# Chapter 6: Conclusion and Outlook

*" This creation is because of water"*

***(Tulsi Dahal, Mrige, Yarsha Khola)[1]***

**Based on the objectives and the needs of the different PARDYP clients, the study concluded by discussing the objectives of the study and answering the top three questions related to water scarcity, flood generation, and land degradation. This is followed by a discussion of the interactions between the water resource components and the three indexes. The main lessons learned are given addressing development actors, policy-makers, and the research community.**

**The outlook focuses on recommendations for the project in terms of measurement set-up, methodology, and future research. The chapter is concluded with a postscript documenting the most important lessons learned.**

For a summary of the results refer to the summary at the end of each chapter. The concluding remarks and the outlook attempt a general discussion of the results and outcomes of this study. As mentioned in the foreword, the study was based on the analysis of data from the past six to ten years collected in the PARDYP catchments with the aim of contributing towards improved understanding of key water-related issues in meso-scale catchments of the HKH.

## 6.1 DISCUSSION OF THE OBJECTIVES

In Chapter 1 several objectives were presented which were central to this study. The objectives are mentioned again in the boxes below and are discussed in detail.

***Contribution towards improved understanding***

***To synthesise water-related information towards an understanding of selected key issues related to water:***

- ***to contribute towards the understanding of water availability issues in a meso-scale catchment of the HKH;***
- ***to contribute towards the understanding of land degradation through water and the relevant processes associated with this degradation;and***
- ***to contribute towards understanding flood generation processes, the role of a catchment in flood generation downstream of the HKH middle mountains, and possible future threats.***

***(—> see Chapters 2 and 3)***

The key issues related to water in the HKH region were identified as water availability (including water quality), floods, and soil erosion/sedimentation. In this context, the findings of this study contribute towards an improved understanding of processes from the perspective of middle mountain catchments in the HKH region. These catchments are mainly rainfed, with a distinct seasonality and one rainfall and runoff peak during the monsoon season in the east of the HKH and two peaks due to the influence of the westerlies and the monsoon in the west. All catchments are intensively used, are under a rice-wheat based cropping system, are densely populated and herewith show high pressure on the natural resources' base. This leads to the top three questions related to the key issues set out below.

[1] Merz et al. (2002)

- **Is water in the selected catchments scarce?**
  The current water scarcity as perceived by the local residents is mainly a function of the seasonality of the water resources and the current management of the available resources rather than the natural water endowment.

  Water demand for domestic purposes is currently about 4 mm per annum in the Nepal catchments. This is based on the current daily water demands of about 20 to 25 l $person^{-1}day^{-1}$, which is about half the basic human requirement according to Gleick (1996). From an overall perspective of water availability, there should be no problem given the current annual rainfall of about 1300 mm in the Jhikhu Khola catchment and about 2200 mm in the Yarsha Khola catchment. The reasons why people perceive this resource to be scarce are mainly due to the often inconveniently located water sources, diurnal flow fluctuations in the supply systems, seasonality of flow, and, increasingly, water quality problems. While there is plenty of water in all water sources (e.g., natural springs, dug wells, spring boxes, rivulets) during the monsoon season, the flow decreases towards the dry season to reach a minimum in March to May. This seasonal difference forces many local residents to change water sources in the dry season, which are less conveniently located. Mainly people in the upper parts of the catchments along the divide face this hardship. In terms of water quality, the main risk of contamination is in the monsoon and pre-monsoon seasons. Microbiological contamination is of particular concern in most of the public and private water sources, while nitrate and phosphate are found in many sources as a result of major agronomic activities and the impact of human settlements. This microbiological contamination was shown to have a major impact on people's health with more than 25 % of the health unit patients suffering from water-related diseases.

  This suggests that a decentralised water supply based on different water sources such as rainfall, groundwater, and surface water (as well as additional, alternative sources such as fog) depending on the location of the beneficiary in combination with appropriate treatment methods and household or community-based management should be further supported. Traditional kuwas should be restored and their management institutionalised. Gravity systems tend to be expensive and inefficient due to the dispersed population. However, in bazaars these systems should be revitalised and put under strong community management. Case studies on access and management issues with particular reference to a large water supply system in the Jhikhu Khola catchment will be undertaken in PARDYP's Phase 3.

  From an agricultural perspective, water availability is adequate for the current cultivation practices. The cropping calendar is adapted to the seasonality of the rainfall as well as the low flows in the irrigation canals during the dry season. Recent intensification and increased cash crop production have led to water shortages in the Jhikhu Khola catchment as perceived by the local farmers. Further intensification of the agricultural production applying the current practices could lead to increased water shortages in the Jhikhu Khola catchment, while in the Yarsha Khola catchment there is still room for intensification. The most critical time from the perspective of natural water availability and the current cropping calendar is the time before the onset of the monsoon for planting maize, establishing rice nurseries, and transplanting rice. For good yields of post-monsoon crops, adequate soil moisture from the monsoon season and a few rains during the post-monsoon and winter seasons are critical. For an improvement of the situation, cash crop production using alternative irrigation methods should be further promoted, which would decrease the vulnerability of the farmers on rainfed agricultural land as well as decrease the demand for water on irrigated land. The storage of monsoon rains in ponds and cisterns should receive further attention in order to cater to the increased water demand during the dry season.

  An assessment of the impact of population growth has shown that future generations will face increased pressure in terms of availability of water resources. However, given that there is adequate management the projected water quantity requirements for domestic purposes will be a minor issue. For food production it is assumed that any further intensification of the agricultural production system in the Jhikhu Khola catchment will be limited, while the Yarsha Khola catchment still has adequate room to allow some intensification. Similarly, the impact of global climate change might reduce the available water resources during the dry season and further reduce the productivity during that time.

In order to satisfy the needs of the communities at the outlet of the catchments as well as support the requirements of the upland communities, water resources should be managed not only at the community, but also at the catchment level, with particular reference to the irrigation systems. Already the water availability in the lower stretches of the Jhikhu Khola catchment does not allow for the extraction of water by conventional canal irrigation.

Conclusively, it can be noted that improved and appropriate water management applying new as well as traditional knowledge in connection with the natural water endowment can support the water needs of the population in these catchments without the feeling of scarcity. This idea will be supported by the activities in PARDYP Phase 3 towards the development of a water management decision support system for rural catchments in the middle mountains of the HKH.

→ ***There is enough water in the catchments, if the resource is managed properly.***
→ ***The main issues related to perceived water scarcity are seasonality and water management.***

- **Is soil loss a problem in the selected catchments?**
Sediment mobilisation and transport can be looked at in several ways. From the perspective of the farmer the loss of fertile topsoil is important, while from the perspective of downstream users the total sediment load in the river at the outlet is of main importance. Looking at these two perspectives separately it can be stated that farmers generally do not perceive soil erosion as a main issue. This view is supported by the soil losses from the agricultural plots, which balance the annual natural soil development. On average, an agricultural plot would lose about 10 t/ha per annum, while the tolerable soil loss rates in Nepal's middle mountains are estimated at about 11 t/ha per annum. Most of this soil loss from the upper catchments is then transferred to the lower irrigated terraces through run-on as well as through irrigation water (Carver 1997; Brown et al. 1999). In addition to this, surface erosion only accounts for a part of the total soil loss from a catchment. Stream bank erosion and gullying tend to be of greater importance and of more concern to the downstream users. These processes, however, only affect a small number of farmers who own land along the rivers. Gullying is often observed along public paths and on severely degraded, often community-owned, land. In addition, the impact of road construction is considerable. This includes not only the VDC road network, often constructed without necessary expertise, but also the national and DDC road network. In terms of nutrient losses on rainfed agricultural land, Brown et al. (1999) estimated that the nitrogen losses by erosion are about 10 % and the phosphate losses are about 1 % of the total losses. On the basis of the current mineral and organic fertiliser input rates, the nitrogen loss is significant, while the loss of phosphorous is negligible. As shown by Brown et al. (1999), the irrigated land recaptures a lot of the lost nutrients from the uplands and therefore gains from the soil losses in the uplands. Improved soil conservation could herewith reduce the requirements for adding mineral fertiliser on the uplands and increase the need for the same on the lowland irrigated land. From a farmer's point of view, it is important to assess which approach requires more inputs (monetary, labour) and has more unwanted side effects. From this perspective, the current surface soil erosion rates on the agricultural land do not warrant any major changes in land management. Carver (1997), however, warns that the current system could become more vulnerable in the near future with increasing intensification. The question is, however, how far can this intensification still go?

From a downstream perspective, the total sediment output of the selected catchments is medium to high in relation to other catchments in the world. However, within the region, a number of rivers — particularly the ones originating in the Siwaliks — show much higher values. This suggests that in terms of upstream-downstream sediment linkages it is important to consider interventions to reduce the sediment loads from these middle mountain catchments in case of downstream development. As discussed above, the major source is believed to be the drainage system itself as well as the road and pathway network in the catchments. In addition, the degraded lands in the catchment were shown to be of particular importance by Carver (1997). To reduce the sediment loads, interventions should focus on the riparian zone as well as roads and paths in the catchments. Proper slope stabilisation of roads and punctual stabilisation of stream banks should be envisaged. The rehabilitation of degraded lands as well as the stabilisation of stream banks should be coupled with the need for fodder for the large number of livestock in the catchments, as the farmers are not likely to put any efforts into these hopeless patches if there is no immediate benefit. As Shrestha (2000b) pointed out, the need for fodder is felt increasingly acutely. First attempts have been reported in the past (Shah et al. 2000) and new approaches are tested in PARDYP's Phase 3 (Shrestha, pers. communication). At this point it should be remembered that the natural catchment soil erosion rates are high in the middle mountains of the HKH as discussed in detail in Chapter 2. The improved soil management will therefore only be able to reduce the losses to a limited extent.

It can be concluded that from the perspective of a farmer in the Jhikhu or Yarsha Khola catchments, improved soil conservation is not a first priority as the need is not obvious and the benefits of currently promoted soil conservation approaches are not directly visible. For the downstream perspective the need for soil conservation will only become important with the development of the water resources downstream. For this purpose the main target should be the degraded land, the stream banks, and the road network. If soil conservation simultaneously addresses a more severe — and by the farmer more clearly perceived — issue such as fodder availability, it will have more chances of success.

→ ***Surface soil loss is only a marginal issue for farmers in the selected catchments, while transported sediment may have an impact on downstream developments.***
→ ***The main sources of sediment are not the agricultural lands, but more the drainage and the road networks in addition to the severely degraded lands.***

- **Can farmers in the selected catchments be held responsible for floods downstream?**
Himalayan farmers are often held responsible for downstream flooding. Many authors have shown that due to the scales involved and the in-channel processes on the flood plains, this hypothesis has to be rejected. In addition, on the basis of the data observed in the two catchments of PARDYP Nepal, this process cannot be demonstrated. In fact, the area of cultivated land in different sub-catchments showed a negative relationship with the flood peaks and flood volumes. Grassland as well as degraded land on the other hand showed a positive relationship, while the forest areas did not show a distinct relationship. The floods at the sub-catchments and the catchment outlet further show a very high correlation with the processes on the degraded and grassland plots. The runoff on these plots is mainly generated by the infiltration excess overland flow generation mechanism. The correlation, therefore, suggests that infiltration excess overland flow or processes similar to this are mainly responsible for flood generation. As the correlation between the floods and the agricultural land is rather low, it is suggested that they only contribute marginally to floods. This suggests that the proper management of agricultural land is beneficial to flood protection for small to medium events. While the importance of catchment characteristics is proven for small to medium flood events, at high events only rainfall characteristics are decisive. In general, these large floods are generated at rainfall events with high rainfall volume or high rainfall intensities. During these events all land uses contribute to the floods. This suggests that watershed management in the traditional sense with small-scale forest plantations may not have the effect required. Large-scale land-use changes have shown differences at this scale (FAO 2002), they may not be practical however in the context of rural catchments in the HKH. The upland conversion policy of the Chinese government discussed in Chapter 2 may potentially have an impact due to its spatial extent. For this the next 10 to 20 years will have to be awaited before first conclusions can be drawn. With respect to the abandoning of agricultural areas, as has been observed in parts of the catchments, an increase in flood volume as well as an increase in the number of flood peaks could be expected. However, this was not shown by the modelling exercise, and this was mainly due to inadequate vegetation parameterisation. In terms of the assessment of future changes it can be shown that a potential climate change may lead to an increase in the number of flood peaks and an overall increase in flood volume.

For improved flood management and protection downstream, flood plain planning and in-channel conditions are far more important and should yield a better response, particularly for large and destructive events.

→ ***Large floods are a natural phenomenon and their destructive force can be reduced by improved downstream planning.***
→ ***For small and medium flood events, cultivated land has shown reducing effects.***

***Provision of data and results of analyses***

***To provide hydro-meteorological data and a number of basic analyses for further use by the project, e.g., diurnal temperature variation for agronomic trials and rainfall frequency for water-harvesting methods.***

***(—> see Chapter 3)***

During the course of this study, the basic hydro-meteorological data collection was ensured culminating in the publication of a CD-based yearbook. These up-to-date data have been used by students, researchers, consultants, and development projects. To mention a few examples, they have been used for:

- culvert design for a DDC road in the Jhikhu Khola catchment;
- appropriate crop selection by CEAPRED;
- general climatic description for the District Livestock Office;and
- several local and international BSc and MSc theses (capacity building).

In addition, results of a number of basic analyses were presented which are themselves important for different actors:

- intensity-duration-frequency curves for engineering applications (Section 3.1);
- rainfall variability for agronomic applications (Section 3.1);
- rainfall frequency for water harvesting design (Section 3.1);
- annual and diurnal temperature variations for off-season vegetable production (Section 3.2);
- reference evapotranspiration rates for crop water requirements (Section 3.2); and
- seasonal groundwater assessment for potential exploration (Section 3.3).

The results of these analyses will further be used for the design of a water management decision support system planned for PARDYP Phase 3 as well as for a comparison of the catchments in a regional water and erosion synthesis (Merz et al., in prep.).

***Modelling***

***To contribute towards the understanding of the dynamics of the above issues and their interaction.***

***(—> see Chapter 4)***

First trials with different hydrological models were carried out to estimate the impact of future scenarios based on global climate change, population growth coupled with increased water demand to meet the basic requirements, and local land-use change with expansion to marginal lands or abandoning of marginal fields. The preliminary results for the Jhikhu Khola catchment have shown the following.

- Hydrological models can be applied to the data from the Jhikhu Khola catchment. Due to certain inconsistencies in the discharge datasets, the efficiencies achieved were rather low.
- The models performed very well on a monthly basis as well as for the identification of the duration curves. This property should be followed up for a possible application in ungauged catchments as proposed by WECS (1990).

- All models applied run at daily time steps due to inadequate data sets of high temporal resolution. However, it was shown that rainfall intensity plays a major role in the generation of floods. For this purpose the models currently applied will have to be modified accordingly to cater for the input of high temporal rainfall data.
- Calculated evapotranspiration rates are based on temperature approaches. These approaches must be substantiated with more physically based methods, with additional data to be collected in future in the Jhikhu Khola catchment (see below).
- Water during the dry season is becoming scarcer due to decreased precipitation, increased evapotranspiration, and decreased runoff.
- Flood events during the wet season are becoming more frequent and are of a marginally higher magnitude.
- The dependency of lower lying administrative units in a catchment on upper administrative units is increasing due to greater water demands in these lower areas, which are generally more accessible. This calls for the introduction of catchment-based management of natural resources.
- Expected land-use changes show only a marginal impact on the flow behaviour of the catchment. It is important to note that, with the current datasets, the model shows an opposite trend from what would be expected from the observed data. This difference will have to be resolved with additional information to be entered into the model later this year.

These results are preliminary, mainly due to the fact that the efficiency of the models used can be further improved with the availability of additional data. The results suggest that more focus should be paid to the storage of surplus water in the wet season so that this can be used during the dry season, as the seasonality will probably become even more pronounced in future. While domestic water use is presently below basic water requirements according to Gleick (1996), water supply should take into consideration both a change in population as well as in terms of daily water demands to improve living standards. This suggests that water management options for the future have to tap into all available resources, minimise losses and inefficiencies, and considerably improve the quality of the water.

***<u>Synthesis and upscaling</u>***

***To provide a methodology framework for the synthesis of a large amount of data and information to be considered for the other project catchments, for comparison of catchments in the region, and potential up-scaling.***

***(—> see Chapters 4 and 5)***

For an objective comparison of the catchments, two tools have been used in this study. An index approach was used to compare the current susceptibilities of the two catchments in Nepal and to a lesser extent in the remaining PARDYP catchments. Catchment modelling has only been used in the Jhikhu Khola catchment to date. The reason for this is the length of the time series available as discussed in more detail in Chapter 4. The issues and results of the modelling are discussed above.

The index approach using three different indexes — the Water Poverty Index (WPI), the Flood Generation Index (FGI), and the Water Induced Degradation Index (WDI), for assessing water scarcity, flood generation, and land degradation susceptibilities respectively — showed first good results and suggested that the chosen approach could be further tested for applicability to other catchments in the region and beyond.

Currently, the data requirements are high and may be a constraint in other catchments with less detailed information resources. It was,nevertheless, shown that, in the case of the PARDYP catchments, most of the data could be assembled within one week without any prior knowledge of the indexes. The indexes have been tested in detail in a comparison of the Yarsha and Jhikhu Khola catchments. It was shown that the Jhikhu Khola catchment has a greater susceptibility towards water scarcity issues, not only based on resources, but also due to more difficult access, greater use, and more degraded conditions. The capacity to deal with water scarcity, however, is estimated to be higher in the Jhikhu than in the Yarsha Khola catchment. These results seem to be plausible, but the sensitivity of the approach has to be improved. Currently the spreadsheet that has been developed incorporates score limits, which allow the input of any data from the region, e.g., the extreme rainfall conditions of the Meghalaya Hills. The application of the approach to two additional catchments showed that current data requirements have to be considered further. In addition, the WPI was used in an example to assess the impact of a hypothetical rural development project and climate change. This application yielded plausible results.

It was learned that for the development of a DSS for improved water management, particular attention should be given to the topographic location and the time of the year, as well as the use of the water. Actual volumes of available water will additionally play a role but only after the consideration of the other parameters mentioned.

## 6.2 LESSONS LEARNED

Over the period of this study a number of lessons were learned, which are compiled below according to the need of the different actors related to the PARDYP project. ICIMOD (2003) lists the following actors relevant to the PARDYP project:

- ***development actors***, who can translate PARDYP's research results into practice;
- ***policy-makers***, who can convert the research results into policies at different spatial levels;and
- ***the research community***, with whom research results and methodologies can be shared.

The message to all actors summarised from Section 6.1 is set out below.

- Adequate water resources are available in the catchments to meet human demand if these resources are properly and adequately managed.
- The major focus of all activities should be on reducing the dependency on water resources and so lessen the impact on human livelihoods by variability and seasonality in the vailability of water resources.
- The soil erosion rates from farmers' lands balance the soil formation, and thus do not warrant major efforts towards soil conservation per se. These methods need to be combined with other effects such as soil amelioration, income, and so on.
- Effective sediment control needs to focus on drainage, road networks, and severely degraded areas.
- Proper land-use planning in downstream areas of the mountains and hills is more effective in reducing risks than changing land use in the upper catchments.

This suggests that development actors:

- promote small-scale irrigation with a high probability of economic return during the off-season, combined with the harvesting of spring water or surface runoff;
- focus on decentralised and family or household-managed water supply based on seasonal groundwater, spring water, or roof water in combination with cheap water treatment;
- promote proper construction and stabilisation of roads of different categories in the catchments; and
- promote small-scale soil conservation with a combined soil amelioration or economic benefit.

The message to policy-makers is to:

- support credit for small-scale irrigation based on harvested runoff;
- support activities towards the achievement of safe domestic water supply for all on the basis of water as a human right;
- introduce adequate planning in flood plains and prohibit encroachment of the river channels;
- introduce a rainfall intensity measurement network for flood management and protection;
- introduce an objective measure to review the water resources' status in all areas of the country which will enable proper targeting of funds towards improved water supply, reduced flood damage, and reduced land degradation; and
- introduce catchment-based water resources management at different authority levels.

The message to the research community is to:

- identify and disseminate more water-saving approaches for staple crops during the dry seasons;
- identify the socioeconomic and political constraints that prohibit proper water management, and propose solutions;
- identify more cost-effective approaches for the storage of monsoon rains for use during the dry season;
- take more notice of local perceptions and include them in the research;
- identify the threat of agrochemical pollution to water resources in the middle mountains; and
- identify the role of groundwater in the middle mountains.

## 6.3 RECOMMENDATIONS FOR THE PARDYP PROJECT

### 6.3.1 Measurement network and stations

The comments on the measurement network and the stations are based on the Jhikhu Khola catchment only, as the activities in the Yarsha Khola catchment were closed down in 2001.

#### *6.3.1.1 Meteorological stations*

During the catchment-based analysis of meteorological parameters, including evapotranspiration, gaps in the network were identified. For water availability considerations with particular reference to the main settlements and the irrigated areas in the valley which all depend on the flows from the upper and western part of the catchment, more data has to be collected by:

- adding one to two meteorological sites in the western and upper part to obtain data for that part of the catchment;
- upgrading Site 20 to a full meteorological station, including tipping bucket and thermistor;
- adding relative humidity sensors at all sites for the purpose of evapotranspiration calculation;
- adding automatic radiation and wind sensors to at least one site in the catchment, preferably at the main meteorological station representing the remaining catchment area; and
- establishing an evaporation pan for evaluation of the calculated evapotranspiration rates.

#### *6.3.1.2 Hydrological stations*

During analysis, the main problem with the hydrological data from the Jhikhu Khola catchment was the low flow insensitivity of the hydrological stations, the missing discharge measurements for high flows, and the changing cross-sections. To solve these problems the following measures have been proposed.

- Improve the low flow sensitivity and at the same time the stability of the cross-section with fixed cross-sections at all sites. It is important to consider the lowest flows, e.g., with a v-notch weir or a v-shaped channel close to the recording device, while not forgetting the high sediment loads at high flows, which often clog up these low flow measurement structures.
- Take one low flow discharge measurement every month (no rain on the day before) at all sites to establish good baseflow information.
- Consider fixed and defined cross-sections which allow the use of formulas for high flows with a cross-check using occasional discharge measurements.

#### *6.3.1.3 Erosion plots*

The use of erosion plots in PARDYP Nepal is currently being reviewed (Nakarmi, in prep). While it is basically agreed that the use of erosion plots for the assessment of monthly, seasonal, and annual soil losses is outdated, their use in the context of the nested approach is still valid.

From a hydrological point of view, the plots should be further used for runoff generation and infiltration studies. With the temporally highly resolved datasets of rainfall and discharge, the daily data of the erosion plots limit the analysis potential for these studies. It would be interesting to consider an automatic approach by using large cup tipping buckets for automatic runoff assessment or an automatic water-level recorder in the first drum. A direct relation between rainfall intensity and runoff could then by established. Infiltration studies could further be refined. Automatic sediment sampling could show interesting results of when exactly the main soil erosion occurs during an event. These are obviously studies that do not fit into the present PARDYP Phase 3 context, nevertheless they should be considered, perhaps through finances from another project. In addition, soil moisture monitoring using time dependent reflectory (TDR) sensors could be considered.

In any case, it would be important to monitor the vegetation cover on all plots for later relation to runoff and soil mobilisation. In addition, it would be interesting to further monitor the degraded plots to study the effects of sediment exhaustion.

Overall, it is important to remark that a hydro-meteorological research monitoring network cannot address all questions that crop up in relation to water. If water availability is the main concern, more focus should be given to proper parameterisation of low flows, evapotranspiration, and soil moisture. For studies of floods and sediment, it is important to capture the most destructive storms. For a more detailed discussion of these issues refer to Merz (2002: Appendix B-6).

### 6.3.2 Methodological thrusts

In January 2003 PARDYP entered Phase 3 of the project, which will last up to December 2005. Phase 3 aims to "increase rural livelihood security and sustainability" (ICIMOD 2003). In this context, the component on water resources contributes to the objective to identify, test, and disseminate "water management options for more efficient use and equitable access" (ICIMOD 2003). In order to achieve the aims identified, the project team decided to:

- analyse the data,
- identify or produce a model for up-scaling the project experiences, and
- produce a decision support system (DSS) to guide the selection of the most appropriate water management options to be tested and improved by applying participatory action research (PAR) methodologies.

This approach roughly follows the applied research side in Figure 6.1 with the aim of solving problems at the local, the meso-catchment scale. The study presented follows mainly the research side of Figure 6.1 with the aim of detecting and describing problems that should be picked up by the applied research for resolution. For this purpose, the presented study has provided a first attempt of a possible base for the DSS, as described below.

- The ***index approach*** proposed in Chapter 5 of this study. The approach is preliminary due to the small number of catchments tested. In the author's view, this approach has great potential for the up-scaling of PARDYP's detailed project findings to the region and beyond, after rigorous testing of the methodology in a number of other catchments. During this process of verification, the number of indicators could be refined, more sensitive indicators included, and indicators that prove to be specific for the catchments in Nepal excluded. With a considerable number of catchments a factor analysis could be performed to identify the most informative indicators. Later, the most similar catchments could be identified with a cluster analysis approach. This would further support the development of a DSS and could be used for a preliminary screening of the catchments to identify the most applicable water management options.
- The results of the **spatial synthesis** at the catchment scale, which concluded that the topographic position of a selected location with access to particular water sources could be used as the entry point for the DSS.
- The results of the **temporal synthesis** at the catchment scale, which concluded that the understanding of the local cropping calendar in combination with the hydrological cycle will be important for the identification of potential solutions from the perspective of water requirements, water availability, economic return, and availability of land.

| | **Research** | **Applied Research** |
|---|---|---|
| **Aim** | **"Detect problems"** | **"Solving problems"** |
| Spatial focus | Regional Key Issues | Watershed Key Issues |
| Focus | Methodological Focus (approach oriented)<br>• Testing and evaluation of new and relevant technologies and methods<br>• e.g., radar, automatic sediment monitoring, automatic nutrient monitoring<br>• Modelling<br>• Synthesis of interdisciplinary research | Water Supply Management<br>• Water harvesting (rainfall, spring, surface runoff)<br>• Groundwater<br>• Catchment protection<br><br>Water Demand Management<br>• Alternative irrigation<br>• Agricultural interventions |
| | Theme Focus (result oriented)<br>• Water availability<br>• Floods<br>• Sediment<br>• Nutrient build-up<br>• Agro-chemical pollution<br>• Role of institutions/gender in water management | Water Quality Management<br>• Treatment<br>• Source and catchment protection<br><br>Soil Conservation<br>• Bio-engineering methods<br>• Engineering methods |
| Methodology | • Monitoring<br>• Data analyses<br>• Collaboration | • PAR<br>• Training<br>• Exposure<br>• Collaboration<br>• Testing<br>• Demonstration |
| Partners | Universities, NARES,….. → research organisations | GO, NGOs,…… → Implementing agencies |

↓

**Dissemination**
to different stakeholders at different levels with different media

Figure 6.1: **Water and erosion studies in a watershed management research project**

Prior to wide dissemination and up-scaling of PARDYP results, rigorous testing of the approaches and methodologies is necessary. For this purpose it will be important to embark on a dialogue with those other projects and institutions in the region and beyond that entertain research catchments. First attempts for this could be undertaken in the catchments that supported the Andean-Himalayan comparison (Schreier et al. 2002) or based on the up-coming FAO consultation on watershed management.

## 6.3.3 Further research in the PARDYP catchments

From this study the following further research needs are formulated in order to substantiate the current knowledge. The list assumes that unrestricted fieldwork is possible and does not limit itself to the current PARDYP project objectives. Activities taken up in Phase 3 of PARDYP, such as the preparation of a DSS, are not mentioned again, although this study has been instrumental in identifying the most appropriate objectives and activities, to:

- improve the understanding of evapotranspiration and crop water requirements;
- investigate the impact of irrigation diversions on hydrological flow;
- evaluate the importance of stream-bank erosion in the overall sediment budget of a middle mountains catchment;
- relate the above findings to a larger catchment scale (e.g., the Sun Koshi basin);
- determine the impact of agrochemical pollution in the catchments; and
- make a detailed assessment of groundwater resources in the Jhikhu Khola catchment.

## 6.4 POSTSCRIPT

"There is a water crisis today. But the crisis is not about having too little water to satisfy our needs. It is a crisis of managing water so badly that billions of people — and the environment — suffer badly." (Cosgrove and Rijsberman 2000)

The study presented here is believed to be a strong basis for the improvement of the current situation in mountain catchments of the HKH. While it does not present solutions to water-related problems, it identifies the issues quantitatively as well as qualitatively. Often it provides thought provoking aspects and introduces methods from other parts of the world that could be used to improve our understanding of key issues in the region and support efforts made towards improved water conditions.

This study provides the ground for PARDYP Phase 3 to indulge in the testing of potential approaches, improving these approaches hand-in-hand with local farmers and finally promoting the most appropriate ways to improve the management of water resources. In all of these activities it is important to involve the different stakeholders — from the farmer to the local government and the line agency. It is evident that water management is crucial, both for improved water availability for agricultural and domestic purposes, as well as to reduce the risk from water masses during the wet season. The most important lesson learned is that the human activity of the rural population of the middle mountains in Nepal overall support the stabilisation of the hydrological system. Fine tuning the current system to cater for new water demands and newly created issues deserves the greatest attention of all those involved in the management of water resources in order to provide further stability and continuation.