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)

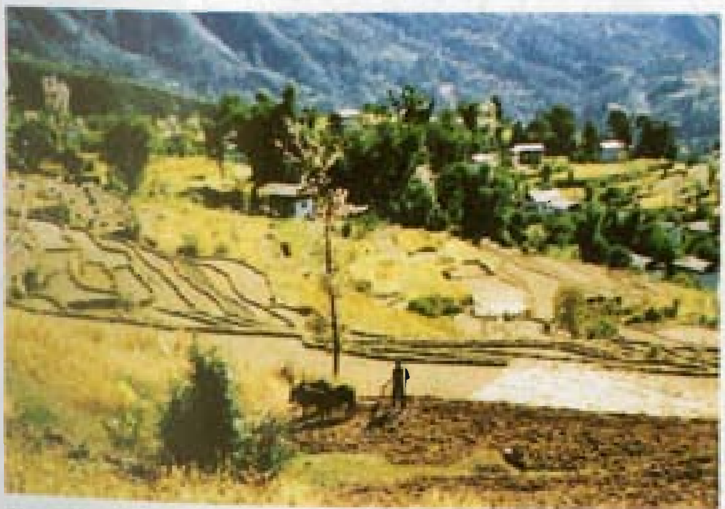


Figure 28: Physical, economic and social parameters are part of a system and strongly influence each other. Detail from the south facing slope in Yarsha Khola Watershed, Nepal (photo: November 1996)

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:

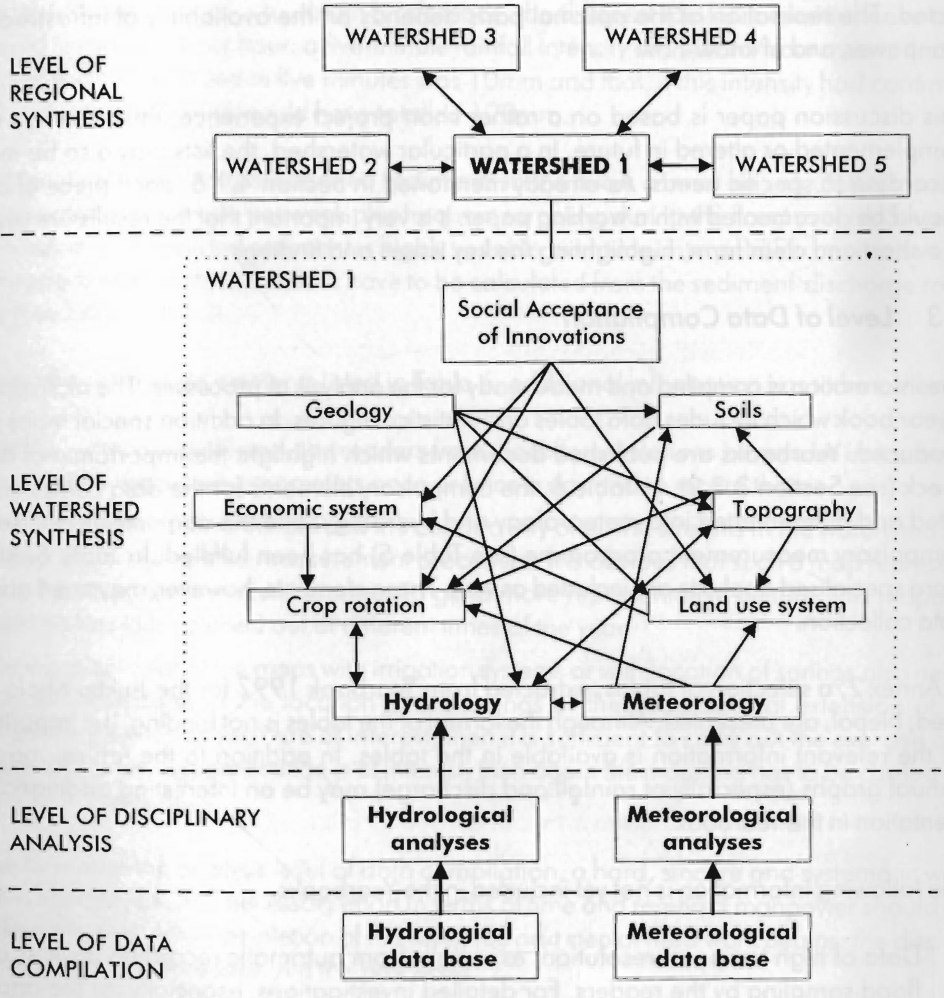


Figure 29: The four levels of synthesis

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 a specific disciplinary topic which in itself can be looked at separately and can be finalised 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 elements are looked at.

- Amount, distribution, and range of rainfall within the watershed for the different time 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 heav rainfall, causing considerable damage.
- Quantification of rainfall for different parts of the watershed, e.g., the subcatchments 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 of the monsoon (Fein and Stephens 1987).

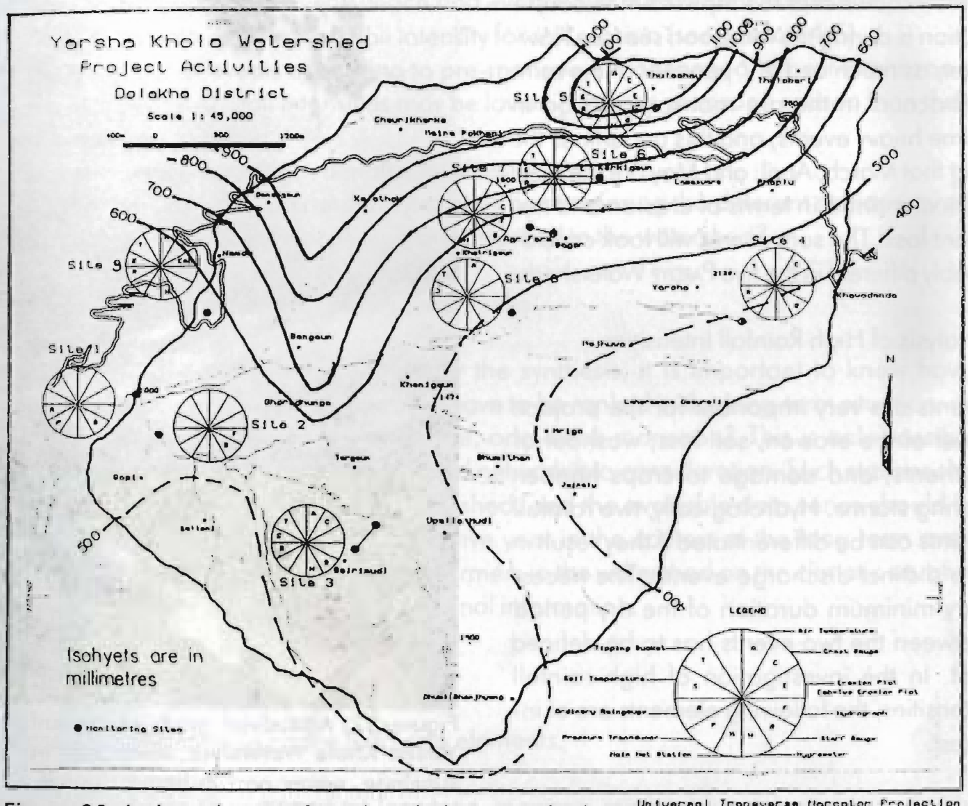


Figure 30: Isohyetal map of Yarsha Khola Watershed

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

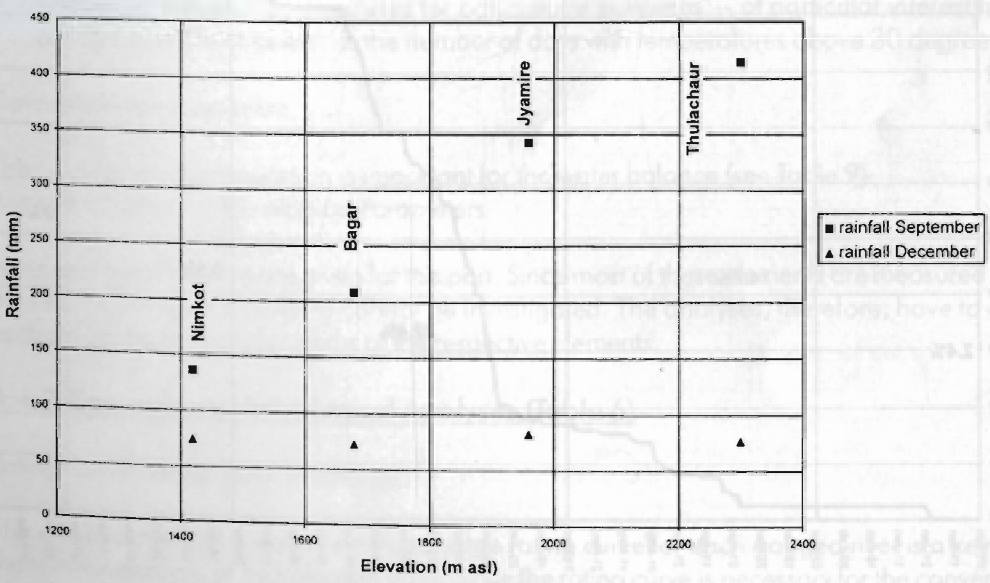


Figure 31: Altitudinal gradient of rainfall in Yarsha Khola Watershed, September and December 1997

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)

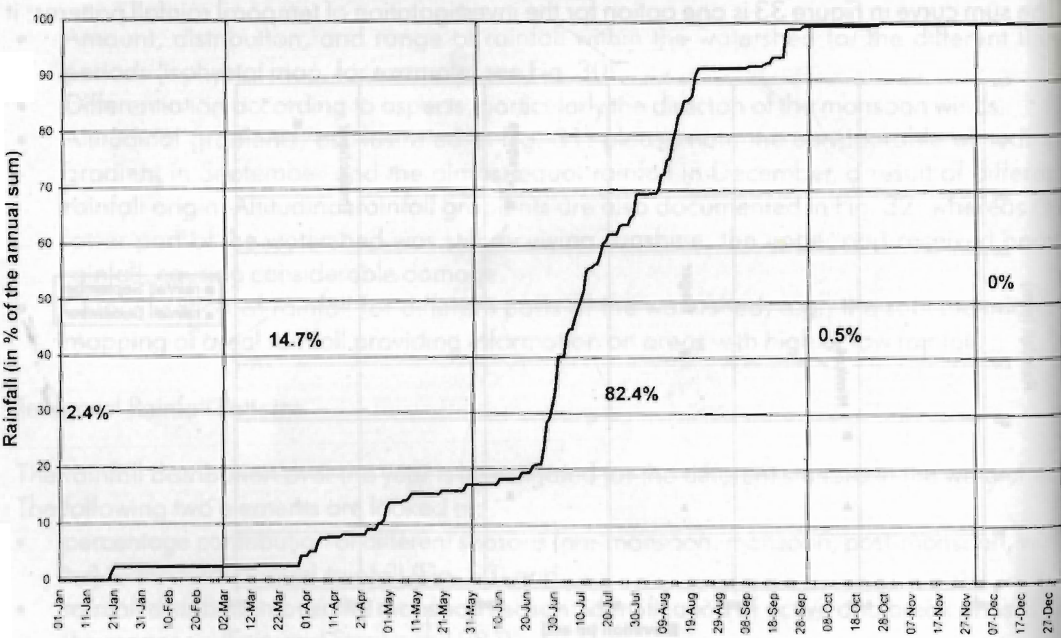


Figure 33: Rainfall sum curve for Dhaireni, Jhikhu Khola Watershed, 1997

- 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 grap 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 i 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.

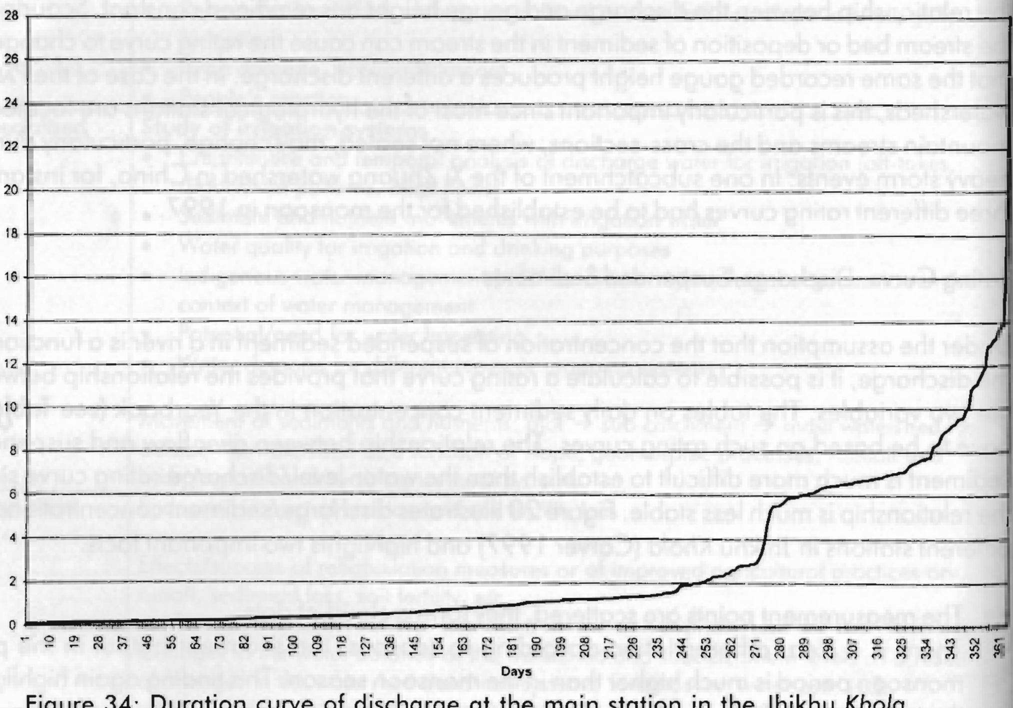


Figure 34: Duration curve of discharge at the main station in the Jhikhu *Khola* Watershed, 1997

- 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

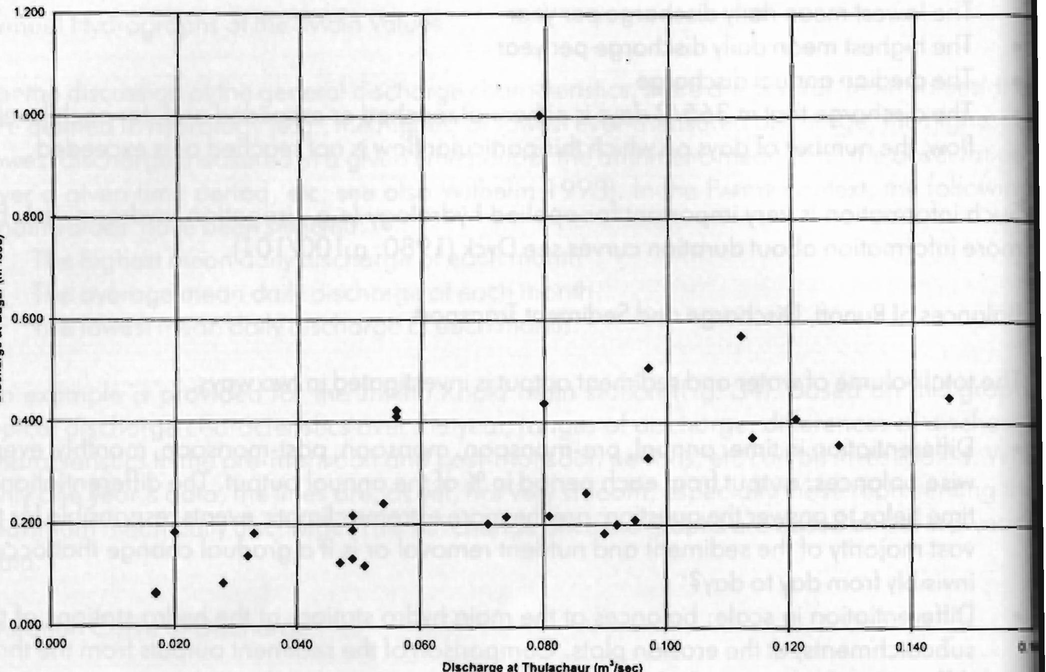


Figure 35: Discharge comparison of two stations on the Kahare *Khola*, Yarsha *Khola* Watershed, 1997

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

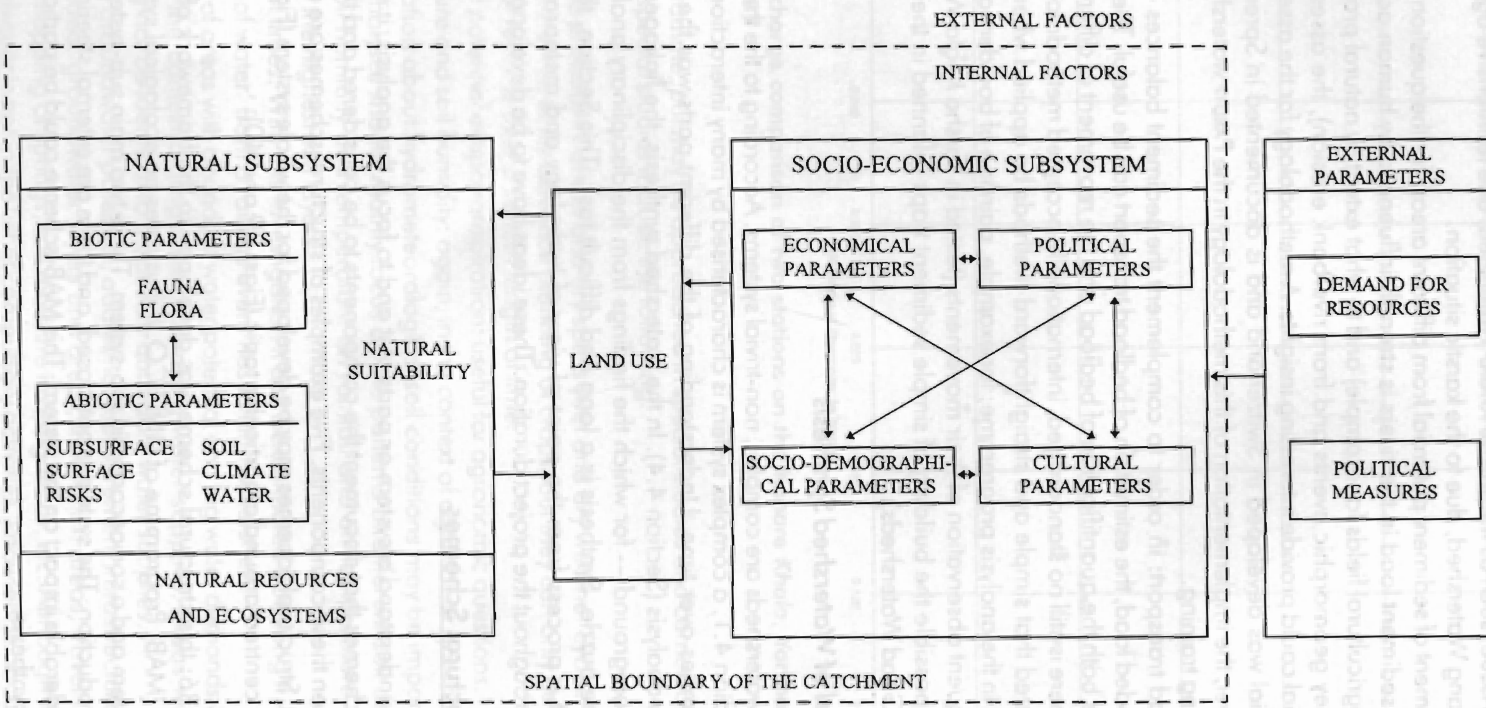
The PARDYP watersheds are complex, non-trivial systems. According to the theoretical considerations in Section 4.1, a complex system is characterised by many interactions between its parts and by changes over time. Understanding of the different parts was the aim of the level of disciplinary analysis (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)



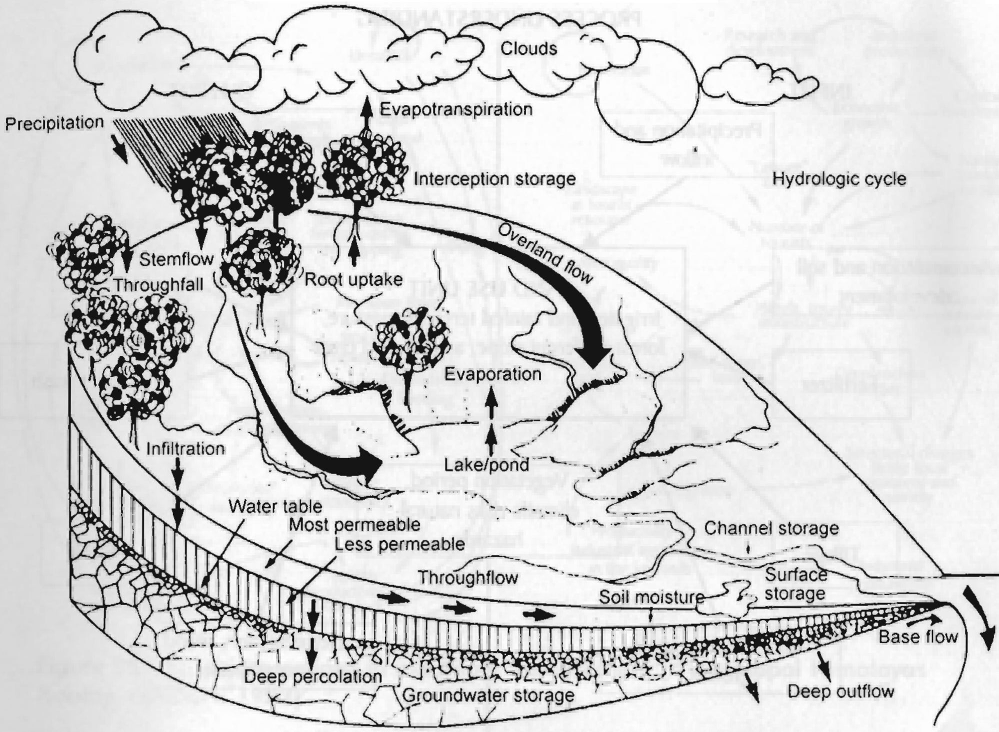


Figure 37: The hydrological cycle in a watershed (source: WARSHALL, 1980)

- 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.

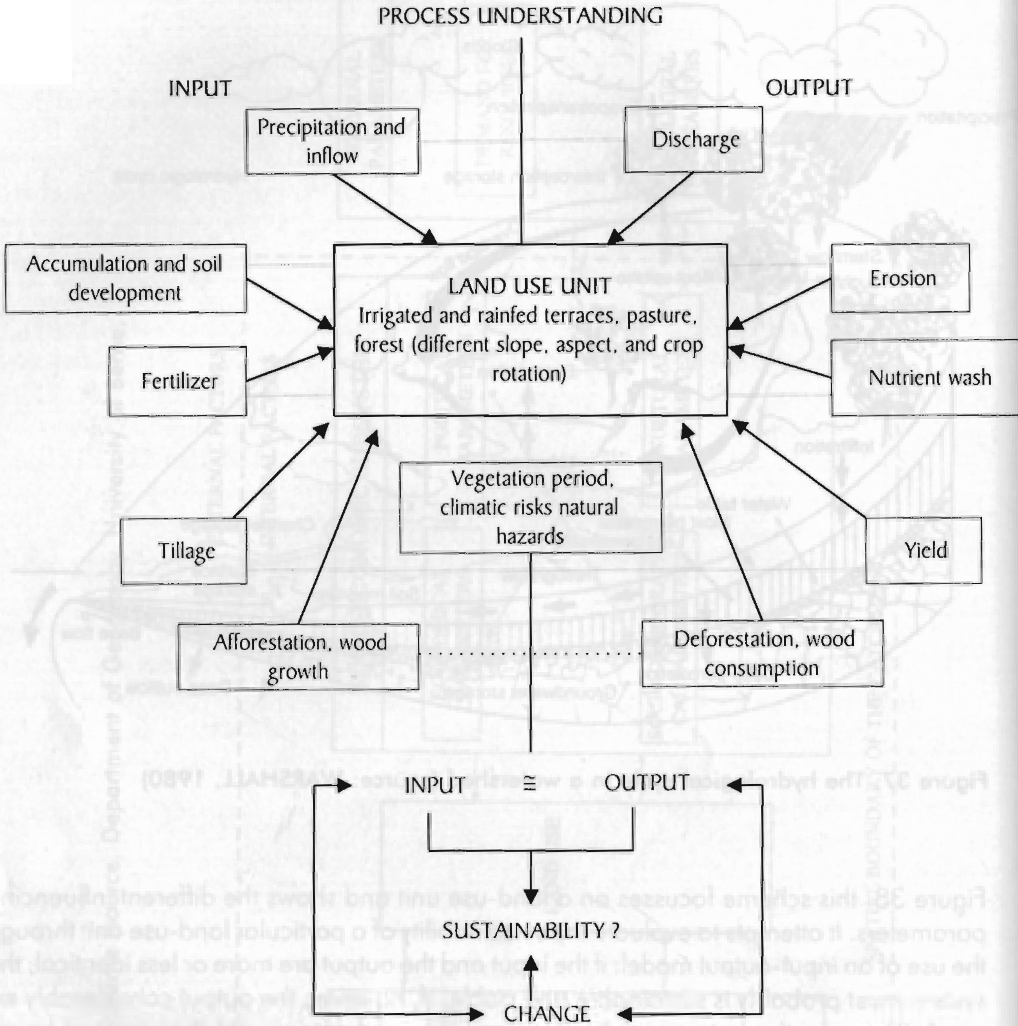


Figure 38: Input-output-model for a land use unit (source: MESSERLI, 1990)

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-

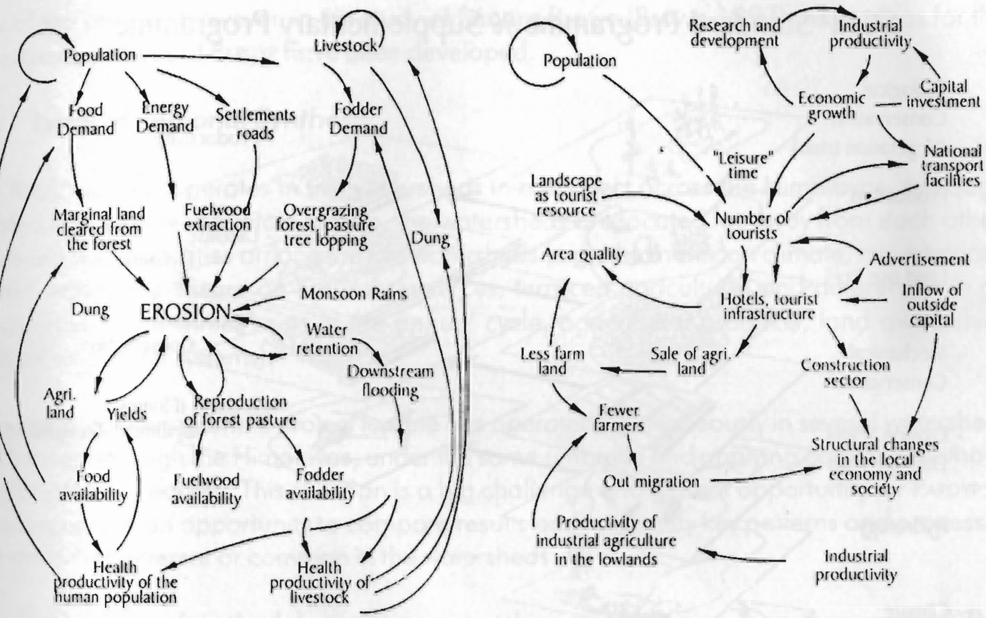


Figure 39: Major interactions in mountain development in the Nepal Himalayas (source: MAUCH, 1983)

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.

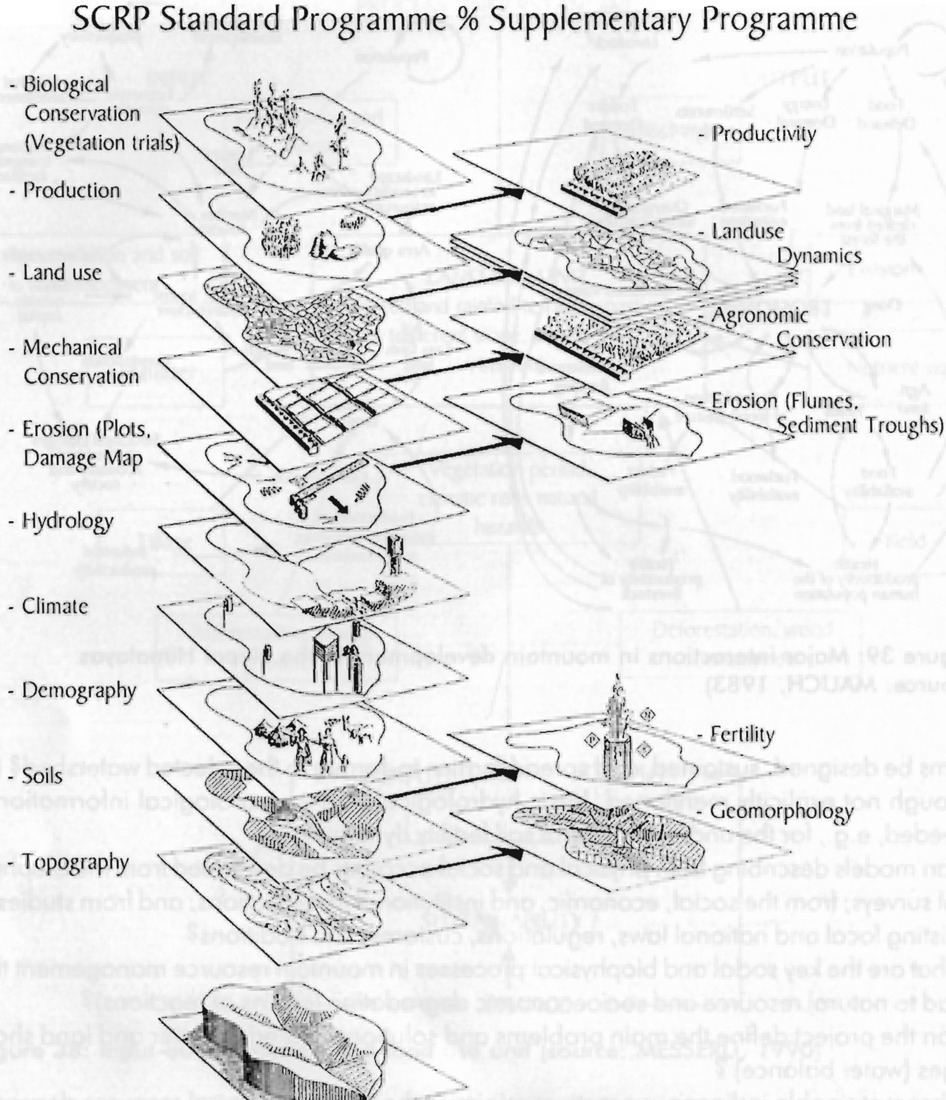


Figure 40: The soil and water conservation research project: standard and supplementary programme (source: Centre for Development and Environment, Department of Geography, University of Berne, Switzerland)

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).

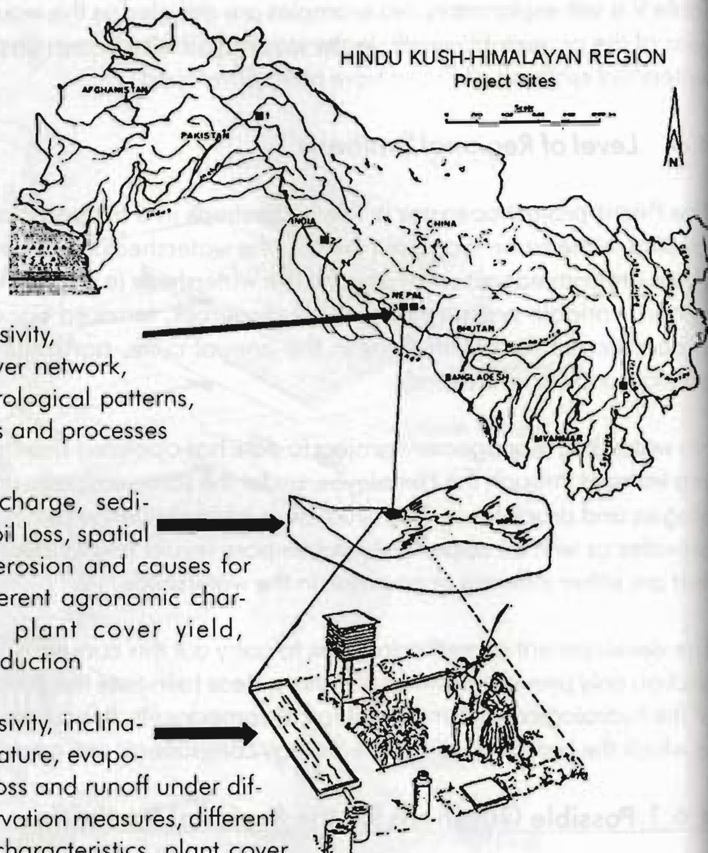
No watershed management project to date has operated simultaneously in several watersheds in a transect through the Himalayas, under the same umbrella and applying common methodologies and procedures. This situation is a big challenge and a great opportunity for PARDYP: it provides us with an opportunity 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, however 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 different levels of aggregation, or of generalisation, from the plot level through the watershed level to the 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	