Mountain Natural Resources

ICIMOD

Discussion Paper
Series No. MNR 98/3

Hydrometeorological Measurements and Analysis in Interdisciplinary Watershed Projects

A strategy paper prepared for the PARDYP project

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International Centre for Integrated Mountain Development
Kathmandu, Nepal
1998

ISSN 1024 - 7556

Published by

International Centre for Integrated Mountain Development
G.P.O. Box 3226
Kathmandu, Nepal

Typesetting at ICIMOD Publications' Unit

ISSN 1024 - 7556

Hydrometeorological Measurements and Analysis in Interdisciplinary Watershed Projects

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July1998

Preface

The work described in this publication has been undertaken as part of ICIMOD's People and Resource Dynamics Project (PARDYP), a multidisciplinary, watershed research-for–development project that began in October 1996.

The goal of PARDYP is to improve the understanding of environmental and socioeconomic processes associated with degradation and rehabilitation of mountain ecosystems and to generate wider adoption and adaptation of solutions proposed by stakeholders in the Hindu Kush-Himalayas (HKH).

PARDYP is funded by the Swiss Agency for Development and Cooperation (SDC), the International Development Research Centre (IDRC–Canada), and ICIMOD. It is actively supported by the University of British Columbia (Canada) for the land resource aspects and the Hydrology Group of the University of Bern (Switzerland) in the fields of hydrology and meteorology. The regional management of the project is carried out by ICIMOD.

In the first year of the project an important aspect of the research activities concerned the establishment of hydrological and meteorological stations within five watersheds of between 5,000 and 10,000 ha in four countries of the HKH. The subsequent aims of the hydrometoerological component of the project are:

a) to collect quality hydrological and meteorological data in five watersheds on an east-west transect across the HKH and build a long-term regional database,
b) to establish the relationships between on-going biophysical and socioeconomic activities and incidents at watershed level,
c) to include the hydrometeorological information in the synthesis of project findings in order to identify and recommend appropriate on-the-ground development activities, and
d) to augment the present knowledge on mountain-plains' dynamics.

This discussion paper provides details of the establishment of the hydrological and meteorological stations, the collection and storage of the collected data both in the field and in the office, and recommends the necessary programmes of analysis. The penultimate chapter looks forward and describes possible methods for synthesising data from all aspects of the project.

It is recognised that the ideas and recommendations within this paper may be adapted in the future as the project and research needs develop. As it stands, however, the present document provides useful details for both the PARDYP project and other similar watershed projects in which there are hydrological and meteorological components.

Acknowledgements

This discussion paper was prepared at the end of my 14-month input as Watershed Management Advisor in the PARDYP project of ICIMOD. I would like to thank all the individuals from the following agencies for their fruitful collaboration and friendship during this period.

The PARDYP team of Nepal
The PARDYP country teams in India, China, and Pakistan
The teams in the collaborating agencies of HMG in Nepal
The collaborating members of Tribhuvan University
The team members from the Department of Geography in Bern
The team members of the University of British Columbia in Vancouver
The team from the Swiss Agency for Development and Cooperation (SDC) in Kathmandu
The International Development Research Centre (IDRC) of Canada.

Abstract

PARDYP is an interdisciplinary watershed research project which begun in October 1996. It is managed by ICIMOD and operates in five watersheds located in four countries of the Hindu Kush-Himalayas: Pakistan, India, Nepal, and China. Hydrology and meteorology are very important elements of the project. This discussion paper is based on one and a half years' experience with the PARDYP project.

In order to be able to compare the results in the five watersheds, common procedures and methodologies for data collection as well as for analysis have to be developed. This document is a contribution to this task and is focussed on the hydrology and meteorology components. It provides guidelines for data collection, data handling, data processing, and analysis. The paper differentiates between compulsory activities in data collection and analysis in all the five watersheds and optional, more specialised steps to be carried out only if the necessary infrastructure and skills are available. For a rapid overview of the elements of data collection and analysis, Tables 5,7,8,9, and 10 can be consulted.

The discussion paper is based on experiences from the PARDYP project. However, the guidelines, the approaches, and the ideas discussed in the document may be useful for other watershed research projects also.

Contents

1. Introduction

There are five chapters in this discussion paper, the first four describe a particular aspect of the hydrological and meteorological components in the People and Resource Dynamics' Project (PARDYP). The fifth chapter is a short conclusion.

Chapter 1 introduces the PARDYP project in general terms of background, objectives, *modus operandi*, and complexity, and then proceeds to define the hydrometeorological component in somewhat more detail, focussing on questions posed by the project document.

Chapter 2 describes the hydromet measurement network in terms of the design philosophy and as it exists in the Yarsha *Khola* watershed in Nepal.

Chapter 3 covers the data handling procedures, and describes the types and frequency of measurement recorded at the field stations, the important role played by the field teams maintaining the stations and recording the results, and the means through which quality data collection, recording, management, and storage are ensured.

Chapter 4 is the longest chapter; it tackles the challenges facing project staff in the analysis of all the results collected from the PARDYP research networks – networks which cover five watersheds in four countries. In Chapter 4, both the theory and practice of analysis are covered in the context of PARDYP. Four levels of analysis are presented, described, and discussed – data compilation, disciplinary analysis, watershed synthesis, and regional synthesis. Sub-sections describe the analytical tasks that need to be carried out at each of the four levels.

Chapter 5 is a short conclusion to the discussion paper.

1.1 Objectives and Challenges of Pardyp

This chapter provides a general introduction to the PARDYP project and then focusses on the questions related to the hydrological and meteorological elements which are posed by the project document. The PARDYP project (people and resource dynamics in mountain watersheds of the Hindu Kush-Himalayan region) officially started in October 1996. It evolved from two successful ICIMOD projects: 'Mountain Resource Management' and 'Rehabilitation of Degraded Lands in Mountain Ecosystems'. The present project is jointly funded by the Swiss Agency for Development and Cooperation (SDC), the International Development Research Centre (IDRC) of Canada, and ICIMOD.

The PARDYP-project is a highly interdisciplinary exercise with a wide thematical framework. According to the project document (ICIMOD 1996), the project goal is 'to further improve the understanding of environmental and socioeconomic processes associated with degradation and rehabilitation of mountain ecosystems and to generate wider adoption and adaptation of proposed solutions by stakeholders in the HKH'.

The overall objective of PARDYP is 'to provide a basic understanding of natural resources' degradation processes and to recommend proven strategies and programmes for community - and farm - based prevention of degradation, and rehabilitation of natural resources in the HKH region'. In view of the very broad formulation of the project objective, it is evident that many disciplines, from the physical as well as from the social side, are involved: geology, geomorphology, meteorology, hydrology, soil and water conservation, soil sciences, forestry, agronomy, socioeconomics, etc. Furthermore, a number of different methods has to be combined in order to achieve the goals: measurements, interviews, PRA, mapping, GIS, conservation activities, rehabilitation measures (Fig. 1), training, etc. With all these issues involved, PARDYP is a watershed management research as well as a development project.

Figure 1: The Rehabilitation Site in Kubindegaun, Jhikhu *Khola* Watershed, Nepal (photo: March 1998)

PARDYP operates in five watersheds in four of ICIMOD's partner countries along a west-east transect through the Himalayas (Fig. 2): Pakistan (Hilkot-Sharkool watershed, Manshera district, see Fig. 3), India (Beta Gad-Garur Ganga watershed, near Almora), Nepal (Jhikhu *Khola* watershed, Yarsha *Khola* watershed), and China (Xi Zhuang watershed, Western Yunnan Province in Baoshan County). All these watersheds are located in the Middle Mountains of the Himalayas where the pressure on the natural resources is, in places, very high (Fig. 4). The altitude of the watersheds roughly ranges from 1,000 to 3,000masl and the size from 30 to 100sq.km. In each country a local team is responsible for all the project operations in the respective watershed.

In view of the interdisciplinary focus of the project as well as the number of watersheds involved, the comparability of data collection and outputs in the different disciplines and the different watersheds is very important and a big challenge. To achieve this goal, common concepts, methodologies, and procedures for data handling as well as analysis have to be developed. Such common methodologies are a condition for comparing the different watersheds with each other and for streamlining the project synthesis.

This discussion paper concentrates on the hydrology and meteorology components of the project. It provides guidelines for focussed, transparent data collection and analysis which is driven by the wide range of topics required to achieve the project goals. In addition, the document discusses the contribution of hydrology and meteorology to the overall aims of PARDYP. Finally, it provides ideas and strategies for the synthesis of PARDYP from the viewpoint of hydrology and meteorology. The discussion paper provides general guidelines for the hydrological and meteorological activities; certain elements may have to be adapted to the specific conditions of an individual watershed. The paper is based on one and a half years' experience of the PARDYP project. Its content may be modified or revised in future. Created originally as a

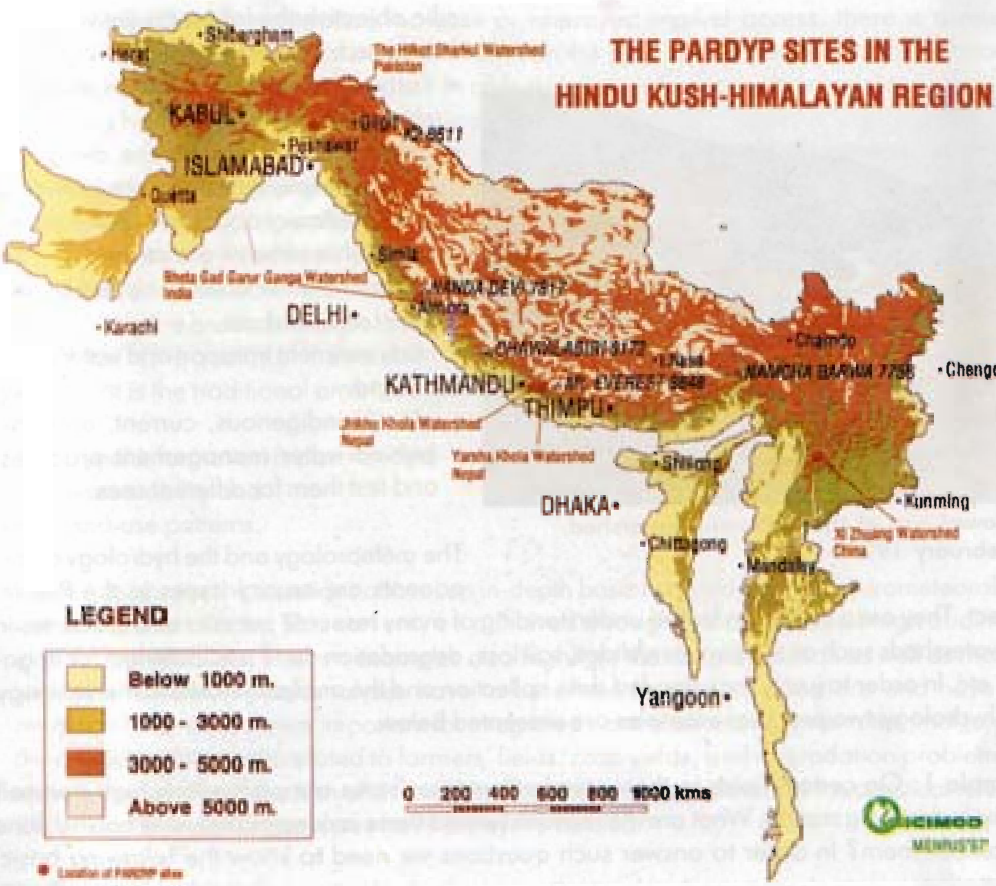


Figure 2: The PARDYP watersheds in the Hindu Kush-Himalayan Region (source: ICIMOD, 1997)

strategy document for PARDYP, this discussion paper may be useful also for other projects related to integrated watershed research and management.

1.2 The Hydrology and Meteorology Component of Pardyp

The first listed output of PARDYP as recorded in the Project Document concerns hydrology and meteorology and specifies the generation of relevant and representative information and technologies about water balance and sediment transport related to degradation on a watershed basis (ICIMOD 1996). Under this spe-

Figure 3: Landscape in the Hilkot Watershed, Pakistan (photo: October 1996)

cific objective the following activities are formulated:

- carry out resource inventories of watershed areas,
- determine and update the design of hydrometeorological stations including water sediment and quality monitoring,
- establish a network of stations,
- determine water balance by season and event and land use,
- study sediment transport and water quality, and
- identify indigenous, current, and improved water management practices and test them for different uses.

Figure 4: The lower part of the Xi Zhuang watershed, China (photo: February 1998)

The meteorology and the hydrology components are crucial issues in the PARDYP project. They are a condition for the understanding of many resource patterns and processes in the watersheds such as erosion, landslides, soil loss, degradation, land use, potential for irrigation, etc. In order to justify the extended data collection and the analysis related to meteorology and hydrology, two practical examples are presented below.

Example 1: On certain fields in the watershed, erosion rates are particularly high and soil fertility is declining rapidly. What are the reasons behind these processes and what can be done to combat them? In order to answer such questions we need to know the following basic information:

- which fields are particularly affected?
- how much soil is eroded?
- which time of year is the most critical for erosion? and
- what is the cropping pattern and agricultural practice on the respective fields?

Information from hydrology and meteorology:
- how much runoff/nutrient loss is occurring (per season, per event)?
- what are the critical rainfall intensities? and
- from which areas is the sediment output particularly high?
- which areas in the watershed might be similarly prone to soil erosion, based on the rainfall patterns?

and information from other components:
- aspect and slope,
- geology,
- soil types,
- land-use patterns, crop rotation,
- vegetation types, and
- results of trials against degradation processes.

Example 2: Due to population increase or improved market access, there is a need for extension and intensification of irrigation. How can this goal be achieved without overexploitation and degradation of water resources? In order to answer such questions we need to know the following hydrological and meteorological facts.

- What is the spatial and temporal pattern of rainfall?
- How are the hydrographs characterised on an annual as well as on a seasonal basis?
- When are the flood flows and the peak flows?
- What does the water balance look like?
- What is the groundwater potential and where are the major recharge areas?
- What is the quality of the water?
- What is the traditional arrangement for water use and what is the system of water rights?

Additional information is also needed - this concerns components of:
- slope stability and
- land-use patterns.

In order to answer the questions above, an in-depth basic knowledge of the hydrometeorological processes is necessary. This can only be achieved through the collection of high quality data and through analysis. The two examples also highlight that data collection as well as meteorological and hydrological analyses have to be driven by applied questions and have to be related to other parameters important for integrated watershed management: the final targets of the project activities are related to farmers' fields, crop yields, and degradation problems. The reasons behind the collection of different hydrometeorological data and the practical relevance and implications of the analyses have always to be clear.

As PARDYP operates in five watersheds, the importance of hydrometeorological data collection and analysis in a specific watershed goes far beyond this particular watershed. The results provide information on the processes and key issues in the Middle Hills of the Himalayas in an east-west transect in general, and they contribute to the understanding of mountain ecology. In this light, PARDYP is an important element in the implementation of Chapter 13 of the Rio Agenda which is concerned with sustainable mountain development (UNCED 1993).

2. The Measurement Network

Chapter 2 describes the hydromet measurement network in terms of the design philosophy and as it exists on the ground in Nepal. There are two main topics - the different levels (or scales) of measurement in the nested approach (small test plot to watershed scale) and the hydrological, meteorological, and test sites that make up the measurement network. in the Yarsha *Khola* watershed in Nepal. The Yarsha *Khola* watershed is one of the five PARDYP watersheds.

2.1 The Nested Approach

In each PARDYP watershed, the project activities are carried out on three scales of study: the watershed as a whole, the subcatchments, and the test plots (Fig. 5). This hierarchical structure can be termed 'a nested approach': each level forms a part of the next higher level, e.g., an erosion plot is part of a subcatchment, a subcatchment is part of the whole watershed. On each scale, the topics and the parameters of interest in the meteorology and hydrology components are slightly different (Table 1).

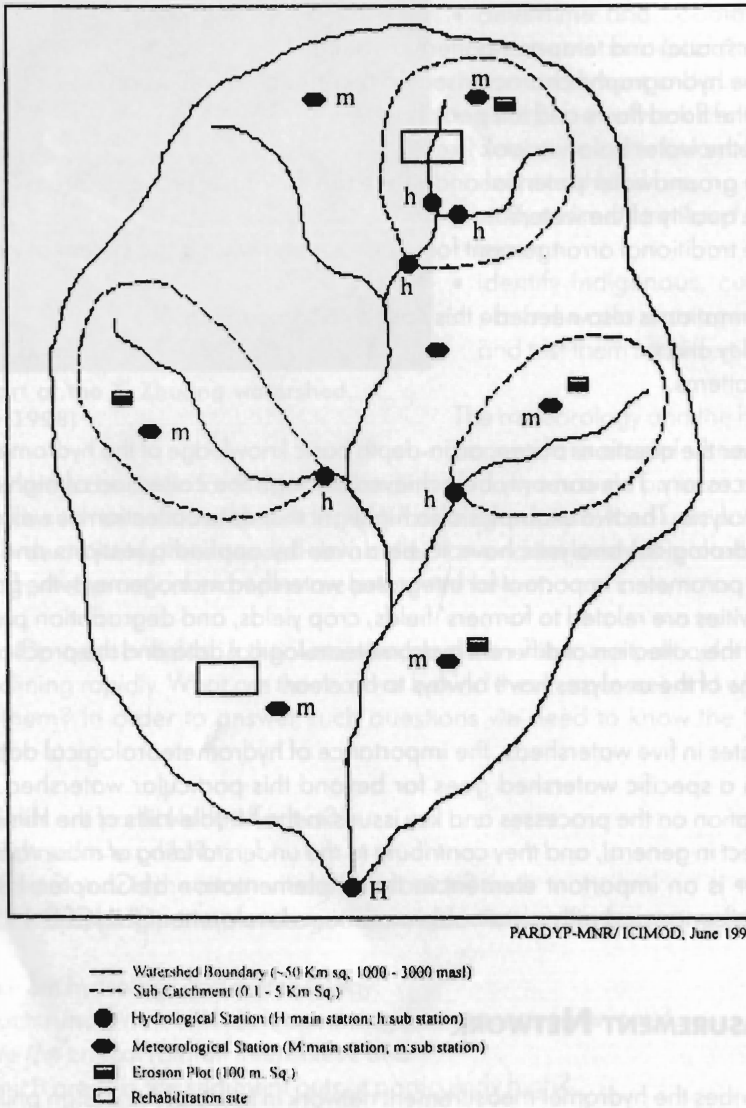


Figure 5: The nested approach of the project activities in the PARDYP watersheds

- The watershed as a whole should be representative of a larger region. Hydrologically the watershed is looked at as a closed system. The data collected at this scale provide insights into the integral response of the system. At the watershed level, the long-term processes and balances (monthly, seasonal, annual) are the centre of interest.

Table 1: Hydrometeorological Programme on the Different Scales of the Watershed

	Watershed	*Subcatchment*	*Test plot*	*Rehabilitation site*
Main topics	• Water balance and sediment output	• Water balance and sediment output • Nutrient balance • Soil fertility	• Processes of runoff generation and erosion • Soil fertility	• Rehabilitation of degraded lands
Main parameters	• Meteorological parameters (main station) • Water level • Discharge • Sediment transport	• Rainfall intensity • Temperature • Water level • Discharge • Sediment transport • Water chemistry • Nutrients (water and sediments)	• Rainfall intensity • Components of runoff • Erosion • Nutrients (water and sediment)	• Meteorological parameters • Surface runoff • Erosion • Nutrients
Representative for	• Watershed and larger region	• Land units (dominant land use, dominant aspect, degree of degradation)	• Small land units with specific, homogeneous land-cover/land-use conditions	• Reaction of the system to interventions

- In the subcatchments, the focus is on the analysis of specific 'local factors': distinct land use, most degraded area, more or less natural conditions, dominant aspect, specific treatment, etc. Each selected subcatchment is as homogeneous as possible in terms of specific physical characteristics. The different time scales (event, month, season, year) are of equal interest.
- An erosion plot represents the conditions and processes under a specific homogeneous land-use or land-cover type (Fig. 6). On the plot level, the processes originating on the smallest scale on farmers' fields are investigated: erosion, runoff, or decline of soil fertility under different conditions. The farmers' fields provide the scale of agronomic interventions and trials as well as of the assessment of appropriate technologies. On the plot level, the main interest lies in single events. Monthly, seasonal, and annual balances are less important.

Figure 6: The erosion plot on red soil in Namdu, Yarsha Khola Watershed, Nepal (photo: May 1997)

Rehabilitation sites are selected in areas of the watershed that are intensely degraded and where measures for rehabilitation should be carried out and tested. The size of the rehabilitation sites is determined by the extent of the degradation. Rehabilitation sites are preferably, but not necessarily, located within selected subcatchments. In the ideal case, a rehabilitation site is situated in one part of a twin catchment (subcatchment with two branches): if one part is rehabilitated and the other is left in the original condition, then the success of the rehabilitation measures can, after several years, be measured quantitatively by discharge and sediment measurements at properly sited hydrological stations.

Figure 7: The site of the main hydrological station in Yarsha Khola Watershed, Nepal (photo: May 1997)

The hydrological network has to fulfill the requirements of the nested approach described above: there has to be a main station at the outlet of the watershed (Fig. 7) and sub-stations at the bottom of each subcatchment (Fig. 8).

The selection of meteorological stations has to cover several criteria:

- spatial coverage of information over the watershed,
- potential to study altitudinal gradients of meteorological parameters, and
- location near to erosion plots (for rainfall intensities) and hydrological stations.

The main meteorological station should be representative of the conditions in the watershed and should be located at the mean elevation of the watershed (Fig. 9).

In the different PARDYP watersheds, the theoretical structure of the 'nested approach' had to be adapted to local conditions. It was, for example, not always possible to find subcatchments with homogeneous or dominant land-use/land-cover conditions. Furthermore, an ideal measuring network may exist in theory, but not in reality: in each PARDYP watershed, a compromise had to be found between an optimum net-

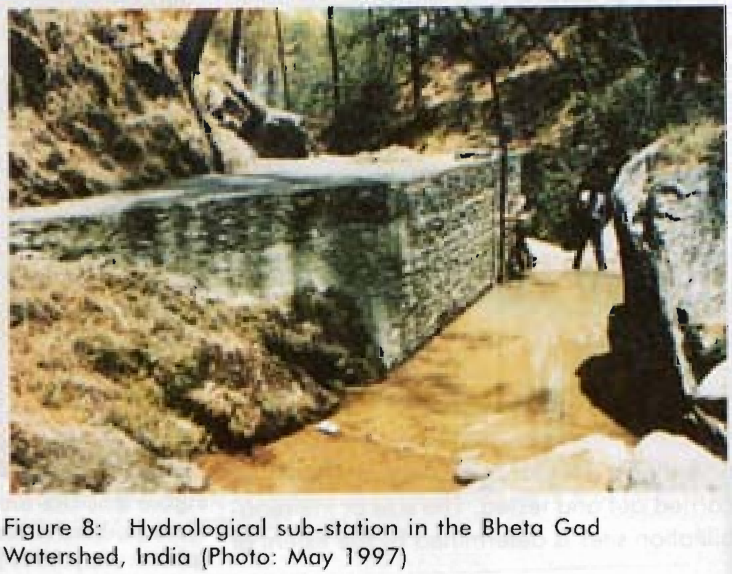


Figure 8: Hydrological sub-station in the Bheta Gad Watershed, India (Photo: May 1997)

Figure 9: The main meteorological station in the Xi Zhuang Watershed, China (photo: February 1998)

work and a manageable network.

The World Meteorological Organization describes hydrological network design in the guide to hydrological practices (WMO 1974) as an evolutionary process in which a minimum coverage (minimum network) is established early in the development of an area, and the network is then upgraded periodically until an optimum network is attained. This approach fits the philosophy in the PARDYP watersheds. In each watershed, an initial station network is established. Based on the experiences with this first set-up, the network is upgraded after the first year of measurements (for more information regarding hydrological network design see Moss 1982).

2.2 The Measurement Network of Yarsha Khola Watershed, Nepal

The Yarsha *Khola* Watershed is situated approximately 190km east of Kathmandu in Dolakha District. The watershed drains into the Tamakoshi River. The size of the watershed is roughly 54sq.km. and the elevation ranges from 1,000 to 3,000masl. The watershed is mainly drained by the Yarsha *Khola* in the north and the Gopi *Khola* in the south. The two rivers merge just upstream of the main hydrological station.

The measurement network of the Yarsha *Khola* Watershed is shown in Figure 10. There are six hydrological stations, 11 meteorological stations, and four erosion plots. The different sites are described in Tables 2, 3, and 4. There is a concentration of monitoring activities on the south facing slope and a strong focus on the Khahare *Khola* catchment.

In the Khahare *Khola*, the nested approach is distinct with two hierarchies of subcatchments (subcatchment 5 being a part of subcatchment 7). It is obvious that only a selection of subcatchments within the watershed can be monitored, and it was difficult to find subcatchments with more or less homogeneous land-use/land-cover conditions. In this respect, subcatchments 4 (see Fig. 11) and 5 are the most appropriate ones. In selecting subcatchment 2 (Fig. 12), it was not intended to monitor a homogeneous subcatchment but to obtain information about the behaviour of the Gopi *Khola*, the second major stream in the watershed.

Regarding the network of meteorological stations, the three main criteria were fulfilled: spatial coverage of information, altitudinal gradients, location near to erosion plots, and hydrological stations.

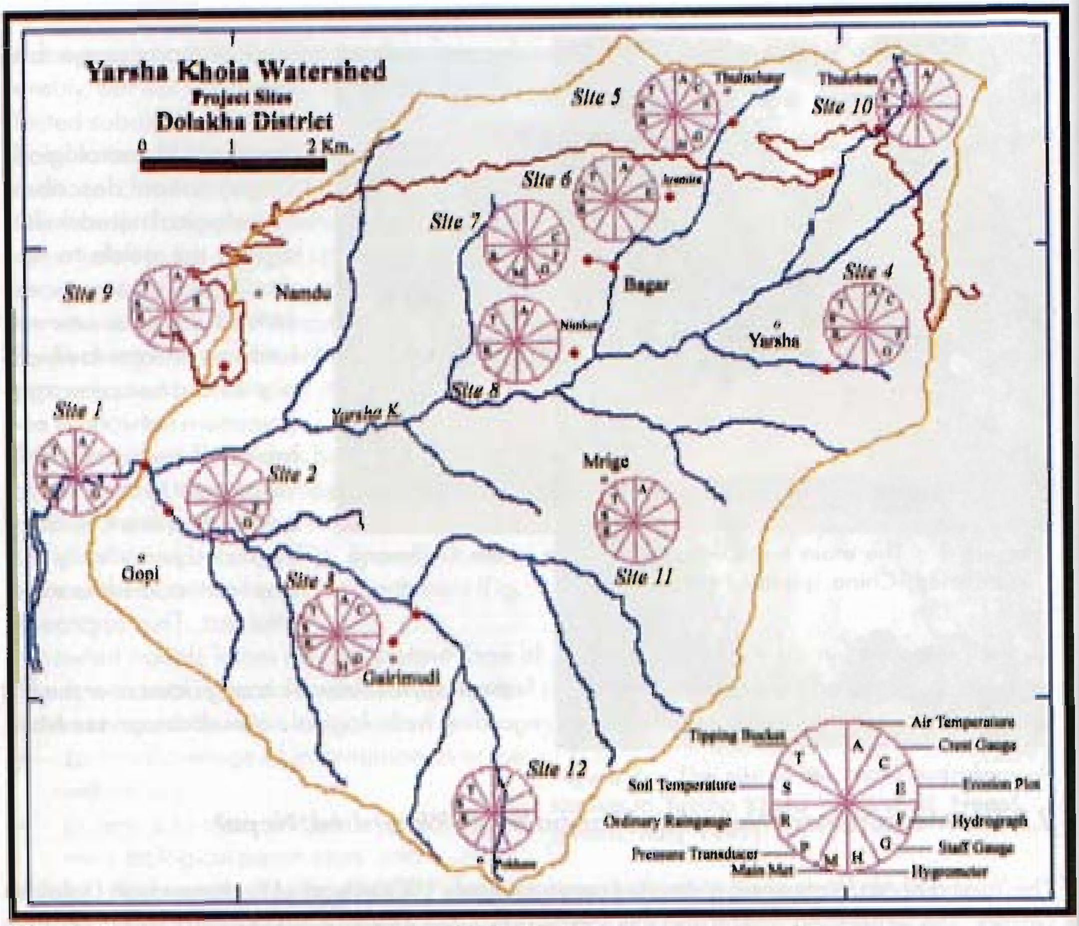


Figure 10: The monitoring sites in the Yarsha Khola Watershed, Nepal

The four erosion plots are located on two land-use types with potentially high soil loss and runoff (grazing/shrub land, *bari* [rainfed agriculture, fields]) on both red soil and non red soil.

The numbering of installations was not carried out according to stations, but according to sites (see Fig. 10). For the data collection and file structure, this approach proved to be much more transparent than the separate numbering of the hydrological and meteorological stations as well as the erosion plots. In Figure 10, the sites as well as the measured parameters are documented.

3. Data Handling

The main topics covered in this Chapter are the types and frequency of measurement recorded at the field stations and the data handling procedures both in the field station and at project headquarters.

Table 2: Yarsha *Khola* Watershed: List of Hydrological Stations and Catchment Characteristics

Site No	River (site)	Elevation (masl)	Catchment size (sq.km.)	Alt. Range (masl)	Land cover (%)	
1	Yarsha *Khola* (hydro main)	1000	53.38	1000-3050	*Khet*: 13.9 *Bari*: 37.4 Forest: 31.5	Grass: 5.7 Shrub: 5.0 Other: 6.5
2	Gopi *Khola* (Gopi)	1040	17.37	1040-2495	*Khet*: 13.3 *Bari*: 40.8 Forest: 31.4	Grass: 3.9 Shrub: 5.0 Other: 5.7
3	Gopi *Khola* (Gairimudi)	1440	4.90	1440-2407	*Khet*: 3.7 *Bari*: 58.0 Forest: 22.7	Grass: 3.9 Shrub: 6.1 Other: 5.7
4	Yarsha *Khola* (Forest Site)	1970	1.11	1970-2594	*Khet*: 0 *Bari*: 16.2 Forest: 82.0	Grass: 0.9 Shrub: 0.9 Other: 0
5	Khahare *Khola* (Thulachaur)	2280	0.32	2280-2731	*Khet*: 0 *Bari*: 15.6 Forest: 40.6	Grass: 3.1 Shrub: 25.0 Other: 15.6
7	Khahare *Khola* (Bagar)	1740	2.08	1740-2731	*Khet*: 0 *Bari*: 50.5 Forest: 14.4	Grass: 10.1 Shrub: 20.2 Other: 4.8

Note: *Khet* – irrigated rice land
Bari = rainfed agricultural land

Table 3: Yarsha *Khola* Watershed: List of Meteorological Stations

Site No	Site name	Elevation (masl)
1	Hydro main	1,020
3	Gairimudi	1,530
4	Forest site	1,960
5	Thulachaur	2,300
6	Jyamire	1,960
7	Bagar	1,680
8	Nimkot	1,420
9	Namdu	1,380
10	Thuloban	2,640
11	Mrige	1,650
12	Pokhari	2,150

Table 4: Yarsha *Khola* Watershed: List of Erosion Plots

Site No	Site name	Elevation (masl)	Plot characteristics
5	Thulachaur	2,300	Grass, shrub; dark brown soil; Slope (deg): 19.1
6	Jyamire	1,960	*Bari*; brown soil (Chimteilo Pusro); Slope (deg): 17
9a	Namdu	1,380	*Bari*; red soil; Slope (deg): 17.5:
9b	Namdu	1,380	Grass, fallow, degraded; red soil; Slope: (deg): 17.5 (see also Fig. 6)

Note: *Bari* = rainfed agricultural land

Figure 11: The forest subcatchment (monitored at site No 4) in the Yarsha Khola Watershed, Nepal: 82% forest, 16.2% bari, 0.9% grass, 0.9% shrub (photo: November 1996)

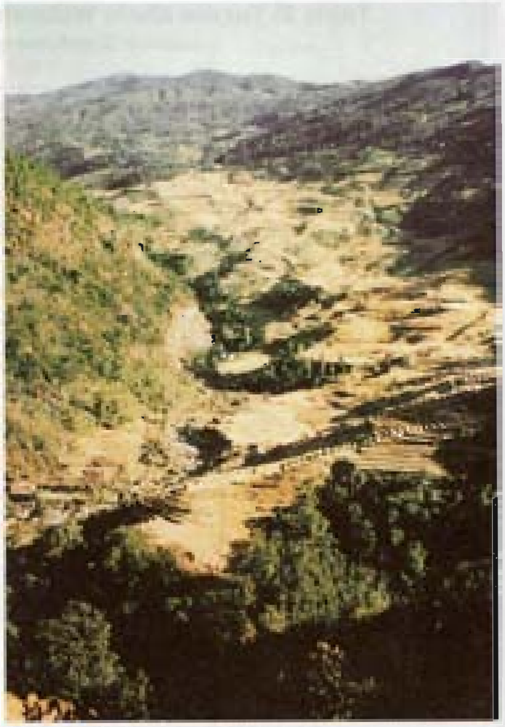


Figure 12: The subcatchment of the Gopi Khola (monitored at site No 2) in the Yarsha Khola Watershed, Nepal: 13.3% khet (lower part of the watershed), 40.8% bari, 31.4% forest, 3.9% grass, 5% shrub, 5.7% others (photo: November 1996)

Sub-topics describe the actual types of measurement recorded at the different field research stations and sites, the vital role played by the field teams maintaining the stations and recording the results, and the means through which quality data collection, recording, management, and storage are ensured in both field and office.

A well-organized and transparent data handling system is essential for good results. The data handling has to be defined and coordinated right from the beginning of project activities in order to achieve comparable data sets and results in the different watersheds of the PARDYP project. Figure 13 provides a flow chart for the data handling. In the following sections, the most important elements of this flow chart are discussed. The analysis is covered in Section 4.

3.1 The Measurement Programme

3.1.1 Overview

Common procedures and methodologies are crucial in the PARDYP project. This key Section specifies the basic, compulsory measurement programme of the hydrology and meteorology components in the PARDYP watersheds (Table 5). On top of these compulsory measurement

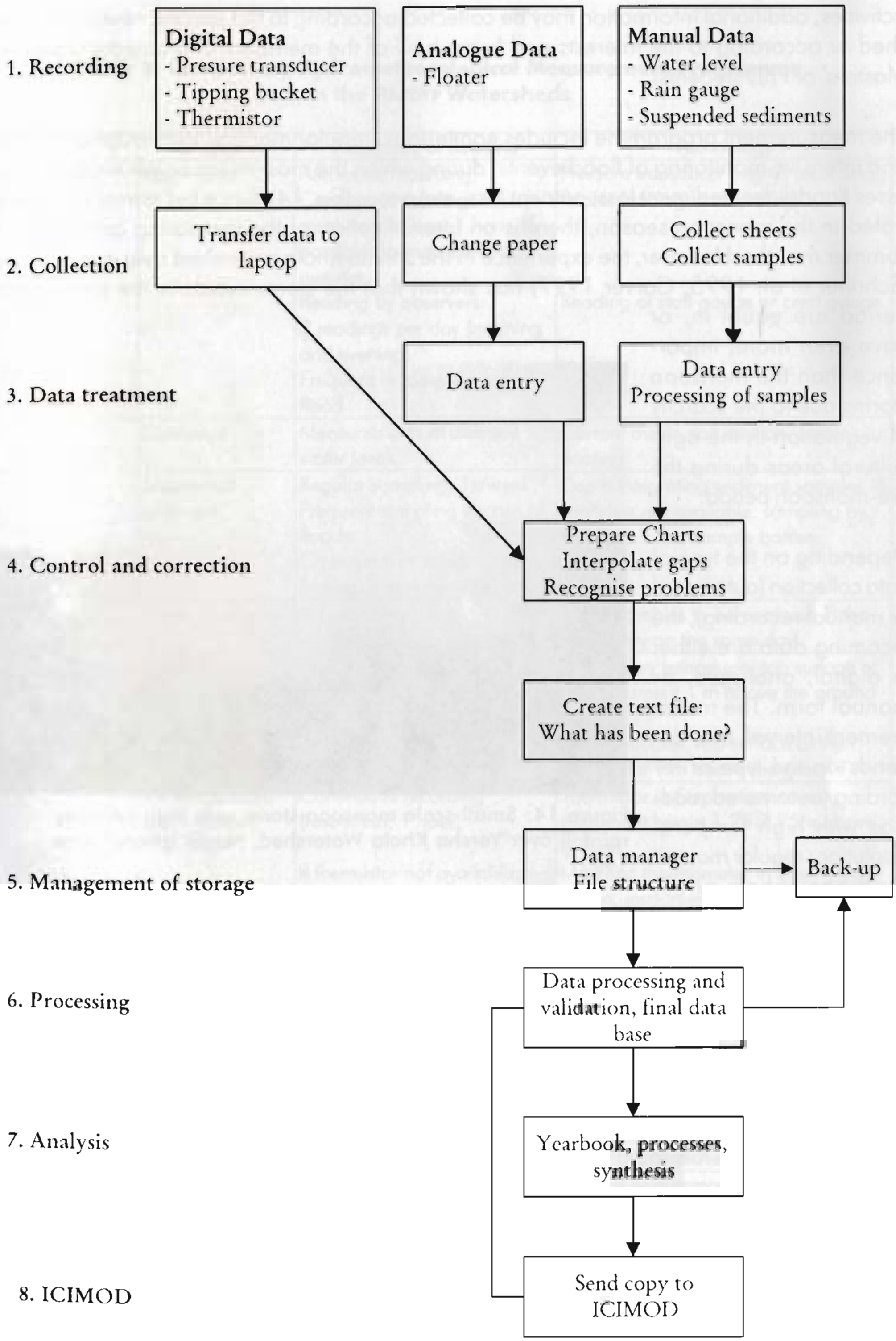


Figure 13: Handling of the hydrological and meteorological data in the PARDYP watersheds

activities, additional information may be collected according to the specific needs of a watershed or according to the interests and know-how of the members of a country team (e.g., Masters' or PhD students).

The measurement programme includes continuous, regular monitoring throughout the year and intensive monitoring of flood events, during which the most dramatic geomorphic processes (landslides, sediment loss, nutrient loss, etc) occur (Fig. 14). Since big storms are concentrated in the monsoon season, there is an intensification of the measuring activities in the summer months. However, the experience in the Jhikhu *Khola* watershed over previous years (Schreier et al. 1995, Carver 1997) has shown that the storm events in the pre-monsoon period are equal in, or have even more, importance than the monsoon storms due to the scarcity of vegetation in the agricultural areas during the pre-monsoon period.

Figure 14: Small-scale monsoon storm with high intensity rainfall over Yarsha Khola Watershed, Nepal (photo: June 1997)

Depending on the type of data collection (automated or manual recording), the incoming data are either in digital, analogue, or manual form. The measurement interval, too, depends on the type of recording (automated readings with high temporal resolution; regular manual readings taken once, twice, or three times a day). The time of the manual measurements has to be defined according to the timing of the readings in the national network; furthermore, it has to be the same for all the stations in the watershed.

The management of the measurement network in the PARDYP watersheds is the responsibility of field technicians (downloading of data, discharge measurements) as well as of local readers (manual data recording, assistance in discharge measurements, supervision of stations). The jobs of the field technicians and the readers are very important and they have a lot of responsibility. The fact that the main monsoon storms occur at night makes their task even more difficult!

The following sections provide details on the measurement programme listed in Table 5.

3.1.2 Water Level

For automated water level recording, pressure transducers (Fig. 15) as well as floaters (Fig. 16) are in operation in the PARDYP watersheds. The installation of pressure transducers is essential on

Table 5: Compulsory Hydrometeorological Measurement Programme in the PARDYP Watersheds

	Parameters	Frequency of Reading	Technology
Hydrological stations	Water level	Automatic recording: Continuous reading: resolution at least 1 hour, if possible down to 15 or 5 minutes Reading by observers: 2 readings per day (morning and evening) Frequent reading in case of flood	Pressure transducer (digital recording), floater (analogue recording) Reading of staff gauge or crest gauge
	Discharge	Measurements at different water levels.	Current meter, salt dilution, tracer, floating
	Suspended sediment	Regular sampling, 1x/week Frequent sampling in case of floods Cross-section sampling (only in special programmes)	Depth integrating sediment samples (if samplers not available: sampling by hand). 0.5 litre sample bottles
	Water chemistry	4-6 samples a year	Water samples to be analysed in the laboratory on the same day!
Meteorological stations	Rainfall (each station)	Daily rainfall (reading in the morning) Rainfall intensity with high temporal resolution	8" ordinary raingauge, top surface of the instrument 1 m above the ground Tipping bucket, top surface of the instrument 1 m above the ground
	Air temperature (each station)	Continuous recording (resolution: 1 hour) If thermistor not available: max/min in 24 hours	Thermistor in Stephensen screen, instrument height 1.25-1.75m above ground Max/min thermometer in Stephensen screen, instrument height 1.25-1.75m above ground
	Soil temperature (at least main stn.)	Continuous recording (resolution 1 hour)	Thermistor, 20 cm below surface If 3 sensors at the main met. station: 5,20, 50 cm below surface
	Air humidity (at least main stn.)	Readings 3x per day (morning, 2pm, evening)	Hair hygrometer in Stephensen Screen, instrument height 1.25-1.75m above ground Dry/wet bulb thermometer in Stephensen Screen, instrument height 1.25-1.75m above ground
	Other parameters (main met station)	Daily or continuous readings, depending on the equipment	Manual or automated instruments
Erosion plots	Erosion and runoff	Reading and sampling after each event	Measurement of water level and sampling from each drum

sites in which fixing a vertical floater pipe is impossible. Crest gauges, which mark the maximum water-level reached during an event, are only useful if there is no automatic water-level recording device or for purposes of comparison. In the monsoon season, the temporal resolution of the automatic water level recording is higher than in the dry season. For example, in the Yarsha *Khola* watershed, the recording interval in the monsoon season is 5' (in statistical mode in the order of average wave actions) and in the dry season 15' (momentary values). In the case of floaters, weekly charts are used in the monsoon season, monthly charts in the dry season. The hydrological monitoring sites are equipped with a station form on which each manipulation carried out at the station, or each observation (functioning of the equipment, comparison of staff gauge reading and reading of the instrument), have to be recorded with date and time.

Figure 15: Pressure transducer installed at the main hydrological station in Yarsha Khola Watershed, Nepal (photo: May 1997)

3.1.3 Discharge

There are three methods for sophisticated discharge measurements: current meter, salt dilution, tracer. These methods are briefly presented. (For more information see WMO 1980; LHG 1982; Fischer 1982; Chow et al. 1988; LHG 1994; and Spreafico and Gees 1997.)

Figure 16: Floater House at the hydrological sub-station in the Xi Zhuang Watershed, China (photo: February 1998)

- For current meter measurements (propeller device), a more or less fixed, homogeneous cross-section is required with a smooth, regular flow.
- The salt dilution method is essentially used in mountain rivers with rough cross-sections, big boulders, and turbulent flows. A conductivity meter is needed for the measurement. Turbulent river flows are a condition for this measurement technique in order to guarantee a good mixing of the

salt. Before starting with 'serious' measurements, experimental measurements are necessary in order to find the sites suitable for salt injection and for conductivity measurements which ensure an optimum mixing length. For river flows above $2m^3$/sec, the application of the dilution method becomes unrealistic due to the amount of salt required (5-10kg).

The tracer measurements (e.g., using fluorescent tracers) are again appropriate in turbulent mountain rivers, and their application has no upper limit in terms of flow. In preparing for the measurements, similar steps to those used with the salt dilution method (identification of injection point, sampling point, optimum mixing length) have to be carried out. The tracer is injected with the help of a Mariott Bottle (Fig. 17). The disadvantage of this techniques is that the calculation of discharge cannot be carried out directly in the field. The water samples (16 per measurement in Yarsha *Khola*) have to be taken to the laboratory for analysis, and the spectrofluorometer required for the analysis is extremely expensive.

Figure 17: Preparation for a tracer measurement with a Mariott Bottle at the main hydrological station, Yarsha Khola Watershed, Nepal (photo: monsoon season 1997)

This short introduction to the discharge measurement techniques illustrates that, for each hydrological station and for each season, the appropriate method has to be used. In Yarsha *Khola* watershed, all three measurement techniques are used. The current meter at Site 1 in low and medium flow, salt dilution at Sites 2,3,4,5, and 7, and the tracer (uranin) technique at Sites 1,2,3, and 4 during high flows (location of sites: Fig. 10). For comparison purposes, it may be interesting to apply different methods simultaneously. Current meter and salt dilution methods are applicable in all the five PARDYP watersheds. Measurement with fluorescent tracers, however, is only feasible in two watersheds of Nepal at present, as a spectrofluorometer for the analysis of the tracer samples is only available at the laboratory of the Department of Hydrology and Meteorology in Kathmandu.

Based on discharge measurements, rating curves are established – these describe the relationship between water level and discharge (see Section 4.4.2 and Fig. 18). In order to get a reliable rating curve for a specific station, discharge measurements for as many water levels as possible have to be carried out. For low flow conditions, this is not difficult as there are many occasions for measurement, and the measurements are easy. Much more difficult is the situation at high or flood flow conditions, as high water levels do not occur very often. Each discharge measurement technique requires a certain time during which the flow should remain constant. High or peak flows, however, are usually of short duration only. The attempt has to be made, therefore, to measure as many high flows as possible, for which the water level does not

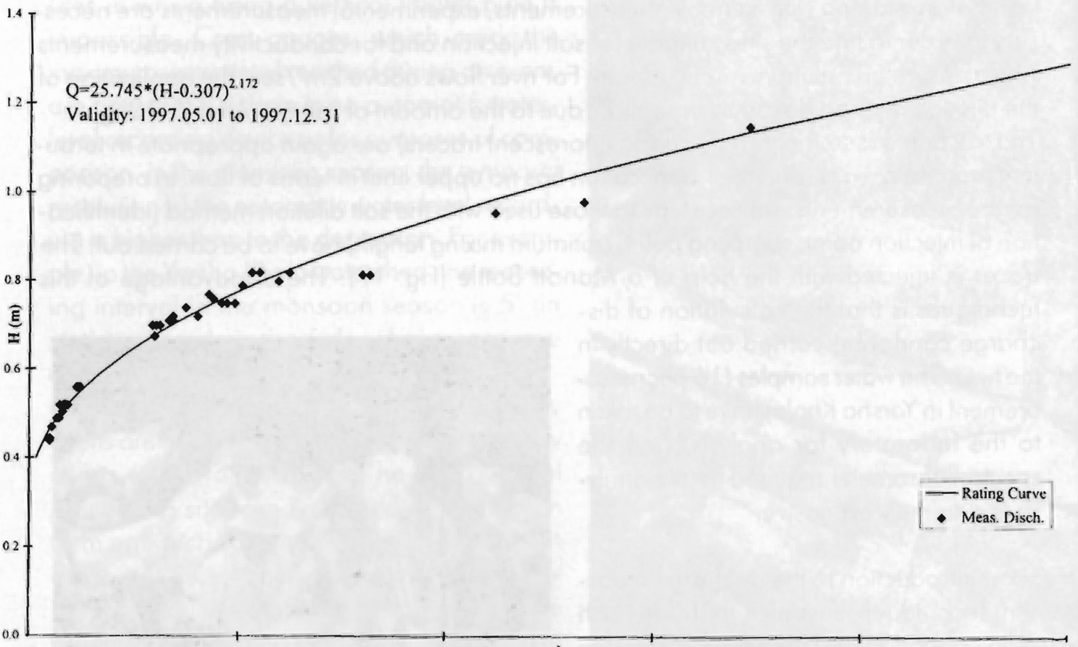


Figure 18: Water level/discharge rating curve of the Yarsha Khola at the main station, 1997

change too fast. However, it is almost impossible to measure peak flows accurately, although a rough estimate can be made, e.g., by using floats, by making one current meter measurement in the middle of the river, etc.

Obtaining good quality discharge measurements is a challenge. To realise such measurements, a small team of three to four persons is required, ideally consisting of a hydrologist, a field technician, the reader, and the assistant reader of the particular measuring site. In view of these personnel requirements and the expensive equipment needed, discharge measurements cannot usually be carried out simultaneously at each station. The team has, therefore, to work out a measurement programme for the monsoon season in which each station receives sufficient attention. Ideally, the team has to spend approximately two weeks at a stretch at a specific station. Within this period, the chances of encountering many different flow situations, including flood flow conditions, are at least moderate.

3.1.4 Sampling of Suspended Sediments

Only the sampling of suspended sediments is included in the compulsory measurement programme of the PARDYP watersheds. The investigation of bedload transport is optional (Table 6). Ideally, the sampling is carried out with depth-integrating sediment samplers, either from the bank of the river using a measuring rod or from a bridge using a handline. If sediment samplers are not available, the sampling can also be carried out manually from the river bank, slowly moving the bottle down and up over a vertical profile (Fig. 19). The sampling is carried out with 0.5 litre sample bottles; each sample has to be labelled properly with date, time, water level,

Table 6: Level of Disciplinary Analyses - Compulsory and Specialised Analyses

	METEO	HYDRO
Compulsory	• Spatial rainfall patterns • Temporal rainfall patterns • Analysis of high rainfall intensities • Comparison of rainfall of a specific season/year with long-term data series • Spatial and temporal temperature patterns • Calculation of evaporation • Analysis of other meteorological parameters	• Rating curve: water level/discharge • Rating curve: discharge/suspended sediments • Annual hydrographs of the 'main values' • Duration curve of discharge • Balances of runoff, discharge and sediment transport • Discharge comparison of different stations
Specialised	• Frequency and probability of wet and dry spells • Calculation of potential evapotranspiration • Analysis of soil temperature and soil humidity	• Concentration times • Space correlation, point correlation of different stations • Map: areas of high water potential and high water demand • Groundwater investigations • Assessment of sediment potential from different areas • Bedload transport

event number, station, and reader's name. For the establishment of a discharge/sediment rating curve, the water level has to be recorded parallel to each sediment sample.

A considerable portion of the sediments and nutrients is transported during events. It is important to know when the peak concentration of sediments is reached in a flood and when the maximum amount of nutrients is washed out. Therefore, sediment sampling periods concentrate on flood events during which at least 10 to 12 samples should be taken on the rising limb, the peak, and the falling limb of the flood hydrograph. In addition, flood sampling is crucial for the establishment of a reliable discharge/sediment rating curve, since the information for the upper part of the curve is rare. For the flood sampling, the reader has to be instructed to start sampling once the water level rises considerably above the base flow of the respective season. Not each sampled event, however, will then be included in the analysis (see 3.2.2).

Figure 19: The reader taking a sample of suspended sediment at the main hydrological station in Yarsha Khola Watershed, Nepal (photo: monsoon season 1997)

Ideally two to four events in the monsoon season, one to three events in the pre-monsoon season, and one to three events in the post-monsoon season should be measured successfully. This temporal differentiation is important as the sediment output during pre-monsoon, monsoon and post-monsoon storms is considerably different (Fig. 20).

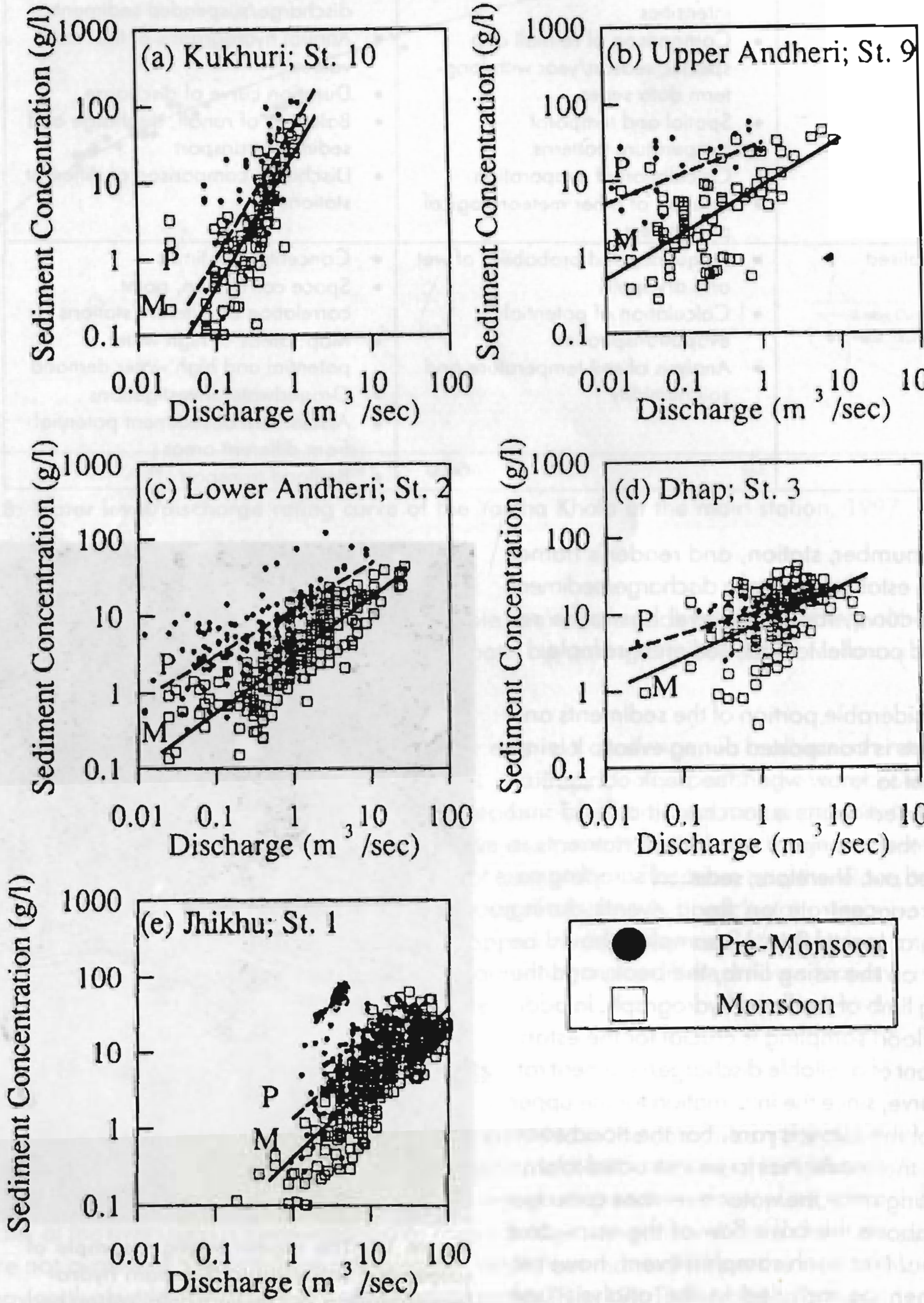


Figure 20: Seasonally stratified sediment rating curves for different stations in Jhikhu *Khola* watershed over several years (source: CARVER, 1997)

In special campaigns and in the different seasons, cross-section investigations should be carried out by sampling the whole transect of the river in order to procure information about the distribution of the sediments across the river.

3.1.5 Water Chemistry

The analysis of water chemistry provides information on the loss of nutrients as well as on water quality, both crucial elements for the monitoring of nutrient loss and balance. As the laboratory analysis is time consuming, the number of samples per station has to be reduced to about four to six per year: one sample during minimum flow, one during pre-monsoon period, and three to four samples during monsoon season.

3.1.6 Meteorological Parameters

For the project, rainfall (amount and intensity) and air temperature are the most important parameters to be monitored at all the measuring sites. For temperature and rainfall intensity, automatic recording devices (tipping buckets for rainfall, and thermistors or thermographs for temperature) are required in order to procure a high temporal resolution of the information. Ideally, devices for the measurement of air humidity and soil temperature are installed at the meteorological sub-stations as well.

Other meteorological parameters (soil humidity, evaporation, wind speed, wind direction, and radiation) are measured at the main meteorological station. As these data should be more or less representative for the watershed, the site selection for the main meteorological station is crucial (Fig. 21).

3.1.7 Erosion Plots

Surface runoff and soil loss are recorded at the erosion plots. In most of the watersheds, four drums are installed to catch the water and sediments with an overflow device from one drum to the next (Fig. 22). As the volume of runoff from an erosion plot is calculated based on the water height in the drums, the latter have first to be calibrated by systematically adding a known volume of water and measuring the depth of water.

Figure 21: The fully automated meteorological station in Yarsha Khola Watershed, Nepal (photo: October 1997)

The recording and the sampling, carried out by the reader, have to be taken after each event. The data recording begins with the measurement of the runoff height in the collection drums. If the depth of the runoff water in the drums equals or exceeds five cm, sediment sampling is carried out for each event. For sampling, water in the drum is first agitated to mix the fine and coarse sediments. A composite sample of a half a litre is taken from each drum. During heavy storms and when

Figure 22: The gutter and the collection drums of an erosion plot in Namdu, Yarsha Khola Watershed, Nepal (photo: May 1998)

there are large sediment depositions in the drums, two samples are taken, one from the upper part of the drum (suspended sediment) and one from the lower part (deposited sediments). Each sample has to be tagged with a reference number indicating the site, drum and sample number, date, and reader's name. Further details on the collection and analysis of data from erosion plots are specified by the Department of Soil Conservation and Watershed Management (1998).

3.1.8 The Readers

The work of the readers is very important.

- The readers are the key persons for the collection of raw data on hydrology, meteorology, and erosion.
- The readers are the watch-persons of the stations and their installations.
- The readers have always to be on the spot for the regular readings, for intensive monitoring during flood events, and to assist during discharge measurements. They have to carry out these duties during day and night.
- The readers are expected to be punctual and precise in carrying out the readings (Fig. 23).

Figure 23: The reader of the meteo substation in Gairimudi, Yarsha Khola Watershed, Nepal (photo: April 1998)

In view of such responsibilities, the readers need incentives. The most important, of course, is a decent salary which motivates them to do a good job. Furthermore, basic equipment such as a raincoat, torchlight, umbrella, watch, and rucksack (for the hydro and erosion plot readers) have to be provided. Finally, the readers need forms on which they can enter their readings and observations. Examples of such forms are given in Annex 1.

In order to fulfill their duties, the readers need regular training. This training has to include, for example, how to carry out accurate readings, methods of sediment sampling, and the level of assistance expected during discharge measurements. In addition to this technical training, the readers need to be informed about the project, the reasons behind the collection of information, and the analyses that are carried out with 'their' data. They need to have an opportunity to exchange ideas, express their views, and discuss their experiences. If such training is provided regularly, the readers will realise that they are part of a whole network and that their contribution is crucial. If they understand the project goals and feel they are a part of the project team, then the readers will be motivated to collect good quality data.

The experience in the Nepal watersheds has shown that such one-day training sessions should be carried out once or twice a year (e.g., before and after the monsoon). All the readers are invited to come to the field station. In the first part of the morning session, the project objectives are highlighted and the state of the project is discussed; readers then ask questions and express ideas or complaints. In the second part of the morning session, results based on the data collected by the readers are illustrated and discussed. The readers are asked to comment critically on these results and to contribute from their long experience information about the physical processes in the area. The afternoon session takes place in the field, directly at the measuring sites (Fig. 24): the measuring and reading techniques are demonstrated and repeated, difficulties or key issues arising from the measurements are emphasised, the measurement programme is highlighted, and the uncertainties of the readers are discussed.

Figure 24: Training of the readers in Jhikhu Khola Watershed, Nepal (photo: May, 1988)

Such training courses have proved to be extremely useful and successful and are an important contribution to the achievement of common methodologies and high quality data.

3.2 *Data Handling in the Field Station*

3.2.1 Data Collection

It has to be ensured that all the hydrometeorological data recorded at the different monitoring sites reach the project field station safely, completely, and on time. Particularly important is the downloading of digital data, either by changing the storage module or by downloading the data to a portable computer. Equally important is the change of the charts of recording instruments (e.g., floaters).

Each digital instrument (e.g., tipping bucket, thermistor) has a different storage capacity and, accordingly, the necessary interval for downloading varies for the different recording devices. In addition, the floaters are equipped with either monthly or weekly charts, depending on the season. Therefore, for each watershed, a strict programme for data collection has to be defined which ensures timely downloading of the data or changing of charts. Ideally, this job is carried out in special campaigns during which all the data from automatic recording devices are collected--even when the storage capacity of certain instruments is greater.

The readers are responsible for organizing the flow of the manually-collected data as well as of the sediment samples from the measuring site to the field office. The sample bottles have to be promptly delivered to the field station in order to ensure timely processing of the samples in the laboratory and the rapid turn-around availability of sufficient empty bottles, particularly during the monsoon season. The labelling of the sample bottles reaching the field laboratory has to be checked thoroughly. The record forms for each specific month should be brought to the field office at the beginning of the subsequent month when the reader receives his salary. The forms have to be checked for clarity, accuracy, and completeness.

3.2.2 Data Treatment

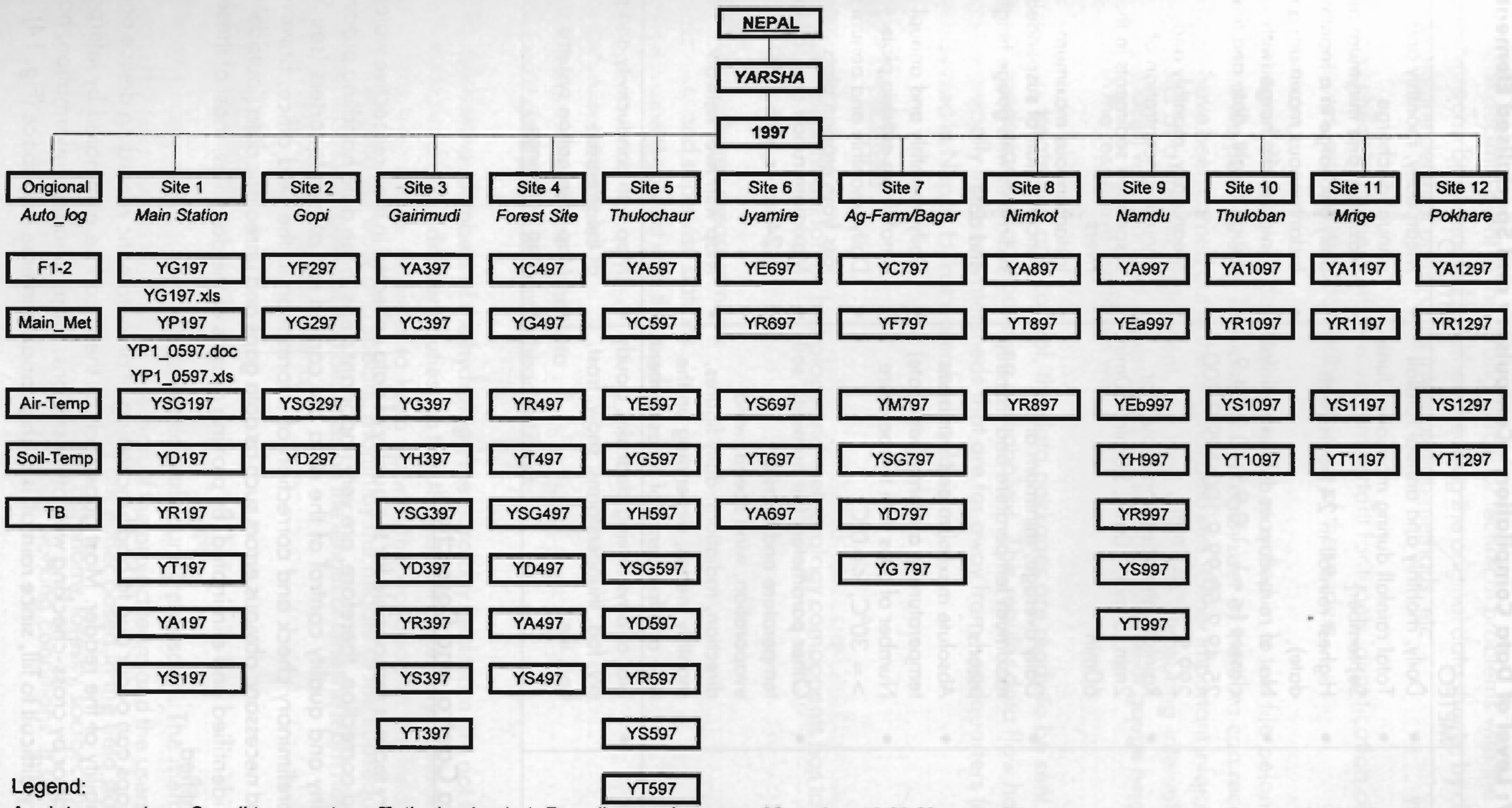
Once the data, forms, charts, and samples have reached the field office, they have to be processed. The necessary steps depend on the type of information, as follows.

- In most cases the digital data are already in the computer as a result of the downloading process. The data files have to be prepared for data storage (Fig. 25), with appropriate file name, file head, and data format.
- The information recorded on the charts has to be transformed into data files. If facilities for digitising charts are available at the project headquarters, then this transformation is not carried out at the field office. If digitising facilities are not available, the information required (see Table 7) has to be extracted manually from the charts by reading the values at regular intervals, and then it has to be entered into the computer. This step can be carried out in the field office.
- Entering the manual data into the computer is the most important, most time consuming, and most challenging work in the field office; it needs a lot of concentration and is tiring. In order to avoid errors in data entry, the data files have to be cross-checked by other members of the team.

The initial processing of the sediment samples (from both the hydrological stations and the erosion plots) is carried out in the field laboratory. The samples are filtered, dried and weighed, and the results are entered into the laboratory book. Chemical analysis (phosphorus content compulsory, calcium and carbon content desirable) of a selection of sediment samples (e.g., samples during particular storm events, single samples during base flow) has to be carried out in a professional laboratory. Ideally, hydrological and erosion plot samples from the same storm events should be selected for chemical analysis.

Based on Table 5, water chemistry is analysed only in special campaigns. Treatment of the water samples has to be carried out on the day of sampling. For these campaigns, an analysing kit has to be available in the field laboratory. The analysis of water chemistry might include nitrate, ammonia, phosphate, calcium, magnesium, conductivity, pH, and hardness; at present, water chemistry is in the test phase in the watersheds of Nepal.

Figure 25: The file structure developed for Yarsha Khola Watershed, Nepal



Legend:
A=air temperature, S=soil temperature, T=tipping bucket, R=ordinary rain gauge, M=main met, H=Hygrometer, C=crest gauge, F=floater, G=staff gauge, P=pressure transducer, SG=sediment sampling, E=Erosion plot

Table 7: Level of Data Compilation - Compulsory and Specialised Elements

	METEO	HYDRO
Compulsory	• Daily, monthly and annual rainfall • Total rainfall during monsoon (June-September) • Highest rainfall in 24 hours (with date) • No. of rainy days in different rainfall classes (<=1, 1.0-9.9,10.0-24.9, 25-49.9,50-99.9,100-199.9,200-299.9,>=300mm) • Rainfall intensities (mm/hour) for 2min, 5 min, 10min, 20min, 30min, 60min • Daily average, minimum and maximum temperature and monthly means • Absolute maximum and minimum temperature in a month (with date) • Number of days with temperature >= 30°C, <=0°C • Other parameters (air humidity, soil temperature and humidity, evaporation, wind speed, wind direction, radiation): daily figures, monthly means, depending on the type and frequency of measurements	• Mean daily, monthly and annual discharge • Maximum and minimum mean daily discharge in a month • Instantaneous maximum and minimum discharge (with gauge height, date and time) • Mean daily, monthly and annual concentration of suspended sediments in the rivers • Instantaneous maximum concentration of suspended sediments with gauge height and date • Daily, monthly and annual runoff from erosion plots • Daily, monthly and annual soil loss from erosion plots • Maximum runoff and soil loss in 24 hours, with date • Map with river network
Specialised	• No. of days having clear sky, cloudy sky, fog, thunderstorms, snow, frost, hail, ice	• Map with conductivity and pH of the streams • Map of irrigation systems • Map of springs

3.2.3 Data Control and Correction

Each country team is responsible for the quality of data collected in their respective watersheds. Control and correction, therefore, are very important steps in the data handling process. The main scrutiny and quality control of the data are carried out at headquarters (see Section 3.3.2). A preliminary check and correction of information in the field office, however, are possible and necessary: obvious errors such as data gaps and unrealistic data ('outside' values) have to be identified and eliminated. By plotting graphs of the data files, most of these errors can be identified.

- Data gaps can occur due to bad functioning of an automatic recording device or due to unreliability of the reader. Most gaps such as these can be eliminated by interpolation methods or by cross-checking with other stations. Gaps in rainfall information, however, are very difficult to fill, since rainfall is highly variable in time and space (Fig. 14).

- Unrealistic data can occur due to mistakes in data entry, mistakes by the reader (e.g., a comma or decimal point in the wrong place) or technical problems with the instrument. Such errors can be eliminated by either checking the original data sheets, by changing the location of the decimal point, or by interpolation methods, etc.

This first data check in the field office is very important for timely identification of problems, instrument failures, and the need for further training of the readers.

Each correction in the original data set has to be recorded in a text file belonging to the respective data file (see Fig. 25). This ensures that each user of the data can reconstruct the changes that have been carried out in the original data sets. Other important information, such as observations at a specific instrument, the time when the measuring interval (e.g., of a pressure transducer) was changed, adjustments of the floater (in time or gauge height), have to be recorded in the respective text file as well.

After collection, treatment, and control, the data packages are ready to be sent to the data manager at headquarters for processing and analysis. This regular data flow has to be well organized, especially in those watersheds that are far away from headquarters (e.g., Yarsha *Khola*, watershed in Nepal, Hilkot watershed in Pakistan).

3.2.4 The Field Team

The field team responsible for the hydrology and meteorology components has to fulfill many important tasks.

- Carry out discharge measurements
- Collect data and supervise stations
- Be in permanent contact with the readers
- Enter data
- Process sediment samples
- Make the first corrections to the data
- Prepare the data sets to be sent to headquarters

It is important that the members of the hydrology/meteorology field team are not too specialised, but well trained in the different duties, so that they can, if necessary, replace each other and also rotate their duties. In order to keep up with the workload in the field office, it is desirable to complete the work of a specific month by the middle of the subsequent month. However, this is not always possible and depends on the length of time the team has to spend in the field, e.g., for discharge measurements.

3.2.5 The Field Station

The field station (Fig. 26) is a busy place, particularly during monsoon. The members of the hydrology/meteorology team are only one section of the project team and the users of the field station. A number of other project collaborators are either based in the field station or visit frequently during specific campaigns (e.g., geology, agronomy, forestry, socioeconomics). The field station has to be a decent living place with good working conditions. It should include sufficient accommodation facilities, a living room, a good kitchen, an office (with sufficient working space, a laptop computer for downloading, at least one desktop computer, and sufficient storage facilities for files and stationery), a laboratory (with facilities for filtering, weighing, and drying samples), and decent toilet and washing facilities. It is important that a good cook is part of the permanent field staff, so that the technicians can concentrate on their technical duties.

Figure 26: The field station in Yarsha *Khola* Watershed, Nepal (photo: November 1997)

3.3 *Data Handling at the Headquarters*

3.3.1 Data Management and Storage

Transparent data management is essential for several reasons.

- In each watershed a huge amount of hydrological and meteorological data is recorded and collected.
- The information is to be used by many institutions and individuals for analysis.
- The hydrometeorological data sets will be used for synthesis with other components of the PARDYP project.
- Data from one watershed will be compared with data from other watersheds.

The Data Manager

Each country team has to identify one person to be in overall charge of data management and storage. This person should have considerable experience in computer technology, preferably a background in physical science, and a good overview of the project. All the data should be stored centrally on the data manager's computer. The data manager:

- has the overview of all the data,
- is in permanent contact with the team at the field office and keeps a record of the data that have arrived from the field,
- is in contact with those individuals or institutions responsible for data processing,
- has to make sure that no data are given out before they are officially cleared and that several versions of the same file are not circulating at any one time, and
- is the 'custodian' of the data: he decides to which users the data are provided and he keeps in touch with them.

The Software

For the time being, it has been decided to use Excel as the common software for data management and storage. Excel is easily available and used widely, and thus ensures access to the information for a variety of users. However, it may create problems for data processing (see Section 3.3.2) since Excel is not a specific hydrological/meteorological software package. At present, there seems to be no alternative to storing the data in Excel, but the processing may be carried out with other, more specialised software packages. In future, it is envisaged that the procedure for data storage and processing for all the watersheds will be standardised by introducing a specialised hydromet programme, but the costs and the training needs have to be evaluated first.

File Structure

Figure 25 provides an example of the data file structure developed for Yarsha *Khola* watershed, Nepal. The files from the erosion plots are not included. This structure is based on the following principles.

- The files are structured according to measuring sites and measuring parameters. Experience has shown that it is easier to handle the file structure if separate files are created for each parameter at one particular measuring site.
- The files in the directory 'original' include the raw data from automatic recording devices; the data files in Excel (extension: xls) include the finalised data (after data processing, see Section 3.3.2); in the text files (extension: doc) interpolated data, station specifications, control measurements, problems observed, and so on are recorded.
- Monthly files are basically created for the parameters measured with automatic recording devices and annual files for manual readings.
- The creation of file names must receive particular attention. File names should include as much information as possible in order to achieve maximum transparency of the data base. Part of the annual file, YG197.xls (Y: Yarsha *Khola*; G: staff gauge; 1: site #1; 97: year 1997), is given in Table 8.

Data Format

The data format provides guidelines for the internal file structure. As for the file structure, a clear and uniform data format is important for the user. Table 8 provides an example of the file for manual water level readings at the main station in Yarsha *Khola*, Nepal. This data structure is based on the following principles.

- The data file includes a text block with the relevant information on the specific station and measuring infrastructure and a data block.
- The data are structured into columns: date, readings in different columns (8 a.m. reading, 4 p.m. reading), and remarks.
- The identical structure of each file of a specific data set and station is a condition for the application of macros in the analysis of the data.

This structure may have to be modified according to the needs of the data processing procedures in any specialised software package that might be acquired for the project in years to come.

3.3.2 Data Processing

Before the analysis can commence, the data have to undergo a strict process of scrutiny, checking, and correction. Data checking in the field office (see Section 3.2.3) is only the first step. Data processing is a very responsible job. It has to be carried out by a specialist who is well aware of the methods of analysis and of the statistical procedures involved. In Nepal, data processing is delegated to the Department of Hydrology and Meteorology of His Majesty's Government of Nepal. The following text specifies the data processing procedure and is extracted from a hand out by Mr. Sunil Kansakar (Department of Hydrology and Meteorology) provided to trainees at the PARDYP Training Workshop in November 1997.

In practice, there is always a difference between the measured and the true values. This difference is known as error. The errors are classified into three groups:

- incompleteness of data,
- errors in observation, and
- administrative errors.

Incompleteness of Data

Incompleteness of data is caused by failure of instruments or by discontinuity in observers' recordings. The missing data can be estimated by:

Table 8: Data Format for the Manual Water Level Reading

Staff Gauge

Instrument:	Ordinary Staff Guage
Site #:	1 (Yarsha *Khola* Watershed)
Station:	Main Hydro Station
Year:	1997
Interval:	24 Hour
File Name:	YG197

File Name: YG197

Day	8:00	16:00	Remark
1-Jun	42	40	
2-Jun	41	40	
3-Jun	40	44	
4-Jun	42	38	
5-Jun	40	41	
6-Jun	43	41	
7-Jun	42	41	
8-Jun	44	42	
9-Jun	43	42	
10-Jun	45	43	
11-Jun	40	39	
12-Jun	40	38	
13-Jun	39	38	
14-Jun	40	38	
15-Jun	40	38	
16-Jun	39	38	
17-Jun	39	40	
18-Jun	44	42	
19-Jun	38	38	
20-Jun	41	39	
21-Jun	38	36	
22-Jun	45	39	
23-Jun	48	40	
24-Jun	50	43	
25-Jun	48	52	
26-Jun	50	52	
27-Jun	48	44	
28-Jun	50	46	
29-Jun	46	42	
30-Jun	52	64	
1-Jul	56	50	
2-Jul	50	50	
3-Jul	52	50	
4-Jul	56	52	
5-Jul	80	68	
6-Jul	64	58	
7-Jul	95	68	
8-Jul	78	74	

- interpolation (linear in the case of slowly changing processes, polynomial in the case of rapidly changing processes),
- comparison with other observations at the same or from nearby stations (double mass curve, regression), and
- rainfall-runoff models to fill in the missing runoff data.

Errors in Observation

- Random errors (accidental errors) occur by chance, both above and below the true value. They do not greatly affect the mean value and hence the effect can be reduced by increasing the number of observations or by improving the accuracy of individual measurements.
- Systematic errors cannot be eliminated by increasing the number of readings or observations. They can be caused by the instrument and also by incorrect rating curves. Systematic errors can be detected by calibration. Systematic errors affect mean results as well as the extremes.
- Gross errors occur occasionally, resulting from random instrument failure, from human error during measurement, from transfer of data or from misinterpretation of data. If the error is small, it can hardly be separated from random errors. If it is large, the extreme values will be incorrect and, in severe cases, also the mean. Gross errors depend largely on the measurement and registration devices, the maintenance and the method of processing (manually or with computer). These errors may be detected in different ways: visual checking (plot), comparison of values with a given physical range, comparison of the consecutive data differences with a given range (delta check), and comparison of data with those from other stations (plotting hydrographs, double mass analysis).

The total error in a measurement consists of random error, systematic error, and gross error. If the systematic and gross errors are removed, there will still be a residual error caused by random errors. Random errors cannot be corrected but must be kept to the minimum.

3.4 *Administrative Errors*

These errors are usually made by the observer and also at the office where the data are being processed. These errors can easily be detected and corrected. Frequent visits to the station(s) by technical personnel can minimise the errors caused by observers. Errors made at the office can easily be detected through the double entry system in the computer and by comparing the files.

During data processing, the information is not only checked, but is also prepared for the first step in the analysis procedure, and the publication in the Yearbooks (see Section 4.3). In reality, the data control and the first level of analysis (Section 4.2) cannot be separated. However, differentiation is made here in this discussion paper in order to keep the sequence of the considerations clear and transparent. Ideally, the data processing is carried out with special software packages. In Nepal, the HYMOS programme is used at present by DHM; as already mentioned, this package may be introduced in the other watersheds in future. Such software packages usually include facilities to carry out different tests for data control, to identify outside values, to produce graphs, to calculate statistical values or to digitise floater charts.

After completion of the data processing, the information has to go back to the data manager. As long as the data are stored in Excel-files, all these files have to be updated with the changes necessary for data processing. If the data management and storage are standardised in HYMOS (or another package), then the data manager needs to get a copy of the actualised version of the data base.

The data are now ready for analysis and for publication. Analysis is the topic of Section 4.

4. Analysis

This Chapter tackles the complex question of how to analyse all the results collected from the PARDYP research networks. Both the theory and practice of analysis are covered in the context of PARDYP. The two main topics described are the four levels of analysis - data compilation, disciplinary analysis, watershed synthesis, and regional synthesis - and the analytical tasks to be carried out at each level of analysis in order to be able to completely assess the results and draw accurate regional conclusions.

The collection of reliable data is crucial and an important challenge in the PARDYP project. A good data base, however, only makes sense if something useful is done with the information. For several reasons, analysis is a big challenge in the PARDYP project.

- PARDYP is a highly interdisciplinary project.
- Large amounts of information on various parameters are collected. The patterns and processes of individual parameters and the interactions between the parameters have to be understood as the principal contribution to the synthesis.
- Data collection and analysis are carried out in five watersheds. The results have to be compared.
- Many individuals and institutions are involved in the analysis.

It is obvious that the analysis has to be well defined, organized, and focussed towards the project objectives. This Section provides basic ideas and guidelines for hydrometeorological analysis in integrated watershed management projects, defines the compulsory analysis steps in PARDYP, and discusses possible approaches for the synthesis.

Several publications were important for the compilation of this Section: the project document (ICIMOD 1996), guidelines for the management of complex systems (Ulrich and Probst 1995), the previous work in Jhikhu *Khola* Watershed (Shah et al. 1991; Wymann 1993; Schreier et al. 1995; and Carver 1997), as well as literature documenting watershed studies in other parts of the world (Hurni 1994; Romang 1995).

4.1 Theoretical Considerations: The PARDYP Watersheds as Complex Systems (after Ulrich and Probst 1995)

4.1.1 The System and Its Parts

A system is an entity which consists of several parts (elements). These parts are linked with each other and influence each other. Systems are dynamic entities. The mechanisms and the reactions of the whole system result from the interactions among its parts; what we consider a system and what we consider its elements is a question of perception. The borders of the system with its environment do not exist, they have to be constructed.

In the PARDYP watersheds, the system can be an erosion plot, a subcatchment, or the watershed as a whole (Fig. 27). In each case, physical, economic, and social parameters are the parts of the respective system (Fig. 28). These elements strongly influence each other. The interactions between the parts make the watershed, the subcatchment, and the erosion plot a dynamic system. The project aims to understand the mechanisms of the system, the dynamics within the system, and the interactions between man and environment. To achieve this goal, the system can be investigated by analysing the interactions between the different parts and by integrating them. The single elements, however, have to be understood before integration can take place: disciplinary analyses (e.g., in hydrology and meteorology) have to be carried out first. These disciplinary analyses, however, have at any time to be guided by the information needs on the system level. The results in the hydrology and the meteorology components have to contribute to the overall project questions.

Figure 27: The Yarsha Khola Watershed as a complex system (photo: November 1996, view from Charikot)

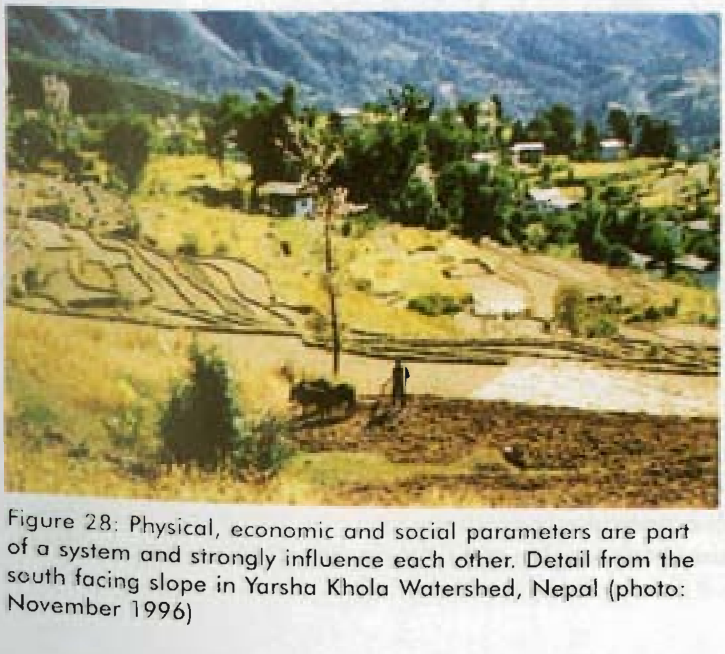


Figure 28: Physical, economic and social parameters are part of a system and strongly influence each other. Detail from the south facing slope in Yarsha Khola Watershed, Nepal (photo: November 1996)

4.1.2 Complexity

Complexity means that a certain matter is complicated and that it permanently changes its state. Complexity, therefore, is the ability of a system to achieve a number of different states within a given time span. Whereas in complex, trivial systems (e.g., a machine) a specific input is always transformed into the same output, in complex, non-trivial systems (e.g., ecological and social systems), this is not necessarily the case. Complex, non-trivial systems, therefore, can never be completely controlled, and it is impossible to make exact forecasts.

The parts of a dynamic entity are connected with each other in a complex network. Linear cause-effect chains are not an appropriate model for the understanding of dynamic entities. The interactions between elements can be very different and can change with time. Circular linkages between several elements result in positive or negative control loops which make the whole system either grow or shrink. In order to understand the mechanisms of a system, it is therefore imperative not only to know the interactions between the elements as such, but also to understand the mechanisms of circular processes with positive or negative control loops over time.

The PARDYP watersheds, subcatchments, and erosion plots are complex, non-trivial systems. The theoretical considerations discussed above are therefore highly relevant.

- Complex, non-trivial systems: a particular rainfall event (input) does not always produce the same discharge or erosion (output) due to the number of factors involved and the linkages between the different factors.
- Control loop, a scenario: the extension of the road network in a watershed may lead to improved market access. This results in an increase of agricultural production -- which represents a positive control loop – and the system grows, at least economically. In the long term, however, this situation may lead to increased pressure on resources, to scarcity of water, to deterioration of water quality, or to decrease in soil fertility, which represents a negative control loop; thus, the system may shrink, not only economically, but also in environmental quality.

Such considerations are highly relevant to PARDYP, especially if interventions are tested and recommended. The linkages have to be defined, the interactions and the circular relationships (positive or negative control loops) have to be identified and investigated. In terms of meteorology and hydrology, the study of water balances, of annual water cycles, and the monitoring of soil erosion and soil fertility on different plots provide important basic information.

4.1.3 Structure

Although entities are complex systems, they are usually characterised by patterns, by rules, or by mechanisms which the systems follow; in other words, by a certain degree of order. Order in a system is documented by specific linkages between parts of the system and by particular patterns. Therefore, in order to understand the mechanisms of a system, it is not necessary to investigate the system in each and every detail. It is, however, important to identify the basic structure of the system, the basic mechanisms in the system, and the rules followed by the processes within the system.

Similarly, although the processes and linkages in the PARDYP watersheds are complex, they follow certain rules: a specific rainfall intensity may produce a specific amount of erosion on rainfed cultivated land (*bari*); a particular bedrock situation may host a specific soil type in similar rainfall and temperature conditions. The tasks of the analysis, therefore, are twofold.

- In the disciplinary analysis (see Section 4.4), the key processes (the guiding principles) have to be understood (e.g., rainfall patterns, discharge characteristics, water potential, trade systems, agricultural production, etc).
- For the synthesis (see Section 4.5), the key linkages and mechanisms have to be understood (soil erosion and soil fertility decline as a function of rainfall, slope, aspect, geology, land-use practices, etc).

4.1.4 The System and Its Environment

A system is part of a bigger entity, it is embedded in an environment. The system influences this environment and is itself influenced by the surrounding or adjacent bigger entity. The mechanisms within a system can only be completely understood if it is known how the respective systems are embedded in their environment.

The systems within the PARDYP framework (erosion plot, subcatchment, watershed) are open to their environment.

- The surface runoff of an erosion plot influences the hydrology of the subcatchment in which the respective plot is located. The hydrological behaviour of a tributary has an impact on the characteristics of the main river of the watershed. The river leaving the watershed at the main station influences downstream areas, e.g., by producing floods, providing potential for irrigation, and contributing to hydropower production.
- Hydrologically, the Xi Zhuang Watershed in China is not a closed system: through karstic processes there may be water inflow from adjacent watersheds.
- Tourists coming to the Beta Gad Watershed in India influence the economy of the area.
- The proximity of the Indian watershed to the regional centre, Almora, provides job opportunities for the inhabitants of the watershed. Furthermore, products from the watershed can be sold in the market at Almora.

4.1.5 Guiding Principles for the Analysis

The considerations on complex systems and their implications for the PARDYP project indicate that the analysis and synthesis are highly challenging. The basic approach must be to understand the watershed or parts of it as complex systems, to identify key processes (in the disciplinary analysis, Section 4.4), key linkages between parameters (in the watershed synthesis, Section 4.5), and to compare the key results from different watersheds with each other (in the regional synthesis, Section 4.6). There are a number of guiding principles to be followed.

- The analysis has to be carried out on different levels (see Section 4.2).
- At least three spatial scales have to be differentiated: whole watershed, subcatchment, and plot. If necessary, the linkages to areas outside the watershed have to be included as well. The scale to be selected depends on the topic of the respective analysis. The combination of different scales (systems) is a big challenge in terms of project synthesis.
- The processes in a watershed can happen in different time spans, the spatial patterns can change over time. Therefore, different time scales have to be looked at in the analysis: year, season, month, event, day or below. In order to identify changes over time (of physical parameters, land-use systems, forest cover, etc) or to see the success of the rehabilitation

measures, a long-term view of the analysis is important as well. This, however, is only possible after several years of data collection. The ideal time scale to be selected again depends on the topic of the particular analysis.

- Balances (water, sediment, nutrient) are very important for the analysis of physical patterns and processes. Balances also have to be studied on different temporal and spatial scales.
- For each step in analysis, pragmatic procedures have to be applied as far as possible: these should be driven by the question: what is the aim of the respective step and what is necessary (data, literature, methodology) to fulfil the task? Since the project is very complex, the analysis must be kept as pragmatic and simple as possible!
- Each block of analysis has to be documented in a working paper which discusses the aims of the analysis, the step by step procedure, the data and references used, the findings, and the conclusions. Working papers ensure that the expertise of a collaborator who focussed on a particular study is made available to the project. They also help to keep records of the state of analysis in the different components of the project. Working papers are particularly important in the disciplinary analysis (see Section 4.4): they are the basic documents, the puzzle pieces of information to be used in the synthesis (Section 4.5).

In the following Sections the theoretical considerations are transformed into an action plan for the analysis of hydrometeorological components.

4.2 The Four Levels of Analysis: Introduction

Due to the complexity of the project, an attempt was made to structure the analysis into different levels (Fig. 29). The levels of data compilation and of disciplinary analyses are completely focussed on the hydrology and meteorology components. For the watershed and regional synthesis, however, meteorology and hydrology are linked to the other parameters of PARDYP. With each level of analysis, the complexity increases, each 'higher level' of analysis builds upon the findings of the 'lower level'.

- Level of data compilation: the information is compiled and made ready for the process analysis. The understanding of processes is not envisaged.
- Level of disciplinary analysis: based on the information prepared in the level of compilation, the analysis is carried out in the context of either meteorology or hydrology in order to identify the basic patterns and key processes. The link with other parameters is not envisaged.
- Level of watershed synthesis: the results from the disciplinary analysis are combined in order to identify the interactions between different parameters. The boxes in Figure 29 are only a selection of many more parameters to be included at this level.
- Level of regional synthesis: the main findings from the data compilation, disciplinary analyses and watershed synthesis are compared with the same elements in the other watersheds in order to identify common, key processes and patterns in the east-west transect through the Hindu Kush-Himalayan region.

According to the project document (ICIMOD 1996), the project should be a research as well as a development undertaking. Therefore the analysis should provide:

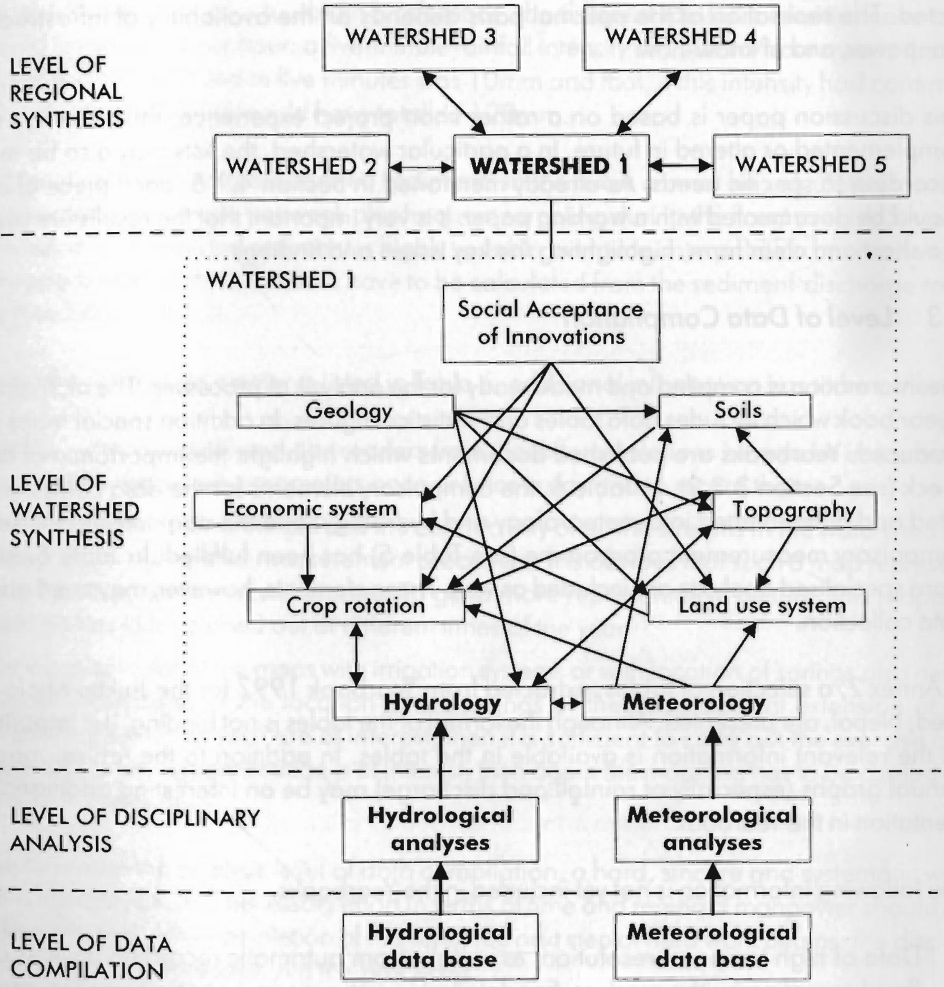


Figure 29: The four levels of synthesis

a) basic information for different research needs of the project as well as of users outside the direct project framework,
b) applied information for the answering of concrete, development-oriented project questions,
c) puzzle pieces to the world-wide efforts of comparative mountain research and development.

Figure 29 only provides the general structure of the different levels of analysis. In the subsequent chapters, details are provided for each level. The catalogue of the hydrological and meteorological elements to be analysed in each level (Tables 6,8,9, and 10) is the key part of the respective Sections as it focusses the analysis on the project objectives. The tables differentiate between the compulsory investigations, which have to be carried out in each watershed and which can be realised within the compulsory measurement programme (see Table 5) and the specialised (optional) analysis for which, in most cases, additional information has to be collected. The realisation of the optional parts depends on the availability of infrastructure, of manpower, and of know-how.

This discussion paper is based on a rather short project experience, thus, the lists may be complemented or altered in future. In a particular watershed, the lists may also be modified according to specific needs. As already mentioned in Section 4.1.5, each piece of analysis should be documented with a working paper. It is very important that the results are presented in a short and clear form, highlighting the key issues and findings.

4.3 Level of Data Compilation

The information is compiled and made ready for the analysis of processes. The main product is a year book which includes data tables and statistical figures. In addition special maps may be produced. Yearbooks are published documents which highlight the importance of the data check (see Section 3.3.2). In Table 6, the compulsory elements for the data compilation are listed and differentiated into meteorology and hydrology; and this can only be realised if the compulsory measurement programme (see Table 5) has been fulfilled. In Table 6, ideas for more specialised analyses are included as well. These elements, however, may need additional data collection.

In Annex 2, a selection of tables, extracted from Yearbook 1997 for the Jhikhu *Khola* Watershed, Nepal, are presented. Although the format of the tables is not binding, it is important that all the relevant information is available in the tables. In addition to the tables, monthly or annual graphs (especially of rainfall and discharge) may be an interesting additional documentation in the Yearbook.

The following information is not yet included in the Yearbooks.

- Data of high temporal resolution, especially from automatic recording devices or from flood sampling by the readers. For detailed investigations, especially for the analysis of events (see Section 4.5), the information has to be collected from the raw data base.
- The results from the chemical analyses of sediment and water samples.
- In the hydrology records, the discharges, not the water level, are published. Discharge data are more common in publications and more useful for analysis. The lists of mean daily discharge are created on the basis of the preceding establishment of the rating curve.

Regarding the meteorological components, the output is specified in detail for rainfall and temperature, these being the two most important meteorological elements for the project. The type of data compilation and the format of the data tables of the other meteorological parameters (mainly recorded at the main meteorological station) depend very much upon the measurement devices and on the frequency of readings.

Experiences in 1997 demonstrated that the calculation of different rainfall intensities is a difficult and time-consuming task. This is particularly true for those tipping buckets that do not record in equal time steps. No automated approach for the identification of the highest intensities has been found yet, although it is possible that this facility exists in some of the more specialised software packages. In order to obtain a reference, the different rainfall intensities have to be expressed in millimètre per hour: a five-minute rainfall intensity of 120mm/hour means that the maximum rainfall recorded in five minutes was 10mm and that, if this intensity had continued for 60 minutes, the rainfall would have totalled 120mm.

The tables of average daily suspended sediments in the rivers cannot be calculated from the single samples (one sample per week plus frequent sampling during the flood events). Since the concentration of suspended sediment is highly variable over time, interpolation methods would create considerable errors. The data have to be calculated from the sediment-discharge rating curves (see Section 4.4.2).

To realise the specialised elements listed in Table 6, additional information has to be collected.

- For the meteorological part, the readers from the different stations have to be instructed to observe the respective parameters once or twice a day and to record them.
- The map documenting the pH and the conductivity of all the streams in the watershed has to be based on a special measurement procedure. It is obvious that such a map represents only the situation during measuring. To get a more representative picture, this mapping exercise has to be carried out at different times of the year.
- The establishment of the maps with irrigation systems or with location of springs also needs special procedures. If the location of the springs or the geographical extension of the irrigation systems as such are of interest, then it is sufficient to carry out the exercise only once. However, if quantification is of interest, then again the mapping has to be carried out in different seasons.

In order to realise the analysis level of data compilation, a hard, sincere and systematic work regime is needed, and the necessary effort in terms of time and required manpower should not be underestimated. After completion of this level, the next step of hard work begins: the disciplinary analysis and a close look into the processes.

4.4 Level of Disciplinary Analyses

The complexity of a system can only be understood if the characteristics of the individual parameters are known. This is the main aim of the level of disciplinary analyses: the hydrological and meteorological patterns and processes within the watershed are investigated. The results are puzzle pieces for the level of watershed synthesis (Section 4.5) contributing to the interdisciplinary questions of PARDYP.

Table 7 lists compulsory and specialised topics to be analysed in meteorology and hydrology. The Table may be extended or modified in future depending on the development of the project objectives or on the skills and know-how of the project collaborators. The catalogue of compulsory investigations provides strict guidelines for the analyses: many interesting things could be done with the amount of data but not all of the results are useful for PARDYP. Therefore, the compulsory requirements have to be fulfilled before going for further, more specialised exercises. On the meteorology side, rainfall receives much attention as it is a very important parameter in the PARDYP framework and in watershed management in general.

The different topics are commented upon and illustrated below. The examples provide som ideas. The most suitable methods of approaching the different elements, however, have yet t be identified. This is mainly the task of the person or the team responsible for the particul analysis.

In the disciplinary analyses, pure documentation is not sufficient. Whatever graphs or tables ar produced, they have to be understood and analysed. The understanding of patterns and proc esses is in the focus of each and every analysing step. The working papers are of particul importance, they are comparable with the 'drawers' of a cupboard: each drawer includes specific disciplinary topic which in itself can be looked at separately and can be finalise individually. The contents of these drawers are the puzzle pieces of the synthesis.

Many analytical steps have to be differentiated into seasons. We suggest standardising th seasons as follow:

Pre-monsoon:	March-May,
Monsoon:	June-September,
Post-monsoon:	October-November, and
Winter:	December-February.

4.4.1 Compulsory Meteorological Analyses (Table 6)

Spatial Rainfall Patterns

The spatial patterns of rainfall in the watershed are investigated for different periods of the yea single months (e.g., monsoon months), monsoon sums, annual sum. The following element are looked at.

- Amount, distribution, and range of rainfall within the watershed for the different tim periods (isohyetal map, for example, see Fig. 30).
- Differentiation according to aspects, particularly the directon of the monsoon winds.
- Altitudinal gradients, as illustrated in Fig. 31: please note the considerable altitudina gradient in September and the almost equal rainfall in December, a result of differen rainfall origin. Altitudinal rainfall gradients are also documented in Fig. 32: whereas th lower part of the watershed was still receiving sunshine, the upper part received hea rainfall, causing considerable damage.
- Quantification of rainfall for different parts of the watershed, e.g., the subcatchment mapping of areal rainfall providing information on areas with high or low rainfall.

Temporal Rainfall Patterns

The rainfall distribution over the year is investigated for the different stations in the watershed The following two elements are looked at:

- percentage contribution of different seasons (pre-monsoon, monsoon, post-monsoon, win-ter) to the total annual rainfall (Fig. 33) and
- rainfall distribution over the monsoon season: identification of active and break phases o the monsoon (Fein and Stephens 1987).

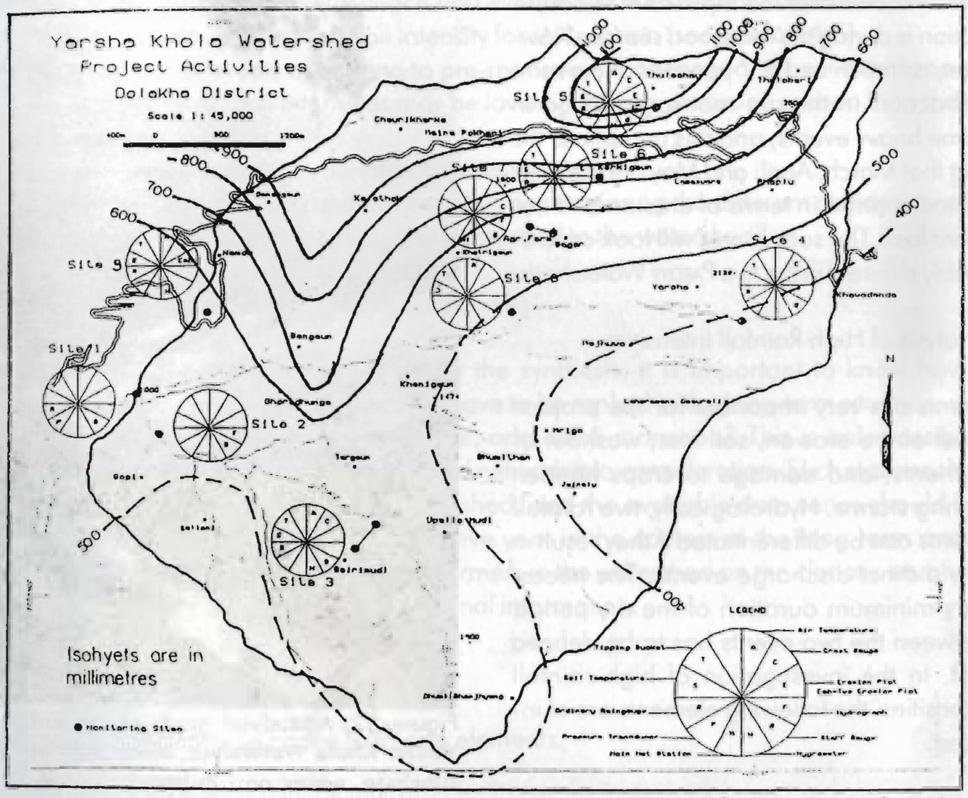


Figure 30: Isohyetal map of Yarsha Khola Watershed

The sum curve in Figure 33 is one option for the investigatation of temporal rainfall patterns: it

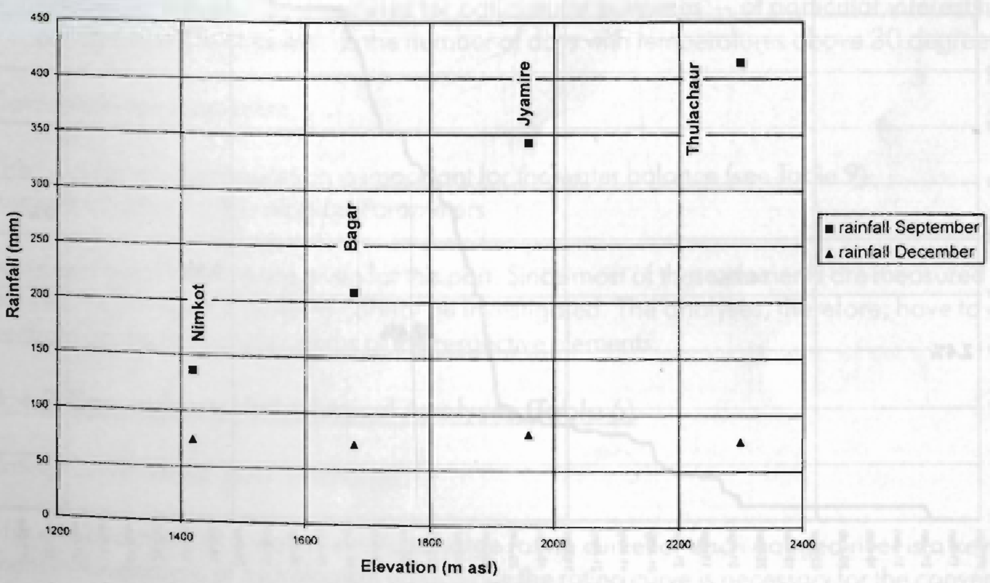


Figure 31: Altitudinal gradient of rainfall in Yarsha Khola Watershed, September and December 1997

is well known that the main rainfall contribution is during the monsoon season. However, as much as 14.7 per cent of the rainfall occurs in the pre-monsoon period in some heavy events, and this underlines the fact that March, April, and May are the most critical months in terms of erosion and nutrient loss. The sum curves will look considerably different in the five PARDYP Watersheds.

Analysis of High Rainfall Intensities

Events are very important for the project: most of the erosion, soil loss, washout of nutrients, and damage to crops happen during storms. Hydrologically, two rainfall events can be differentiated if they result in two distinct discharge events. The necessary minimum duration of the dry period between the two events has to be defined first. In the investigation of high rainfall intensities, the following elements are of interest.

Figure 32: Altitudinal gradient of rainfall in Yarsha Khola Watershed: lower part in sunshine, upper part in heavy rainfall (photo: July 1997)

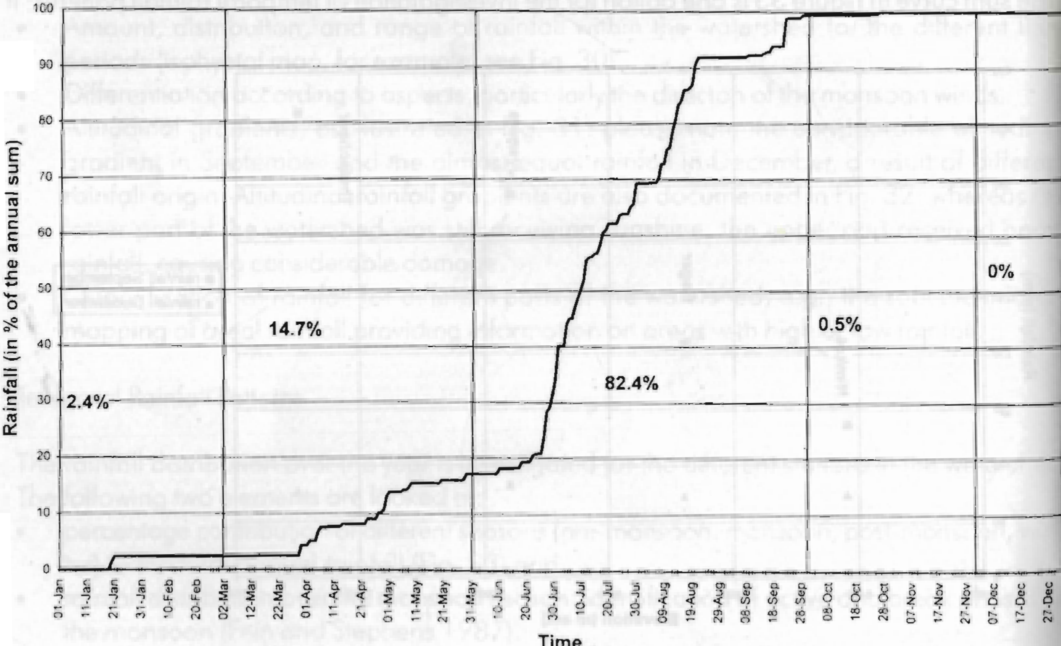


Figure 33: Rainfall sum curve for Dhaireni, Jhikhu Khola Watershed, 1997

- Classification of rainfall events: each and every event is not equally important. There are certain threshold values of rainfall intensity for soil erosion (see Section 4.5).
- Differentiation of events according to pre-monsoon, monsoon, and post-monsoon seasons: the critical rainfall intensities may be lower in the pre-monsoon season than they are in the monsoon season.
- Frequency analysis of high rainfall intensities.
- Regional patterns of high rainfall intensities by comparing the different stations: are high rainfall intensities usually localised or widespread in the watershed?

Comparison of Rainfall with Long-term Data Series

For the disciplinary analyses as well as for the synthesis, it is important to know how the meteorological processes of a specific year have to be ranked in the long-term situation: was it a wet or dry year? Was it a heavy, a normal, or a weak monsoon? This is only possible by taking data series of stations from the national network into consideration. Such stations should be located as close as possible to the watershed, and the available data series should be as long as possible in order to see the respective year in the context of the long-term average situation and variability. The perception of farmers in the watershed on the climatic situation of the respective year provides valuable additional information.

Spatial and Temporal Temperature Patterns

The analyses have to focus on the following elements.

- Spatial patterns of temperature (average, maxima, minima) for different periods (single months, monsoon season, winter season) and different expositions (mainly north- and south-facing slopes) -- isoline maps are very convenient tools for this investigation
- Temperature gradients with elevation.
- Analysis of extreme temperatures for agricultural purposes -- of particular interest is the occurrence of frost as well as the number of days with temperatures above 30 degrees.

Calculation of Evaporation

The calculation of evaporation is important for the water balance (see Table 9).
Analysis of Other Meteorological Parameters

Not many specifications are given for this part. Since most of these elements are measured only at one site, the spatial patterns cannot be investigated. The analyses, therefore, have to concentrate on the temporal patterns of the respective elements.

4.4.2 Compulsory Hydrological Analyses (Table 6)

Rating Curve: Water-level/Discharge

The establishment of a water-level/discharge rating curve for each gauged river is a key element in the analysis of hydrological data. Since the rating curve is necessary for the conversion of water level into discharge, the establishment of this relationship is a precondition for the

Table 9: Level of Watershed Synthesis - Compulsory, Specialised and Long-term Analyses

Compulsory	**Studies on the watershed level** • Water balance (rainfall=discharge+evaporation+reservoir change) per year, per season, per month • Relationship between spatial and temporal climatic conditions (rainfall/temperature) and agricultural systems (annual cycles, crop types, crop rotation, rainfed/irrigated systems) • Regional water potential and recommendation for crop types and the amount of crops. **Studies on subcatchment level** • Water balance (rainfall=discharge+evaporation+reservoir change) per year, per season, per month • Rainfall/discharge/suspended sediment/nutrient loss as a function of geology, soil type, elevation, slope, aspect, land use (spatial and temporal differentiation) **Studies on the plot level** • Erosion, sediment and nutrient loss as a function of rainfall, slope, aspect, elevation, soil characteristics, crop type, technique of land preparation, season • Rainfall/runoff/soil loss relationships: threshold values of erosion with different rainfall intensities • Cash value on the loss due to erosion • Indigenous practices for prevention of excessive surface runoff and soil loss **Analysis of the 3 major storm events during one monsoon season** • Rainfall patterns, intensities • Rainfall-discharge relationships • Hydrographs (characteristics of rising and falling limbs, range of discharge) • Runoff/discharge/sediment output/nutrient output on plot, subcatchment and watershed level • Reports on landslides, slumps, mud flows, terrace failures, slope failures, gully formation • Crop damage, economic impact • People's reaction
Specialised	**Study of irrigation systems** • Quantitative and temporal analysis of discharge water for irrigation (off-takes, distribution patterns, back flows) • Sediment and nutrient movements with irrigation water • Water quality for irrigation and drinking purposes • Indigenous water management practices, water rights, social organization in the context of water management • Potential/need for water harvesting • Water demand for different crops or cropping systems Movement of sediments and nutrients: plot → sub catchment → main watershed → outside the watershed as a function of slope, geomorphic processes, rainfall and hydrological conditions, agricultural systems
Long-term	Economic impact of erosion and soil fertility loss Effects/success of rehabilitation measures or of improved agricultural practices on runoff, sediment loss, soil fertility, etc. Changes in the water balance at the watershed and subcatchment levels as a result of changes in the watershed (land use systems, forest cover, water use, etc). Impact of the use of fertilizer on water quality

tables of mean daily discharge in the Yearbook (see Table 8). Therefore, this step has to be carried out parallel to the activities in the level of data compilation (Section 4.3). The following considerations are partly extracted from a hand out provided to the trainees of the workshop in November 1997 by Mr. Sunil Kansakar from the Department of Hydrology and Meteorology, Kathmandu.

Once a number of flows at a specific hydrological station has been measured, it is possible to determine the relationship between the different flows and the corresponding water levels: The most accurate curve is obtained when the measurements are spread evenly over the complete range of occurring water levels. However, experience shows that this is difficult to achieve: high water levels are much rarer than low water levels and high river flows are very difficult to measure. Accordingly, rating curves are usually quite accurate in their lower parts, but get more uncertain in the higher part.

For the preparation of rating curves, it is customary to plot discharge on the x-axis, the water level on the y-axis. Due to varying natural conditions during a series of discharge measurements, it is obvious that the plotted points will not be located on one smooth curve. Therefore, a regression curve has to be drawn that fits the points. For this purpose, a sufficient number of measurements is required, suitably distributed over the whole range of water levels and each measurement preferably made in steady conditions. In the PARDYP watersheds, it has been suggested that the power trend line equation be used for the construction of the rating curves (for more information about the establishment of rating curves and the respective formula see WMO 1980). An example of a rating curve is documented in Figure 18.

According to Chow et al. (1988), the rating curve must be checked periodically to ensure that the relationship between the discharge and gauge height has remained constant. Scouring of the stream bed or deposition of sediment in the stream can cause the rating curve to change so that the same recorded gauge height produces a different discharge. In the case of the PARDYP watersheds, this is particularly important since most of the hydrological stations are located in mountain streams and the cross-sections, where not sealed, may change, particularly during heavy storm events. In one subcatchment of the Xi Zhuang watershed in China, for instance, three different rating curves had to be established for the monsoon in 1997.

Rating Curve: Discharge/Suspended Sediments

Under the assumption that the concentration of suspended sediment in a river is a function of the discharge, it is possible to calculate a rating curve that provides the relationship between the two variables. The tables on daily sediment concentration in the Yearbook (see Table 8) have to be based on such rating curves. The relationship between river flow and suspended sediment is much more difficult to establish than the water-level/discharge rating curve since the relationship is much less stable. Figure 20 illustrates discharge/sediment concentrations for different stations in Jhikhu *Khola* (Carver 1997) and highlights two important facts.

- The measurement points are scattered, they form a cloud of dots.
- There is a clear differentiation according to seasons: the sediment output in the pre-monsoon period is much higher than in the monsoon season. This finding again highlights the importance of March, April, and May in terms of erosion and movement of nutrients.

Annual Hydrographs of the 'Main Values

For the discussion of the general discharge characteristics, there are several 'main values' th are defined in hydrology (e.g., the highest or lowest ever-measured discharge, the highest lowest discharge measured in a given time period, the arithmetic mean of all the observatior over a given time period, etc; see also Wilhelm 1993). In the Pardyp context, the followin 'main values' have been selected.

- The highest mean daily discharge of each month
- The average mean daily discharge of each month
- The lowest mean daily discharge of each month.

An example is provided for the Jhikhu *Khola* main station (Fig. 34). Based on this grapl typical discharge characteristics over the year, ranges of discharge, differences of discharg characteristics in the pre-monsoon and post-monsoon periods, etc can be investigated. Wi only one year's data, the lines are, as yet, not very smooth, especially those representing th maximum mean daily discharge. This will change once the graphs are based on several year data.

Duration Curve of Discharge

The duration curve is the most important graph for the plotting of hydrological observations. It basically a sum curve with 365 days on the x-axis and the sorted discharge values on the y-ax (see Fig. 34). From this graph some very important information can be extracted.

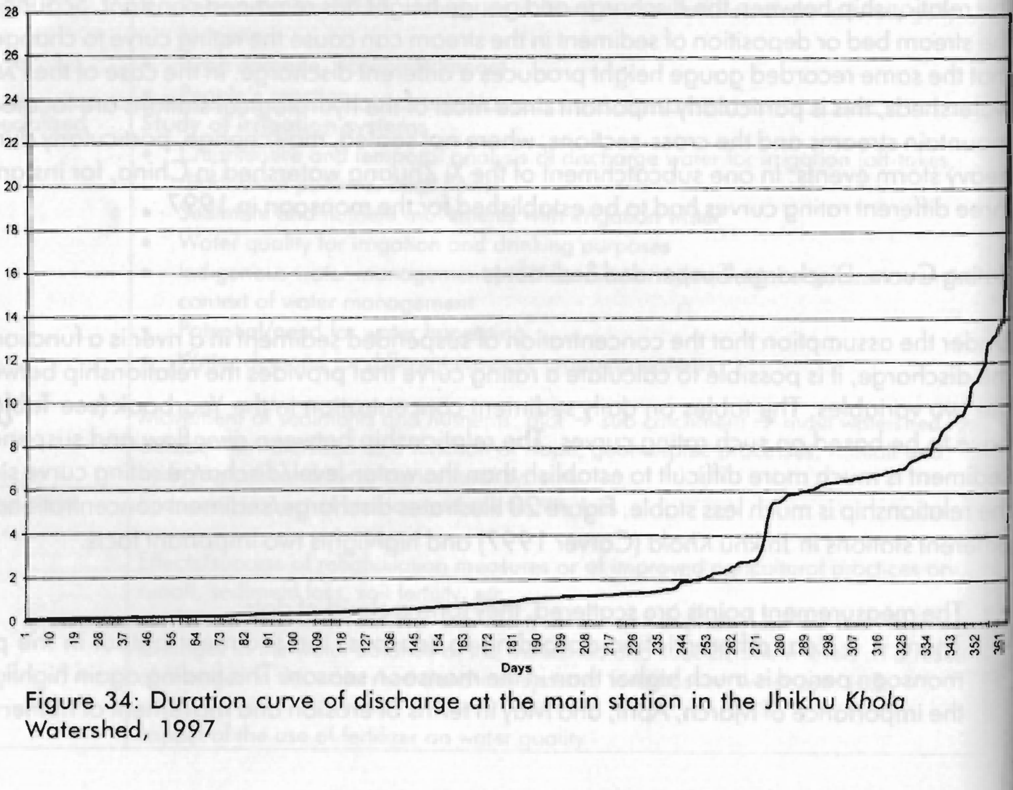


Figure 34: Duration curve of discharge at the main station in the Jhikhu *Khola* Watershed, 1997

- The lowest mean daily discharge per year
- The highest mean daily discharge per year
- The median annual discharge
- The discharge that in 365/2 days is either not reached or exceeded and, for each level of flow, the number of days on which this particular flow is not reached or is exceeded.

Such information is very important for applied hydrology (e.g., irrigation, hydropower). For more information about duration curves see Dyck (1980: p 100/101).

Balances of Runoff, Discharge and Sediment Transport

The total volume of water and sediment output is investigated in two ways.

- Differentiation in time: annual, pre-monsoon, monsoon, post-monsoon, monthly, event-wise balances; output from each period in % of the annual output. The differentiation in time helps to answer the question: are the more extreme climatic events responsible for the vast majority of the sediment and nutrient removal or is it a gradual change that occurs invisibly from day to day?
- Differentiation in scale: balances at the main hydro station, at the hydro stations of the subcatchments, at the erosion plots. Comparison of the sediment outputs from the three different scales is particularly interesting: on the erosion plot, the per area output may be rather high. With increasing scale, the per area sediment output (sediment delivery ratio) will decrease as the number of potential sites for deposition increases.

Comparison of Discharge from Different Stations

This investigation is carried out with two stations along a tributary, if available, or two stations along the main river. It provides insight into the changes of hydrological characteristics along the river courses and may be useful for quantification of the:

- hydrological contribution of a specific area,
- loss of water for irrigation,
- loss of water due to karstic phenomena (important in the Xi Zhuang Watershed, China).

In Figure 35, an example is given for the two stations Thulachaur and Bagar on the Khahare *Khola* (Yarsha *Khola* Watershed, see Fig. 10). The upstream catchment at Thulachaur is smaller and dominated by forest and shrubland, the downstream catchment at Bagar is larger and dominated by *bari* and shrubland.

4.4.3 Specialised Meteorological and Hydrological Analyses (Table 6)

This part of the analysis should only be undertaken when the compulsory investigations have been completed, if the specific hydrological and meteorological know-how is available in the team (ideally by involvement of Masters' or PhD students), or if required by other parts of the project. Many of these analyses cannot be carried out with the data collected in the compulsory measurement programme (Table 5). Additionally, more specific information may have to be collected. Therefore, these steps in the analysis are not part of the annual, basic data collection

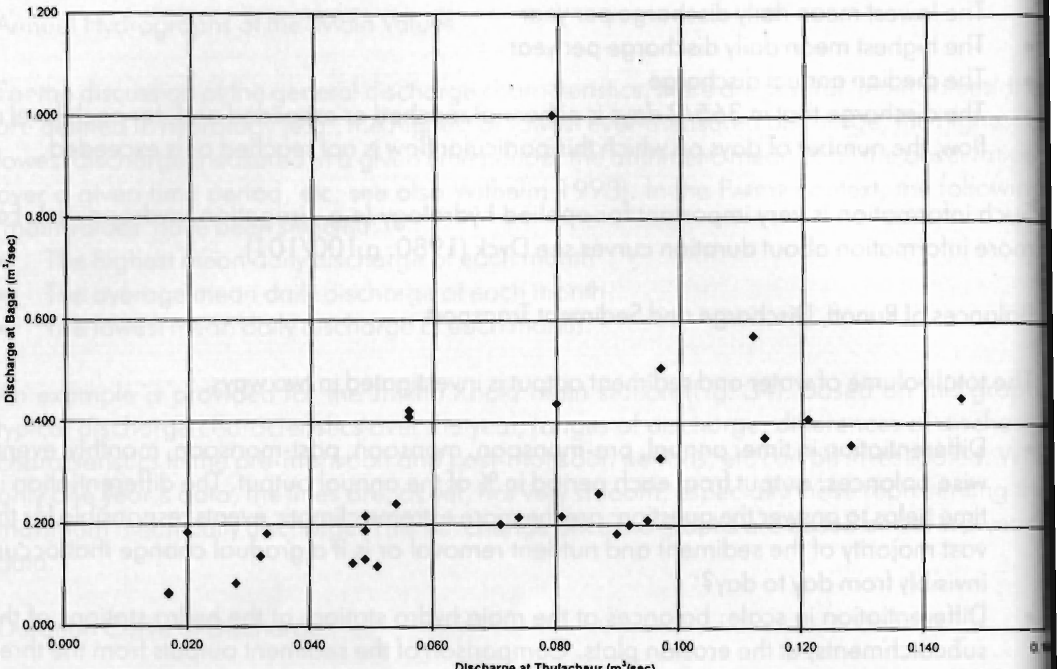


Figure 35: Discharge comparison of two stations on the Kahare *Khola*, Yarsha *Khola* Watershed, 1997

and analysis programme, but may be approached in special studies and carried out only once. Examples of such special studies include the following.

- Frequency and probability of wet and dry spells (wet and dry weather cycles): such cycles play an important role in the advance planning of crops, but they can only be identified by examination of records over a certain length of time.
- Calculation of potential evapotranspiration: useful for agronomic questions.
- Soil temperature and soil humidity: again, in the context of agronomic questions, more in-depth information about hydrometeorological soil conditions may be important and required. The analyses should mainly focus on the patterns at different soil depth and the reaction of soil humidity and temperature on rainfall and air temperature and on frost occurrence in the highest soil layers.
- Concentration times: With this investigation it can be estimated how long it will take until the 'last drop of water' from a rainfall event has left the watershed.
- The mapping of areas with abundant water potential and big water demands is particularly interesting in the context of irrigation or drinking water supplies. Areas with big water demands may not be identical to areas with abundant water supplies.
- To investigate groundwater potential, additional measurement infrastructure and knowledge are needed: groundwater layers and areas, infiltration areas, travel times, underground flow, mapping of springs, soil moisture investigations, etc. Although the investigation of groundwater is not in the list of compulsory activities, knowledge about subsurface water can be very important and is a strong application component in the PARDYP framework of studies. This is especially the case in those watersheds in which water supply is a

critical issue, such as the Jhikhu *Khola* Watershed, due to intensive agriculture, and in the Xi Zhuang Watershed, due to the karstic situation.

- Assessment of sediment potential from different areas: for the question concerning to what extent sediment load in the rivers is strongly influenced by human activities (contributed from agricultural fields for example) and to what extent by natural processes (contributed from key geomorphic events and from riverbank erosion), the assessment of sediment potential could provide interesting insights. A methodology for the assessment of sediment potential was developed in Switzerland and is documented in Spreafico et al. (1996). However, the implementation of this methodology in the PARDYP watersheds is only feasible following training.
- Bedload transport: in order to complement the sediment balances calculated with the suspended load, the estimation of bedload transport can be useful. The investigation could include both the quantification of bedload and the movement of different boulders. However, there is still no standardised, internationally-accepted methodology for this study. It is suggested that simple and straightforward methods be applied wherever bedload is included in the analysis programme; for example, painting of boulders of different sizes and subsequent observation of their movements (tested in Yarsha *Khola* Watershed in 1997); where possible the building of simple sediment traps (planned in the Xi Zhuang and the Bheta Ghad Watersheds).

4.5 *Level of Watershed Synthesis*

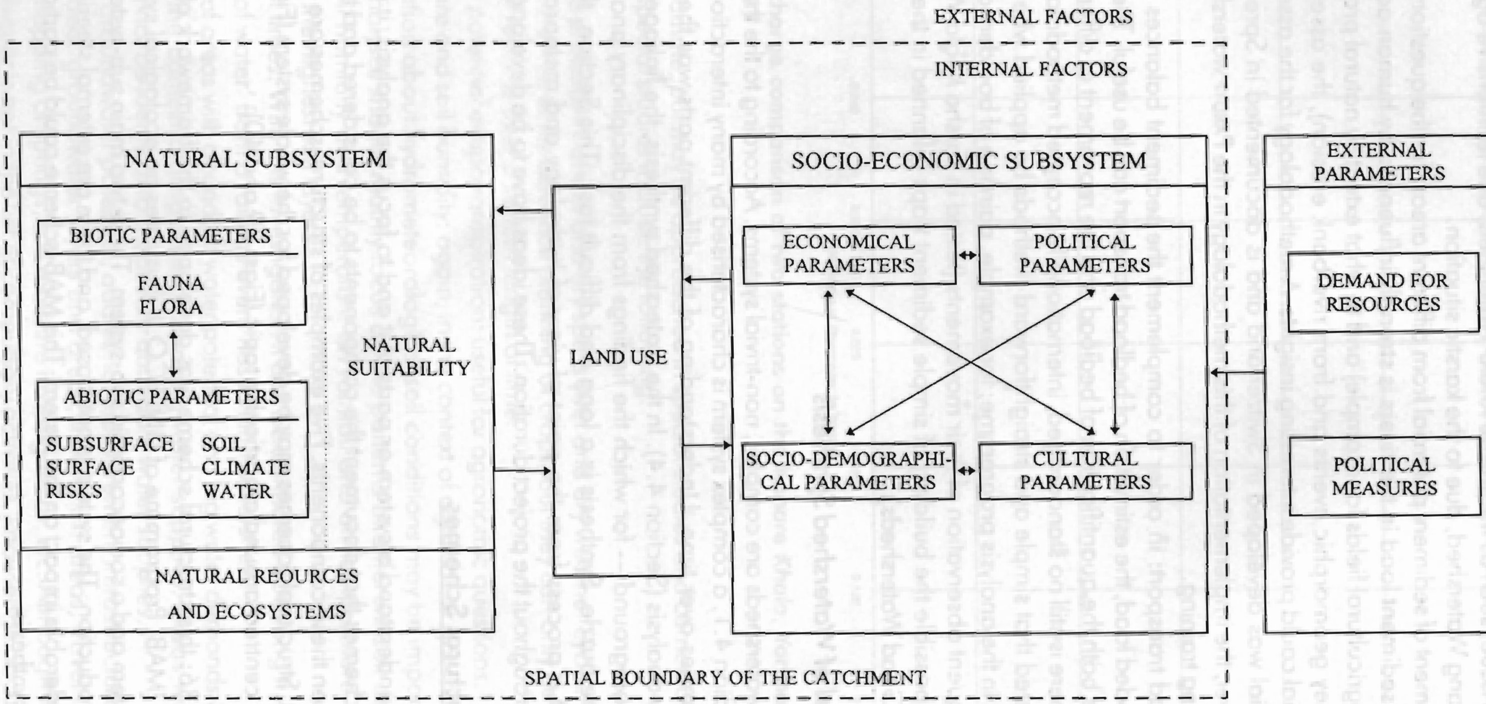
The PARDYP watersheds are complex, non-trivial systems. According to the theoretical considerations in Section 4.1, a complex system is characterised by many interactions between its parts and by changes over time. Understanding of the different parts was the aim of the level of disciplinary analysis (Section 4.4). In the watershed synthesis, the linkages between the parts are in the foreground -- for which the findings from the disciplinary analyses are important pieces in the puzzle. Synthesis is a long and difficult task. This Section, therefore, is just the initiation of a process from the point of view of hydrology and meteorology, which has to continue throughout the project duration. These ideas have to be developed further.

4.5.1 Structural Schemes

In order to understand a system or parts of it and to focus the analysis, it is useful to develop structural schemes that document the components to be considered and the anticipated linkages between these components. Five examples of structural schemes are documented in Figures 36-40. Structural schemes may be developed for the whole system (Fig. 37), for parts of it (Fig. 38) or centred around a particular topic (Figs. 39 and 40).

- Figure 36: this structural scheme was developed in the framework of the Man and Biosphere (MAB) Programme of UNESCO. It illustrates an ecological system with a natural sub-system and a socioeconomic sub-system. These two main sub-systems meet in agricultural production. The system is not closed, and there are external steering factors that have a considerable impact on the system. This MAB-scheme could be particularly useful for the PARDYP synthesis.
- Figure 37: this scheme focusses on the physical part of a watershed system. It displays the elements and processes of the hydrological cycle and links together the meteorological and hydrological elements.

Figure 36: The MAB-Scheme (source: Department of Geography, University of Berne, Switzerland)



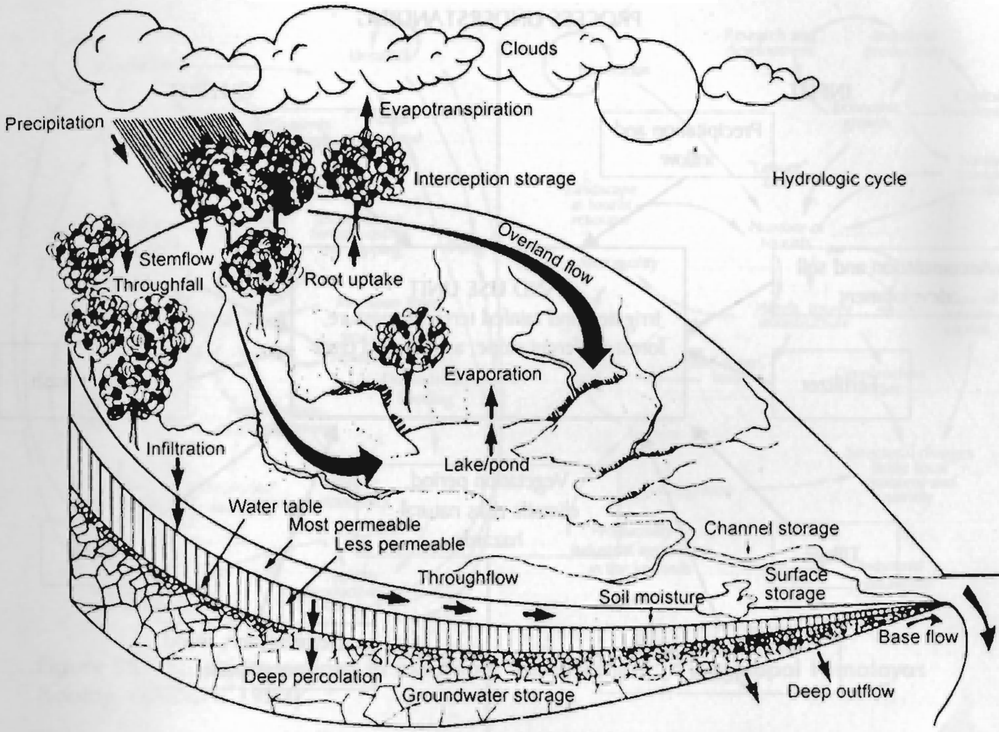


Figure 37: The hydrological cycle in a watershed (source: WARSHALL, 1980)

- Figure 38: this scheme focusses on a land-use unit and shows the different influencing parameters. It attempts to evaluate the sustainability of a particular land-use unit through the use of an input-output model: if the input and the output are more or less identical, the system most probably is sustainable and stable; if, however, the output considerably exceeds the input, the system may be unsustainable and detrimental changes can be expected.
- Figure 39: the left hand part of this scheme is even more specific. It puts soil erosion in the centre and documents all the influencing parameters, the interactions between the parameters and the different control loops (see Section 4.1.2).
- Figure 40: this scheme was developed in the framework of a project on soil conservation in Ethiopia. It shows the different layers and sub-layers that are important in soil conservation. This type of scheme is particularly suitable for developing a GIS system.

These examples provide very useful ideas for the PARDYP project and for watershed management activities in general. In the process of interdisciplinary analysis, the development of such structural schemes is essential, and they have to be developed for the different steps in analysis listed in Table 9. To put a concrete, specific question in the centre and to construct around the structural scheme for the synthesis, it may be a particularly useful approach for the PARDYP project.

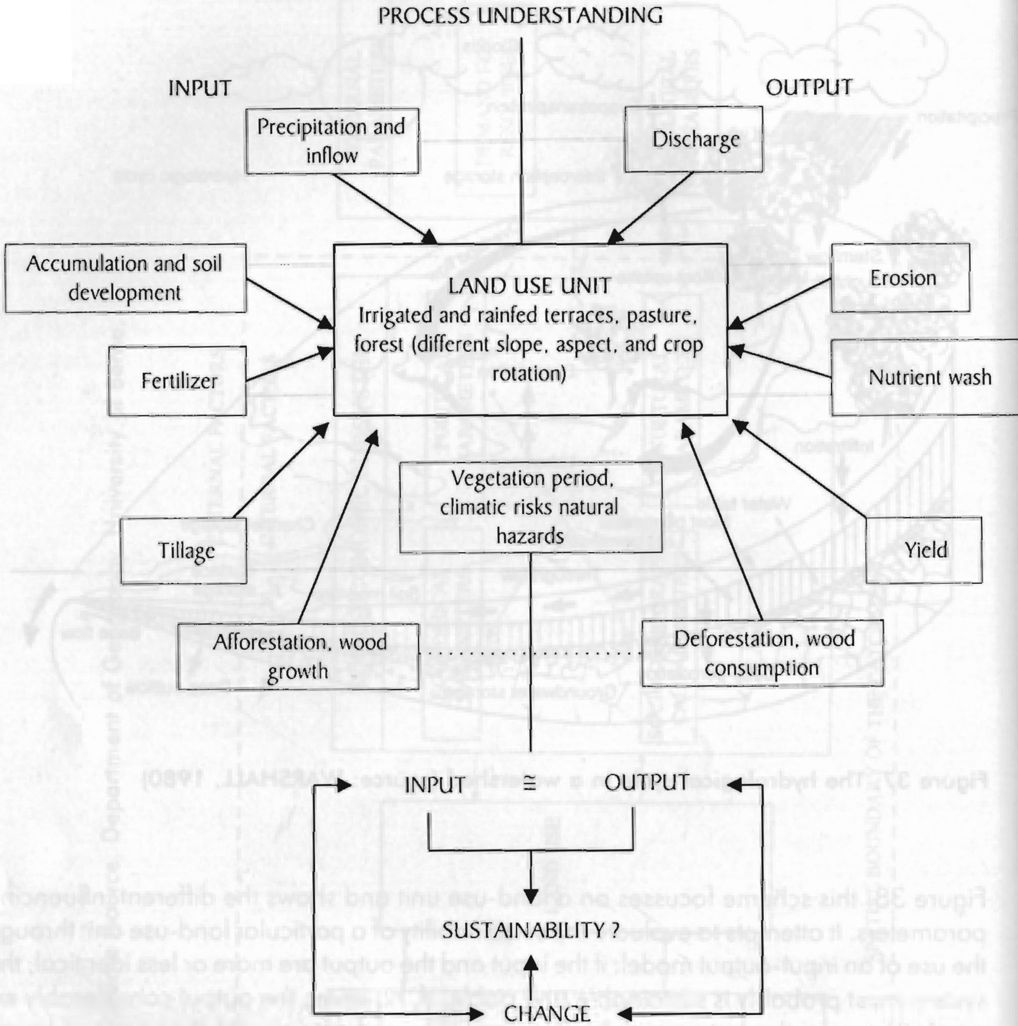


Figure 38: Input-output-model for a land use unit (source: MESSERLI, 1990)

4.5.2 Guidelines for the Analysis

Based on the project document (ICIMOD 1996), interdisciplinary questions can be formulated, to which the hydrology and meteorology components will contribute (questions formulated by Richard Allen, Project Coordinator of PARDYP).

- Through studies on different scales (plot to watershed) of water balance, sediment transport, water chemistry, and indigenous water management practices, can improved management of both land and water resources be defined and even translated into appropriate programmes through community understanding and committed participation?
- Through studies of farming systems, soil fertility dynamics, and farm management procedures, as well as through participatory, farmer-defined action research, can more appropriate, innovative, and economically beneficial approaches to on-farm productivity prob-

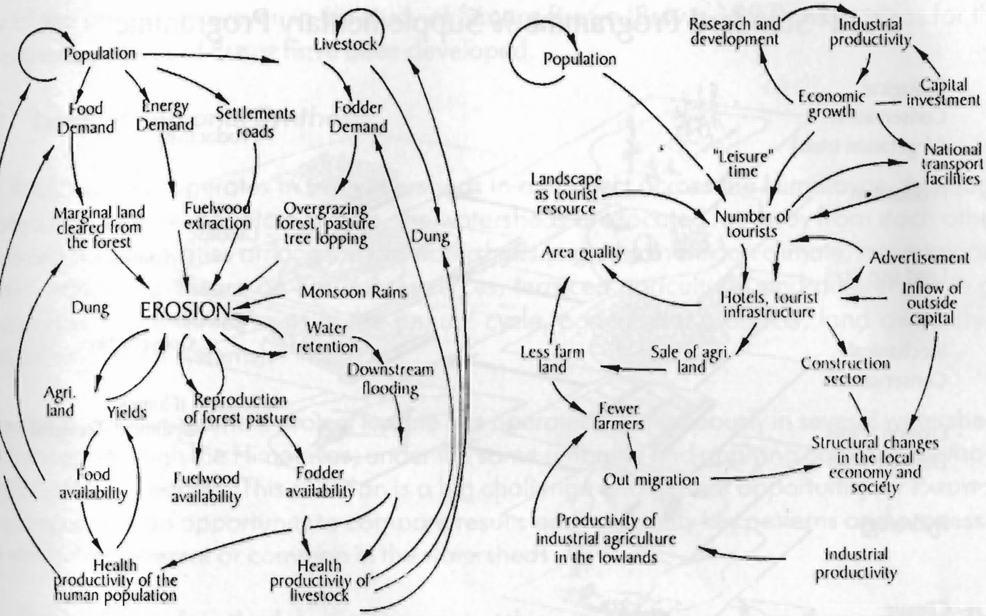


Figure 39: Major interactions in mountain development in the Nepal Himalayas (source: MAUCH, 1983)

lems be designed, sustained, and spread farmer-to-farmer in the selected watershed? (Although not explicitly mentioned, basic hydrological and meteorological information is needed, e.g., for the understanding of soil fertility dynamics.)

- Can models describing both physical and social accounts be developed from the biophysical surveys; from the social, economic, and institutional investigations; and from studies of existing local and national laws, regulations, customs, and traditions?
- What are the key social and biophysical processes in mountain resource management that lead to natural resource and socioeconomic degradation (chains of reactions)?
- Can the project define the main problems and solutions related to water and land shortages (water balance) ?
- What sustainable indigenous practices minimise the effects of natural resource degradation and promote better livelihoods and standards of living in the Middle Mountains?
- Can the PARDYP research findings lead to regionally-appropriate policies, programmes, and initiatives aimed at preventing further environmental and social degradation, improving the productivity of both common lands and farms, and raising the standards of living of the HKH communities involved (pieces of the puzzle from each part and discipline of the project)?

Based on such interdisciplinary project questions and on information generated in the disciplinary analysis (Section 4.4), a catalogue of topics for the watershed synthesis was developed (Table 9). The list includes only those issues to which the hydrology and meteorology components contribute. To develop this catalogue, strong collaboration and interaction among the project members of the different disciplines are essential.

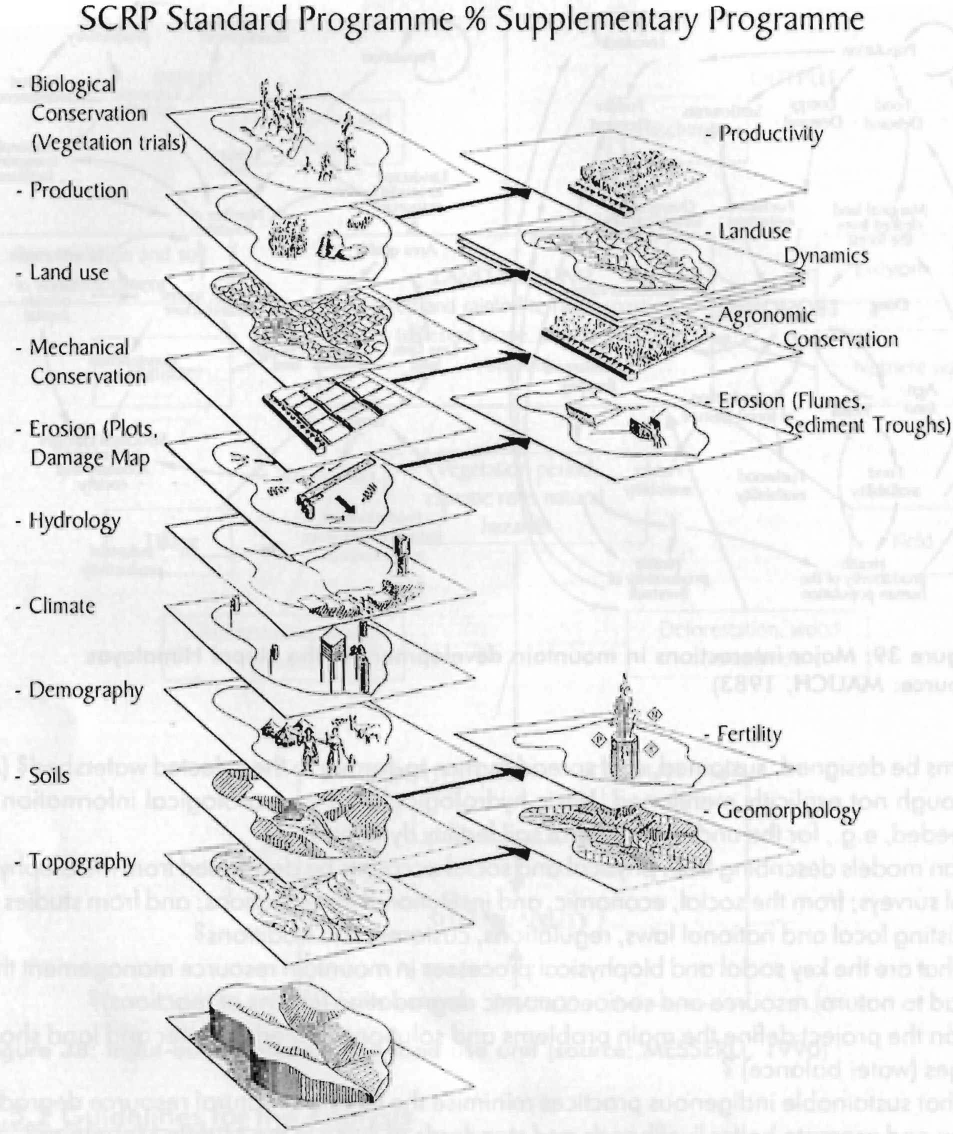


Figure 40: The soil and water conservation research project: standard and supplementary programme (source: Centre for Development and Environment, Department of Geography, University of Berne, Switzerland)

nents contribute. To develop this catalogue, strong collaboration and interaction among the project members of the different disciplines are essential.

The catalogue is again structured into a compulsory part, which can be developed with the obligatory programme of hydrometeorological data collection (Table 5) and which has to be achieved in all the watersheds, and into a specialised optional part. In addition, there is a long-term analysis list which can only be approached after some years of project experi

Table 9 is self-explanatory. No examples are included as this would be premature after only one year of the project. However, in the study of Sandra Brown (Brown 1997) many ideas for the watershed synthesis of PARDYP have been developed.

4.6 *Level of Regional Synthesis*

The PARDYP project operates in five watersheds in a transect across the Himalayas. Although located in the same mountain system, the watersheds are located far away from each other. There are commonalities among the five watersheds (e.g., the monsoon climate, mountainous terrain, variable pressure on natural resources, terraced agriculture) and differences (e.g., importance of the winter rains in the annual cycle, agricultural products, land ownership, political and social systems).

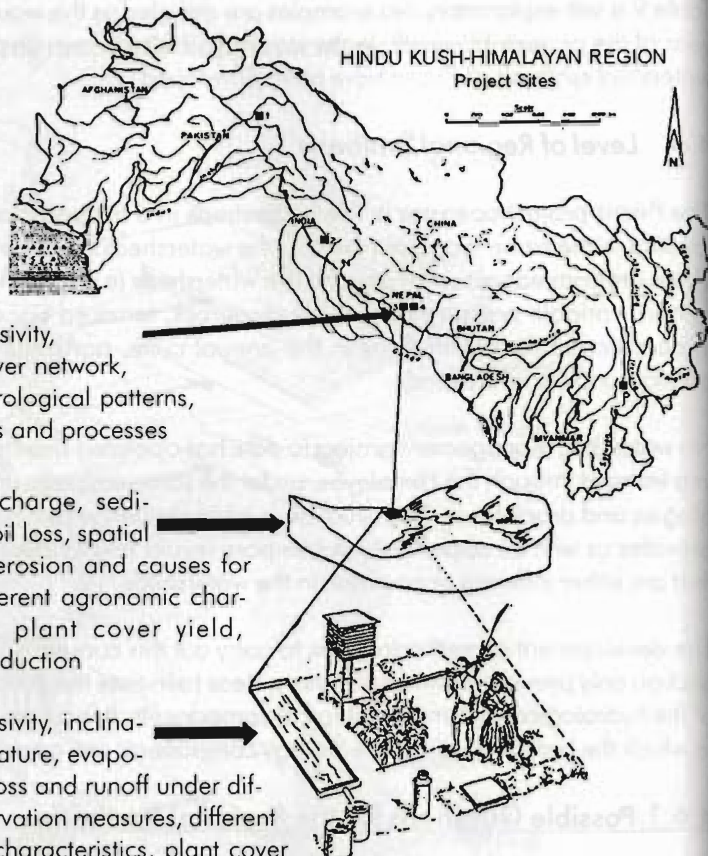
No watershed management project to date has operated simultaneously in several watersheds in a transect through the Himalayas, under the same umbrella and applying common methodologies and procedures. This situation is a big challenge and a great opportunity for PARDYP: it provides us with an opportunity to compare results and to identify key patterns and processes that are either different or common in the watersheds.

The development of methodologies to carry out this comparison is a long-term process. This Section only provides some preliminary ideas to initiate this process, again from the viewpoint of the hydrological and meteorological components. It focusses on those parts of the synthesis to which the hydrology and meteorology components can contribute.

4.6.1 Possible Questions for the Regional Synthesis

The following catalogue of questions was formulated by the Project Coordinator. The questions not only contribute to the comparison of the watersheds but the last question also provides scope for the discussion of large-scale issues.

- Are the key processes (e.g., sedimentation and flooding) similar throughout the HKH region?
- Are there social and cultural links to land-use management practices in the region and do these affect the overall picture of sediment and nutrient movements in the middle mountains?
- Can we generalise about degradation, erosion, and sedimentation processes? Can results at one end of the HKH under one land-use type provide an indication of the losses that might be expected in another location?
- Is soil fertility declining in the middle mountains?
- From which land-use or land-cover types are soil losses greatest?
- What are the effects of new systems of participatory, natural resource management on physical processes?
- When farmers define their needs, are there any common links from one end of the HKH to the other?
- Can we confirm that human impact in the middle mountains has less impact than natural events on the floods and sedimentation in the plains and in the deltas (Hofer 1993; Hofer and Messerli 1997; Hofer 1997; and Hofer 1998).



Research scale	Information
Regional	Rainfall, erosivity, elevation, river network, general hydrological patterns, key elements and processes
Watershed	Rainfall, discharge, sediment loss, soil loss, spatial patterns of erosion and causes for erosion, different agronomic characteristics, plant cover yield, biomass production
Plot/experiment/ household	Rainfall, erosivity, inclination, temperature, evaporation, soil loss and runoff under different conservation measures, different agronomic characteristics, plant cover yield, biomass production, soil type, physical and chemical characteristics relationships, status (hierarchy?) - time-efforts, work-efforts, production and consumption, environmental perception, indigenous approaches for solving environmental problems, politics, risks

Figure 41: Methodological approach for the regional synthesis of PARDYP (sources: ICIMOD, 1997; Centre for Development and Environment, Department of Geography, University of Berne, Switzerland)

4.6.2 Guidelines for the Analysis

For comparison of the watersheds and to identify the key factors, data and information from the different watersheds and the different levels of analysis have to be used. The analysis, howeve is carried out at a highly aggregated level: details lose importance in favour of average figures main patterns, and key processes. As a methodological idea, Figure 41 documents the differen levels of aggregation, or of generalisation, from the plot level through the watershed level to th regional level.

Based on these considerations, Table 10 presents those elements of the compulsory hydrometeoroogical studies that can contribute to the regional synthesis.

Table 10: Level of Regional Synthesis - Catalogue of Information Needed for the Comparison of Watersheds

Information from the level of data compilation (Table 8)	METEO • Monthly, annual rainfall • Monsoon rainfall totals • Highest rainfall in 24 hours • No. of rainy days in different classes • Rainfall intensities • Monthly and annual means of temperature • No of days >=30°C, <=0°C	HYDRO • Mean monthly and annual discharge • Instantaneous max/min discharge • Mean monthly and annual sediment concentration • Monthly and annual soil loss and runoff from erosion plots • Max. runoff and soil loss from plots in 24 hours
Information from the level of disciplinary analyses (Table 6)	• Isohyetal map of rainfall • Altitudinal gradients of rainfall and temperature • Percentage contribution of rainfall from different seasons • Frequency of high rainfall intensities	• Hydrographs of the 'main values' • Duration curve of discharge • Balances of runoff, discharge, sediment transport
Information from the watershed synthesis (Table 9)	• Watershed, sub watersheds: water balances • Plots: erosion, sediment and nutrient loss as a function of slope, aspect, elevation, rainfall, soil characteristics, crop type, technique of land preparation, season; threshold values of erosion with different rainfall intensities • Events: effects of a given rainfall event on the plot level, the sub-catchment level and the watershed level • Effects/success of rehabilitation measures or of improved agricultural practices	

5. Conclusion

A discussion paper is typically a document that provides information and ideas in progress. Its contents are neither complete nor final. In the course of the project, new elements may be added and other elements will be modified. However, the paper provides some compulsory guidelines that have to be followed by each country team involved in the watershed project. In order to realise the requirements of the discussion paper, very clear and transparent data management is necessary for each step, from the measurements, through the data collection, the tasks in the field office, the data check at headquarters, the analysis and all the way to the synthesis. To a great extent, this is a question of personnel: clear responsibilities, work programmes, and deadlines have to be defined. Each single collaborator involved has to know exactly what his/her responsibilities are and has to fulfill the tasks in a very thorough and systematic way. If the tasks and ideas outlined in this discussion paper are realised successfully, then the hydrology and meteorology components will contribute in a very meaningful way to the goals of the PARDYP project. Furthermore, it is hoped that the contents of this paper will be useful for many other watershed management projects.

PARDYP is a big challenge and a great opportunity. The outputs of the project, if they are based on good quality work and innovative thinking, will be a crucial contribution to Chapter 13 of Agenda 21 for the better understanding of mountains as fragile ecosystems.

ANNEX 1

FORMS FOR THE READERS

METEOROLOGICAL RECORD SHEET

PEOPLE AND RESOURCE DYNAMICS PROJECT (IDRC/ SDC/ ICIMOD)

Station no: ________ **Location:** ____________________

Year______ **Month** ____________ **Observer (s):** ____________________

Day	Time (0000)	Temperature Max (°C)	Temperature Min (°C)	Rainfall (mm.)	Remarks
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3.					
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31.					

Checked by ____________________ **Data entered by** ____________________

DAILY GAUGE READING SHEET

PEOPLE AND RESOURCE DYNAMICS PROJECT (IDRC/ SDC/ ICIMOD)

Station no: __________ **Location:** ______________________________

Year ______ **Month** ______________ **Observer (s):** ______________________________

Day	Time (0000)	Gauge Height (cm)	Sampled	Remarks	Day	Time (0000)	Gauge Height (cm)	Sampled	Remarks
1					17				
2					18				
3					19				
4					20				
5					21				
6					22				
7					23				
8					24				
9					25				
10					26				
11					27				
12					28				
13					29				
14					30				
15					31				
16					Checked by ______________________				

Data entered by______________________

DISCHARGE MEASUREMENT SHEET

PEOPLE AND RESOURCE DYNAMICS PROJECT (IDRC/ SDC/ ICIMOD)

Station no: __________ **Location:** ____

Year: 199 ____ **Month:** ___ __**Day**____**Reader (s)**______________________________

Section Start From ...... **Left** or ...... **Right** Bank Looking Downstream.

Rev < 40, Vel = (Rev/Time * 2.18 + 0.02) * 0.3048 m/s, Rev > 40, Vel = (Rev/Time * 2.17 + 0.03) * 0.3048 m/s

Time (0000)	Dist. From bank (cm)	Width (cm)	Depth (cm)	Method .6 or .2 or .8 or S	Revol ution	Dura tion (sec)	velocity at point (m/s)	Area (m^2)	Discharge (m^3/sec)	Gauge height (m)	Remarks

Checked by ______________________________ Data entered by ______________________________

FLOOD SAMPLING SHEET

PEOPLE AND RESOURCE DYNAMICS PROJECT
(IDRC/SDC/ICIMOD)

Station No:____________ **Location:**______________________________

Year: 199____ **Month:**_______________ **Day:**________ **Observer(s)** ______________

Day	Time (0000)	Gauge Hieght(cm)	Sample	Remarks	Day	Time (0000)	Gauge Hieght(cm)	Sample	Remarks

Checked by ____________________ **Data entered by** ____________________

MONTHLY RECORD OF EROSION PLOT

PARDYP/ICIMOD-SDC-IDRC

PLOT #__________ LOCATION__________ YEAR__________ MONTH________ Reader__________

DAY	TIME	Drum#			Drum#			Drum#			Drum#			Remarks
		water	sedi	स्याम्पल छ?	water	sedi	स्याम्पल छ?	water	sedi	स्याम्पल छ?	water	sedi	स्याम्पल छ?	
दिन	समय 0000	पानी cm	माटो cm	(✓, x)	पानी cm	माटो cm	(✓, x)	पानी cm	माटो cm	(✓, x)	पानी cm	माटो cm	(✓, x)	EP# कति हो ?
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Checked by __________________ Data entered by__________________

EVENT-WISE RECORD SHEET OF EROSION PLOT

PARDYP/ICIMOD-SDC-IDRC

EVENT# .... LOCATION: ....
(इभेन्ट नं.) (स्थान)

I. Sampled time and person involved

स्याम्पुल लिएको समय र लिने व्यक्तिको विवरण

Sampled : Year .... Month .... Day .... Time ....
स्याम्पुल लिएको (साल) (महिना) (दिन) (कतिबजे ?)

Sampler .... Assistant ....
लिने व्यक्ति सहयोगी

II. Rainfall Description

(पानी/झरी परेको विवरण)

Start date
झरी पर्न शुरू भएको

Date ....
मिति

Time ....
समय

Stopped
झरी पर्न बन्द भएको

Date ....
मिति

Time ....
समय

Remarks ....
कस्तो खालको झरी हो?

III. Sampling details

	Depth of		Sampled स्याम्पुल लिएको छ/छैन्, छ भने कति वटा ? (✓, ✗)		Remarks (Cropping activities) बारीमा के काम गरेको छ ?
	Water (पानी) cm	Sediment (माटो मात्र) cm	१ (लिटरको)	१/२ (लिटरको)	
Drum#					
Drum#					
Drum#					
Drum#					

बोटलहरु कति .छन् ? १/२ लिटरको .... वटा र १ लटरको .... वटा

Checked by .... Entered by ....

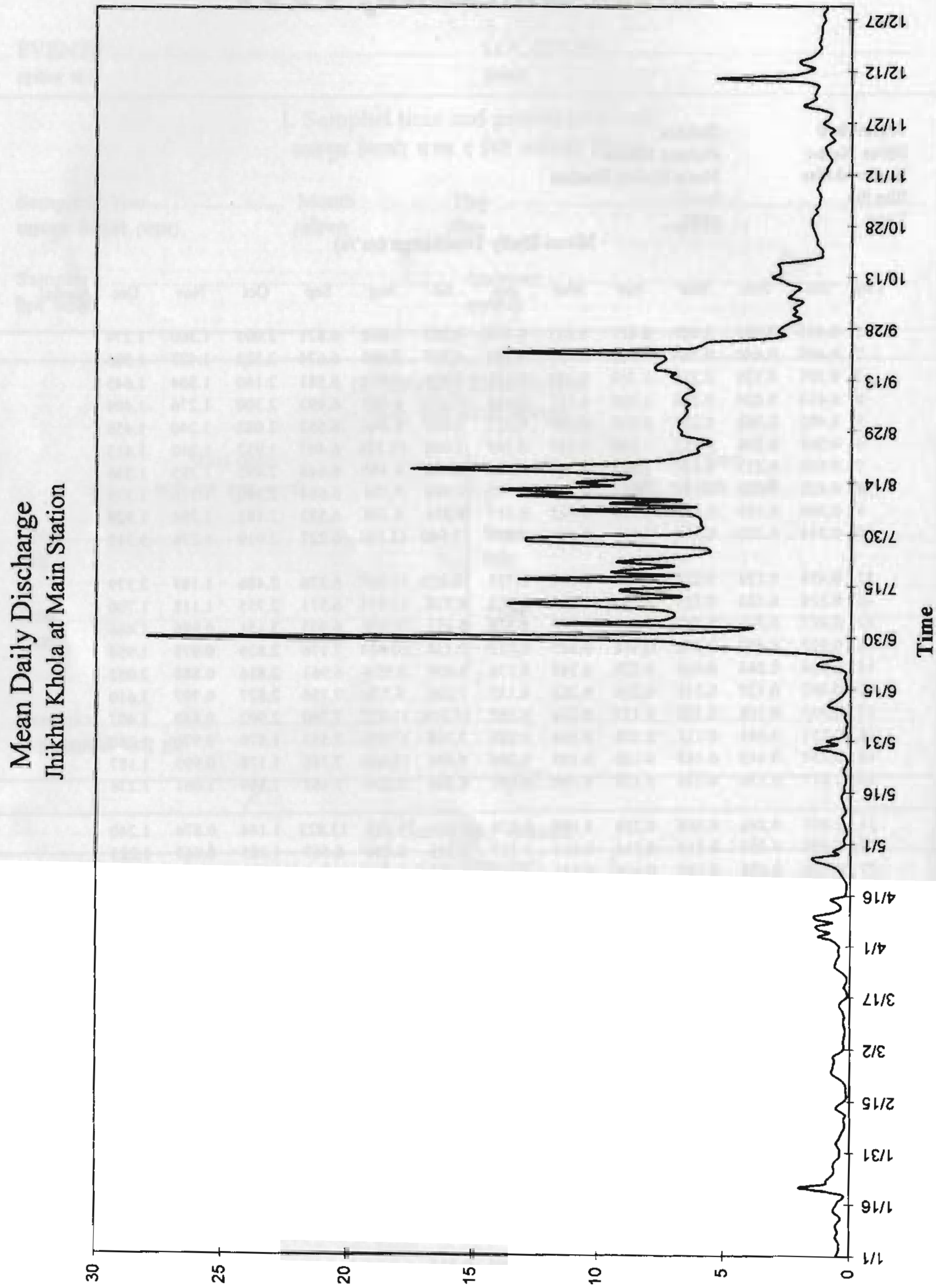
ANNEX 2: SELECTION OF YEARBOOK PAGES FOR JHIKHU *KHOLA* WATERSHED, 1997

Watershed	Jhikhu
River Name	Jhikhu Khola
Name of Site	Main Hydro Station
Site No	1
Year	1997

Mean Daily Discharge (m^3/s)

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1	0.494	0.384	0.409	0.421	0.213	0.416	9.253	5.862	6.821	2.005	1.360	1.274	
2	0.467	0.456	0.265	0.552	0.261	0.194	4.737	5.960	6.674	2.322	1.427	1.906	
3	0.391	0.526	0.234	0.774	0.232	0.180	3.971	5.954	6.581	2.160	1.304	1.645	
4	0.414	0.424	0.254	1.266	0.127	0.165	11.654	6.060	6.493	2.300	1.276	1.409	
5	0.402	0.362	0.224	0.805	0.149	0.122	7.692	6.446	6.552	2.082	1.240	1.456	
6	0.503	0.298	0.212	1.250	0.187	0.169	7.066	11.116	6.407	1.937	1.240	1.415	
7	0.530	0.217	0.182	1.343	0.229	0.240	6.988	6.140	6.648	2.495	1.285	1.336	
8	0.452	0.182	0.189	0.687	0.287	0.185	7.508	9.576	6.684	2.340	1.378	1.329	
9	0.506	0.199	0.229	1.316	0.323	0.357	9.934	6.776	6.532	2.181	1.294	1.929	
10	0.544	0.227	0.254	1.430	0.191	0.893	13.640	13.165	6.227	2.019	1.276	5.315	
11	0.458	0.154	0.224	0.749	0.189	0.755	10.072	11.067	6.376	2.486	1.187	2.379	
12	0.338	0.323	0.231	0.395	0.229	0.533	6.728	13.915	6.571	2.755	1.118	1.700	
13	0.427	0.531	0.287	0.384	0.275	0.358	8.413	9.539	6.903	3.151	0.986	1.466	
14	0.621	0.447	0.378	0.548	0.325	0.253	9.120	10.904	7.176	2.826	0.978	1.954	
15	0.604	0.244	0.414	0.770	0.345	0.176	6.439	8.924	6.961	2.816	0.888	2.052	
16	0.502	0.120	0.316	0.224	0.262	0.153	7.102	8.770	7.756	2.827	0.797	1.610	
17	0.443	0.118	0.125	0.172	0.234	0.187	13.224	11.922	7.760	2.902	0.849	1.407	
18	0.251	0.141	0.111	0.138	0.244	0.229	7.108	17.486	7.553	1.870	0.970	1.288	
19	0.259	0.143	0.145	0.120	0.185	0.244	9.495	11.400	7.356	1.178	0.995	1.187	
20	1.017	0.170	0.238	0.159	0.180	0.185	8.326	8.254	7.461	1.169	1.061	1.276	
21	2.001	0.296	0.169	0.238	0.199	0.450	7.024	7.017	13.823	1.144	0.874	1.240	
22	0.930	0.484	0.115	0.336	0.261	1.329	9.305	6.486	6.567	1.285	0.663	1.223	
23	0.928	0.698	0.135	0.438	0.247	1.146	7.630	6.035	5.937	1.378	0.799	1.178	
24	0.771	0.697	0.248	0.558	0.169	0.365	6.298	6.117	5.639	1.360	0.859	1.178	
25	0.629	0.640	0.422	0.889	0.122	0.842	5.559	5.913	3.448	1.409	0.678	1.178	
26	0.583	0.620	0.605	1.393	0.149	2.952	5.724	5.558	2.633	1.446	0.927	1.118	
27	0.632	0.601	0.567	1.499	0.248	5.537	8.998	6.158	2.892	1.514	1.137	1.035	
28	0.620	0.642	0.533	0.475	0.788	6.472	12.913	6.723	2.833	1.565	0.948	1.084	
29	0.524	*****	0.437	0.686	1.445	7.708	12.896	6.707	2.625	1.575	0.841	1.110	
30	0.382		0.444	0.395	0.527	28.002	6.747	6.854	2.368	1.575	0.829	0.986	
31	0.371		0.463	*****	0.959	*****	6.051	6.831	*****	1.504	*****	0.978	
Min.	0.251	0.118	0.111	0.120	0.122	0.122	3.971	5.558	2.368	1.144	0.663	0.978	0.111
Mean	0.580	0.369	0.292	0.680	0.316	2.027	8.310	8.375	6.209	1.986	1.049	1.537	2.665
Max.	2.001	0.698	0.605	1.499	1.445	28.002	13.640	17.486	13.823	3.151	1.427	5.315	28.002

Instantaneous Maximum			Instantaneous Minimum		
$Q(m^3/s)$	GH (m)	Date	$Q(m^3/s)$	GH (m)	Date
95.800	3.60	97/6/30 14:20	0.111	0.78	11/2/97 08:00


Mean Daily Discharge
Jhikhu Khola at Main Station
Discharge (m3/s)
Time
0
5
10
15
20
25
30
1/1
1/16
1/31
2/15
3/2
3/17
4/1
4/16
5/1
5/16
5/31
6/15
6/30
7/15
7/30
8/14
8/29
9/13
9/28
10/13
10/28
11/12
11/27
12/12
12/27

Rainfall Summary of 1997

S. No	St. No	Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Amount	Max in 24 hrs	Date	Mons-oon Total	>= 1.0	1.0-9.9	10-24.9	25-49.9	50-99.9	100-199.9	200-299.9	>= 300
			Rainfall amount in mm																No of days Precipitation mm							
1	3	Acharya-tol	18.8	8.4	13.6	90.0	44.8	220.6	374.4	234.7	84.0	13.7	6.4	76.2	1185.6	66.0	1-Jul	913.7	93	60	18	12	3	0	0	0
2	4	Luitelgaun				41.0	52.1	255.7	390.2	227.9	91.4	7.2	1.3	74.8				965.2								
3	6	Bela	21.5	11.5	16.7	111.7	52.1	229.6	396.9	249.6	94.8	5.5	1.8	86.0	1277.7	100.2	1-Jul	970.9	102	63	24	12	2	1	0	0
4	9	Dhulikhel	20.0	7.2	9.0	79.2	78.4	312.4	371.4	406.5	91.5	9.0	4.9	80.8	1470.3	136.0	11-Aug	1182	97	55	27	11	2	2	0	0
5	10	Bagrapare							341.5	280.6	66.1	36.6	3.7	66.3												
6	12	Panchkhal	19.3	10.5	13.4	110.9	77.7	194.3	405.2	246.0	46.0	21.0	2.4	67.4	1214.1	84.1	29-Jul	891.5	66	25	24	16	1	0	0	0
7	14	Kubhindegaun			11.6	93.2	77.5	194.8	415.8	227.7	64.7	9.7	6.3	63.3				903								
8	15	Bhimsensthan	20.5	12.7	12.9	94.2	73.3	223.5	474.9	261.8	40.7	11.7	3.5	70.6	1300.3	82.0	29-Jul	1001	88	54	17	15	2	0	0	0
9	16	Bhetwalthok	21.5	8.4	12.9	86.7	67.3	231.1	487.1	243.4	42.9	10.2	3.3	67.1	1281.9	74.3	1-Jul	1005	98	65	13	16	4	0	0	0

Daily Precipitation (mm)

Watershed : Jhikhu
Name of Site : Acharya Tole
Site No : 3
Year : 1997
Observation Time : 0845 NST

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.0	0.0	0.0	0.0	4.5	0.0	66.0	0.4	0.0	0.1	0.0	4.7
2	0.0	0.3	0.0	6.5	0.0	0.0	0.4	3.2	0.0	1.3	0.2	7.5
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.3
4	0.0	0.0	0.0	13.6	0.0	1.0	43.5	0.0	0.0	0.2	0.2	0.2
5	0.0	0.0	0.0	0.0	0.0	0.0	9.0	6.5	0.0	0.2	0.2	0.3
6	0.0	0.0	0.0	5.0	4.8	0.8	4.7	29.0	0.6	0.2	0.2	0.4
7	0.0	0.0	0.0	0.0	2.4	0.0	7.9	0.0	4.9	0.1	0.1	0.2
8	0.0	0.0	0.0	0.0	6.4	0.0	16.1	25.8	0.2	0.1	0.2	0.1
9	0.0	0.0	0.0	3.3	5.7	0.0	13.3	0.0	0.0	0.1	0.1	7.3
10	0.0	0.0	0.0	3.1	0.0	14.0	1.8	30.6	0.0	0.2	0.1	40.6
11	0.0	0.0	0.0	0.0	0.0	1.2	40.5	25.5	0.0	0.2	0.1	2.6
12	0.0	0.0	0.0	0.0	0.0	0.0	5.5	21.5	0.0	0.2	0.3	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	4.2	3.3	6.0	0.2	0.1	0.0
14	0.0	0.0	0.8	0.4	0.0	0.0	7.7	16.6	0.2	0.3	0.1	0.3
15	0.0	0.0	0.0	5.8	0.0	0.0	3.8	0.0	0.0	0.3	0.0	7.6
16	0.0	0.0	0.0	0.0	0.0	2.0	14.9	12.8	0.0	0.2	0.1	0.4
17	0.0	0.0	0.0	0.0	0.0	0.0	25.1	3.5	14.8	0.2	0.1	0.4
18	0.0	0.0	0.0	0.0	0.0	9.9	2.3	35.4	0.0	0.2	0.0	0.3
19	0.0	0.0	0.0	0.0	0.0	0.0	11.7	11.3	0.0	0.2	0.4	0.2
20	9.6	0.0	0.0	0.0	4.5	0.0	1.2	3.1	3.8	0.2	0.1	0.2
21	9.2	0.0	0.0	0.0	1.5	0.0	0.7	0.0	44.0	0.2	0.3	0.4
22	0.0	0.0	0.0	0.0	0.0	8.8	1.0	0.0	0.5	2.6	0.7	0.3
23	0.0	7.2	0.0	8.7	0.0	12.0	16.3	0.0	0.0	0.2	0.2	0.2
24	0.0	0.0	0.0	0.0	0.0	0.0	1.8	3.8	0.0	0.2	0.1	0.2
25	0.0	0.0	0.0	0.2	0.0	0.0	0.6	0.6	0.0	4.0	0.3	0.2
26	0.0	0.0	0.0	0.0	0.0	54.5	0.0	0.8	0.0	0.3	1.0	0.2
27	0.0	0.0	0.0	15.1	0.0	38.0	12.5	0.0	4.5	0.5	0.7	0.2
28	0.0	0.9	0.0	1.4	5.4	9.1	5.6	0.6	4.5	0.2	0.2	0.2
29	0.0		0.0	7.1	9.6	24.0	53.8	0.4	0.0	0.2	0.1	0.3
30	0.0		12.8	19.8	0.0	45.3	2.5	0.0	0.0	0.2	0.0	0.1
31	0.0		0.0		0.0		0.0	0.0		0.2		0.3
Total	18.8	8.4	13.6	90.0	44.8	220.6	374.4	234.7	84.0	13.7	6.4	76.2
Highest in24Hrs	9.6	7.2	12.8	19.8	9.6	54.5	66.0	35.4	44.0	4.0	1.0	40.6
& Date	20-Jan	23-Feb	30-Mar	30-Apr	29_May	26-Jun	1-Jul	18-Aug	21-Sep	25-Oct	26-Nov	10-Dec

Temperature & Humidity Summary

Watershed : Jhikhu
Name of Site : Acharya Tole
Sire No : 3
Year : 1997

Month	Air Temperature °C							No of days		Mean Relative Humidity% at	
	Mean			Absolute Extreme				Max	Min	0845	1745
	Max	Min	Daily	Max	Date	Min	Date	>=30°C	<= 0°C	NST	NST
Jan	20.7	4.1	12.4	25.0	3	1.0	13,16,17,18,19	0	0		
Feb	21.3	4.1	12.7	24.0	17,22	2.0	6,10,11,20	0	0		
Mar	27.3	8.7	18.0	31.0	22,23	4.0	4,5	6	0		
Apr	27.2	12.8	20.0	31.5	20	7.0	6,7	7	0		
May	32.2	16.3	24.3	36.0	18	12.0	9	25	0		
Jun	33.2	19.6	26.4	36.0	18	16.0	1,11	28	0		
Jul	32.0	22.0	27.0	34.0	28	21.0	2,3,12,21,31	31	0		
Aug	32.2	21.8	27.0	34.5	5	20.0	27,30	31	0		
Sep	31.5	20.0	25.8	34.0	6,9	16.0	30	30	0		
Oct	28.1	11.0	19.5	32.0	7,8	9.0	6,26,27	11	0		
Nov	26.6	9.0	17.8	30.0	3,6,8	6.0	14,16,24,27	3	0		
Dec	21.7	6.05	13.9	25.0	6,21	3.0	28	0	0		
Year	27.8	13.0	20.4	36.0	18-May,18-Jun	1.0	13,16,17,18,19 Jan	172	0		

Daily Minimum Temperature ^{0}C

Watershed : Jhikhu
Name of Site : Acharya Tole
Site No : 3
Year : 1997

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	4.0	3.0	9.0	8.0	15.0	16.0	22.0	22.5	22.0	16.0	10.0	8.0
2	3.0	4.0	8.0	11.0	14.0	18.0	21.0	22.0	20.5	12.0	9.0	9.0
3	4.0	5.0	8.0	11.5	14.0	20.0	21.0	23.0	21.0	14.0	10.0	7.0
4	6.0	5.0	4.0	11.0	14.0	18.0	22.0	24.0	20.5	8.0	10.0	6.0
5	6.0	3.0	4.0	10.0	14.0	18.5	22.0	23.5	20.0	8.0	10.0	8.0
6	7.0	2.0	6.0	7.0	13.0	18.5	22.5	22.5	19.0	9.0	9.0	5.0
7	7.0	3.0	8.0	7.0	15.0	19.6	22.5	22.0	21.0	12.0	9.0	6.0
8	6.0	3.0	8.0	10.5	15.0	19.0	22.0	22.5	20.5	12.0	10.0	5.0
9	5.0	3.0	8.0	12.5	12.0	19.0	23.0	21.0	21.0	13.0	10.0	5.0
10	5.0	2.0	9.0	13.0	14.0	19.0	22.0	22.0	21.5	11.5	9.0	11.0
11	2.0	2.0	12.0	13.0	14.0	16.0	22.5	22.0	20.0	10.5	10.0	8.0
12	2.0	3.0	9.0	15.0	15.0	17.0	21.0	21.5	20.5	11.0	8.0	10.0
13	1.0	4.0	10.0	14.0	15.0	20.0	22.5	22.0	22.0	10.5	7.0	9.0
14	2.0	3.0	9.0	16.0	16.0	20.0	22.0	21.0	20.5	12.0	6.0	9.0
15	2.0	4.0	8.0	16.5	14.0	20.5	22.5	21.0	20.5	12.0	7.0	6.0
16	1.0	4.0	9.0	14.0	10.0	20.0	23.0	22.5	20.5	12.0	6.0	6.0
17	1.0	4.0	9.0	13.0	14.0	20.0	22.0	22.5	21.0	12.0	7.0	4.0
18	1.0	5.0	8.0	11.5	16.0	20.0	22.0	21.0	20.0	12.0	10.0	5.0
19	1.0	4.0	10.0	11.0	20.0	21.0	22.0	21.0	20.0	11.0	13.0	6.0
20	6.0	2.0	12.0	11.1	20.0	20.0	22.5	22.0	21.0	12.0	9.0	6.0
21	6.0	3.0	10.0	11.0	22.0	19.5	21.0	22.0	19.0	13.0	8.0	5.0
22	4.0	5.0	10.0	13.0	20.0	21.0	22.0	22.0	20.0	12.0	12.0	4.0
23	2.0	5.0	9.0	13.5	17.0	22.5	21.5	23.0	20.0	13.0	8.0	5.0
24	4.0	7.0	9.0	14.0	19.0	20.5	22.0	21.0	19.0	11.0	6.0	4.0
25	4.0	10.0	9.0	18.0	19.0	22.0	22.0	22.5	18.0	10.0	12.0	4.5
26	5.0	6.0	8.0	14.0	20.0	21.0	22.5	21.0	18.5	9.0	8.0	4.0
27	6.0	4.0	7.0	16.0	18.0	20.0	22.0	20.0	19.0	9.0	6.0	4.0
28	6.0	8.0	8.0	17.0	19.0	21.0	22.5	21.0	19.5	10.0	7.0	3.0
29	5.0		10.0	18.0	22.0	22.0	21.5	21.0	19.0	11.0	8.0	4.0
30	6.0		11.0	14.0	20.0	19.0	21.5	20.0	16.0	10.0	8.0	6.0
31	6.0		10.0		16.0		21.0	21.0		11.0		5.0
Mean	4.1	4.1	8.7	12.8	16.3	19.6	22.0	21.8	20.0	11.3	8.7	6.0

Daily Maximum Temperature (^0C)

Watershed : **Jhikhu**
Name of Site : **Acharya Tole**
Site No : **3**
Year : **1997**

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	23.0	19.0	25.0	24.0	28.0	32.0	32.0	32.5	32.0	28.5	27.0	22.0
2	23.0	19.0	24.0	27.0	29.0	34.0	31.0	34.0	32.0	25.0	29.0	19.0
3	25.0	20.0	25.0	27.5	29.5	35.0	33.0	32.0	32.5	27.0	30.0	21.0
4	23.0	20.0	24.0	24.0	31.5	35.0	32.0	33.5	31.0	29.0	29.0	22.0
5	22.0	19.0	24.0	24.0	31.5	35.0	32.0	34.5	33.0	29.0	28.0	24.0
6	23.0	18.0	26.0	24.0	32.0	35.0	32.0	33.0	34.0	31.0	30.0	25.0
7	23.0	19.0	27.0	24.0	31.0	35.0	31.0	33.0	31.0	32.0	29.0	24.0
8	23.0	20.0	26.0	24.0	32.0	34.0	32.0	32.0	32.0	32.0	30.0	23.0
9	22.0	22.0	27.0	27.0	26.0	35.0	31.5	33.0	34.0	31.0	28.0	22.5
10	23.0	22.0	26.0	24.0	30.0	35.0	30.5	32.0	31.5	31.0	28.0	15.0
11	23.0	21.0	28.0	25.0	31.5	32.0	30.0	32.0	32.0	29.0	27.0	19.0
12	22.0	21.0	28.0	26.0	32.0	34.0	31.0	32.0	31.5	31.0	25.0	19.0
13	21.0	22.0	30.0	27.0	33.0	34.0	30.5	32.0	32.0	30.0	26.0	21.0
14	22.0	23.0	27.0	27.0	33.0	33.0	32.0	31.0	31.5	29.0	26.0	21.5
15	22.0	21.0	28.0	26.5	34.0	33.0	33.0	31.0	31.0	30.0	27.0	17.0
16	21.0	23.0	29.0	28.0	33.0	34.0	32.0	32.5	30.0	31.0	26.0	17.0
17	21.0	24.0	27.0	31.0	35.0	35.0	32.0	32.0	31.0	29.0	26.0	19.0
18	21.0	23.0	28.0	30.5	36.0	36.0	33.0	31.0	30.0	30.0	26.0	22.0
19	20.0	22.0	29.0	31.0	34.0	33.0	32.5	31.0	30.0	30.0	26.0	23.0
20	18.0	22.0	28.0	31.5	34.0	33.0	31.5	32.0	32.0	29.0	23.0	24.0
21	10.0	23.0	30.0	30.0	35.0	29.5	32.0	33.0	32.5	28.0	25.0	25.0
22	18.0	24.0	31.0	30.0	35.0	33.0	32.0	32.0	32.0	26.0	25.0	24.0
23	19.0	20.0	31.0	29.5	35.0	34.0	33.0	32.0	31.5	23.0	26.0	23.5
24	18.0	21.0	30.0	29.0	35.0	31.0	32.0	32.0	31.0	23.0	26.0	23.5
25	18.0	22.0	30.0	30.0	34.0	33.5	33.0	32.0	31.5	19.0	27.0	22.0
26	19.0	22.0	28.0	24.5	35.0	33.0	32.5	32.0	31.0	20.0	25.5	22.5
27	18.0	22.0	28.0	26.5	34.0	32.0	33.0	32.0	32.0	26.0	23.0	22.0
28	20.0	22.0	29.0	26.5	31.0	33.0	34.0	32.0	31.0	27.0	25.0	22.0
29	21.0		28.0	28.0	29.0	30.0	33.0	31.0	28.0	28.0	25.0	22.0
30	21.0		22.0	29.0	29.5	25.0	32.0	32.0	31.0	28.0	23.0	22.0
31	18.0		23.0		31.0		32.0	32.0		29.0		23.0
Mean	20.7	21.3	27.3	27.2	32.2	33.2	32.0	32.2	31.5	28.1	26.6	21.7

Plot: YE 9a

Month: July **Soil type: Red** **Land use: Cultivated Terraces**

Rainfall	Runoff	Soil Loss
617.25 mm	91.07 mm	8.18 T/ha

Date	Time	Rainfall		Runoff			Soil loss		
		mm	mm/hr	m3/ha	mm	coeff.	kg/ha	mm	kg/ha/mm
1-Jul	9:15	32.70		4.25	0.43	0.013	3.20		0.098
2-Jul	8:45	0.40							
3-Jul	8:50	14.20		4.02	0.40	0.028	3.26		0.230
4-Jul	8:55	10.10		2.77	0.28	0.027	6.31		0.625
5-Jul	8:50	42.90		15.27	1.53	0.036	17.36		0.405
6-Jul	8:45	2.60							
7-Jul	11:00	40.60		12.76	1.28	0.031	18.16		0.447
8-Jul	9:10	24.60		9.57	0.96	0.039	9.19		0.373
9-Jul	12:00	41.80		20.35	2.04	0.049	31.68		0.758
10-Jul	8:48	6.80		2.10	0.21	0.031	1.86		0.273
11-Jul	9:00	32.90		23.02	2.30	0.070	98.81		3.003
12-Jul	9:00	7.40		2.22	0.22	0.030	3.11		0.421
13-Jul	8:45	4.30							
14-Jul	9:25	51.10		19.54	1.95	0.038	109.00		2.133
15-Jul	8:50	17.30		5.85	0.59	0.034	6.10		0.353
16-Jul	9:25	48.00		44.82	4.48	0.093	436.81		9.100
17-Jul	9:30	61.19		222.53	22.25	0.364	2991.65		48.891
18-Jul	9:00	4.40		1.26	0.13	0.029	2.13		0.485
19-Jul	8:55	36.80		223.42	22.34	0.607	679.13		18.455
20-Jul	8:57	20.00		76.35	7.64	0.382	1908.98		95.449
21-Jul	8:50	9.80		10.41	1.04	0.106	28.64		2.922
22-Jul	9:05	8.50		10.36	1.04	0.122	27.18		3.198
23-Jul									
24-Jul	9:15	20.60		32.28	3.23	0.157	343.35		16.668
25-Jul	8:51	9.60		15.10	1.51	0.157	27.63		2.878
26-Jul	8:45	0.70							
27-Jul	8:50	8.20		2.17	0.22	0.026	5.98		0.730
28-Jul	8:30	6.00		1.29	0.13	0.022	0.91		0.152
29-Jul	8:50	20.70		17.30	1.73	0.084	18.63		0.900
30-Jul	9:00	31.16		131.67	13.17	0.423	1409.06		45.220
31-Jul	8:45	1.90							
Total - July		617.25		910.68	91.07	0.1475	8188.15		13.26554

REFERENCES

UNCED, 1993. *Agenda for Change*. Geneva: Centre for Our Common Future.

Brown, S., 1997. 'Soil Fertility, Nutrient Dynamics, and Socioeconomic Interaction in the Middle mountains of Nepal'. PhD Thesis. Canada: University of British Columbia.

Carver, M., 1997. 'Diagnosis of Headwater Sediment Dynamics in Nepal's Middle Mountains: Implications for Land Management'. PhD Thesis. Canada: University of British Columbia.

Chow, V.T., Maidment, D.R., Mays, L.W., 1988. *Applied Hydrology*. Singapore: McGraw-Hill Book Company.

Department of Soil Conservation and Watershed Management, 1998. 'Soil Erosion Study in Jhikhu and Yarsha *Khola* Watersheds in Nepal'. Annual Technical Progress Report of PARDYP-1997. Kathmandu, Nepal

Dyck, S., 1980. Angewandte Hydrologie, Teil 1: Berechnung und Regelung des Durchflusses der Fluesse. Berlin, Muenchen: Verlag von Wilhelm Ernst und Sohn.

Fein, S.J., Stephens, P.L., 1987. *Monsoons*. London: John Wiley and Sons.

Fischer, M., 1982. 'Abflussmessungen mit Tracern nach dem Verduennungsverfahren'. *Beitraege zur Geologie der Schweiz-Hydrologie*, Bd. 28 II (447-458), Bern, Switzerland

Hofer, T., 1993. 'Himalayan Deforestation, Changing River Discharge and Increasing Floods: Myth or Reality'? In *Mountain Research and Development*, 13 (3): 213-233

Hofer, T., 1997. *Meghalaya, not Himalaya. In HIMAL* South Asia, September/October

Hofer, T., 1998. 'Do Land Use Changes in the Himalayas Affect Downstream Flooding? - Traditional Understanding and New Evidences'. In *Memoir of the Geological Society of India*, No 41

Hofer, T., Messerli, B., 1997. 'Floods in Bangladesh - Process Understanding and Development Strategies'. A synthesis paper prepared for the Swiss Agency for Development and Cooperation.

Hurni, H., 1994. 'Methodological Evolution of Soil Conservation Research in Ethiopia'. In *IDRC Currents*, Vol. 8: 17-21. Uppsala: Swedish University of Agricultural Sciences.

ICIMOD, 1996. 'People and Resource dynamics in Mountain Watersheds of the Hindu Kush-Himalayas. Project Document. Kathmandu, Nepal: ICIMOD.

ICIMOD, 1997. *People and Resource Dynamics*, Project brochure. Kathmandu, Nepal: ICIMOD.

LHG, 1982. 'Handbuch fuer die Abflussmessung'. *Swiss National Hydrological Survey Mitteilung No. 4*. Bern, Switzerland

LHG, 1994. 'Manual fuer die Abflussmessung nach dem Salzverduennungsverfahren'. *Swiss National Hydrological Survey. Technischer Bericht*.

Mauch, S.P., 1983. 'Key Processes for Stability and Instability of Mountain Ecosystems. Is the Bottleneck Really a Data Problem'? In *Mountain Research and Development*, 3(2): 113-119.

Messerli, B., 1990. 'Land and Water Resources in the Higher Himalaya (Chilime Khola Langtang, Nepal)': Unpublished project proposal. Department of Geography. Switzerland: University of Berne.

Moss, M.E., 1982. *Concepts and Techniques in Hydrological Network Design*. Geneva Switzerland:World Meteorological Organization, Operational Hydrology Report No. 19

Romang, H., 1995. *Hydrologische Untersuchungen im Spissibach, Leissigen, mit besonderer Beruecksichtigung des Teileinzugsgebietes Bachli*. Publikation Gewaesserkunde No. 159. Bern: Department of Geography, University of Berne.

Schreier, H., Shah, P.B., and Brown, S. (eds), 1995. *Challenges in Mountain Resource Management in Nepal. Processes, Trends, and Dynamics in the Middle Mountain Watersheds*. Proceedings of the workshop held in Kathmandu, 10-12. April. Kathmandu: ICIMOD, IDRC.

Shah, P.B., Schreier, H., Brown, S., and Riley, K.W. (eds.), 1991. *Soil Fertility and Erosion Issues in the Middle Mountains of Nepal*. Workshop proceedings, Jhikhu *Khola* Watershed, 22-25 April. Ottawa: IDRC.

Spreafico, M., and Gees, A., 1997. Manual: Determination of Discharge in Open Channels Using the LHG Dilution Method. Bern, Switzerland: Swiss National Hydrological and Geological Survey.

Spreafico, M.; Lehmann, C., and Naef, O., 1996. 'Empfehlung zur Abschaetzung von Feststofffrachten in Wildbaechen'. *Arbeitsgruppe fuer operationelle Hydrologie, Mitteilung No. 4*. Bern, Switzerland

Ulrich, H. and Probst, G.J.B., 1995. *Anleitung zum ganzheitlichen Denken und Handeln: ein Brevier fuer Fuehrungskraefte*. Stuttgart, Wien: Verlag Paul Haupt Bern.

Warshall, P., 1980. 'Streaming Wisdom: Watershed Consciousness in the Twentieth Century'. Brand, S. (ed), *The Next Whole Earth Catalogue: Access to Tools*. Sausalito, Californi

Wilhelm, F., 1993. *Hydrogeographie, Grundlagen der allgemeinen Hydrogeographie*. Das Geographische Seminar. Braunschweig: Westermann Schulbuchverlag GmbH.

WMO, 1974. *Guide to Hydrological Practices*: Third edition, WMO-No 168. Geneva, Switzerland:
World Meteorological Organization,

WMO, 1980. *Manual on Stream Gauging, Volume 1: Field Work.* Operational Hydrology No. 13. Geneva, Switzerland: World Meteorological Organization.

Wymann, S., 1993. 'Land Use Changes and Soil Fertility Status in a Small Watershed in the Middle Hills of Nepal: signs of pressure. In Messerli, B., Hofer, T., Wymann, S. (eds): *Himalayan Environment: Pressure-Problems-Processes. 12 Years of Research. Geographica Bernensia* G38, Bern, pp. 189-204

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ICIMOD serves as a multidisciplinary documentation centre on integrated mountain development; a focal point for the mobilisation, conduct, and coordination of applied and problem-solving research activities; a focal point for training on integrated mountain development, with special emphasis on the assessment of training needs and the development of relevant training materials based directly on field case studies; and a consultative centre providing expert services on mountain development and resource management.

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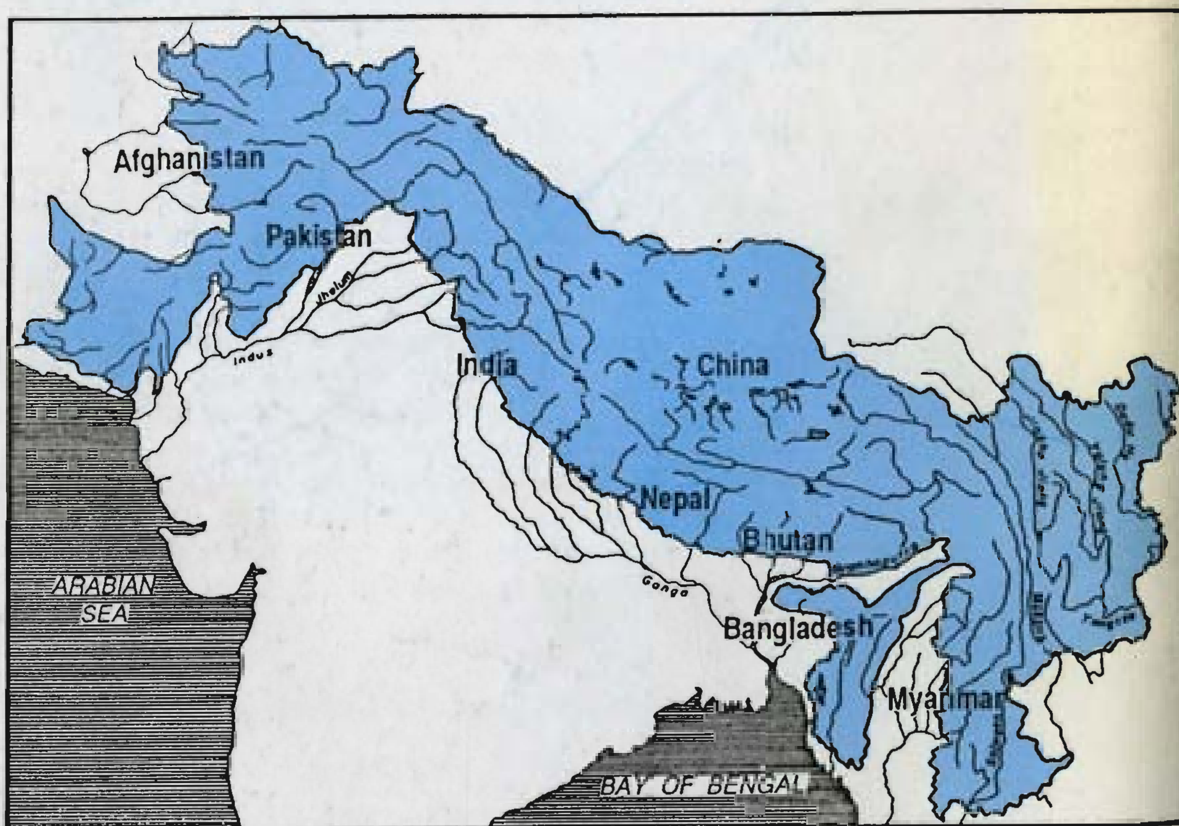
Participating Countries of the Hindu Kush-Himalayan Region

- Afghanistan
- Bhutan
- India
- Nepal
- Bangladesh
- China
- Myanmar
- Pakistan



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