Present Status and Problems of the Hydrology of Mountainous Areas of Pakistan

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Abstract

The water resources of Pakistan depend mainly upon the Upper Indus basin system. The Upper Indus River basin is a part of the Hindu Kush-Karakoram-Himalayan range of mountains. The objective of this paper is to study the present status and problems of the hydrology of the Indus Basin, in general, and of the Upper Indus basin, in particular, and to discuss the possible solutions. Hydrological problems of mountainous regions are related to poor accessibility, hydrological disasters, installation of recording instruments, hydropower development, storage and reallocation of high flows, demand and supply of water for multipurpose use, operational inflow forecasting, and other socioeconomic conditions. Various technical projects which are currently being carried out for the development of the area by different agencies in Pakistan have been discussed. On the basis of a review of these projects, the shortcomings and problems of current projects are considered and preliminary conclusions are drawn for the solutions to various problems.

Hydrology and Climate

Hydrology

Mountains occupy about 60 per cent of Pakistan's total territory of 776,260sq.km. The total area of the Indus basin is about 934,000sq.km. The Upper Indus hydrological system, which is the major source of water resources, is part of the Hindu Kush-Karakoram range of mountains (Shankar 1990). About 70 to 80per cent of the annual flow of the Indus River and 40 to 50 per cent of that of its main tributaries , viz., The Kabul, Jhelum, and Chenab, is due to snow- and glacier melt. The area draining the Himalayan waters into the Arabian Sea is called the Indus basin, as shown in Figure 1. The major western tributary is the main feeder of the Indus, the headwaters of which lie in the Karakoram Mountains. The other major tributary is the Jhelum, which flows from the greater Himalayan Range. Snow accumulates in both watersheds during the period from October to March and melts during summer. The major portion of runoff in these rivers occurs between June and September. Most of the melt water contributing to streamflow originates at from 3,000-5,500masl and dominates the summer hydrograph. Above 5,500masl there is often heavy snowfall accumulation but little melting, due to freezing temperature (Shah 1990).

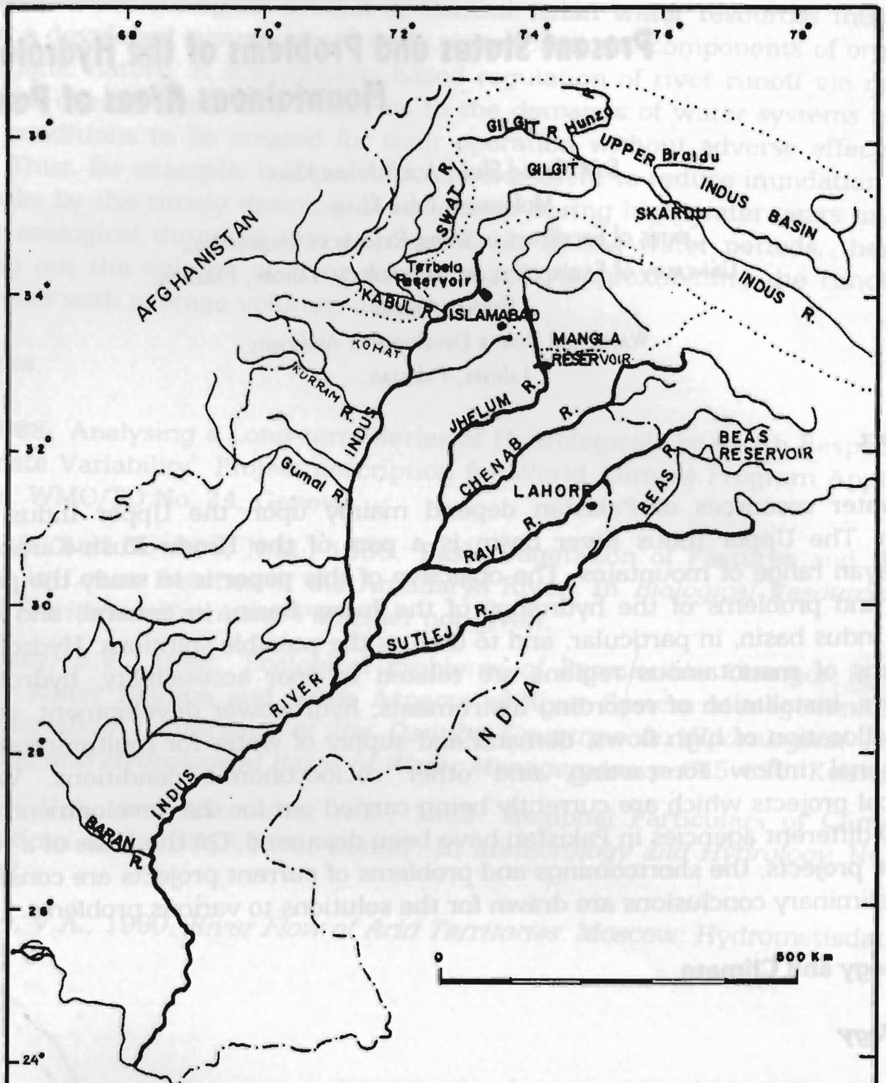

Figure 1: The Drainage Basins of the Indus, Jhelum and Kabul Rivers (The watershed of the Upper Indus Basin (UIB) above Besham, Jhelum Basin above Mangla, and Kabul Basin above Nowshear are delineated by a pecked line.)

Climate

The mountainous region of Pakistan may be divided into two major weather systems, the monsoon and the westerly disturbances. Precipitation varies greatly in quantity and regime with altitude, topography, and aspect. The tropical pattern of rainfall is predominant during summer. The mountain barrier has a significant effect on the extent of the rainfall towards north and west. Snowfall occurs during the winter season in all mountainous regions with altitudes above 2,100m.

However, under conditions of cold air flow, snowfall may occur at altitudes of 1,200-1,500m as well. Snowfall over the mountains starts towards the end of November and at high altitudes may extend until March. However, at an altitude of more than 1,800m, snowfall may occur even during the summer months. The total glacier cover of the mountainous headwaters of the Indus is not more than five per cent. The highest altitude of the snow line is around 4,876m. The heavily glacierised Nanga Parbat massif is an important exception, making a large glacier-melt contribution to the Himalayan catchments (Hewitt 1990).

Hydrological Problems of the Mountainous Regions

The problems of mountainous regions are briefly discussed below.

Provision of Drinking Water Supply and Irrigation

The population in Pakistan's mountainous areas which stretch over a distance of about one thousand miles is situated in the north and north-west part of the country. The population in these areas is living under extremely difficult conditions as far as the water supply for drinking and irrigation is concerned.

Flash Flooding

Flash flooding in the mountainous areas of Pakistan is responsible almost every year for large-scale localised damage to the population in terms of life and property. Typical hydrological hazards in the mountain regions are cloudbursts, rock- and landslides, soil erosion, and debris flows. Due to financial constraints only a limited amount of mitigation work has been carried out so far.

Hydrological Impacts due to Human Activities

The Hindu Kush-Himalayas are considered to be geologically young and tectonically unstable mountain ranges. Because of the steepness of the slopes and the high variability of the climate, the mountains in the region are much more susceptible to any unwise land-use changes and human activities.

Sedimentation

The characteristics of sedimentation are quite different in mountain areas compared to those in the plains. The application of the results of sedimentation studies made in the lowlands and in laboratories has already contributed to the failure or inefficiency of many water resource projects developed in the mountains or their adjacent plains (Tejwani 1987).

Accurate Assessment of Water Resources

Most of the precipitation in the Upper Indus basin occurs in the elevation belt 2,500-5,500masl. Unfortunately, no climatic station in this zone is available to yield information on snow water equivalents, temperature, solar radiation, etc. These parameters are essential for inflow forecasting on a scientific basis. So too is the use of satellite imagery and historical records of discharge and weather at permanent observing stations, all of which are below, 3,000m. This serious problem will be solved after the completion of Phase-II of the Snow and Ice Hydrology Project (SIHP). Accurate assessment of the water resources in any region depends mainly upon a hydromet network. Previously the hydromet network was sparsely distributed, and was confined to below 1,500m in elevation. Now the use of remote-sensing techniques can help to solve the problems of representativeness of the measurement of meteorological parameters at high altitudes (2,500-6,500m).

High Percentage of Errors in Hydrological Data

The other major problem concerning the proper assessment of water resources is the higher percentage of errors in hydrological data compared to the errors in data from lowland areas. This is due to the difficulty involved in the proper operation of the station and the high variability in flow characteristics in respect to space as well as time. The errors in the data will be reduced to some extent by the use of satellite imagery, a dense hydromet network at high altitudes, and the availability of automatic data loggers. The errors, however, cannot be completely eliminated.

Power Shedding

The serious problems of load-shedding in the electricity supply will be definitely improved after the accurate assessment of water resources on a real-time basis.

Hydrological Projects

Snow and Ice Hydrology Project (SIHP) Phase-I

With the mentioned problems and circumstances in mind, a joint Canada-Pakistan project for hydrology investigations, training, and transfer of technology relating to snow and glacier resources was embarked upon (Annual Report 1985). The activities of the Snow and Ice Hydrology Project Phase-I (study phase) began in 1985. Initially a three-year venture, the project was extended to June 1989.

<u>Scope and Objectives</u>

The main objectives of the Snow and Ice Hydrology Project Phase-I were as follow.

1. To initiate research into glacio-hydrologic aspects of the Upper Indus basin relevant to water resource development and forecasting.
2. To introduce and test technical methods and models appropriate to the environment of the Himalayan Indus.
3. To define the terms of an on-going monitoring and forecasting system for snow and ice regime basins.
4. To train a core of Pakistani scientists/engineers to continue this work.

Results and Achievements

The main outcomes of the Snow and Ice Hydrology Project Phase-I were as follow.

1. A group of trained, experienced personnel was created in the Water and Power Development Authority (WAPDA) to form the nucleus of its proposed Snow and Ice Division, and eight scientists were given field working experience for at least one field season in snow and ice hydrology investigations in the Himalayas or the Karakoram.
2. An operations' manual was produced for snow and ice investigations in the Upper Indus basin.
3. A long-range research and operational plan was drafted for snow and ice investigations by the WAPDA.
4. A model was constructed for the hydrologic balance of at least one of the snow and ice basins which were studied.

Snow and Ice Hydrology Project Phase-II

The WAPDA, with technical assistance from British Columbia Hydropower, launched a project entitled the Snow and Ice Hydrology Project Phase-II, effective from July 1989, for forecasting inflow into the Mangla and Tarbela reservoirs. The duration of the project is 90 months (July 1989-December 1996).

Scope and Objectives

The major objectives of the Snow and Ice Hydrology Project Phase-II (operational phase) are:

1. To establish ground-based data measurements in the elevation zone of from 2,500-5,500m above mean sea level.
2. To develop a data transmission and reception system on a real-time basis.
3. To establish runoff forecasting procedures and computer-based models.
4. To train personnel who can understand and use the model to meet future needs within the WAPDA.

The work has concentrated on the development of an operational river flow model for the Upper Indus basin (upstream of Tarbela Dam and upstream of Mangla Dam and the Kabul basin in order of priority). It has involved much more intensive meteorological and hydrological data gathering to provide inputs for the model's operation (Annual Report 1990). The system is to allow the development of scenarios based on actual and simulated weather conditions and is to be composed of the following.

- Ground-based data measurements
- Data transmission and reception (on a real-time basis)
- Runoff forecasting procedures and computer-based models
- Remote sensing and data analysis (satellite imagery)
- Training and applied research

The ultimate goal of SIHP Phase-II is the creation of an operational river flow forecasting system for the Upper Indus basin (including the major tributaries the Jhelum and Kabul rivers). The data/information collected under Phase-I and the experience and knowledge gained so far are proving very valuable in implementing Phase-II.

Results and Achievements

The Snow and Ice Hydrology Project concentrated its activities in three main basins, those of the Kunhar (Kaghan), Biafo, and Barpu-Bualtar. Water balance studies of each of these, based mainly on SIHP field observations, have been carried out. The UBC (University of British Columbia) Watershed Model has been applied to data from the Swat River and the Jhelum and Hunza catchments. The computational scheme of flows in the upper Indus Basin is shown in Figure 2.

The flows simulated by the UBC Watershed Model in sub-basins were compared with actual observed flow patterns and routed downstream. A routing feature to transfer flows from sub-basins downstream does not exist within the model and is carried out using another programme.

The main achievements of Snow and Ice Hydrology Project Phase-II are as follow.

a. Ground-based Data Measurement

Hydrometeorological stations are now installed in remote areas at varying altitudes within the sub-basin to measure changes in temperature, precipitation, and snow water equivalents that occur in various elevation belts. Snow depth and density are being measured manually, using traditional equipment, in representative snow courses. In some places solar- or battery-powered data loggers with a manual readout capability are used.

b. Data Transmission

The timely reception of measured data at a central location (Lahore) is very essential for the effective operation of the system, which is meant to produce short-term forecasts of runoff. The remoteness and terrain of the Karakoram Himalayas precludes the use of the usual methods of telephone or VHF radio system for digital data transmission.

The transmission of daily data from stations established at from 2,500 - 5,000m is therefore proposed by satellite telemetry or the meteorburst system. Most of the stations consist of a Data Collection Platform (DCP) which will send the sensor data for automatic transmission through the satellite/Meteorburst system. The locations of the DCPs are shown in Figure 3.

c. Installation and Testing of the System

It was planned to install in all about 25 DCPs equipped with sensors to cover the major part of the Upper Indus basin. The idea is to establish procedures and ensure that the instrumentation can be made to work satisfactorily in the extreme conditions of altitude and weather in the Himalayas before investing a large amount of money.

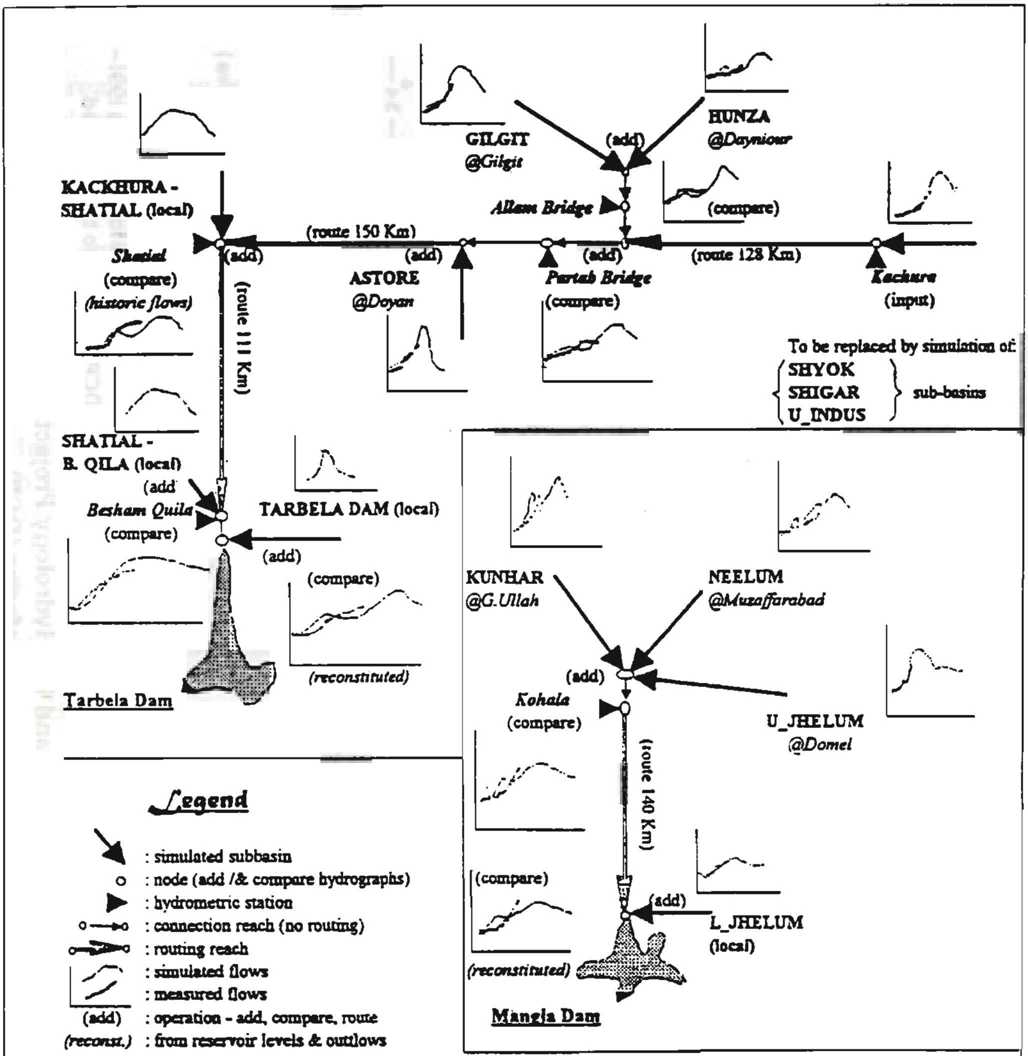

Figure 2: Computational Scheme for the Inflows in Tarbela and Mangla Dams

d. Forecasting Procedures and Models

Some procedures for forecasting seasonal and short-term (5-10 days) runoff from watersheds with a large snow-melt component are well developed. However, the substantial glacier-melt runoff that occurs in the Upper Indus basin necessitates collection of additional data and modernised runoff estimation techniques. The UBC Watershed Model is being used for the Mangla catchment which has a very small or no glacier component. Due to lack of a hydromet network, the model is not producing reliable results.

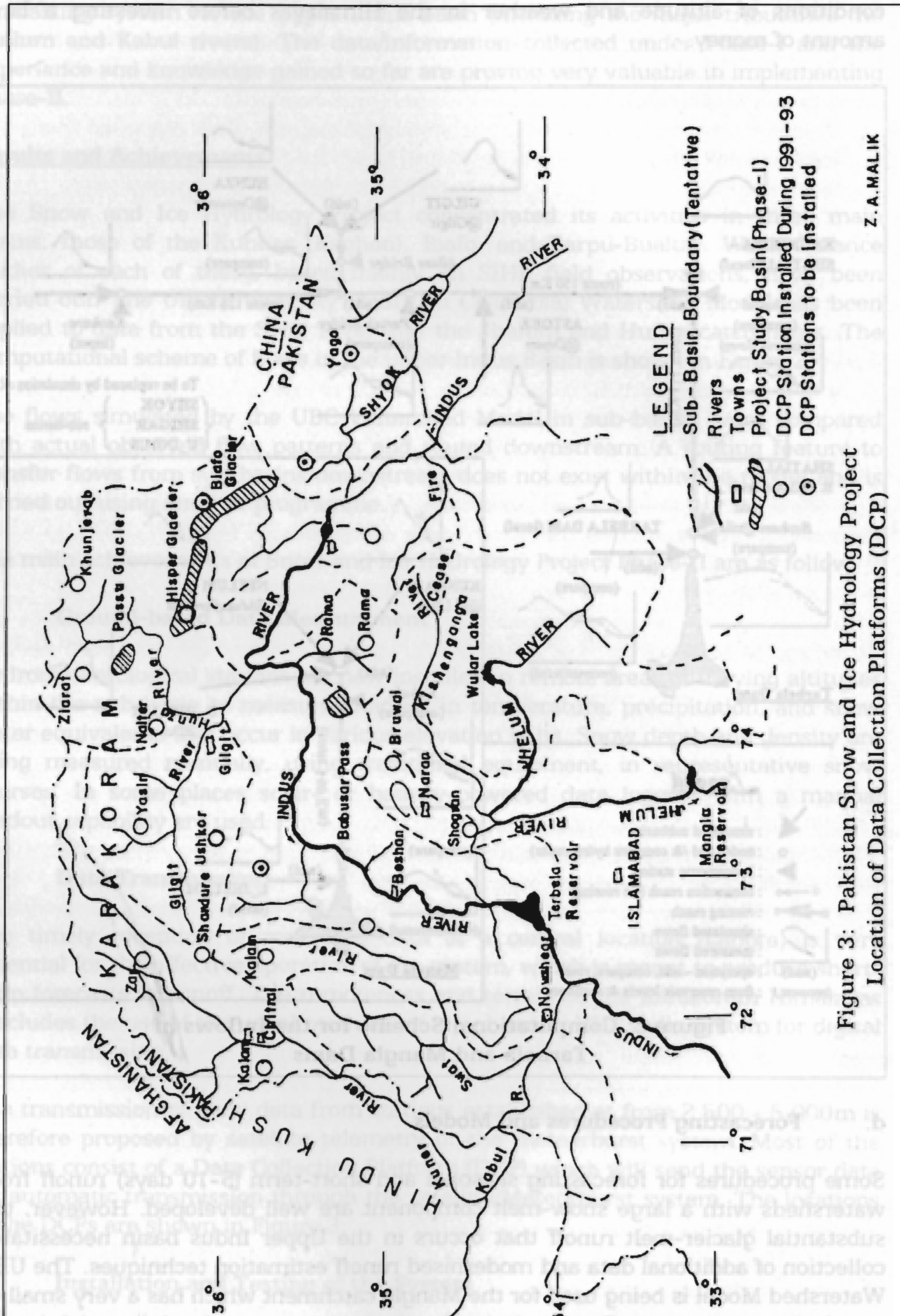

Figure 3: Pakistan Snow and Ice Hydrology Project
Location of Data Collection Platforms (DCP)

e. **Remote Sensing and Data Analysis**

The basic source of remote-sensing data for use in operating systems is satellite imagery, in either photographic or digital format. The parameters which can be measured from satellite imagery are:

- area of snow cover,
- glacial area,
- extent of debris cover on the glacier, and
- cloud cover.

For acquisition and analysis of satellite data, Space and Upper Atomosphere Research Committee (SUPARCO) facilities have been utilised. The locations of remote-sensing stations are shown in Figure 4.

f. **Training and Applied Research**

Under the first phase of the project a group of WAPDA personnel has been trained to carry out field studies, and additional training is it be undertaken within the snow and ice runoff forecasting and operational project.

g. **Outputs**

With the implementation of the above-mentioned activities, it is envisaged that an infrastructure will be established for improved snow and ice data monitoring and quick transmission/reception to provide accurate inputs to forecasting models.

Hydropower Project

The northern areas of Pakistan, being far from the national grid, have been facing severe power supply shortages. The tributaries of the Indus River have been considered for the development of hydropower resources to meet the local energy requirements and eventually to transfer power south, if surplus energy is available. The study was started in July 1992 by the Hydro Electric Planning Organisation (HEPO) of the WAPDA, in collaboration with the German Agency for Technical Cooperation (GTZ) of the Federal Republic of Germany. For the purpose of this study, the project area was divided into 12 regions in an order of priority fixed in consultation with the Northern Areas' Public Works Department (NAPWD).

Scope and Objectives

The detailed study was carried out by the WAPDA to propose schemes on tributaries which seemed attractive for hydropower developments. Field visits were made during December 1992 by WAPDA engineers and geologists along with GTZ experts to examine these schemes on site, as part of reconnaissance missions to (i) assess the access conditions for each site; (ii) assess the topographical conditions at each site; (iii) study the regional geology and assess geological features of the area around the identified site; and (iv) appraise the sediment loads of *nullah*(s).

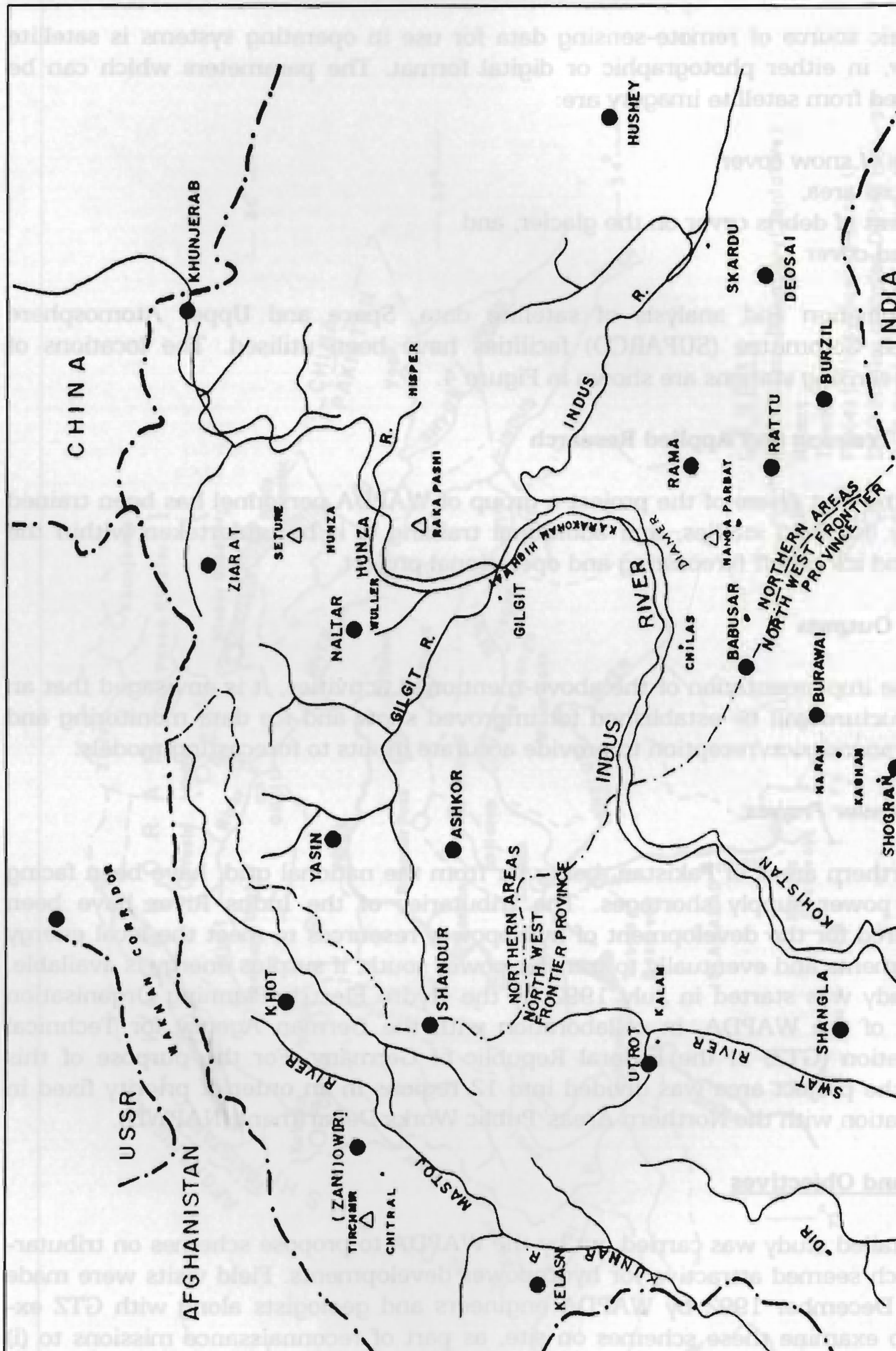

Figure 4: Pakistan Snow and Ice Hydrology Project Remote Stations 1994

Results and Achievements

Altogether 15 schemes with a total capacity of about 40MW were identified to meet the 20-year demand in Region-3 (Gilgit) along with existing stations and already planned schemes. There are 11 small schemes (below 5MW) with an aggregate capacity of 17.77MW and two medium schemes (above 5MW) with a total capacity of 22.79MW among identified sites. The existing installed capacity of the hydel power stations in Region-3 is 7.952MW, out of which 4.722MW are available in January. There are three hydel power stations with a total installed capacity of 3.0MW under construction in Region-3. The total identified and planned potential is enough to meet the 20-year demand of Region-3, with excess capacity available for transfer to other regions.

Hydropower potential is a function of discharge and available head. A computer programme WAPPO (Water and Power Potential) helped to focus on attractive reaches of main tributaries. The approach adopted for the environmental study of hydropower schemes in Region-3 (Gilgit) is based on the work and publications by the World Bank. These schemes are beneficial and have little adverse impact on the environment because of their small size. All of them are without seasonal reservoirs.

Keeping in mind the cold temperatures in winter and the scarcity of firewood in the area, the proposed hydroelectric projects constitute a renewable source of energy which can help to reduce deforestation of the already endangered woodlands.

Socioeconomic Benefits of the Current Projects

Water is the most basic requirement for improving the social base. The provision of drinking water to the sparsely populated and widely scattered population is a major priority. Also, the provision of water channels, with little effort, can enable the people of the mountainous areas to plant double crops. NGOs, such as the Sarhad Rural Support Programme, sponsored by the Potato Research Institute (Agricultural Research Department, Pakistan), are working on the basic problems of the people of the area, sharing their ideas with farmers, and involving them in the development of their own areas. One example is vegetable production in Batakundi. Batakundi is located 30km from Naran village in the Kunhar River basin, as shown in Figure 4. A winter snow cover develops above 1,800m from early November onwards, reaching a maximum depth in March or April. The Agricultural Research Department began research on off-season vegetables in Batakundi to improve the socioeconomic conditions of the people of the area and succeeded in getting them to grow such vegetables, from which they are now earning well, from an area which was previously barren.

The poverty of the population and the high rates of population growth are the major factors influencing hydrological balances in the watersheds. Any development work in the area acts as a significant factor for their betterment. The above-mentioned projects have improved the socioeconomic conditions of the inhabitants of the area to some extent. Hydrological projects have contributed to the development of the area, and the economic prosperity of the region is gradually rising.

Concluding Comments

The following can be stated, on the basis of the information available on the achievements of the hydrological projects.

1. Serious problems of irrigation, water supply, and electricity load-shedding in mountainous areas will definitely be improved after updating the data network to accurately assess water resources on a real-time basis.
2. The problems of hydropower development in mountainous areas of Pakistan have been tackled along quite rational lines, although attention has been devoted to these problems only recently. Due to financial constraints, only a limited amount of construction work for hydropower plants has been carried out so far.
3. The use of remote-sensing technology, including satellite pictures, aerial photographs, radar and telemetric systems satellite-based or Meteorburst, will help solve the problem of the representativeness of measurements of meteorological parameters at high altitudes (2,500-6,500m). Remote-sensing stations will provide real-time data on snowpack, precipitation, temperature, wind speed and duration, snow cover area, glacial area, extent of debris cover on glaciers, cloud cover, etc.
4. The serious problem of errors in data will be reduced to some extent by the use of satellite imagery, a dense hydromet network at high altitudes, and the use of automatic data loggers.
5. It can also be concluded, from the success of experiments in Batakundi, that if water is available for irrigation purposes, people can reap double harvests and so improve their earning capacities

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References

Annual Report, 1985. Pakistan Snow and Ice Hydrology Project-WAPDA-IDRC-WLU, Phase-I. Pakistan: WAPDA.

Annual Report, 1989. Pakistan Snow and Ice Hydrology Project-WAPDA-IDRC-WLU, Phase-I. Pakistan: WAPDA.

Annual Report, 1990. Pakistan Snow and Ice Hydrology Project-WAPDA-IDRC-WLU, Phase-II. Pakistan: WAPDA.

Hewitt, K., 1990. 'Glacier Hydrology'. In Hewitt, K. (ed), Handbook of Snow and Ice Hydrology. Canada: Cold Regions Research Centre, Wilfred Laurier University (WLU),

Shankar, K., 1990. 'Mountain Hydrology in reference to the Hindu Kush - Himalayan Region'. Working paper prepared for the Regional Working Group (RWG) Meeting on Mountain Hydrology, Kathmandu, Nepal.

Shah, S.M., 1990. 'Present Status and Problems of Mountainous Areas of Pakistan'. Working paper prepared for the Regional Working Group (RWG) Meeting on Mountain Hydrology, Kathmandu, Nepal.

Tejwani, K.G., 1987. 'Sedimentation of Reservoirs in the Himalayan Region - India'. In Mountain Research and Development 7(3), 323-327