The Snow and Ice Hydrology Project; a Pakistan-Canada Research and Training Programme

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Abstract The paper describes the inception, implementation and possible future developments of the Snow and Ice Hydrology Project (SIHP), a joint Pakistan-Canada venture. Conceived in 1981, the project entered its first of five summer field seasons in 1985. The project was requested by Pakistan's Water and Power Development Authority (WAPDA), and was funded jointly by WAPDA and by Canada's International Development Research Centre. It involved several Canadian and other universities. In Canada the project was coordinated by the Cold Regions Research Centre of Wilfrid Laurier University. Recognizing that the Indus river is fed largely by melting ice and snow in the Karakoram Mountains and that there is insufficient understanding of the processes of snow and ice melt in this region, the SIHP's main objectives have been to set up within WAPDA a capability for undertaking relevant research, initiating and developing that research and laying the basis for a more operationally focused programme in the future. Field projects have included the setting up of meteorological monitoring stations at relatively high elevations, monitoring snowmelt in basins with and without glaciers and monitoring glacier ice melt in several basins in the Central Karakoram. Office work has included analysis of the data collected as well as the setting up of data bases and inventories of glacier coverage of the region. Technology transfer has been achieved through Canadian professors and students undertaking field work in Pakistan with their counterparts and through several Pakistani officers undertaking formal studies at Canadian universities. Based on the understanding and the experience gained through SIHP, the project has now entered an operational phase with involvement of the Canadian International Development Agency. Recommendations for future work are given.

INTRODUCTION

Pakistan is similar to many countries in the Central Asian region in that within its borders lie regions of extensive high mountains juxtaposed with lowlands. The mountains provide the principal sources of water supply for large populations living in the nearby plains. Thus there is a strong interdependence
between highlands and lowlands. This interdependence is particularly felt in Pakistan where the mountain hydrology is dominated by glaciers and snowfields which are the most extensive in Asia and where the lowlands have no other significant untapped surface water sources than the Indus River and its tributaries.

Another common theme in Central Asian hydrology is that major rivers cross international boundaries. Thus, as with the Ganges and Brahmaputra, the waters of the Indus system are shared between several countries, making for uneasy international relationships.

The Karakoram mountains of northern Pakistan provide the only areas of the country with substantial precipitation and an annual moisture surplus. Most of the remainder of the Indus Basin has low precipitation and a water deficit in most or all of the year. Historically, surface water supply in Pakistan depended more upon the easterly Indus streams and rainfall; both mainly derived from the summer monsoon. Under the terms of the Indus Waters Treaty, and through large-scale development works since it was signed, Pakistan has become increasingly dependent on the main Indus and its westerly tributaries. These are primarily fed by melting of snow and ice in the high mountains.

The level of water development now achieved means that the actual flow of the rivers in all but the 2-3 months of high summer flows is controlled and utilized. Without reservoir storage there would be a severe deficit in water and power throughout these months. A major goal of water development has been storage and reallocation of the summer high flows. While the larger part of these flows still goes directly to the sea, irrigation and power are critically dependent upon what can be stored in the major reservoirs. The adequacy, and efficient management of these systems, in turn depends upon the timing, fluctuations and scale of the river runoff. However, as demand has approached or exceeded the capacity of these systems, severe problems of irrigation water shortage and electricity load-shedding have begun to occur at certain times of the year. These, but also proposed projects for further reservoirs on the main stem of the Indus, point to the need for greater knowledge and a forecasting capability with respect to the high mountain sources of runoff.

Up to the 1980s there had been no comprehensive, long-term hydrological investigations in the Karakoram region. Intensive short-term investigations had been undertaken by several groups, for example the Batura Investigation Group and the International Karakoram Project. Many mountaineering expeditions had gathered data, but on a more or less ad hoc basis.

With these circumstances in mind, and bearing in mind, too, that Pakistan had little internal capability for snow and ice research, a joint Canada-Pakistan project for hydrology investigations, training and transfer of technology relating to snow and glacier resources was undertaken. It was initially conceived in 1981. The programme and goals of the research were developed and approved by relevant agencies in Pakistan and Canada over the next three years, and
activities began in 1985. Initially a three-year venture, the project was extended to June 1989.

THE SNOW AND ICE HYDROLOGY PROJECT (SIHP)

SIHP was a cooperative project between Pakistan's Water and Power Development Authority (WAPDA), the International Development Research Centre (IDRC) in Ottawa, and various Canadian universities. In Pakistan, project coordination was undertaken by the Hydrology Research Directorate (HRD) of WAPDA in Lahore. In Canada, the project was coordinated within the Cold Regions Research Centre at Wilfrid Laurier University (WLU), Waterloo, Ontario. Scientists from the universities of Waterloo, Ottawa, British Columbia and the Inland Waters/Lands Directorate of Environment Canada also contributed. The universities of Manchester (UK) and New Hampshire (USA) provided additional expertise. The project budget of some $1.6 million (Canadian) was shared about equally by Canada and Pakistan.

The main objectives of the project were to:
(a) Initiate research into glacio-hydrologic aspects of the Upper Indus Basin relevant to water resource development and forecasting.
(b) Introduce and test technical methods and models appropriate to the environment of the Himalayan Indus.
(c) Define the terms of an on-going monitoring and forecasting system for snow and ice regime basins.
(d) Train a core of Pakistani scientists/engineers to continue this work.

The project involved four years of studies which combined analysis of existing river discharge and meteorological observations, some applications of remote sensing, and development of a forecasting model. Both Pakistani and Canadian scientists participated in all phases of the work.

The availability of hydrological and meteorological data within the Upper Indus Basin (UIB) is woefully inadequate. Existing records of discharge and weather collected at permanent observing stations, all pertain to areas below 3000 m. Given this state of knowledge and the technical capacity for undertaking studies within WAPDA, it was decided that the outstanding need was for investigations and training in the zone 2500-6500 m asl. It is at these elevations that most of the moisture input, fresh water storage and supply of runoff occurs. Without knowledge of conditions here, intelligent and effective development of a monitoring network and forecasting system is severely hindered.

The main areas in which it was felt investigations, involving "hands-on" training in the field, were needed, were:
(a) Glacier mass balance.
(b) The behaviour and especially the melting of seasonal snow packs.

Such studies would involve the determination of altitudinal gradients in the input, storage, transfer and melting of snow and ice. They would involve
identification of the factors most likely to cause variations in the above over time-frames from weeks to decades. Differences in these factors for the major contributing basins of the UIB would also have to be investigated.

At the same time, the approach had to be one that identified measures, equipment and procedures; the sites and networks for observation that would:
(a) be dependable in this environment,
(b) be capable of extending the usefulness of existing stations measuring river discharge and weather in the UIB,
(c) be capable of giving "ground truth" or calibrating satellite-generated data,
(d) help define the form and potential of an operational monitoring network and inputs to the forecasting system,
and not least,
(e) lead on to a reasonable programme of continuing observations and investigations by trained officers of WAPDA.

STRATEGY FOR SIHP AND CANADIAN PARTICIPATION

There was never any doubt for both the Canadian and Pakistani principals, that there was a need to address the interrelated needs for hydrological investigations and training in, and defining of an operational system for the UIB. To achieve that, SIHP had to carry out two related sets of activities:
(a) field work in the UIB in locations which were reasonably safe and accessible while being good for training and which would yield hydrological knowledge relevant to water development and of broad application;
(b) compilation of all relevant data from past expeditions, WAPDA stream gauge and weather stations, satellite imagery etc., to compare with SIHP snow and ice data and to be used in developing relevant forecasting tools.

At the same time it was realized that the UIB is a vast, hydrologically complex and logistically demanding environment, and that resources were sufficient only for a very basic and limited programme. Reviewing what was known about the UIB, it was felt that the best strategy would be to concentrate upon areas of predominantly snow-fed or glacier-fed streams, and look for relatively manageable, accessible catchments. Since the southerly half of the UIB is largely nival and the northerly rim (Hindu Kush/Karakoram) mainly glacial, study basins on a north-south section in these two regions were selected.

The Kunhar-Kaghan basin was chosen in the south, partly because WAPDA already had some snow survey data from there, and to give a study area within the Mangla Dam catchment area. In the Karakoram investigations began in the large Biafo Basin, which allowed some critically important work in the accumulation zone. However, this is a very large basin, three days march from the road head and proved difficult to maintain. Most SIHP glacier investigations were undertaken in the more accessible Barpu-Bualtar Glacier
area in Nagyr (SIHP Annual Report, 1986). Recommendations for future research focus on this area.

While those proved to be good choices, given the limited resources, problems which neither the Canadian nor the Pakistani principals foresaw forced a change in the original design. This, and the solutions arrived at, are in many ways as important in their implications for future work as the scientific and technical results. In particular, the role the Canadians had to play and probably would have to play in similar projects here or elsewhere reflect the unusual problems of development projects in high mountain environments.

Originally, it was expected that a small number (3-5) Canadian specialists would make short visits to Pakistan to provide Workshops and help set up field stations and equipment. WAPDA's officers would then man the field sites and develop the data communications system. It was known that WAPDA officers had carried out snow surveys, had participated in several snow survey training workshops and that there were experienced mountaineers in the country. The main research work by the Canadians was to involve methods to integrate, analyze and refine information received from existing WAPDA stations, satellite imagery and the new snow and ice programme, so as to define key hydrological features and develop appropriate models.

Two insurmountable obstacles to this strategy were encountered. First, HRD-WAPDA was unable to find even two or three officers with Northern Area and high mountain experience. Only one (invaluable) sub-engineer was available from the days of the WAPDA snow surveys. Not one officer had been near glaciers or worked at altitudes much above 2500 m asl. Second, there seemed little prospect of having the relevant hydrological data sets delivered and none at all of obtaining appropriate and timely satellite imagery. A proposed SUPARCO programme to receive high quality imagery and pass it on to WAPDA did not come on stream in the lifetime of the project, and there was no means to obtain it from other sources and in a fashion that could form the basis of a WAPDA system. Most of what could have been done in this regard would have been to repeat past studies.

The only solution, if the major goals were not to be abandoned, was to opt for a much larger Canadian involvement in the programme of investigations in the Northern Areas. Once IDRC approved a budget supplement to cover more travel and logistic support, the programme was largely one in which all investigations were carried out jointly by Canadian and WAPDA participants. Only in this way could the investigation goals be achieved with reasonable safety. It was of course, an exceptionally good way to provide safe, hands-on training and experience. Only as SIHP came to a close, and as a major part of its achievement, has WAPDA obtained a core of experienced officers able to function effectively in the glacio-nival environments of the UIB.

Since few senior professionals are able, or willing, to leave Canada for extended periods of high altitude field work, it was necessary to seek out young (mid-twenties) graduates with the relevant mountain and academic backgrounds.
The policy was that any field area should be manned by at least two Canadians and two WAPDA participants, taking account of the safety and psychological stresses of extended field seasons in these remote, dangerous areas. A total of 6 Canadians was usually present throughout each field season. WAPDA could not provide senior personnel able to direct and supervise operations in the Northern Areas. The Canadian Principal Investigator undertook this task: Dr. Hewitt in the first three years and Dr. Young when the project was extended for a fourth year.

However, what had been improvised now seems to us a solution that has more general validity. Without ground-based investigation and training no significant or useful contribution could have been made. It is clear that short-term or overseas workshops and training are entirely inadequate to prepare officers to work in the UIB, while overseas consultants, however expert, without considerable experience in the region are unlikely to ever appreciate the scientific and organizational needs. Even the scientific and technical results are of limited benefit, unless in the hands of WAPDA officers or other scientists who know the conditions to which they refer, first hand. At the same time many of the Canadian participants have become friends of Pakistan and gone to do other, related work there and elsewhere in Asia and revisit the country on their own initiative.

In summary, the SIHP experience has highlighted the particular problems of undertaking research for water resources development in high mountain and glacier environments. There are particular logistical and safety requirements which cannot be ignored; on-site training is a necessity over extended periods of time; long-term continuity of the research and data collection programmes is essential; practical expertise resides within the individuals who participate in the programme and this expertise must be maintained through long term commitments. A particular concern is that the funding and executing agencies involved must understand the nature of the work and its outputs.

ACHIEVEMENTS OF THE SNOW AND ICE HYDROLOGY PROJECT

There have been several major achievements of the SIHP:

(a) The creation of a group of trained, experienced personnel in WAPDA to form the nucleus of its proposed Snow and Ice Division. Eight WAPDA personnel were provided with working field experience of at least one field season in snow and ice hydrology investigations in the Himalaya or Karakoram. Five had three or more years field experience. Two research officers spent two years studying for Masters’ Degrees at WLU, one concentrating on glacier-related, the other snow-related work. Several workshops were held in Pakistan and one at WLU. Some months were spent by Mr Pipes (University of British Columbia) in Lahore developing and giving training in relation to the Watershed Model.
(b) The production of an Operations Manual for snow and ice investigations in the UIB. The Canadian principals have prepared a series of manuals to provide such a handbook. An extensive library of research and handbook materials has been sent to WAPDA.

(c) The drafting of a long-range research and operational plan for snow and ice investigations by WAPDA. Several of the Canadian recommendations based on SIHP experience which were passed on to IDRC, the Canadian International Development Agency (CIDA), the World Meteorological Organization (WMO) and Wapda, are listed below.

(d) The building of a model for the hydrological balance of snow and ice basins. SIHP 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 made. The Kaghan and Barpu-Bualtar are recommended as long-term study and training basins. In addition, less intensive studies have been carried out in the Rakhiot Glacier Basin (Nanga Parbat), in Shishkat Valley, at Pasu Glacier and Khunjerab Pass. Reconnaissance of features and possible monitoring sites have been carried out in the Upper Gilgit, Swat, Astor, Hunza, Hispar and Braldu valleys. The University of British Columbia Watershed Model has been applied to data from the Swat, Jhelum and Hunza catchments. The Jhelum results, which relate mainly to the WMO flood forecasting project appear in a separate report (Quick & Pipes, 1989).

Scientific publications and theses resulting from the investigations have been numerous. They are detailed in the SIHP Final Report (1990).

RECOMMENDATIONS FOR FUTURE ACTION

Many of the suggestions and concerns of the Canadian team have been discussed at length with WAPDA colleagues over the several years of cooperation. Some have been incorporated into standard practices and WAPDA is aware of a range of specific issues relevant to this work. Canadian investigators were consulted extensively in connection with the Canadian International Development Agency’s reports and proposed follow-up activities (CIDA, 1987, 1988a, 1988b) and gave assistance to WMO in the specifications for its proposed improvement of the River Forecasting and Flood Warning System for the Indus River — Phase II (WMO, 1989). Here the recommendations largely deal with matters where snow and ice hydrology, research and training and experience in the UIB are relevant. However, in some matters, they turn upon administrative and planning issues within WAPDA which were raised by the SIHP experience. Suggestions in this regard derive essentially from Canadian experience during SIHP since, unfortunately, no final review meeting of the WAPDA and Canadian Principals was arranged to prepare a joint set of recommendations. Clearly, the nature and
extent of Snow and Ice work in the future will depend on WAPDA’s development plans, funding possibilities and the priority chosen for future work. Canadian suggestions are somewhat hampered by not having clear directions in that regard.

The following is a summary of Canadian recommendations, elaborated more fully in the SIHP Final Report:

1. **Belief in the need for a snow and ice capability**, as a permanent responsibility of WAPDA has only increased with SIHP experience.

2. **Basic requirements of a snow and ice capability include:**
   (a) An on-going hydrological survey, hydrometeorological monitoring network and programme of glacio-hydrological investigations in the Northern Areas.
   (b) A set-up for the systematic collection, analysis and dissemination of snow and ice information as a normal function of surface water and meteorological intelligence.
   (c) Development of a forecasting system (i.e. model plus data base and network plus communications), for river control works and water users (irrigation, power, water supply and flood warning) in which a Snow and Ice capability is integrated with existing forecasting provisions.

3. **Technical requirements specific to the above include:**
   (a) Trials and establishment of high altitude (2500-6000 m asl) monitoring stations and instrumentation at suitable locations.
   (b) Reliable arrangements for real time or near real time communication of data to the forecasting centre, whether by observers with access to radio or telephone and/or automatic electronic communications.
   (c) A system for real-time receipt of high quality satellite imagery going directly to a centre dedicated to rapid analysis and input to the forecasting system. A coordinated system for using both remote and ground-based snow and ice monitoring is the best prospect for an effective operational system. Because topography and altitudinal controls are of overwhelming importance in the UIB these information gathering systems should be coupled with a Geographic Information System capability to generate the information most useful for forecasting purposes.
   (d) Establishment of at least two study and control basins (with the option of more at a future date, funds permitting), one in the glacierized Karakoram catchments and one in the predominantly snow-fed Himalayan catchments, for training and experiments looking at the interrelations of snow and ice hydrology as the foundation of a long-term data base.
   (e) Establishment of a (modest) "Snow and Ice Bulletin" to distribute the knowledge of the status and work of snow and ice.
   (f) Career development and training goals for an expanding number of WAPDA officers addressing scientific and technical aspects of snow and ice hydrology, and the special needs of field competence, logistics and safety for work in the Northern Areas.
(g) Training and manpower goals of a Snow and Ice capability should include an ever-greater involvement of personnel from and resident in the Northern Areas.

(h) Provision of more realistic WAPDA regulations and better incentives for personnel required to work in the difficult and remote areas where snow and ice investigations are needed; appropriate study leave and awareness-training for senior managers responsible for hiring and directing snow and ice officers.

4. **Administrative restructuring and integration of a snow and ice capability into normal operations.** The above recommendations are unlikely to serve WAPDA's needs unless accompanied by a review of and changes in existing arrangements within WAPDA for the development of a Snow and Ice capability. Most important is to put in place organizational and administrative arrangements that:

(a) integrate snow and ice monitoring with an on-going set-up for standardized surface water and weather measurement and record-keeping;
(b) incorporate snow and ice briefing as a normal ingredient of management, planning and decision-making in each sector of WAPDA, and snow and ice expertise in the development works dependent upon the Upper Indus rivers;
(c) allow existing gauging and weather stations, and extension of the network in the UIB for existing or new projects, to be reviewed in relation to their snow and ice sources.

5. **Research.** An on-going arrangement is needed for hydrological reconnaissance and survey; basin investigations and the tackling of specific research questions should be a permanent part of WAPDA’s programme in the Northern Areas. That will require scientific and technical assistance from overseas for the foreseeable future, but WAPDA officers, especially those now trained in snow and ice investigations should identify priority questions, phenomena and basin areas.

(f) **Snow and ice planning and programme design.** Overall, the demands of a snow and ice capability on personnel, financial resources and for experienced consultants and upon the existing arrangements in WAPDA and relations with people and conditions in the Northern Areas are complex and costly. SIHP has been a suitable pilot project, defining and conducting preliminary research. What is now needed is preparation of a project planning and design document for a Snow and Ice capability, also taking account of matters beyond snow and ice hydrology. These include existing and projected demand profiles and projects, institutional arrangements, inter-Directorate and external demands for WAPDA services where they would involve snow and ice, a fully fledged forecasting and monitoring system for the Indus Basin, and a regular funded programme of in-house and overseas training, exchanges and upgrading of WAPDA officers.
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