Snow and Glacier Hydrology in Nepal: Project Results for the Provision of Data and Information for Water Resources' Development

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Abstract

Information about hydrometeorological conditions in the high Himalayas is required for the optimisation of water resources' management in Nepal. The principal achievement of the project is the institutional capability of the Department of Hydrology and Meteorology (DHM) to carry out the necessary field work to establish and maintain hydrometeorological stations in the Nepal Himalayas, to maintain a hydrometeorological database and deliver relevant data products to users for the assessment of water resources in Nepal. Technical and institutional approaches to obtaining the required information are discussed, and relevant data products, such as yearbooks, flow-duration curves, and flow simulations using a conceptual snow and glacier melt model, are demonstrated.

Introduction

Water is a key factor for the economically sound and environmentally sustainable development of Nepal. Meltwater from snow- and glacier melt are the prime source for the sustenance of low flow of many potentially important rivers for hydropower generation. To optimise the efficiency of water resources' planning and management, knowledge is necessary about the seasonal and regional distribution of river flow originating from the snow and glacier fields of high mountain areas. The government of Nepal and the government of Germany, therefore, in 1987, agreed to a technical cooperation project between the Department of Hydrology and Meteorology (DHM) and the German Technical Cooperation Agency (GTZ) to establish a measuring service for snow and glacier hydrology in Nepal.

Institutional Setup

The Department of Hydrology and Meteorology is the responsible implementing agency. Under its hydrology branch, the Snow and Glacier Hydrology Unit (SGHU) is organised into the following sections: Field Activities, Data Processing, Laboratory, and Administration. These sections are controlled by a responsible officer. The staff is organised into task-oriented teams who are responsible for the six hydrometeorological stations which have been established (Fig. 1). The SGHU staff is trained to perform hydrological and meteorological measurements and primary data processing, including plausibility control of the station data. At the officer level, the data are further scrutinised and processed into data products. The staff training had an emphasis on the training of technical staff rather than on academic staff to impart operational experience in the handling of conventional and modern technologies used in the project, with the objective of obtaining high-quality field data. Selected staff and officers serve as multipliers who conduct training for new or seconded staff and station observers.

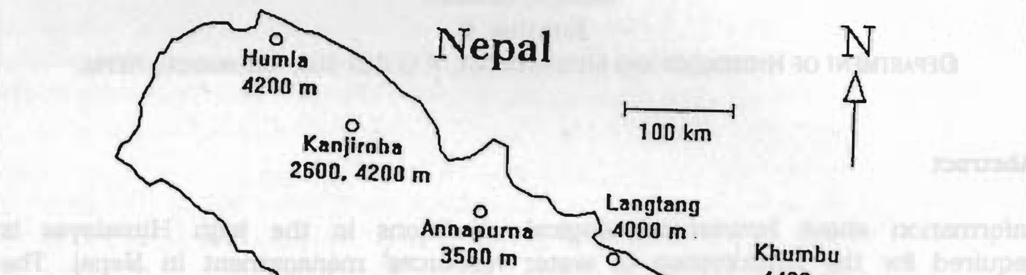

Figure 1: Location of SGHU Stations

For the implementation of the project, the executing agencies agreed on a set of principles to ensure sustainable routine operations of the SGHU under conditions of scarce financial and manpower resources (Grabs and Shankar 1995).

- Modern technologies are introduced and routinely used in those cases in which satisfying data cannot be obtained with conventional technologies. Modern technologies have to be adapted to country conditions before transfer and use.
- An infrastructure is created to ensure the maintenance of instruments and their handling by properly trained staff.
- A 'technology-mix' (modern and conventional technologies) is used to ensure a year-round operation of all stations with minimum loss of data due to inappropriate technologies.
- A monitoring system is introduced to enable staff to control instrument functions, shorten repair times, check data plausibility, analyse causes for data losses, and maintain control on deadlines for data products and services to end users of the data and derived products.

Instrumentation and Data Processing

Under difficult environmental conditions, six hydrometeorological stations have been established in the High Himalayas for the acquisition of selected hydrometeorological variables for basins of sizes between 100 and 300sq.km (Grabs and Pokhrel 1993). This basin size is of particular interest for the planning and construction of small- and medium-sized hydropower stations in Nepal. Modern technologies have been introduced with regard to station instrumentation, discharge measurements, data processing, and modelling. While the remoteness of the stations would call for the installation of automatic stations, the difficulty in detecting sensor errors and problems in maintaining and repairing electronic parts on site, and also in Kathmandu, favours conventional mechanical or electro-mechanical instruments. Therefore, the station network is based on a mix of conventional instruments and automatic stations where sites are inaccessible over long periods during the year. Automatic stations are backed up by conventional instruments in the same region. With regard to water-level recorders, piezo-electric pressure sensors and electro-mechanical recorders have been selected to minimise the cost of installation, operation, and maintenance. For the simulation and forecast of snow- and glacier melt runoff, rating curves had to be established for the gauging stations. For discharge measurement, state-of-the-art tracer hydrological methods have been preferred instead of conventional methods of discharge measurements (Spreafico and Grabs 1993). The field samples are analysed in the tracer laboratory at the DHM in Kathmandu. Field errors can be detected and partly corrected.

The SGHU has the capacity for data processing, database management, and the production of yearbooks, as well as certain data products which are discussed in more detail below. The quality of the data is controlled by graphic plausibility analysis. A station-based monitoring system has been introduced to enable staff to control instrument functions, shorten repair times, check data plausibility, and analyse causes of data losses. Mainly due to the adverse environmental conditions at high altitudes, on an average only about 75 per cent of the data can be retrieved from the station network. Yearbooks with mean daily data have been produced and published, including the 1994 data (SGHP 1993, 1995, 1996). With the compilation of data on an hourly basis in a relational database system, it is now also possible to make detailed data analyses with a relatively high temporal resolution. This feature is important as it has allowed the use of mathematical models for runoff simulations and prediction on a daily basis for three of the six basins up to now.

Generation of Data Products

From the conception of the project, the elaboration of data products as input for water resources' planning and development was envisaged as the overriding objective. "*From data to operationally useful information*": under this motto, a three-pronged approach was selected.

- The provision of quality-controlled basic data to data users in the form of yearbooks and selected time series of hourly values,

- The provision of primary data products, such as mean and extreme values for the observed variables and project-oriented information, viz. flow-duration curves and flow estimates using simulation techniques,

- Advanced data products, such as flow predictions from a conceptual snow- and glacier melt runoff model (ETH5) and information derived from the regionalisation of station data to ungauged basins.

For four of the six stations, gaugeheight — discharge relations have been obtained for the generation of flow-duration curves and as calibration input for the ETH5 model described below. The flow-duration curves are a principal requirement for the flow assessment, e.g., for hydropower generation. Figures 2, 3, and 4 show the flow - duration curves for the stations of Langtang, Khumbu, and Annapurna where sufficient data are available for calibration. The missing data in the flow-duration curves are put at the beginning of each curve, and the duration curve is then computed for the period without missing values. The curves show the maximum, minimum, and mean flow duration and the duration curve for an actual year. It is apparent in the case of the Annapurna station that, for particular years, data losses may occur mainly due to environmental influences, such as avalanches and inaccessibility of the station. To close the data gaps in the time series, a number of neighbouring reference meteorological and hydrological stations have been selected for each SGHU station to obtain additional temperature, precipitation, and discharge data. Simple linear regression analysis is sufficient to describe the temperature relationship between SGHU stations and the best-suitable reference station. For precipitation, multiple linear regression analysis is used to establish the relationship between several reference stations and the respective SGHU station. The regression equations and the adaptation of the ETH5 model allow the reconstruction of flow time-series, which are then used for the re-analysis of the flow-duration curves with the ETH5 model, as shown in Figures 2 to 4. The main precondition for the valid reconstruction of flow time-series is the proper calibration of the ETH5 model.

In addition to the acquisition and processing of project-related hydrometeorological data, basic information is required to assess the water resources' potential and seasonal availability in the Himalayas. It is therefore necessary to develop regionalisation concepts for ungauged basins. Ground-based methods had to be preferred over remote-sensing techniques because of financial and technical constraints in the current project. The use of reference stations to validate data of key hydrometeorological stations and to close data gaps is a modest approach which can be further developed. Another option for regionalisation and hydrological comparison is the use of specific discharge as a regionalisation criterion. For drainage basins with similar geographical attributes, such as topography, altitude distribution, and extent of glaciers and snowfields, comparable specific discharges can be expected which can be used for a first assessment of water resources' availability and seasonal distribution in an ungauged basin. Additional meteorological and hydrological measuring campaigns can then be used to establish more accurate relationships between the SGHU stations and hydrometeorological conditions in ungauged basins. Figure 5 shows the mean monthly specific discharges for the Langtang, Khumbu, and Annapurna stations. On the basis of runoff estimates from specific discharges and the available temperature and precipitation time-series of reference stations, a stepwise basin-by-basin approach seems feasible for the application of the conceptual model in glacierised basins of the Nepal Himalayas.

A conceptual snow- and glacier melt model (Braun et al 1993) has been selected and adapted to the Himalayan conditions to simulate and forecast snow- and galcier melt discharge on a daily basis (Fig. 6).

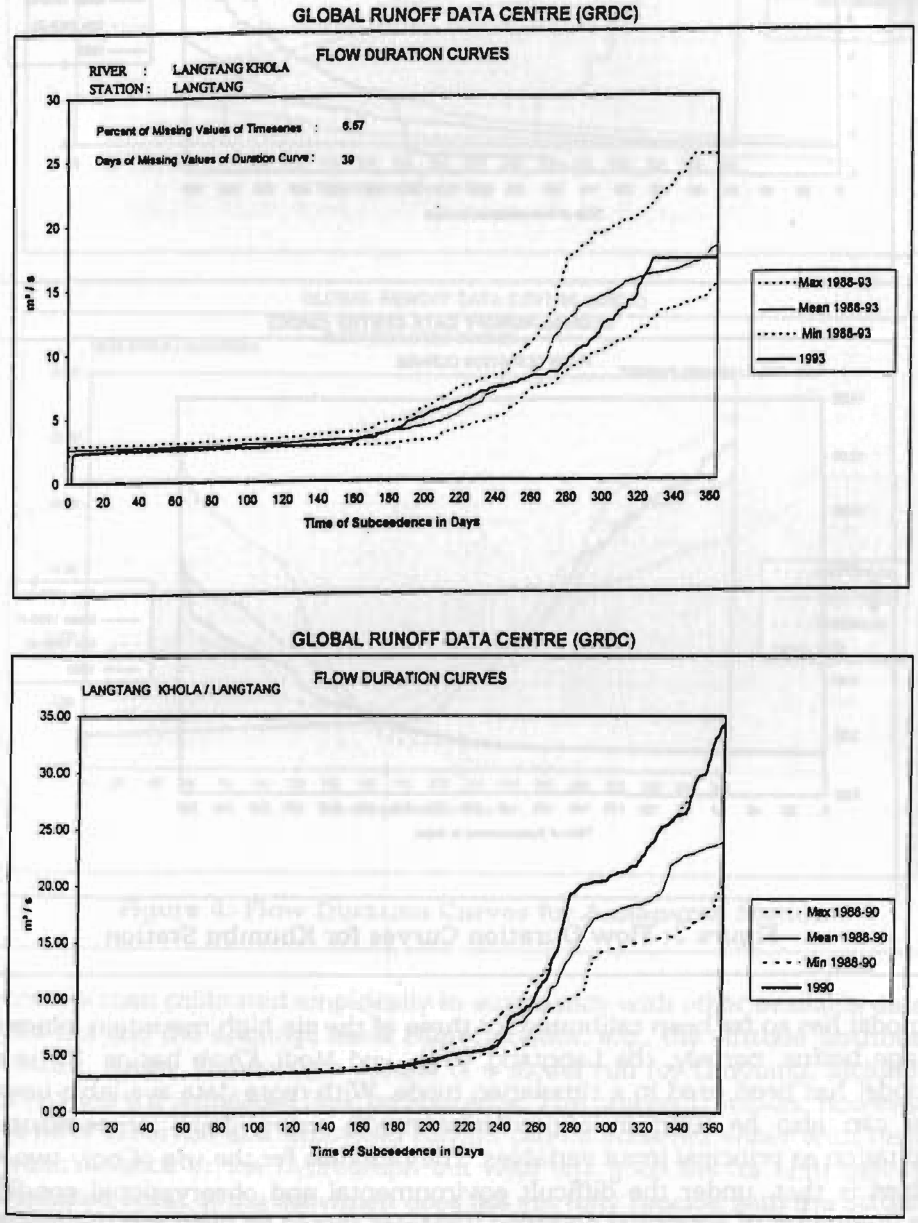

Figure 2: Flow Duration Curves for Langtang Station

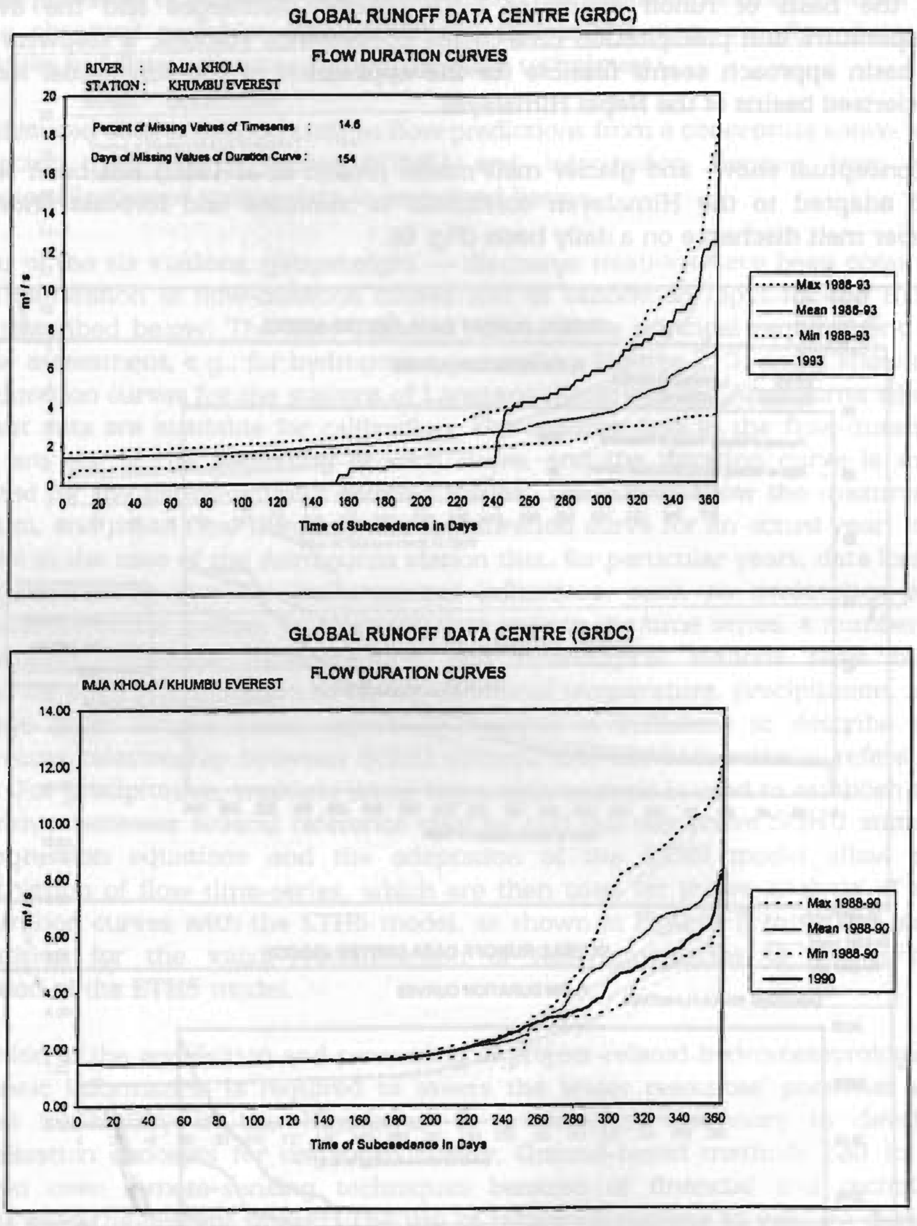

Figure 3: Flow Duration Curves for Khumbu Station

The model has so far been calibrated for three of the six high mountain, glacierised drainage basins, namely, the Langtang, Imja, and Modi *Khola* basins. Up to now, the model has been used in a simulation mode. With more data available now, the model can also be used in a predictive mode, using daily temperature and precipitation as principal input variables. The rationale for the use of only two input variables is that, under the difficult environmental and observational conditions, only a limited set of physically observed variables should be used and the model

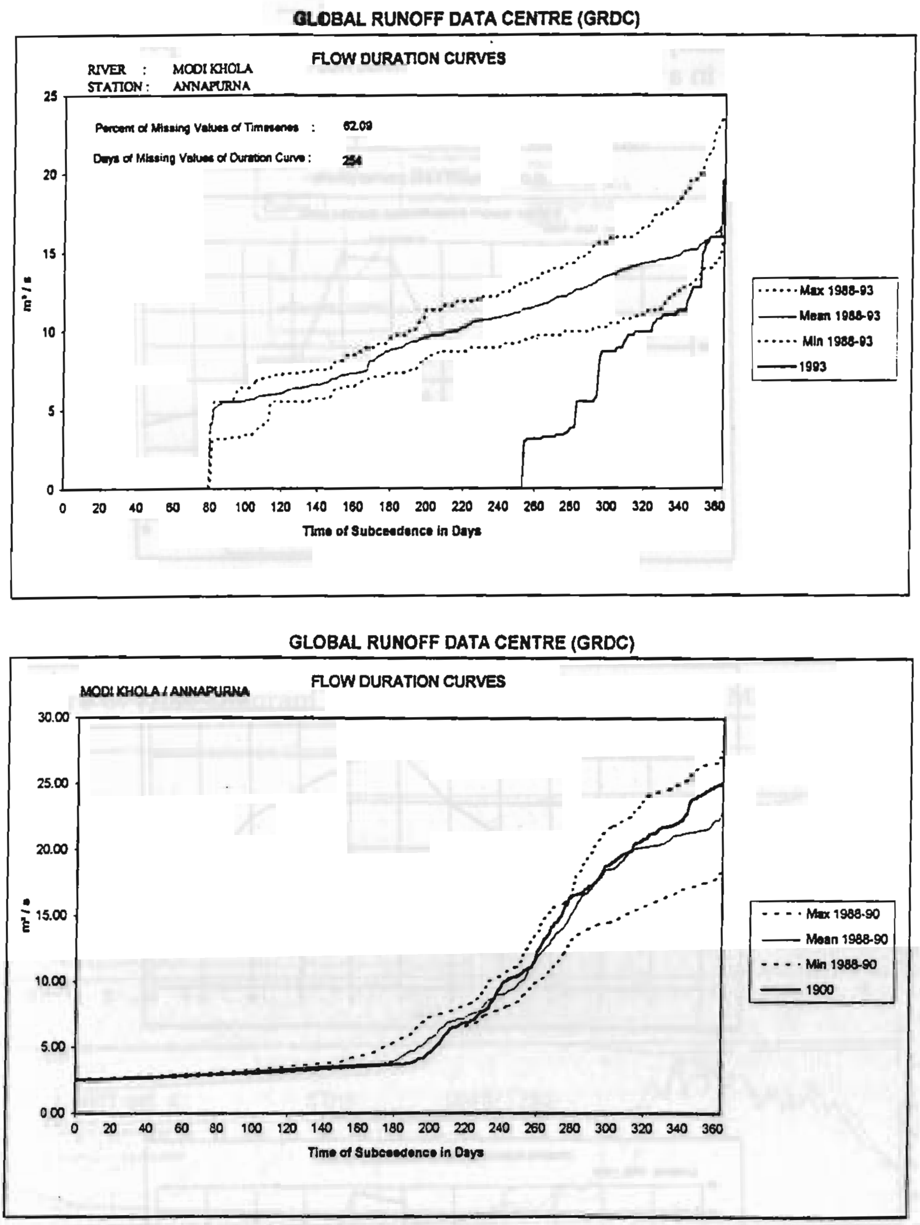

Figure 4: Flow Duration Curves for Annapurna Station

parameters then calibrated empirically in accordance with other available data from the stations and the drainage basin characteristics, e.g., the altitude distribution of each basin. Figure 7 shows the results of a model run for Langtang, including the observed and the simulated flow hydrographs. The problem remains, however, that a best fit of observed and simulated runoffs can be achieved either with respect to the water balance or the hydrograph but with less good fits for both together, as the modelled onset of the snowmelt does not yet fully concide with the actual start. Progress in model development will bring a better solution to this problem. The results from the simulation runs demonstrate that — together with information obtained from the daily radio contacts to all stations — it is possible to use the model operationally in a near real-time mode.

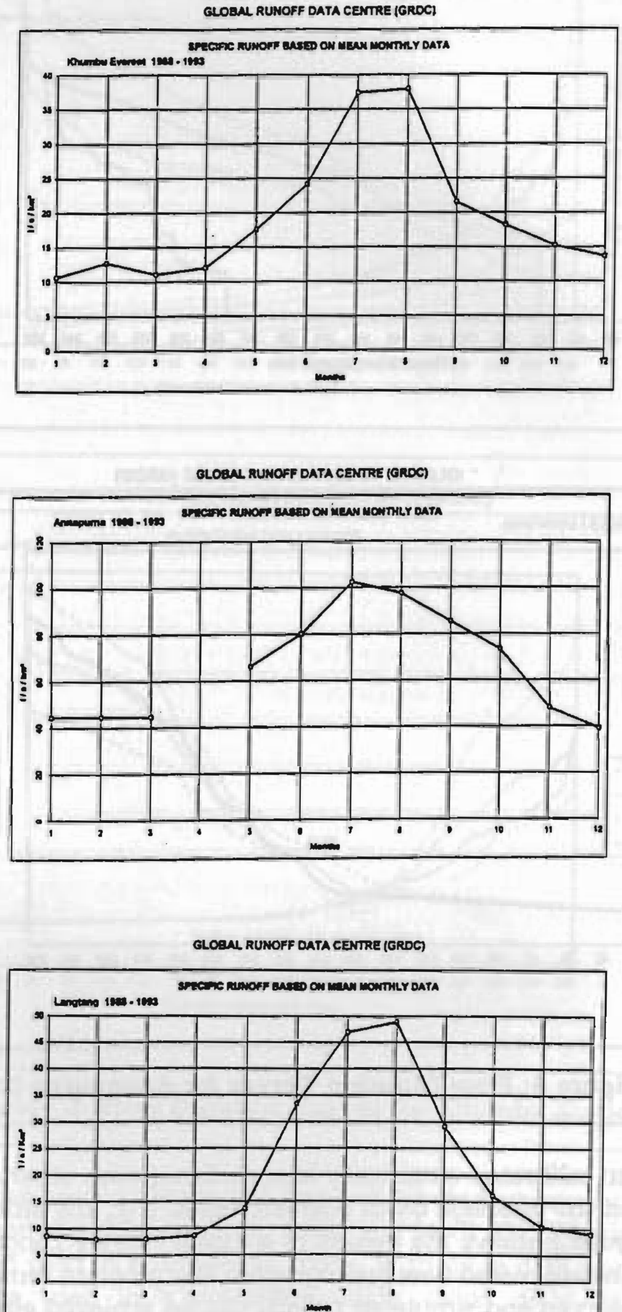

Figure 5: Specific Runoff of the Three SGHU Stations

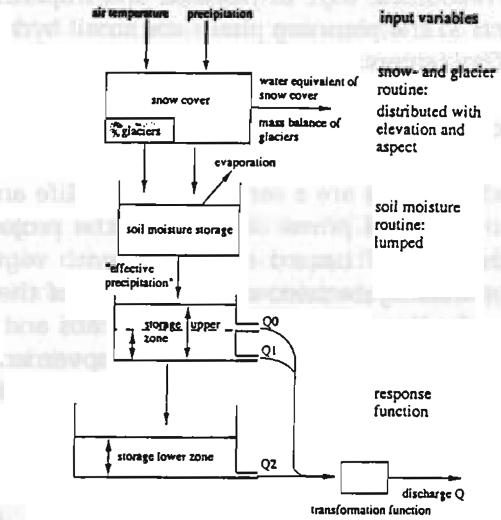

Figure 6: Flow Diagram of the ETH5 Snow and Glacier Melt Model

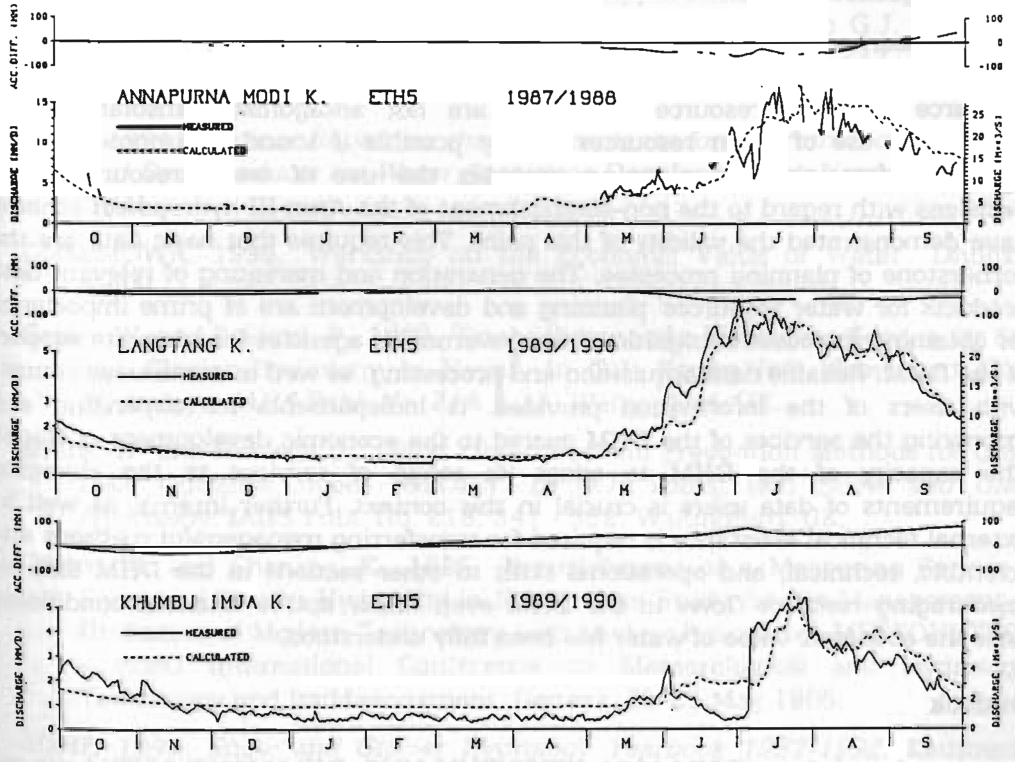

Figure 7: Model Run of the ETH5-Model for the Langtang Station

An important step for the operationalisation of the system for forecast purposes is the provision of a telemetric capacity to stations which are of economic interest for the harnessing of water resources, e.g., in planned and implemented hydropower projects. Two such projects in the planning phase are small hydropower stations on the Langtang and Modi *Khola* rivers.

Glacial Lake Outburst Floods

Glacial lake outburst floods (GLOFs) are a serious threat to life and infrastructure in many parts of Nepal. Though not a prime objective of the project, the project has also yielded results in the area of hazard mitigation with regard to glacial lake outburst floods, mainly by making decision-makers aware of the potential dangers and methods for hazard mitigation and early warning (Grabs and Hanisch 1993), by training staff to work on glaciers, and by taking glacier movement observations and by observing glacier hazards in liason with staff from the Water and Energy Commission Secretariat (WECS) in the Ministry of Water Resources (MOWR). A major result is the hazard mapping for the Imja *Khola*/Dudh Kosi valley.

These latter activities have recently gained strong support from the relevant authorities of His Majesty's Government of Nepal and donor agencies in connection with the risk assessment of planned and existing hydropower plants and infrastructure in valleys of the Nepal Himalayas which are endangered by possible glacial lake outburst floods (Bajracharya and Grabs 1995).

Lessons Learned

Resource use and resource protection are not antagonistic, insofar as the sustainable use of water resources is only possible if sound environmental and ecological foresight and planning precedes the use of water resources. The decisions with regard to the non-establishment of the Arun III hydropower scheme have demonstrated the validity of this point. This requires that basic data are the cornerstone of planning processes. The generation and marketing of relevant data products for water resources' planning and development are of prime importance for obtaining increased recognition from government agencies for adequate support of the DHM. Reliable data acquisition and processing, as well as continuous contact with users of the information provided, is indispensable for expanding and improving the services of the DHM geared to the economic development of Nepal. The capacity of the DHM to adapt its range of services to the changing requirements of data users is crucial in this context. Further internal as well as external technical assistance is required for transferring management methods and scientific, technical, and operational skills to other sections in the DHM and for encouraging resource flows to the DHM even under scarce financial conditions, once the economic value of water has been fully understood.

Outlook

A series of workshops (DHM 1994, WECS/DHM 1995, DHM/MOWR 1996) have set the direction for further activities in the generation of application-oriented data products for data users, with the understanding that water is one key factor for the socioeconomic development of Nepal. Adapting approaches chosen in the Snow and Glacier Hydrology Project to other activities of the DHM will enable the DHM to strengthen its profile as a capable partner in the development process of Nepal. This requires further technical and managerial assistance of the DHM at a time when the role and service profiles of hydrological services worldwide are rapidly changing.

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