed (PC-text processing). Figures, tables, etc shall be of good report quality.

Table of contents, list of figures, list of tables, list of references and other relevant references shall be included.

All documents and data shall be written on a CD thereby producing a complete electronic documentation of the results from the project. This must be so complete that all computations can be reconstructed from the CD.

Finally, the candidate is requested to include a signed statement that the work presented is his own and that all significant outside input has been identified.

The thesis shall be submitted no later than **Wednesday 12 June 2002**

Department of Hydraulic and
Environmental Engineering, NTNU

Ånund Killingtveit
Professor

1 INTRODUCTION

1.1 Physical Aspects of Nepal

Situated in the lap of Himalayas, Nepal is located in between latitude 26° 22' N to 30° 27' N and longitude 80° 4'E to 88° 12'E and elevation ranges from 90 m to 8848 m. It has an oblong shape stretching approximately 885 km in east-west direction and 193 km in north-south direction. The country is bordering between the two most populous countries of the world, India in south, east and west and China in the north. Geographically Nepal is divided into three regions: the Mountain, Hill and Terai. The northern mountain range (Himalayas) is covered with snow all over the year where the highest peak of the world, the Mount Everest stands. The middle range (Hill) is captured by gorgeous mountains, high peaks, valleys and lakes. The Southern range (Terai) is the Gangatic plain of alluvial soil and consists of dense forest area, national parks, wild life reserves and conservation areas. The Mountain Region covers 35% of the land area of the country but only 2% of the land is suitable for cultivation. The Hill Region is located between the Mountain Region and Terai Plain. The Hill Region has several fertile basins, which have served as the political centres of the country such as Kathmandu and Pokhara. The Region accounts 42% of the total land area of Nepal. The Terai Region is the narrow strip of plain attached to the south of the hill with its 23% share of the land area.

Nepal in general is not endowed with natural resources but one resource that is abundant is its water resources. Nepal is the second richest in water resources possessing 2.3% of the world's water resource with its 6000 rivers of 45000 km in length. The main rivers are Koshi, Gandaki (Narayani), Karnali, Mechi, Mahakali, Bagmati and Rapti. [20]

1.2 General Climate

The climate in Nepal is generally classified into two seasons in terms of the magnitude of precipitation: one is the rainy season from June to September and the other is the dry season prevailing in winter. Ample rainfall in the rainy season is brought from the Bay of Bengal by the monsoon, which whirls from southeast in the summer of northern hemisphere.

Westerly or northwesterly wind, which is dominant in winters, brings dry air from Siberia resulting in a dry season. When wind comes from the Mediterranean, it brings winter rainfall especially in western part of Nepal.

The climate of Nepal is divided into five zones in terms of elevation: subtropical, warm temperate, cool temperate, alpine and arctic zones. The Terai and the Siwaliks fall in the sub-tropical zone with ample rainfall in the monsoon period of June to September. The middle mountain is in the warm temperate zone with occasional snowfall in winter in the highest areas. The climate of the cool temperate zone extends in the High Mountains. Snow falls in winter and stays on the mountaintops throughout the winter. Alpine climate appears in the higher mountain regions with low temperature in summer and extremely frosty conditions in winter. Arctic climate is above snowline where there is perpetual frost.[3]

1.3 Hydropower Development in Nepal

Hydropower potential in Nepal ranks second in the world after Brazil. The estimated potential is 83000 MW out of which 42000 MW can be developed economically. However the majority of this hydropower potential is still under developed and most of the energy depends on traditional energy sources like wood. Due to this situation, withering of forest has been increasing causing soil efflux to the downstream areas.

His Majesty's Government of Nepal (HMG/N) has listed up the transition of traditional energy to commercial energy as one of the most important governmental strategies. Among the commercial energy sources, hydropower has been considered as the most economic and stable base energy compared with coal and thermal energies. It has been expected that hydropower development will become a motive power for economic development of the country.

The total installed capacity is 584 MW comprising 527 MW of hydroelectric power facilities and 57 MW of diesel power facilities. Among the hydroelectric facilities, only Kulekhani No. 1 (60 MW) and NO.2 (32 MW) are of reservoir type power facilities and the others are of run-of river types[8]. Details of existing power projects are shown in appendix C table 1.1.

Power demand analysis shows an increase of about 10% recently but power supply condition is still unstable and a chronic insufficiency of power supply has been continuing. Due to this, power supply to about 4 to 10 hours is being restricted. In addition, it is anticipated that power demand will increase about 10% annually in the future. Against this background of power demand and supply, the development of new hydroelectric power sources is urgently required and Bheri-Babai project has been ranked as top priority for an early development.

1.4 Project Background

The Bheri-Babai hydropower project (BR 1-0) option was recommended in the master plan study for Water Resources Development of the Upper Karnali river and Mahakali river Basins completed in 1993. However concerns over the potential conflicts with the objectives of Royal Bardia National Park (RBNP) have resulted in the screening of four additional project options, BR 1-1, BR 1-2, BR 1-3 and BR1-4 as shown in appendix A drawing no. 1 located upstream of RBNP. The nominated optimum for development is the BR 1-3 base load option based on 40 m^3/s diversion with an installed capacity of 48 MW and an indicated output of 420 Gwh/year.[3]

1.4.1 Climate in the Study Area

Rainfall

There are 17 rainfall-gauging stations in the Bheri and Babai river basins. Rainfall data from some of these stations were collected on daily basis from Department of Hydrology and Meteorology. Precipitation gradient was plotted for these basins and gradient curve shows that the least rainfall occurs at the Dunai Station (312), which is located at upper reach in the Bheri river basin while the highest annual rainfall takes place at Nayabasti station (507), which is located in the Babai river basin. The estimated annual mean rainfalls for the Bheri and Babai river basins are 964 mm and 1156 mm respectively.

Snowfall

A certain percentage of total annual precipitation falls as snow in Nepal. In particular, a ratio of snowfall to rainfall is high in the Himalayan Region. However, few meteorological stations in Nepal measure snowfall due to difficulty in measurement.

Snowline descends to elevation 3500 m in winter and ascends to elevation 6000 m in the summer. Snow accumulated between these two contour lines melts and drains in the river as run off as the snowline goes up. That is to say that snow acts as a balancing reservoir in the hydrological cycle due to delay in run off.

1.5 Run off Characteristics of Bheri and Babai river Basins

Run off at the Jamu station is slow to response to rainfall in Bheri river basin during rainy season because of the large catchment area and therefore long time lag between tributaries and mainstream for rainfall and run off. On the other hand, run off at Bargadha station has sensitive response because the catchment area is one fourth of the Bheri river basin. The hydrology of the two river systems is most important as Bheri is a mountain snowmelt and Rainfed River and Babai is a hill rainfed river.

1.6 Limitations of Study

- Lack of literatures on river water temperature regime study.
- One-year river water temperature data was insufficient for river water temperature regime study.
- Meteorological stations (air temperature) were not established at the project sites. Air temperature based on temperature gradient in the region was used in the analysis.

2 HYDROLOGICAL ANALYSIS OF THE RIVER BASINS

2.1 Description of River Basins

2.1.1 Bheri River Basin

The Bheri River, which is one of the main tributaries of the Karnali River originates in the glacier of the Himalayas and flows westwards and joins the Karnali river about 15 Km upstream from Chisapani. It is about 400 Km long and its catchment area is 13870 Km^2 at the confluence of the Karnali River and 11255 Km^2 at dam site, the latter is located about 65 km upstream from its confluence with Karnali river. The bed slope is 1/30, 1/70 and 1/400 at the upper, middle and lower reaches of Bheri river respectively. Annual average discharge at intake site is 396 m^3/s with maximum and minimum monthly discharges being 3132 m^3/s and 44 m^3/s respectively. Elevation of water level at intake site would be 461m.

Since diversion of water from Bheri River is a potential source of water for supplementing dry season flows in Babai river, a cursory analysis of the flow regime of Bheri river was undertaken. The proposed diversion site is about 60 km upstream of Jamu, which is Bheri river gauging station located 5 km above the confluence of Bheri and Karnali rivers. The catchment area at the diversion site is only 9 % smaller than that of Jamu (This is because the catchment area surrounding the river is long and narrow in this area).

2.1.2 Tributaries of Bheri river

Streams and rivulets joining Bheri river up to 6.5 km upstream from dam site are described here. This is shown in appendixA drawing no 2. Rivulets on the left bank are Lore khola, Natne Khola, Jhighni Khola, Deuti Khola and Gocche Khola. Rivulets on the right bank are Khaskhase khola, Khahare khola , Gorju Khola, Betni Khola and Mangra Khola. [17] Rivulets joining downstream area are shown in appendix A drawing no 1.

Left bank of Bheri River

Lore Khola is small and originates from alluvium hill forest. This rivulet flows only in rainy season. Excessive drainage of hill flows on the river and occasionally carries gully materials; sometimes it contains heavy stone, sand, mud and gravel.

Natne Khola is bigger than Lore Khola. It originates from densely forest hills. The catchment of the rivulet is wider than Lore Khola but the flow depends upon rainfall. The drainage carries heavy stone in rainy season and deposited on its channel as well as on Bheri riverbed.

Jhingni Khola has also a similar behaviour of Natne Khola. Jyamire and Deuti Khola are small rivulets of low land forest and drainage of village. These rivulets do not carry heavy materials. Gochhe Khola is a larger rivulet and originates from the mixed dense forest area. This rivulet is wide and its bed is gravelled.

Right bank of Bheri river

Rivulets on the right bank are Khaskhase Khola, Khahare Khola, Gorju Khola, Betani Khola and Mangra Khola. Khaskhase Khola has drainage of low land forest. Flow is small and depends on the intensity and duration of rainfall.

Khahare Khola is a larger rivulet originating from the mixed dense forest having large carchment area up north-hills. This rivulet is wide and brings heavy material to the downstream at the confluence of Bheri river.

Garlu Khola is a rivulet having large catchment and wide channel responsible for landslide and erosion causing the eroded materials on the river bed.

Betani Khola is a large rivulet and braided upstream from its confluence with Bheri river has a capacity to carry heavy stone, sand, mud and gravel.

2.2 Babai River Basin

The Babai river is a tributary of the Karnali River and it joins the Karnali river about 50 Km downstream from Nepal-India border. It originates from a low mountain in Siwalik and flows northwestward parallel with Bheri river then southward passing through Royal Bardia National Park. The Babai Irrigation weir is located at about 45 km downstream from the proposed outlet site. The catchment area at outlet is 2602 Km^2.

Annual average discharge at outlet site is 71 m^3/s with maximum and minimum monthly discharges being 588 m^3/s and 4 m^3/s respectively. Elevation of water level at outlet site would be 309 m.

2.2.1 Tributaries of Babai River

The major tributaries of Babai river located 1.5 Km downstream from outlet and 4 km upstream are briefly described here. [17]

Major tributaries on the left bank of Babai river are Chepang Khola, Chisa Khola, Dhondre Khola and Khote Khola. All these rivulets originate from north sloping dense forests in upper middle Siwaliks. During winter, these rivulets are almost dry.

Left bank of Babai river

Khote Khola is very steep and flow increases tremendously during rainy season. Each year it brings disaster to riparian bank particularly at the confluence with Babai river. It also carries big boulders, mud and gravel.

Dhondre Khola is very steep and carries big boulders, mud and gravel during heavy rainfall.

Chisa Khola is meandering one , not too steep like Dhondre Khola but carries boulders, mud and gravel during rainy season.

Chepang Khola is much larger and joins Babai river at Chepang: Flows are very high during rainy season while there is a little water in the rivulet during winter. It also carries large amount of boulders and gravel like Khote Khola.

Right bank of Babai River

Thulo Kakkre Khola , Sano Kakkre Khola, Milmile Khola, Chiuribas Khola, Dhondre Khola and Giddhe Khola are the major streams on the right bank of Babai river 4.5 Km upstream of Outlet and about 2 km downstream. All these streams originate from south facing degraded forests in lower Siwalik. Similar to streams on the left bank, they also carry heavy sediments during rainy season and there is very little water in winter months.

2.3 Flood Frequency Analysis

Determination of frequency of occurrence of extreme hydrological events like floods and severe storms are important in water resources planning and management. There is a definite relationship between the frequency of occurrences and magnitude; the ordinary events occur almost regularly than the severe storms. Frequency or probability distribution helps to relate the magnitude of these extreme events with their number of occurrences such that their chance of occurrence with time can be predicted successfully.

Flood frequency analysis considers the annual peak flows at a site for all the years. The method of analysis and predicting flood from the data of run off peaks is called frequency analysis. It gives only the magnitude of flood peak of desired recurrence interval or return period, but does not provide information about the complete hydrograph or the flood volume. Prediction of flood peaks from the flood data of recorded maximum series is reliable when the analysis is carried out for return period of less than the data length. However, when the data is to be extrapolated, for example when flood peaks of 1000 or 10000 years are required to be predicted from an annual maximum series of say 30-40 years, then the prediction should be carried out with caution as the sample data may not be true representative of the population. There may be a long-term trend or a cycle associated with the system. For such predictions, confidence bends or limits are to be estimated at 95% or other acceptable percentages, depending upon the precision requirement.[19]

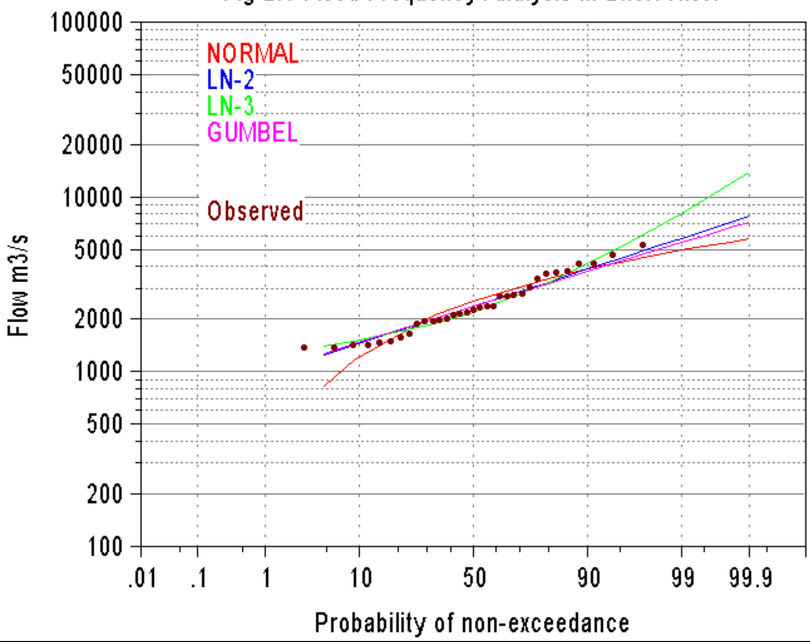
Data on annual maximum peak discharges at Jamu and Bargadha stations were collected from ‘ Hydrological Records of Nepal’ published by Department of hydrology and meteorology. The collected data are shown in tables 2.1 and 2.3.

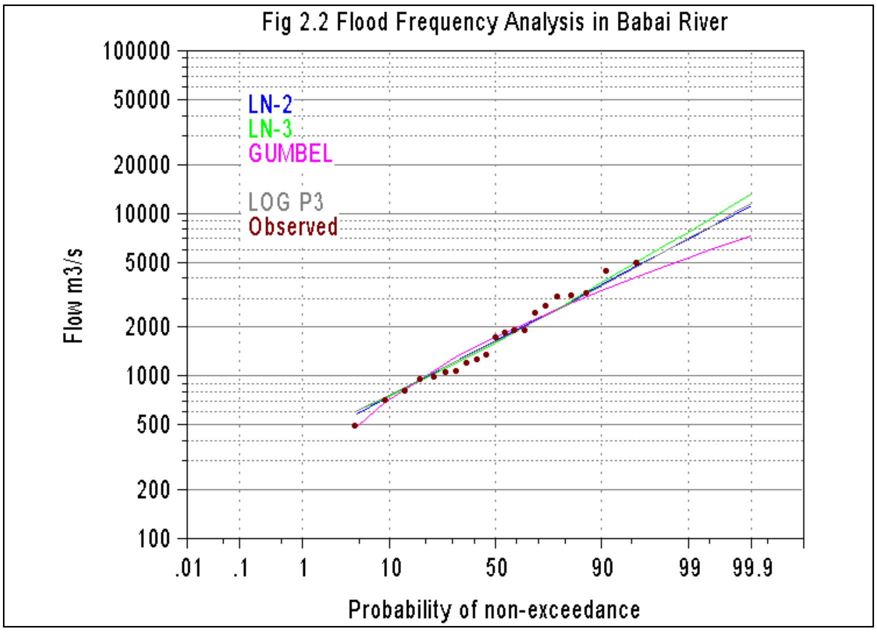
Maximum-recorded peak discharges at the Jamu and Bargadha stations are 6820 m^3/s and 6480 m^3/s respectively.

Flood frequency analysis was carried out using the recorded annual maximum observed flow series with help of software FREQ2000 developed by A. Killingtveit. Different theoretical distributions –Normal, Lognormal and Gumbel were fitted to the data. The estimated flood values for different return periods obtained from each distribution for each gauge are presented in tables 2.5, 2.6 and shown in figures 2.1 and 2.2. From the table and visual inspection of the plot, log-normal2 and log normal3 distribution were found to have the best fit for Bheri and Babai series. Although the catchment area of Jamu gauging station is four times than that of Bargadha gauging station, probable peak discharge for Bargadha station is larger than that of Jamu station. This is due to the following reasons:

1.) In spite of a large catchment area of Bheri river basin, its annual rainfall is smaller by 200 mm than that of Babai river basin.
2.) A large time lag of peak discharge between mainstream and tributaries takes place in the Bheri river basin.
3.) Rainfall pattern in both basins is quite different. In Bheri river basin, rainfall in the mountainside is remarkably small and large amount of rainfall takes place in the low land areas while, on the contrary, rainfall pattern in the mountain area and low land area is almost the same in Babai river.

Fig 2.1 Flood Frequency Analysis in Bheri River





2.4 Flow Frequency Analysis

Flow duration curve is needed to determine the installed capacity of a hydropower project. The flow duration curve in this project is the most important because this project is planned as run of river type. Flow duration curve in Bheri river basin was calculated by using daily run off data at Intake. The flow duration curve in Babai river was calculated by using data at the outlet site. The estimated flow duration curves of Bheri and Babai river are shown in figures 2.3, 2.4 and tables 2.9, 2.10. The 95% dependable discharge at Intake site, which is the basis for power planning, is 67 m^3/s.

2.5 Estimation of Probable Maximum Flood

The probable maximum flood (PMF) is the largest flood likely to occur in a basin, given the geographic, meteorologic and hydrologic characteristics of the region. Its occurrence depends upon a combination of extreme events, and it is probably the maximum flood that can occur, but not certainly so, for all the extreme events have a probability of being exceeded. The PMF does not depend upon the statistical analysis of flow records but rather on determining the most adverse meteorological conditions that would be expected to occur in the basin. Consequently, a great deal of basin specific data must be collected in order to perform a PMF analysis. Generally the following two techniques (For Pre-feasibility level) are used for quickly estimating the PMF if such an estimate is required[16]:

- A technique developed from the work of Hershfield (WMO, 1973) has been widely used for preliminary estimates. The PMF estimate is approximately 15 standard deviations greater than the mean annual flood. Hershfield's developments were originally made for probable maximum precipitation (PMP) analysis and have sometimes been extended to PMF analysis.

- A general rule of thumb frequently used for PMF evaluations says that PMF is approximately twice the 10000-year flood estimate. This has been based on the values of PMF and 10000-year flood for many projects throughout the world. The range of ratios is 1.34 to 2.94. Therefore, a factor of 2 seems reasonable (table 2.12).

Hershfield's technique was not used in the analysis because the theoretical argument of extending from precipitation to floods seems weak. Therefore, a general rule of thumb for estimating PMF was used.

Bheri River is a tributary of Karnali river and for Karnali river, PMF is 1.91 times the 10000-year flood as shown in table 2.12. Therefore for Bheri river, a factor of 2 seems reasonable for PMF Estimation.

FREQ program used for flood analysis could calculate only 1000-year flood. Therefore Gumbel method was used to calculate 10000-year flood, needed for PMF estimation. The 10000-year flood from Gumbel method was found to be 9507 m^3/s and thus PMF to be 19014 m^3/s as shown in fig 2.5 and table 2.11. The PMF is used by designers of large structures the failure of which can have very severe consequences.

2.6 Flood Release Capacity in Intake dam

The gated spillway has been proposed after preliminary investigation at Bheri intake site as shown in drawing no 3 and 4. For gated outlets, the discharge has been calculated using the formula $Q = C*L* H^{3/2}$, Where Q is Discharge, m^3/s through gated spillway structure, C is Coefficient of discharge, determined from drawing no 5 and H is the head over the crest. The detail of calculation is shown in table 4.4 d. The proposed spillway structure is safe enough to handle 1000-year flood. But for the small dam (height below 10 m) like in Bheri, 100-year flood depending upon hazard potential has been recommended by ICOLD as shown in appendix C table 2.13.

2.7 Location of Power House

Powerhouse should be located in such a way that it should not be flooded/ inundated by the floods during the operation period of power plants. Location of powerhouse for different return period discharges was calculated based on rating equation at outlet site of Babai river as shown in fig 2.6 and table 4.5 g. The location of powerhouse depends upon whether it is underground or surface and types of turbine. In case of underground, the powerhouse is safe enough from being flooded where as Francis turbine can work even in submerged condition and one can have better head than the Pelton turbine. Since it is still unknown the type of powerhouse and turbine for the proposed project, 1000-year flood was selected to find out the location of powerhouse, as there would be question of economy beyond this discharge. Therefore the powerhouse based on stage discharge curve, for 1000-year discharge, should be located at 15 m from the bed level of the river.

3 DATA COLLECTION, PROCESSING AND QUALITY CONTROL

3.1 General Considerations

Advances in scientific hydrology and in the practice of engineering hydrology are dependent on good, reliable continuous measurements of the hydrological variables. The measurements are recorded by a wide range of methods, from simple writing down of number by a single observer to the invisible marking of electronic impulses on magnetic tape. Although the most advanced techniques are used in the developed countries, many nations of the third world like Nepal employ direct manual methods. Therefore data collection, data transmission, data quality control, storage and retrieval should always be considered as one consistent information system, and as much attention should be paid.

For hydrological analysis of water resource development project, it is important to make sure that time series of appreciable length are available and it is too late to start data collection when the data is needed. It is these hydrological variables that determine the potential of water resources. An effective system for routine collection, processing and quality control of data is therefore an essential part of hydrological services. In this study it is assumed that the responsible agencies had made their own quality control technique at various stages from collection to storage.[1]

3.1.1 Data collection

Following are the sources of data collection made by the author during field study:

- Department of Electricity Development, Kathmandu
- Department of Hydrology and Meteorology
- Department of Survey
- Ministry of Water Resources
- Iteco Nepal Pvt. Ltd
- Department of Irrigation
- Nepal Electricity Authority
- Water and Energy Commission secretariat
- Central Bureau of Statistics

Type and length of data collected are summarised in table 3.1

Type of data	Source
Topographic Maps of scale 1:20000, District maps, Zone Map of 1:125000, Trail Maps	Department of Survey
Report on Feasibility Study of Sharada-Babai and Bheri Babai Hydroelectric Project, Master Plan Study for Water Resources Development of The Upper Karnali and Mahakali River Basin	Department of Electricity Kathmandu
Run-off, Rainfall. Air temperature for both Bheri and Babai basin	Department of Hydrology and Meteorology
Discussion on the current development regarding the study project	Ministry of Water Resources, Department of Electricity Development
Data on existing and on going thermal and hydropower project	Nepal Electricity Authority
Report on Babai Irrigation Project	Department of Irrigation
Software on hydrology	Water and Energy Commission Secretariat

Almost all the data collected were in hard copy except run-off.

3.2 Rainfall data

3.2.1 Bheri River Basin

Rainfall data of seven metrological stations were collected in this river basin. The length of records is shown in the table 3.1 and location in appendix A drawing no 5.

Out of these stations, stations 312, 502 and 406 were selected for the homogeneity test of data based on continuity of data and elevation. There are only few days break in the annual values of these station and records are longer. The stations 418, 514, 501 and 513 having longer and frequent breaks were discarded from further study.

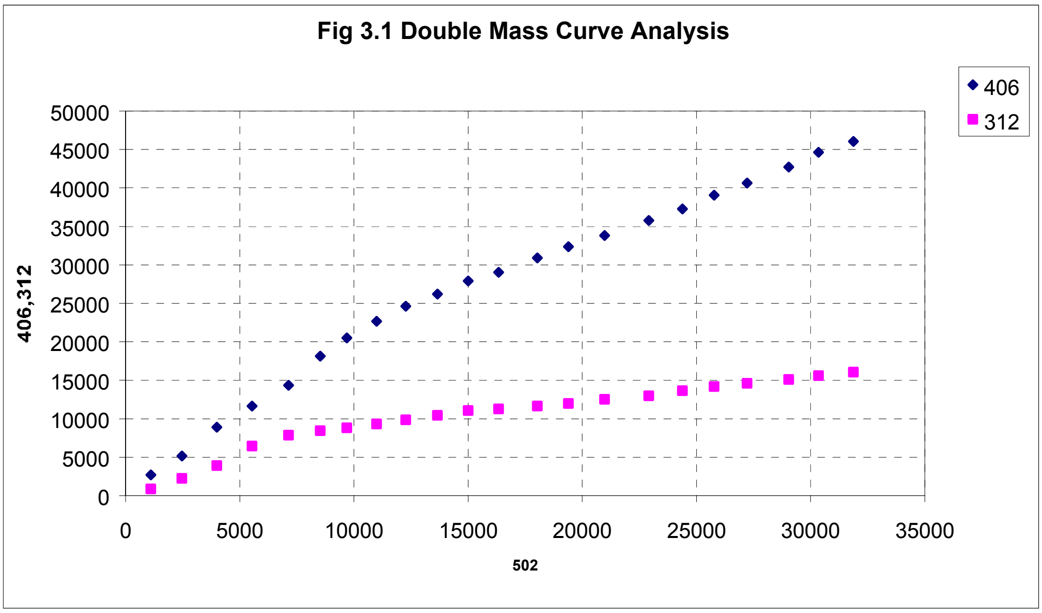
Double Mass Curve Analysis

In climatic research it is important to have access to reliable data, which are free from artificial trends or changes. One way of checking the reliability of a climate series is to compare it with surrounding stations. This is the idea behind all tests of the relative homogeneity. As non-homogeneous climate data are a poor source of information for climate research, hydrologists have often preferred to use double mass analysis to obtain information on the relative homogeneity of precipitation series. This technique is purely qualitative. Here the accumulated sums of the total annual precipitation are plotted against each other for the traditional mass curve.

For the purpose of quality control of rainfall data of Bheri river basin, double mass curve analysis was carried out for rainfall stations 312, 502 and 406. Since there are some breaks in the series of these stations, only existing years common to all these stations were selected for the analysis. Station 502 has been selected as reference station as it has almost continuous data for 38 years; only few days in year 1971 and 1972 are missing. The analysis showed inhomogeneity in both stations 312 and 406 in year 1963 and 1968 respectively as shown in figure 3.1. To check whether there is a break in the reference station chosen; double mass curve plotting was conducted on stations 312 and 406.

If we look into the double mass curve data in table 3.2, the mean annual value of station 312 from year 1960 to 1963 is quite different from the rest of years. In case of station 406, it is difficult to explain exactly why there is a break in year 1968 where one can find different statistical properties before and after 1968.The reason could be (i) unreported shifting of the rain gauge site, (ii) Significant construction work in the area might have changed the surroundings, (iii) Change in observational procedure incorporated from that period or (iv) a heavy forest fire, earthquake or landslide might have taken place in that area. Use of double mass curve helps to correct the data and corrections are to be applied when the change of slope of double mass curve is observed for more than five years.

Unless the change is significant i.e. exceeds 10 % of the original slope, it should be confirmed whether the deviation of the line is not part of the usual scatter. Correction should be applied for the change in slope exceeding 10 % of the original trend line. A change in slope of the line points to an inconsistency and adjustments are made to record on the basis of the ratio of original slope to that of the inconsistent slope (K.C.Patra) [19]. It is recommended to use the recent trend after break for further analysis.



Precipitation Gradient in the Basin

Variation in precipitation with respect to elevation was plotted as shown in fig 3.2. The chart shows that the least rainfall occurs at Dunai Station 312 that is located in the upper reach in Bheri river basin, while the highest annual rainfall takes place at station 406, which is located in lower reach based on limited number of stations.

Rainfall Run off Relationship

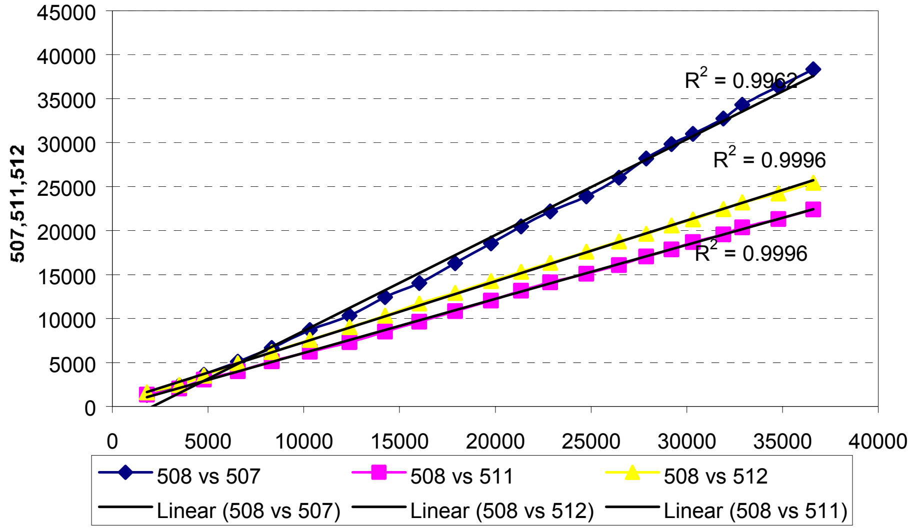
To check the homogeneity between rainfall and run off in the basin, a cumulative value of rainfall was plotted against cumulative run off for the same period based on data in table 3.3 The graph shows a good correlation between rainfall and run off as shown in figure 3.3.

3.2.2 Babai River Basin

Double Mass Curve Analysis

Double mass curve analysis was carried out for rainfall stations 507, 508, 511 and 512 in Babai river basin taking station 508 as reference one. The curve shows that station 511 and 512 has homogeneous data while the data of station 507 seems deviating from the trend line moving up and down and it is not practical to bring all those data scattered to meet trend line. Therefore it is recommended not to use the data of this station as we already have data for the same elevation as shown in table 3.4.

Fig 3.4 Double Mass curve for Babai River Basin



Precipitation Gradient in the basin

Based on the available data, precipitation gradient was plotted for the basin as shown in figure 3.5. The curve shows that the maximum precipitation occurs at the elevation around 700 m and it decreases with the elevation.

Rainfall Run off Relationship

The cumulative rainfall was plotted against the cumulative run off to check the homogeneity/correlation and the plot is shown in the figure 3.6. The curve shows a good correlation between run off and rainfall.

3.3 River Flow Data

Daily run off data are available at the two hydrological stations, Jamu and Bargadha, in Bheri and Babai rivers respectively. These hydrological stations have been operated and maintained by the Department of Hydrology and Meteorology (DHM). The recorded water levels at these stations are converted into discharge data by applying the rating curves developed by DHM. The development of rating curves is mainly based on discharge measurements carried out during the rainy season. The rating curve is modified with the frequency more than one measurement in a year when the variation in cross section is found at the gauge site.

The runoff in Bheri river has been measured at Samjighat and Jamu stations. Since the rating curve for Samjighat Station (near intake) has not been developed and published by DHM so far, run off data of from Jamu station (Station 270) were used for analysis.

The run off in Babai river is being measured only at Chepang station (nearby outlet). This station was established in 1989 but still the rating curve has not been developed by DHM and the daily run off is not published yet. During the period of 1976-1987, water level in Babai river was measured at Bargadha station (Station 290) by DHM and daily runoff was converted from water level using rating curve. Therefore, run off data of Bargadha station was chosen for the analysis.

There are two stations near Bheri and Babai river basins. One station is the Chisapani (Station 280) in Karnali river, and other is the Jalkundi (Station 360) in Rapti river. The monthly mean runoff at these 4 stations Jamu, Bargadha, Chisapani and Jalkundi gauging stations are shown in table 3.7 to 3.10. The location map of gauging stations is shown in appendix A drawing no 6.

3.4 Quality Control

Quality control of hydrometric data will usually be based on the use of comparative data in one form or another. Data will either be compared to earlier values from the same series; with the corresponding data from the nearby stations.

To check the consistency of the data double mass curve analysis was performed for both Jamu and Bargadha stations with near by Chisapani and Jalkundi stations. Fig 3.7 and Fig. 3.8 show graphical plots for Bheri and Babai river.

Fig. 3.7 Double mass curve for Bheri river

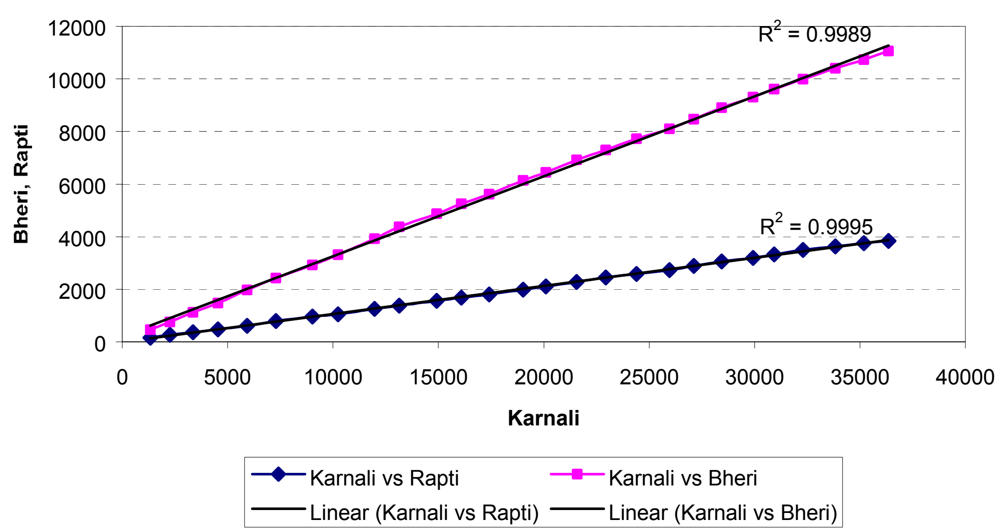
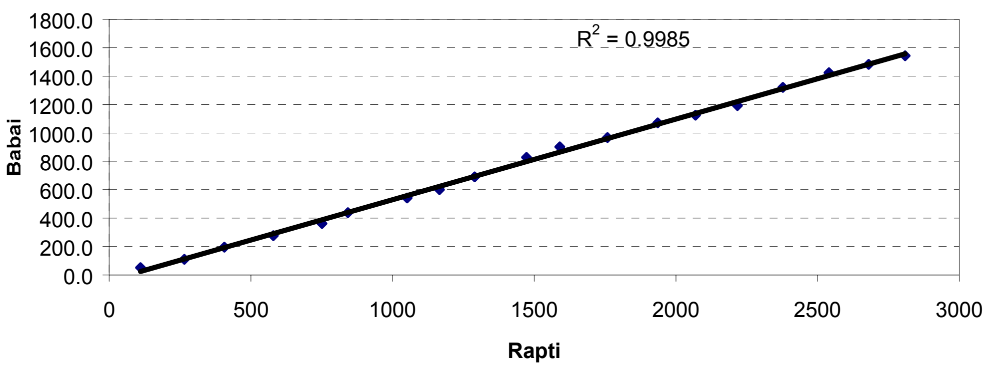


Fig. 3.8 Double Mass Curve for Babai River



Chisapani station (Karnali river) was chosen as reference one for double mass curve analysis as data collected at this station has been accepted as good quality. The curve shows that Bheri river station has good consistency while Rapti has little deviations. Deviation in Rapti may be as it has different catchment characteristics than Karnali (Fig 3.7)

Jalkundi station (Rapti river) was chosen as reference station for Babai river basin and the curve shows that data of Bargadha station is homogeneous although correlation is poor.

3.5 Correlation and Regression Analysis

3.5.1 General

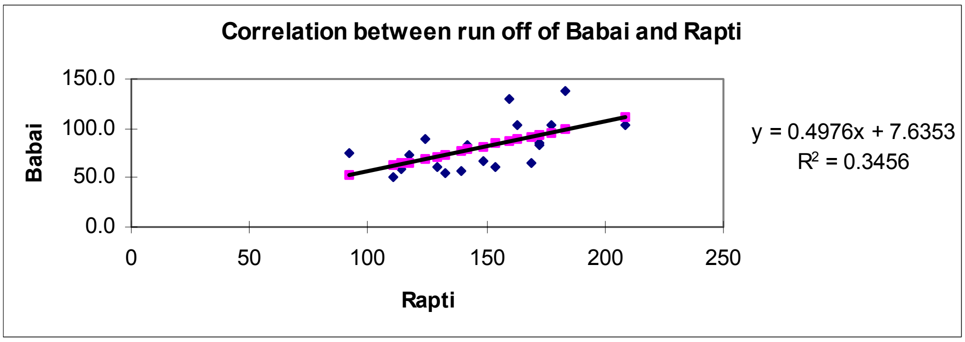
So far, the analysis and prediction of the hydrological data are limited to a single variable. However, in hydrologic design, it is necessary to evaluate relation between two or more variables simultaneously. For example, a mathematical relation between rainfall and corresponding runoff or river discharge at two or more tributaries along with that of the main river needs to be developed so that one event can be predicted from the knowledge of others. Thus a future sequence can be synthesized preserving the characteristics of the historical data. This can be achieved by regressing one set of variables on the other set in a plot called scatter diagram[19].

3.5.2 Filling in missing data

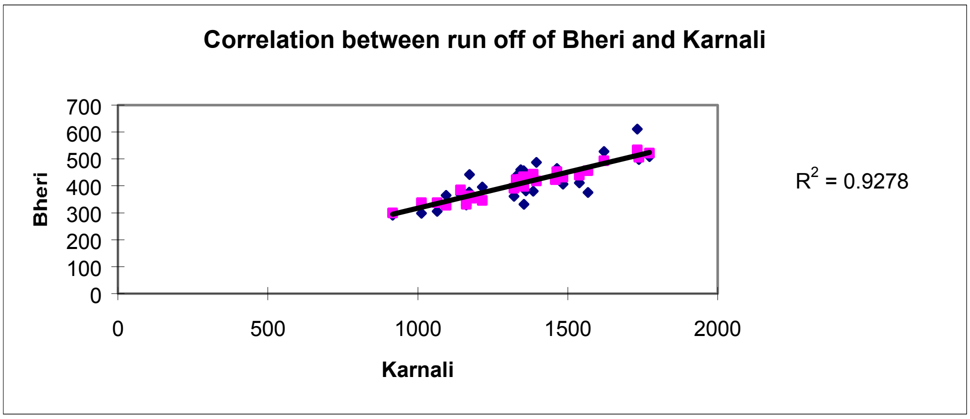
Correlation analysis was carried out to fill the missing data. The period of which the daily run off data is missing for Jamu and Bargadha stations is shown below:

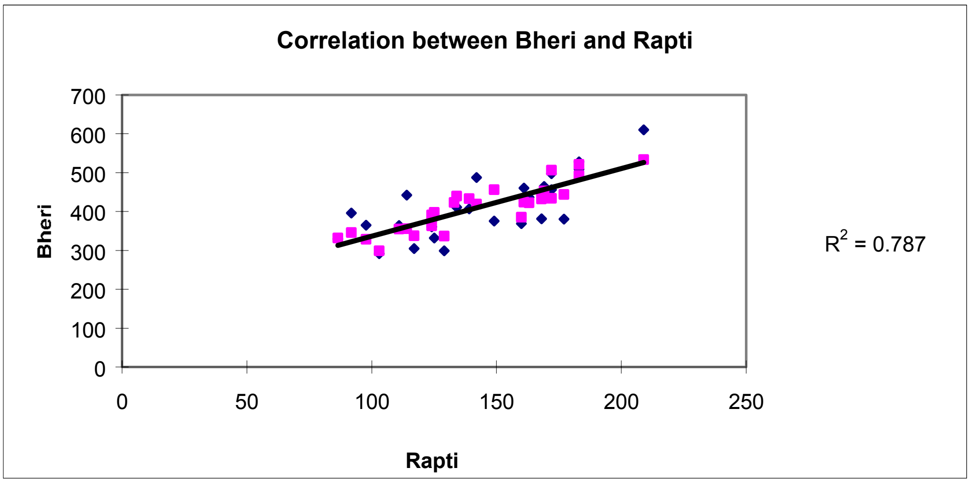
Jamu	July1, 1968 to December 31, 1968 and Sept. 1to Sept. 30, 1995
Bargadha	Year 1975 and 1976

An analysis of the run off of the Babai and West Rapti rivers indicated that the precipitation geomorphology complex of the both the catchment basins has similar run off characteristics. The mean annual discharges are 83 and 141 m^3/s for Babai and West Rapti implying specific discharges of 0.0276 $m^3/s/km^2$ and 0.0273 $m^3/s/km^2$ respectively. The specific discharge of Bheri river is 0.0352 $m^3/s/km^2$ indicating that a good correlation with Babai river basin is unlikely. The basis of correlation is the record of West Rapti River at Jalkundi station, which commands a catchment area of 5150 sq. km. The data of this station are of acceptable quality. The correlation coefficient and the number of run off data are shown in table 3.11 and 3.12. Table 3.11 shows the regression analysis of Babai river with both Bheri and Rapti river basin where one can see that variable for Bheri River has negative value. The table 3.12 shows the correlation analysis with Rapti River only. The correlation coefficient was found poor. This is due to the fact that the gauging site for Babai River suffers from an unstable rating because of cross section changes due to shifting of sand bars; stone diversion weirs built by local farmers further accentuate the quality. The relationship between Babai and Rapti is shown in the next page.



Similarly, by applying the data at Chisapani station (Karnali river) and Jalkundi , the missing data of Jamu station was filled up. The mean annual discharge of Karnali river is 1360 m^3/s with catchment area of 43769 km^2. The correlation coefficient was improved taking these two stations in comparison to Chisapani alone as shown in table 3.13 and 3.14. The relationship between Bheri , Karnali and Rapti is shown in figured below.





4 FLOW REGIME AND WATER TEMPERATURE REGIME IN THE BHERI AND BABAI RIVER BASINS

4.1 General

The expected pattern of river flow during a year is known as the river flow regime. Flow records for 20-30 years are required to provide a representative pattern, since there may be considerable variations in the seasonal discharges year to year. The averages of the monthly mean discharges over the years of record calculated for each month, January to December, give the general or expected pattern, the flow regime of the river. The river flow regime is the direct consequence of the climatic factors (like air temperature, rainfall) influencing the catchments run off, and can be estimated from knowledge of the climate of a region[1]. Similarly, long term mean monthly average of water temperature is required to give expected temperature regime of the river. But due to lack of data, available data has been assumed to represent the temperature regime of the river basins for the analysis.

4.2 Physical environment of the project

The general climate of the project area within Bheri and Babai valleys is similar. The hydrology of the two river systems is most important as Bheri is a mountain snowmelt and rainfed river and Babai is a hill rainfed river. The associated key issues include minimizing daily and seasonal fluctuations in river levels, attaining environmentally acceptable increased water depth in Babai river, maintaining minimum water depth/flow in Bheri river and minimizing decreased water temperatures in Babai during critical months of fish migration and spawning, and fingerling maturation periods[3].

4.3 Environmental Criteria Set by Project

The basic physical criteria relating to hydrology considered appropriate after preliminary investigation to minimize effects on aquatic ecology and river fisheries are as follows: [3]

Babai River

a) To ensure adequate protection of aquatic life, long-term changes in water temperature should not exceed 2° C

b) Due to power generation, the shallow river section and sand and gravel banks, which have been used for feeding and breeding fish, reptiles, waterfowl and small mammals would be affected by their inundation. An increase in water depth up to 0.3 m is within the allowable limit for the submergence because sandbar in the river may adjust flow conditions. Besides, for crossing the main larger terrestrial mammals making substantial use of the riverine zone in Royal Bardia National

Park including deer, wild boar, rhinoceros and elephant, increased depths of up to 0.3 m would be acceptable as river gravel bars would adjust to flow rates. Thus water depth over the shallow river sections should be less than 0.3 m.

Bheri River

a) Maintaining at least 0.3 m of water depth in shallowest and widest river sections downstream of the weir site to facilitate upstream passage of larger fish.

4.4 Climatic Condition of the Project Area

Bheri River extends to high Himalayas with cool temperate to alpine climatic conditions. The project sites are located in Siwalik group of Himalayas and the elevation range between dam site (465 m) and outlet site (305 m) is narrow indicating little difference between sites in terms of climate.

There is no climatological stations in project sites and its close vicinity, however, four data collection points have been recently established, 2 in each Bheri and Babai rivers, which since june 1998 have been collecting information on water level and water temperature in these rivers. But the measurement is not continuous.

4.4.1 Air Temperature

Temperature gradient based on available monthly data was drawn to find out the temperature data for project sites. The calculated temperature data was used for the analysis. The temperature gradient is shown in figure 4.1. Temperature gradient was found to be +/- 0.6° c / 100 m. Mean monthly air temperature in project areas is the lowest in winters (13.7 to 15.4 ° c) and the highest in May and June (29.5 to 32.9° c) as shown in table 4.1 and fig 4.2.

4.4.2 Water Temperature

Available one-year daily water temperature data common to all years has been assumed for the analysis. Data has been measured thrice everyday at 6:00 AM, 12:00 and 6:00 PM in the evening. Mean monthly data was used for analysis to account for seasonal variations especially in dry season. Mean monthly water temperature in both rivers is lowest in January (13.56 to 16.6 ° c) and highest in May /June (23.77 to 28.47° c) as shown in water temperature regime curve in fig. 4.3. The water temperature in the month of July and August is lowered in Bheri river as a result of melting of snow during this period within the catchment area. The figure 4.3.1 shown below shows the comparison of difference between maximum and minimum water temperature for Bheri and Babai rivers. The difference was found the highest in the month of May (the driest month) and the lowest in the month of December. The difference is higher in Babai river than Bheri river in all months as Babai has lower discharges as well as located at lower elevation than that of Bheri.

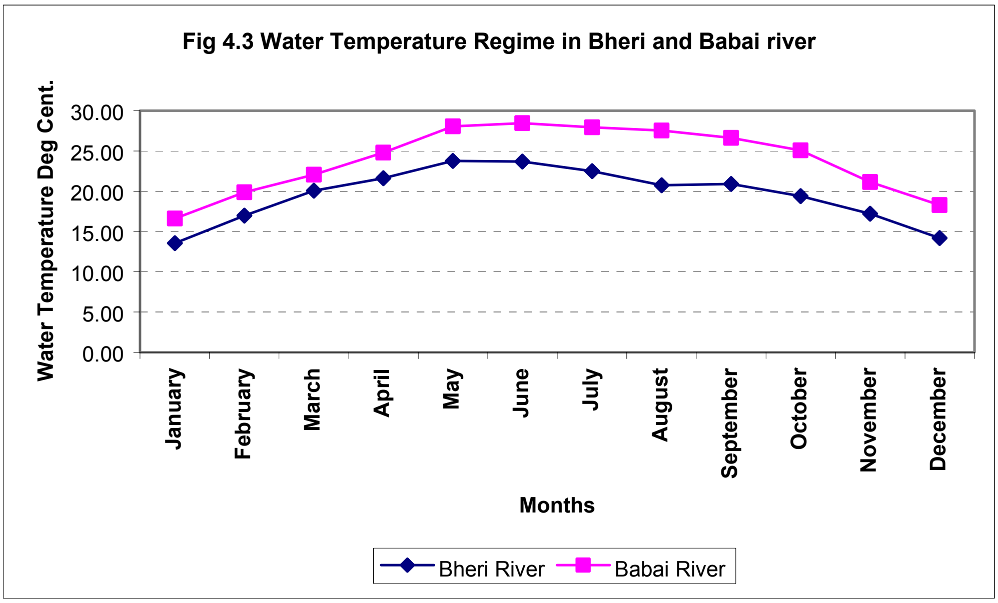


Fig 4.3 Water Temperature Regime in Bheri and Babai river

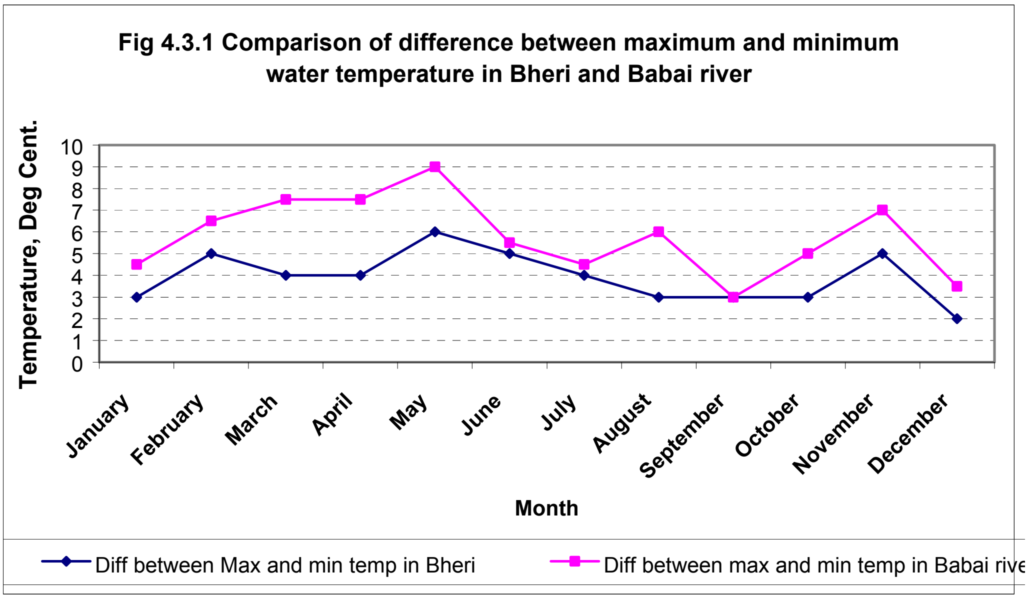
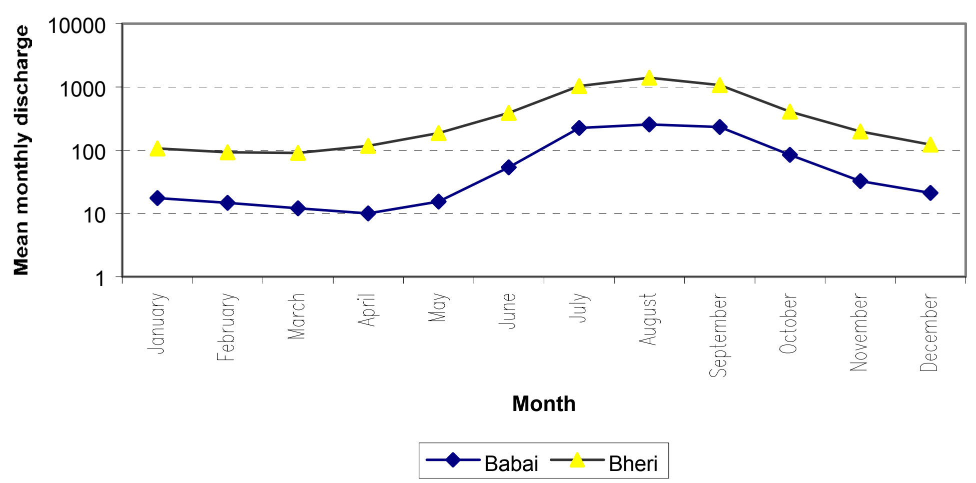


Fig 4.3.1 Comparison of difference between maximum and minimum water temperature in Bheri and Babai river

4.4.3 Runoff

The Jamu and Bargadha stations are represented in Bheri and Babai rivers because there is no other station in these rivers having long-term measurement data. Annual mean runoff at Jammu and Bargadha gauging stations are 409 m^3/s (1963-1995 data) and 81 m^3/s (1967-1987 data). Monthly flow regime in Bheri and Babai rivers is shown in figure 4.4.2. The maximum monthly runoff at Jammu station is 1400 m^3/s and Bargadha station is 255 m^3/s both in August. The minimum run off at these stations is 90 m^3/s (March) and 10 m^3/s (April) respectively.

Fig. 4.4.2 Flow regime in Babai and Bheri River



4.5 Water Depth and Regime Changes

The project will bring hydrological changes in downstream areas from dam site in Bheri river and from power house/outlet site in Babai river. Seasonal changes in water temperature and increase in water depths are the major effects in downstream of Babai.

4.5.1 Downstream of Bheri River from Diversion site

There will be a decrease in water budget in downstream area after 40 m3/s water will be diverted from Bheri river at the intake. After thorough monthly analysis of all the available 33 years data, it was found that about 23-72 % reduction in water discharge is expected between December and April due to diversion except year 1977 and 1993. In yea1977, reduction in discharge is 48-91 % as it is the driest year found during 33 years period while only 12-28 % reduction in year 1993, which is the wettest one. The details of analysis are shown in table 4.2 and table 4.6.1. Water discharge during these months in the downstream area with project remain in the range of 16 m3/s to 123 m3/s where as 4 m3/s to 44 m3/s will be available in March 1977. Besides, there are six medium size tributaries (Khola) which enter in to the river from right bank between Intake and Bheri bridge, a stretch of about 15 Km, and these Kholas increase water discharge of 15 cumecs in downstream areas as shown in drawing no1 and 2 and table 4.8.1.

The hydrological study of selected Nepalese rivers indicate that release of 5 % of the mean flow for driest month is sufficient for mandatory compensation flow to support downstream aquatic life (NEA/CIWEC, 1997) [17]. The mean flow for the driest month March is 83 m3/s in the analysis and the downstream flow after diversion is far above this threshold. Only one month of March 1977 in 33 years has only 4.6 % of mean flow for driest month, which is very close to the mandatory compensation flow and also the tributaries downstream would fulfil the purpose. Also the water depth of more than 30 cm calculated in the widest section of river is well above the criteria set by the project. Therefore the project fulfils mandatory compensation flow to support the downstream aquatic life. The depth of water was calculated by using Manning' s Formulae $Q = MAR^{2/3}S^{1/2}$. Manning's Coefficient was calculated by Strickler's formula based on mean size of particle in rivers as shown in table 4.4.

Rafting in Bheri River is done usually between June and October starting from Bheri River Bridge on Surkhet road. During this period only about 3 to 11% of water discharge will be reduced due to diversion and the discharge will remain in the range of 318 m^3/s to 1243 m^3/s as shown in table 4.3. The water depth available at the rafting point is 2-4.5m as shown in table 4.4 c. Therefore there will not be an impact on rafting in Bheri river.

4.5.2 Downstream of Babai River from Outlet Site

Maximum plant discharge 40 m^3/s which will be diverted from Bheri river intake site through 12.7 Km long tunnel to power house located on the right bank of Babai river will have an increased flow of 40 m^3/s in Babai river.

Mean monthly discharges from Bheri and Babai rivers, discharge rate with project and percentage of increased in Babai river and decreased in Bheri river is shown in table 4.3 & table 4.6.1 and figures 4.4, 4.5 and 4.6.

Fig. 4.4 Percentage of water flow increase in Babai and decrease in Bheri River based on average discharge data for all existing years

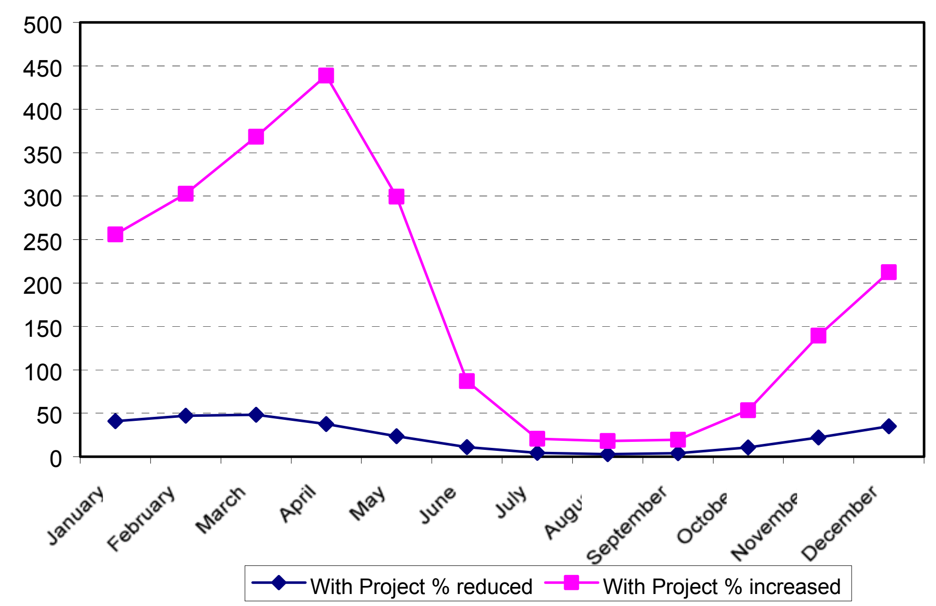


Fig 4.5 Comparison between Existing Situation and With Project Discharge in Bheri River at Dam site

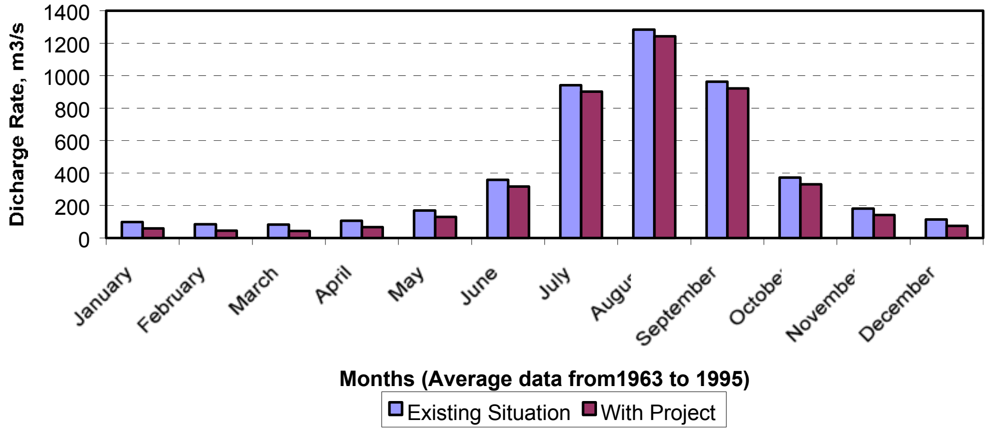
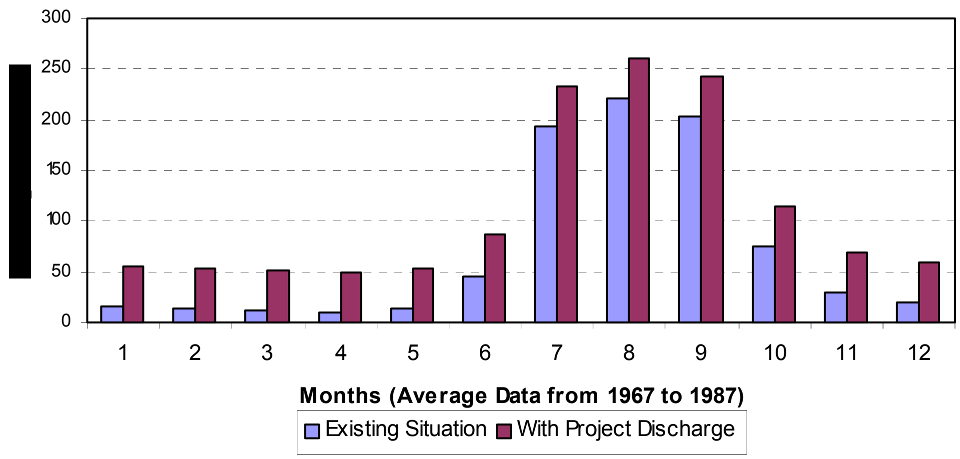


Fig. 4.6 Comparison between Existing Situation and With Discharge in Babai River at Outlet Site



There will be significant flow between November and May after diversion and mean monthly flows will be in the range of 44-86 m^3/s based on all available 21 years monthly flow analysis shown in appendix C table 4.6.1. At present discharge between November and May range between 4 to 46 m^3/s. Babai river is virtually dry between January and May (Mean monthly flow of 4 –29 m^3/s except the wettest year 1971 where flow ranges between 13-55 m^3/s) in Babai valley where the river is braided becoming wider from 65 m at outlet up to 250 m between Shivpur in Guthi areas as shown in appendix A drawing no 8. The seasonal differences in rate with and without project based on average 21 years monthly flow data are as follows:

Month	Without Project	With Project
November-January	16-29 m^3/s	56-69 m^3/s
February-June	9-46 m^3/s	49-86 m^3/s
July-October	75-221 m^3/s	115-261 m^3/s

With the increased flows of 40 m^3/s, the expected water depth would increase about 30 cm in the driest months at Chepang (Outlet) and would spread over gravel bar and sand of river width in range between 150 m and 250 m in the flood plains giving a much lower increase in water depth of 15-20 cm in dry season between November and June, between Shivpur and Guthi areas as shown in table 4.5 and Drawing no 1. Therefore an increase of 15 to 20 cm in water depth of Babai River fulfils the criteria well set by the project.

4.6 Changes in Water Temperature

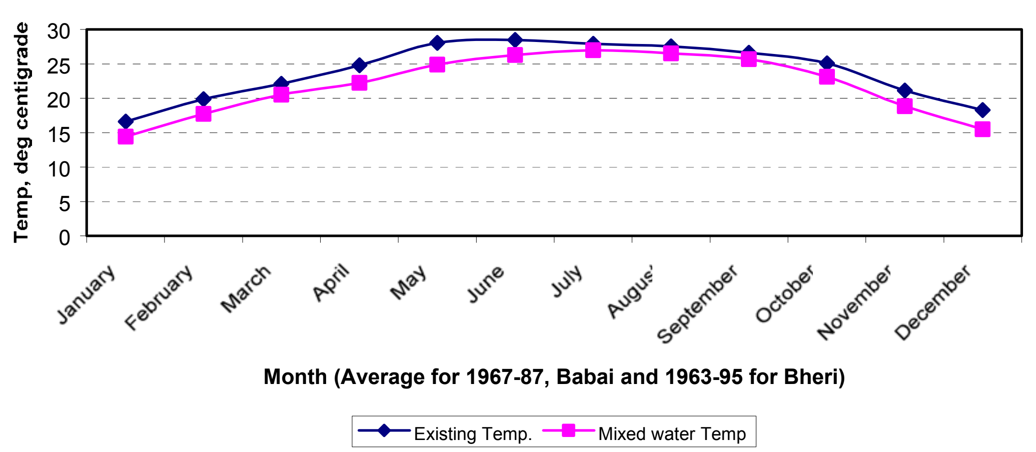
One of the major concerns has been the change in water temperature of Babai river due to diversion of 40 m^3/s water from Bheri into Babai River at outlet point in Chepang, which is located at 700 m upstream from the national park boundary at Babai Bridge, Chepang. The analysis has been carried out on monthly basis taking available one-year 1999 daily water temperature data assuming common to the monthly average discharge of the river basin to look in to the seasonal variations. Daily water temperature data recorded in four sites, two in each Bheri and Babai river are presented in electronic copy. Bheri river originates from glacier and flows through high mountain regions and Siwalik (area between 200-1000m elevation) where as Babai originates at mid hill and flows through Swalik. Therefore Bheri river water temperature is lower (2°C-6.8°C) compared to Babai river. But there is seasonal temperature difference between these two rivers, the maximum being in the months of July, August and September as shown below:

Water temperature (°C) changes due to Project

Months	Temperature difference Bheri-Babai	Current Temperature, Babai river	Mixed Temperature Babai river	Difference from existing temperature
January-March	2-3	16.6-22.07	14.4-20.7	1.6-2.2
April-June	3.2-4.8	24.78-28.47	22.2-26.3	2.2-3.2
July-September	5.4-6.8	26.61-27.92	25.7-27	0.9-1.0
Oct-December	3.9-5.7	18.26-25.06	15.5-23.1	1.9-2.8

Temperature of mixed water in Babai River has been calculated on the basis of discharge rates and the temperature of mixed water as shown above (See details in table 4.6). Water temperature determination for Babai River is based on water temperature data recorded in Bheri-2 at intake site and Babai-1 outlet site. Temperature differences of mixed water from outlet and Babai River range from 0.9 °C in July to 3.2 °C in May (Table 4.6). The highest temperature difference is in the months of April, May and June (2.2 –3.2 °C) because these are the months when the river has low flows (9-46 m^3/s) as shown in fig 4.7. The temperature of mixed water at Chepang (outlet) during this period would range between 22.2 and 26.1 °C, which is within the range of temperature tolerance to aquatic flora and fauna found growing in this subtropical riverine environment when we compare mixed water temperature with the existing water temperature.

Fig 4.7 Comparison of Babai waterTemperature before and after mixing



Modification is required to temperature calculation in reference to

- Water Surface area
- Kinetic energy through flow
- Kinetic energy from wind driven flow

The role of average sunshine hours and wind velocity in the project area that may lower the maximum temperature difference need to be assessed. However thermal stratification probably may not be necessary in Babai river where water depth is less than 1 m in most of the months except in July, August, September and October. Thermal stratification is a phenomenon, which occurs in natural water when turbulence is not strong enough to overcome heating of the upper water layer. The result is the vertical temperature gradient, which can be clearly recognised in lake, pond and reservoir. Besides long time series of river temperature data is needed for more comprehensive statistical analysis.

4.7 Temperature Regime downstream after mixing

The temperature difference after mixing of Bheri River with Babai would gradually decrease with distance. Heating of water is a function of air-water temperature difference and discharge. When depth/discharge is low, air temperature is close to water temperature and vice versa as shown in figure 4.8, 4.9 and 4.10. Also as shown in Figure11, water temperature is reduced in Babai river after diversion and the difference is small during the period of high flows and vice-versa. In case of Bheri River, air temperature is very close to water temperature during the period of low flow and as discharge increases water temperature seems lagging behind air temperature because air cannot heat large quantity of water. But in case of Babai, water temperature is higher than air temperature during the month of January February, October, November and December at both the stations, which is not usually the case. The reason behind this may be because air cools faster than water due to its less specific capacity and since the measurement is being done thrice daily at 6:00, 12:00 and 18 hours, the weightage of measurement may have played role indicating water temperature higher than air temperature.

Fig 4.8 Relationship among Discharge, Water temperature and Air Temperature in Bheri River at Intake

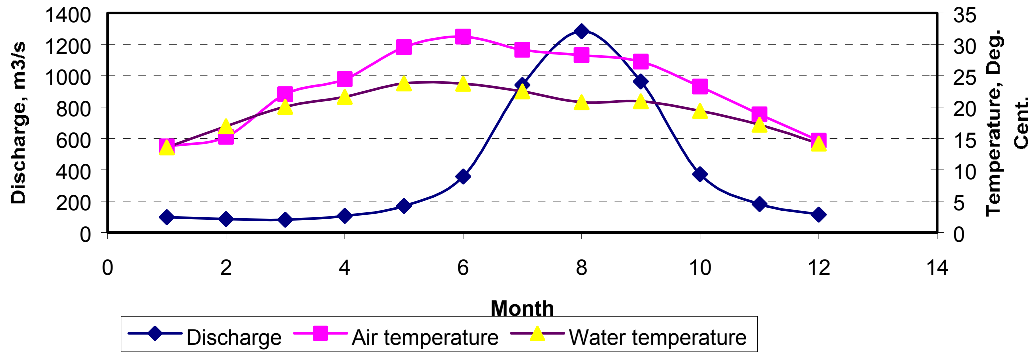


Fig. 4.9 Relationship between Discharge ,water temperature and Air temperature in the Babai River at Outlet

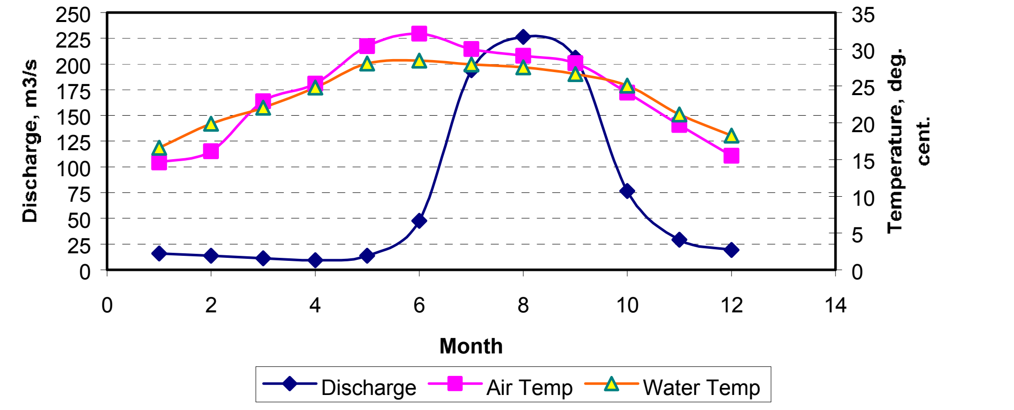


Fig. 4.10 Relationship between Discharge, Water Temperature and Air Temperature in Babai River (Station 2)

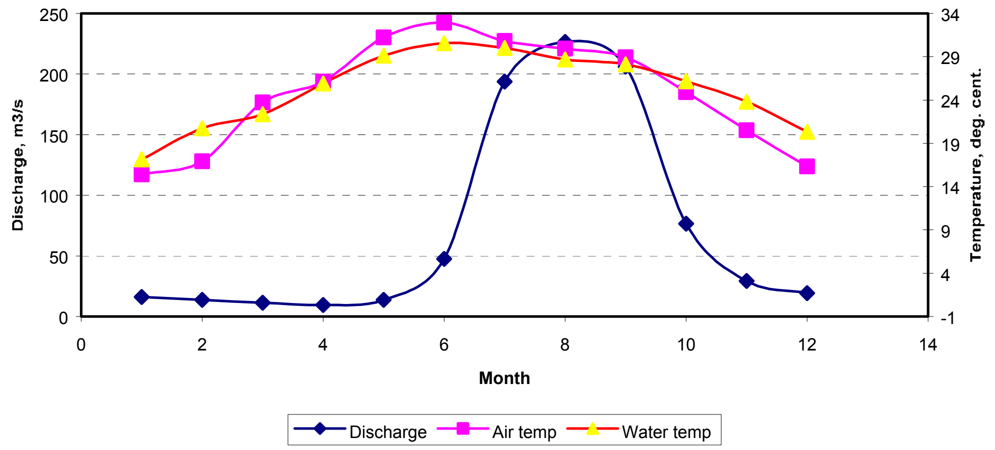
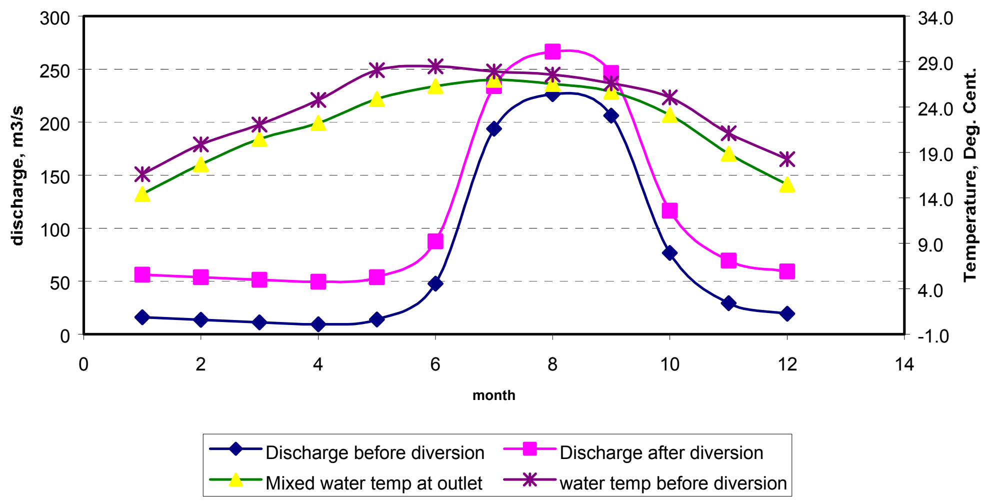


Fig.4.11 Relationship between discharge and water temperature before and after diversion in Babai river



Babai River

The author tried to establish relationship between air-water temperature differences and discharge so that water temperature at any point downstream can be calculated based on known discharge and known air temperature as shown in figure 4.12, 4.13 and table 4.7. In Babai river, correlation was found poor because of lower discharge range but the correlation was found better in Bheri river basin. The nature of curve is similar in both river basins, air-water temperature difference being small at lower discharges and vice-versa. Since the climatic condition is similar in both the river basins, it was decided to use the trend line equation of Bheri river to Babai river basin and the water temperature at Babai 2 was calculated based on known discharge and air temperature. The calculated water temperature was compared with the measured water temperature at Babai 2 as shown in figure 4.14 and table 4.8. The figure shows that in first six months the calculated temperature is higher than the measured one while for the next six months, the scenario is opposite and the difference between calculated and measured was found up to 5.59°C. Also the temperature calculated downstream at Babai 2 after mixing by using trend line equation was found higher in months March to June (Table 4.8) than the measured one before mixing, which should not be because the river has more colder water after mixing and the discharge should be less than before.

Fig. 4.12 Relation between discharge and difference of water and air temperature in Babai river

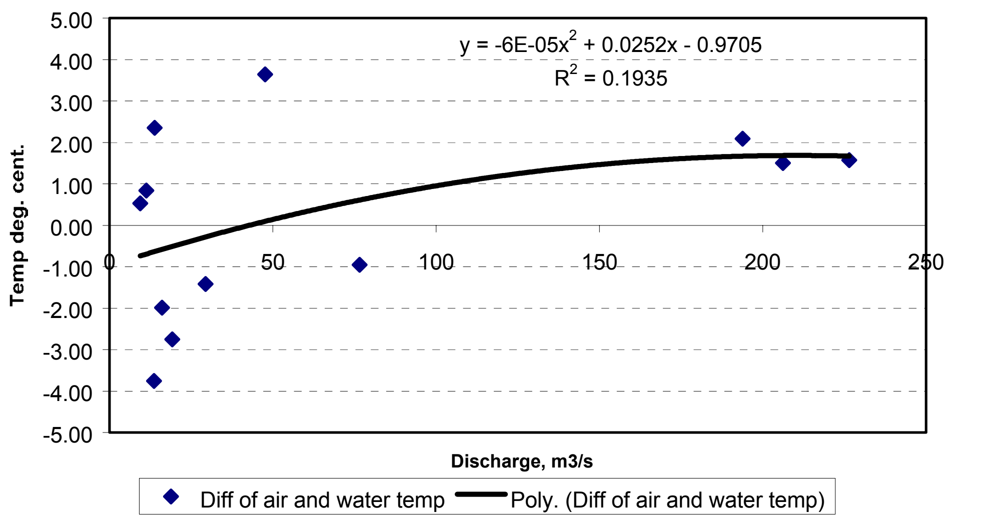
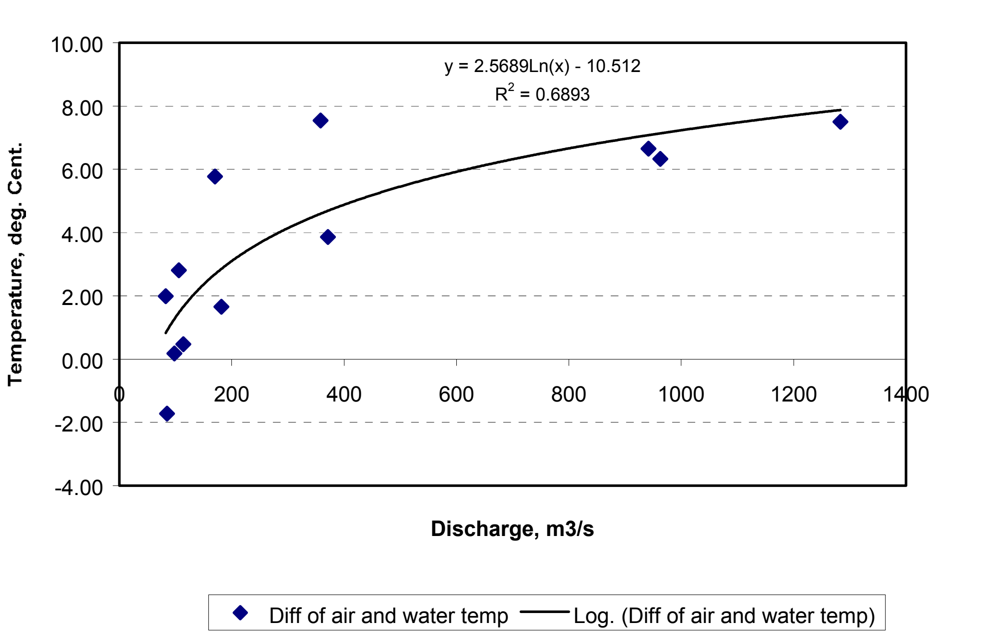
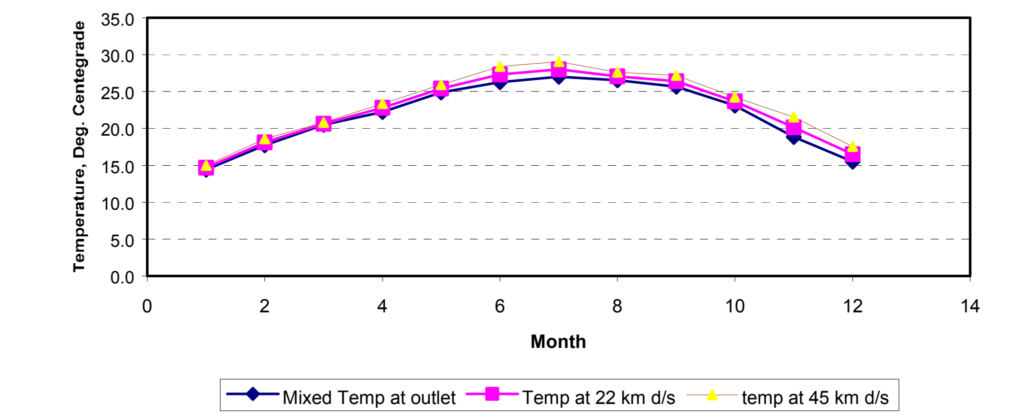


Fig. 4.13 Relation between discharge and Air Water Difference in Bheri River at Intake



Lastly, the author tried to use the river temperature data of both Babai 1 and Babai 2 stations to calculate temperature regime downstream after mixing. Water temperature difference per kilometre (∂T/L) between two stations was calculated where ∂T is the difference in water temperature and L is the length between the stations, and the water temperature at 22 Km d/s (Guthi area) and 45 Km d/s (Babai 2) were then calculated as shown in figure 4.15 and table 4.9. The result shows that Babai River after mixing has lower water temperature than the measured one before mixing at Babai 2, which is not true in case of calculation based on trend line. The increased discharge in Babai river after diversion will spread over larger width downstream giving rise to depth of only 15 – 20 cm, the linear assumption i.e. the rate of heating of water before and after diversion being same to is reasonable.

Fig. 4.15 Temperature Regime in Babai River



Bheri River

Generally river water temperature increases as it travels downstream like in Babai River. But it was found to be opposite in case of Bheri river after looking in to the data of two stations. The catchment areas of tributaries between these two stations were analysed for the drainage discharge and it was found that tributaries having catchment areas of 425 km^2 originating from 2000 m elevation contributed (based on specific discharge in Bheri river) average annual discharge of 15 m^3/s. This discharge is only 3.5 % of mean annual discharge of Bheri river. This additional small discharge of 15 m^3/s, which is not of glacier origin should not lower the water temperature at the downstream station. Therefore there might be error in measurements.

Since the analysis is based on available only year time series of daily water temperature data assumed same and air temperature has been calculated based on temperature gradient, the further analysis is recommended based on long time series of data. Modification is required to temperature calculation in reference to water Surface area, kinetic energy through flow and kinetic energy from wind driven flow.

5 SEDIMENTATION

5.1 Sediments

5.1.1 General- The Himalayan Context[6]

Natural phenomenon

The sediment transport of all Himalayan Rivers is mainly a natural phenomenon. In a geomorphologic context, land erosion and sediment transport processes are balancing the tectonic uplift of the Himalayan range caused by the continental drift. The Indian plate and the Eurasian plate meet in the Himalayan area.

Human impacts

Human activities, however, in the basins have caused an increase in the pressure on land resources due to road construction, livestock grazing, agriculture and use of forest resources. The general land use practice in the hills has intensified land erosion and thus increased the sediment transport rates in most Himalayan Rivers. It is not likely that these man made contributions to the erosion and sedimentation processes will be reduced during lifetime of the Bheri –Babai Diversion Scheme. The general trend in the Himalayan basins is increased sediment yield and not reduced yield even though some efforts are made through watershed management and erosion mitigation measures.

Complex pattern

The sediment transport pattern in the river is complex ranging from fine clay particle origin from the glaciers to large boulders of tens of tons of local origin. The sediment transport pattern in Bheri is not known in details, but expectedly it is guided by the general characteristics of sediment processes in Himalayan Rivers.

Annual variations

The sediment load in a river varies largely from year to year. The fluctuation in the annual sediment load is much higher than the variations in water runoff.

Seasonal variations

There are furthermore large seasonal variations in the sediment load. The major part of the sediment load is transported during the monsoon season (assumed to be 80% to 90%). High sediment concentrations must, however, be expected during relatively small pre-monsoon floods.

Mass wasting

The sediment supply to rivers like Bheri, is guiding the amount of sediments transported by the river, and not the sediment transport capacity of the river. Mass wasting (mainly in tributaries) plays a dominant role in the pattern of sediment yield. The sediment yield is increasing in the downstream direction in almost all Himalayan Rivers. This is mainly attributed to the variations in geology, rainfall and land-use pattern.

Flow and concentration

The correlation between water flows and observed suspended sediment concentration is poor. Water flow is therefore not a reliable parameter to determine the sediment concentration in the river. Sediment sampling in Himalayan Rivers is difficult and the available data are often questionable with respect to data quality. The operation of the head works with respect to the sediment exclusion devices can therefore not be guided by the water flow only. There are rapid and unpredictable changes in the water flow as well as in the suspended concentration.

High Transport Capacity

The river is able to transport almost any size of boulders during floods. The bed load is in most cases not known, as it is practically impossible to observe bed load transport rates in Himalayan Rivers. The bed load transport rate is often assumed to be a fixed percentage of the suspended sediment load (15% to 25%). Underestimation of bed load (or unmeasured load) may be one of the reasons why reservoir sedimentation studies almost always show a higher sediment load than what has been observed through a suspended sediment-sampling programme. The actual sediment loads are often found to be from two to five times the estimated sediment loads based on sampling programme.

River reaches

A river may generally be divided in to four different reaches with respect to the sediment transport capacity and the sediment supply. These reaches are shown in the following table:

Classification of river reaches

Reach of the river	**Sediment supply situation**
Erosion	Transport capacity > sediment supply
Regime	Transport capacity = sediment supply
Deposition	Transport capacity < sediment supply
Delta	Transport capacity << sediment supply

The resulting sediment transport of the river is guided by its hydraulic capacity to transport sediments in the three lower reaches. In fact most, most of Nepal is located within the first category labelled erosion.

Physiographic Zones and Sediment yields

Nepal is classified into physiographic zones. General sediment yield studies are associated with these zones. These are the Terai Zone (below 200 masl), the Siwalik Zone (below 1000 masl), the Middle Mountain Zone (from 1000 to 2000 masl), the High Mountain Zone (from 2000 to 3000 masl), the High Himalayan Zone (from 3000 to the water divide along the main mountain range) and finally the Tibetan Zone which is the area north of the main mountain range. Also mountains and ridges higher than 3000 masl somewhat south of the main mountain range belong to the high mountain zone.

The sediment yield is generally the highest in the Siwalik zone (5000 to 15000 tonnes/km^2/year). Most of the Bheri catchment (about 60 %) is located in the High Himalayan zone where the sediment yield is expected to be in the range from 300 to 1000 tonnes/km^2/year. In the high mountain zone the sediment yield is expected to be in the range from 1000 to 4000 tonnes/ km^2/year.

5.2 Sediment Data Needs[6]

Large storage schemes and run-of-river schemes are the only feasible hydro projects in sediment-loaded rivers. Small sized reservoirs are not feasible due to the reservoir sedimentation problem. Most sediment sampling networks as well as sediment sampling programmes are made to meet the needs for large reservoir schemes. The sediment data needs for large reservoir schemes and run-off-river schemes are different. The sediment data needs for these two types of projects are briefly addressed in the following section[6]. Bheri- Babai hydropower project is planned to be run-off-river type after preliminary investigation. Japan International Cooperation Agency (JICA) is doing detail study of the project.

5.2.1 Large Reservoir Schemes

Reservoir sedimentation

The main objective for the sediment study for a reservoir scheme is to collect data needed to determine the long-term average sediment transport rates in the river. This provides the basis for reservoir sedimentation studies and estimation of the life of the reservoir.

Sediment rating and Sand bed rivers

The main study approach is to establish the sediment rating equation valid for the given river and the given site. The single variable in the sediment rating equation is the river flow. This enables us to compute the concentration of suspended sediment from an observation of the river flow. Continuous and high frequent sediment sampling has therefore not been considered needed in order to record the sediment transport pattern of the river as long as the river flow has been carefully monitored. Variations in sediment concentrations due to the role of vegetation, landslides etc. are not of interest as long as the long term average sediment load estimates are expected to be correct.

The sediment concentration is relatively well correlated with the river flow in sand and silt bed rivers where the river can pick up bed material when it has the necessary transport capacity. Sediment will settle out when the flow is reduced and the transport capacity goes down due to less turbulence and less shear stress along the riverbed.

5.2.2 Run-off-river schemes

Abstracted load

The total sediment load over time is the main issue with respect to sediments and reservoir schemes while the sediment content in abstracted water from river is more important than the total sediment load at run-of-river schemes. The data is needed for planning and design of settling facilities and for computation of the resulting sediment content in the water supplied to the turbine. The particle size distribution of the sediment is more important with respect to the possibilities of trapping the sediment load in settling basins. The bed load is important with respect to the hydraulic performance of the head works structures, including wear and repair of the weir and bed load sluices.

Variations important

Sediment data needs for planning and design of run-of-river schemes are therefore different from sediment data needs at large reservoir schemes. The consequences of extreme concentrations during moderate flows are much more severe. Information on the type and concentration of suspended sediments in the water abstracted for diversion is more important than information on the total sediment load of the river. Information on possible variations in sediment concentrations is equally important as the long-term mean values.

Mountain Rivers

Sediment transport in steep mountain rivers is not following the basic theories of sediment transport mechanics developed for sand bed and silt bed rivers. Gravel bed and boulder bed rivers have normally a much higher sediment transport capacity than the actual sediment transport in the river. The river channel is often boulder-lined or rock-lined in critical sections, which prevents a large exchange of sediments between water body and the bed for most flows. The main sediment production is carried out along the slopes of the riverbanks and in the tributaries where mass wasting plays an important role. Small and large landslides are more likely to occur during heavy rain and high flows than during low flows, but there is not always a landslide of a given size every time the flow exceeds a given flow level. The sediment transport has therefore a much more random character in mountain rivers than in the lower reaches of the same rivers. Downstream at the plains the river will behave in accordance with our rather simple theories. As the sediment concentration varies largely with time, and major bulk of the annual sediment load may be transported within a few days, a large quantity of the sediment load may easily pass a sediment gauging station unmeasured if the sampling frequency is poor.

A sediment sampling programme in a mountain river tailor-made for a run-of-river scheme should preferably have a high sample frequency of one sample or more per day over a period of several years. The data records will then contain information on short-term variations in the sediment load as well as the long-term trends.

5.3 Sediment Study in Bheri- Babai Hydropower Project

GEOCE, a local Consultant, is collecting sediment data for both Bheri and Babai rivers on behalf of JICA. But the current data could not be made available. Therefore the available time series of sediment data of only one year 1984 was used in estimating sediment load. Besides, sediment rating curve based on long time series of data of Karnali river (Bheri is a tributary of Karnali river) and one year observed Karnali river were also used for the estimation. Finally the estimated sediment loads were checked with the sediment yield range calculated by Vic Galay/WECS method based on physiographic zones as shown in table 5.1-5.4. The table shows that the annual sediment load estimated by different methods fall in Vic Galay 's preliminary sediment load estimate range for Himalayan rivers. Annual sediment calculated based on developed rating curve is 1.5 times that of observed one. The zone specific sediment yields (ZSSY) are shown in appendix A drawing no 7.

Table 5.4 Summary of Annual Sediment yield (Mill. tonnes) at Bheri Intake site

Vic/WECS Method	Based on Karnali observation	Based on Karnali Rating curve	Based on Bheri Observation
16 - 45	**24.7**	**36.3**	**29.3**

Sediment rating curve of Bheri River has been plotted based on available limited data as shown in figure 5.1. The rating curve clearly shows the random behaviour of sediment and poor correlation with the discharge. Water flow is therefore not a reliable parameter to determine the sediment concentration in the river .The sediment rating curves of Karnali river based on both observed and long time series of data are shown in fig 5.2 and 5.3.

The estimated mean annual sediment loads by different methods are closer to each other. The estimated annual sediment yield based on Karnali river is more reliable in comparison to one year daily data. The annual sediment load estimated based on one-year data of Karnali river is quite closer to estimated by one-year data of Bheri river. It shows computation of annual sediment load based on Karnali river is quite reasonable. As the sediment concentration varies largely with time, and major bulk of the annual sediment load may be transported within a few days, a large quantity of the sediment load may easily pass a sediment gauging station unmeasured if the sampling frequency is poor. Also the estimated sediment load in Bheri river is based on only one-year data, the expected sediment load may be even higher or may be less in other years. Therefore to account for the unmeasured load and its random characteristics, the expected annual sediment load was estimated to be 50 million tones (approximately 1.6 times than that of load estimated based on observation of Bheri river data). The estimated sediment concentration based on this expected load is shown in table 5.5 and fig 5.4.

The sediment transport has a much more random character in mountain rivers than in the lower reaches of the same rivers. One can predict certain year's flood but to predict return period of sediment load is difficult. For example T-year's flood discharge can be a certain integral multiple of mean annual flow but T- years flood sediment can be much higher. The sensitivity analysis sediment concentration was carried out as shown in Appendix C table 5.6 and fig 5.5.

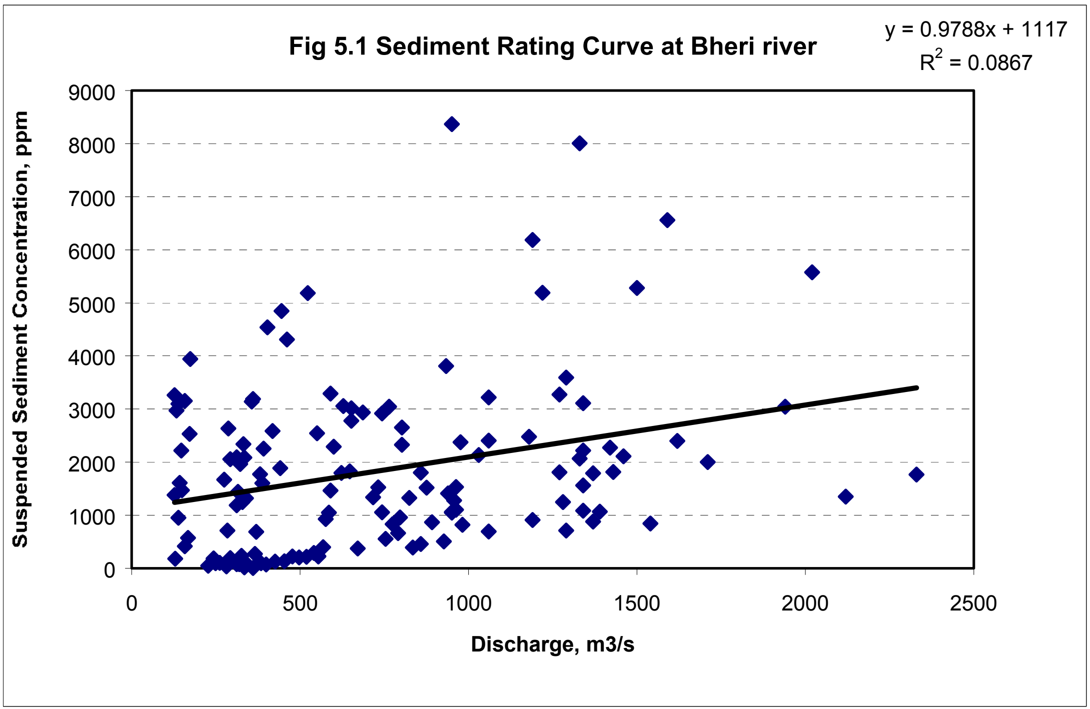


Fig 5.1 Sediment Rating Curve at Bheri river
y = 0.9788x + 1117
R2 = 0.0867
Suspended Sediment Concentration, ppm
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0
500
1000
1500
2000
2500
Discharge, m3/s

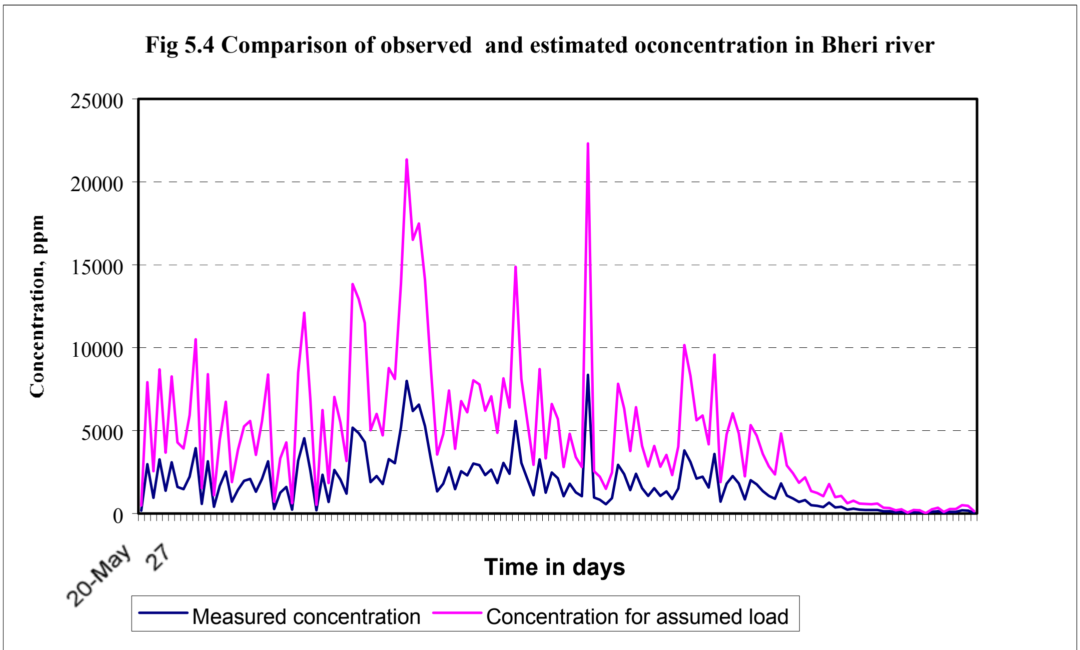
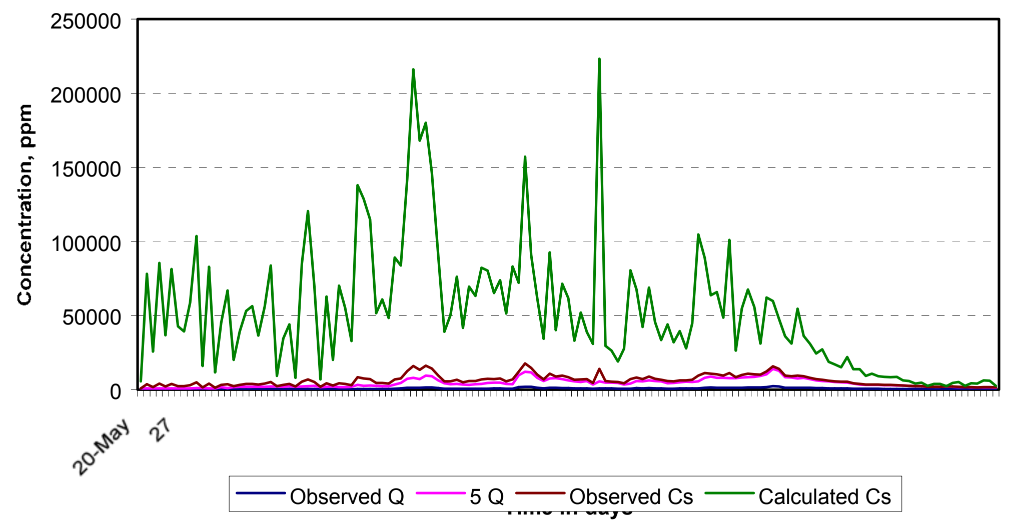


Fig 5.4 Comparison of observed and estimated oconcentration in Bheri river
Concentration, ppm
25000
20000
15000
10000
5000
0
20-May
27
Time in days
Measured concentration
Concentration for assumed load

Fig 5.5 Sensitivity analysis of sediment Concentration in comparison to discharge in Bheri river for 2 year flood



Since the proposed Bheri-Babai diversion scheme is a run off river type, concentration (ppm) is important for the design of settling basins and their operational practice. The mean concentration is far away from the expected one, the designer should be aware of the complex phenomenon of sediment transport mechanics and either the turbine should be designed against wear and tear during high sediment concentration or the plant should be closed when the concentration reaching plant is higher than expected. For this, there should be a monitoring system to know the concentration passing the turbine. Therefore headwork design should be flexible with respect to sediment loads and flushing capacity as well as discharging capacity. Design and operation must be linked together to obtain safe and reliable power generation to reasonable cost at run-off-river plants**.**

It is recommended to have long time series of sediment and river flow data with sufficient high frequency to give a true picture of the natural variations we will experience during operation of the hydropower plants. The quality of data should also be high to have reduced risk and optimum investment in operation and maintenance. The settling basin at run-of-river plants should be designed in such a way that removal of sediments should be carried out while basins are operational.

6 Conclusions and Recommendations

6.1 Conclusions

General

The thesis was aimed at investigating the effect of flow regimes and river water temperature regime on aquatic ecology from intake site in Bheri river and downstream from the outlet in Babai river after qualitative analysis of hydrological and meteorological data. In addition, estimation of sediment load at intake site by different methods to look into the variations as well as sediment data needs for run-off- river plants was another objective.

Quality Control

A very clear inconsistency was seen in the rainfall data of Bheri river basin during the analysis. Although the runoff data of Babai river was found homogeneous, the correlation coefficient was found poor.

Flow Regime

The project fulfils the mandatory compensation flow to support the downstream aquatic life and required water depth set by the project even after diversion in Bheri river. In case of Babai river, the water depth calculated is within the range set by the project.

Temperature Regime

The temperature difference of mixed water and Babai river water was found to be highest during the period of low flows and vice versa. The analysis showed that when depth/discharge is low, air temperature is close to water temperature during the period of low flows and vice versa. In case of Bheri river, air temperature was found to be very close to water temperature during the period of low flow and as discharge increases, water temperature lags behind air temperature because air cannot heat large quantity of water. But in case of Babai river, water temperature was found to be higher than air temperature in the month of January, February, October, November and December at both stations, which is not usually the case. The reason may be because air is cooling faster than water due to its less specific heat capacity and since the measurement is taken thrice daily, the weightage of measurements may have played a role indicating water temperature higher than air temperature.

Determination of water temperature at any point downstream of mixing point was based on linear assumption that the rate of heating before and after mixing is same. The analysis showed that the temperature difference decreases as it travels downstream and is less than 2 ° C thus fulfilling the project requirement to ensure adequate protection of aquatic life. The assumption seems reasonable because the increased discharge in Babai river after diversion spreads over a larger area giving rise to depth of only 15- 20 cm.

Generally river water temperature increases as it travels downstream. But it was found to be opposite in case of Bheri river after observing the data of two stations. After analysing the discharges from the tributaries between stations Bheri2 and Bheri1, it was concluded that there might be some errors in measurement.

Sedimentation

Sediment rating curve of Bheri River clearly showed the random behaviour of sediment and poor correlation with the discharge. Water flow is therefore not a reliable parameter to determine the sediment concentration in the river .The estimated mean annual sediment loads by different methods were calculated and found some variations. As the sediment concentration varies largely with time, and major bulk of the annual sediment load may be transported within a few days, a large quantity of the sediment load may easily pass a sediment gauging station unmeasured if the sampling frequency is poor. Also the estimated sediment load in Bheri river is based on only one-year data, the expected sediment load may be even higher or may be less in other years. Therefore to account for the unmeasured load and its random characteristics, the expected annual sediment load was estimated to be 50 million tonnes (approximately 1.6 times than that of load estimated based on observation of Bheri river data).

6.2 Recommendations

It is recommended to use the recent trend after break and adjustments are to be made on the basis of the ratio of original slope to that of the inconsistent slope, for the further analysis.

The water depth was calculated at the typical cross sections only assuming trapezoidal shape, side slope and Manning's number, it is recommended that depth calculation should be done at suitable intervals downstream accurately based on detailed cross-sections.

Since the analysis is based on one-year daily water temperature data and the air temperature at the project sites has been calculated based on air temperature gradient, the further analysis is recommended based on long time series of temperature data. It is also recommended to measure water temperature by putting river water in a bucket rather than just dipping thermometer in river and taking measurement in air. This method helps in eliminating error in measurement.

It is recommended to use a long time series of sediment data and river flow data with a sufficient high frequency to give a true picture of the natural variations experienced during operation of the hydropower plants. The quality of data should also be high enough to have reduced risk and optimum investment in operation and maintenance. The settling basin at run-of-river plants should be designed in such a way that removal of sediments should be carried out while basins are operational.

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