CS(AR)-131
Restricted

SNOW AND GLACIER CONTRIBUTION IN THE CHENAB RIVER AT AKHNOOR

National Institute of Hydrology
Jal Vigyan Bhawan
Roorkee 247 667
1993-94

Preface

All the major rivers in India originate in the Himalayas. The Indus, Ganga and Brahmaputra which receive substantial amount of flow as snow and glacier melt runoff from the Himalayas are considered as the life-line of the Indian subcontinent. The role of all these major rivers and their tributaries in irrigation, hydropower generation and water supply is very vital. The hydrology of mountainous catchments dominated with snow and glacier melt is complex and less understood as compared to the drainage basins at lower elevation which respond primarily to rainfall.

A few studies on snow and glacier melt contribution in the Himalayan rivers were carried out earlier. These were, however, not comprehensive and do not provide reliable estimate of snow and glacier melt runoff. Realizing theimportance of runoff derived from snow and glaciers, Ministry of Water Resources, Govt. of India, New Delhi, desired that National Institute of Hydrology may take up the study to estimate snow and glacier contribution in Chenab and Ganga rivers. Methodology adopted and findings of the project were discussed in a meeting held under the chairmanship of Secretary, Ministry of Water Resources, Govt. of India, New Delhi in 1993.

This study was carried out in the Mountain Hydrology Division at National Institute of Hydrology, Roorkee. Dr Pratap Singh, Scientist C, Mountain Hydrology Division, NIH,was the Principal Investigator for this study. Shri S K Jain, Scientist C, Central Technical Facility Cell, NIH and Sri Naresh Kumar, Senior Research Assistant and Shri U K Singh, Research Assistant, both from Mountain Hydrology Division were associated with this study. Shri K S Ramasastri, Divisional Head, Mountain Hydrology Division provided valuable guidance in this study.

(S M Seth)
Director

SNOW AND GLACIER CONTRIBUTION IN CHENAB RIVER AT AKHNOOR

List of Figures

List of Tables

Abstract

The contribution of snow and glacier melt runoff in the all the Himalayan rivers originating from Himalayas is significant and required for water resources development of the region. The water derived from the snow and glaciers make these rivers perennial in nature. In the present study, the average contribution of snow and glacier melt runoff in the annual flow of Chenab river at Akhnoor has been estimated. A water balance approach is adopted for this purpose. The total water budget of the basin was made for a period of 10 years (Oct. 1982- Sept. 1992). Daily rainfall data of 25 stations is used to compute total annual input to the basin and total annual volume of flow for 10 years period is computed using flow data at the Akhnoor gauging site. Evapotranspiration losses are estimated for the same period. Evapotranspiration losses from the basin are considered only from the snow free area and evaporation losses from the rain falling on the snow covered area are considered negligible. Snow covered area in the basin was determined using satellite data for the same period. The variability of the snow cover area in the basin was also studied. Snow and glacier contribution in the flow at Akhnoor is found to be 49.10% and rest from the rain.

1.0 INTRODUCTION

Snow is the solid form of water and occurs as a part of nature's hydrologic cycle. Snow and glaciers are the reservoirs with vast storage of fresh water. About 80% of fresh water on our globe is locked up in the form of snow and ice. Although only 3% of this permanent snow and ice is distributed over mountains in various continents outside Polar region (Flint, 1971). This small amount is source for sustenance of major part of population of the world. Out of the mountain glaciers, central Asian mountains contain about 50% of the glacier, a large portion of which drain into the land mass of Indian sub-continent. The present estimate of the glaciated area is 14.9 million km^2 which is about 10% of the land area of the globe (IAHS, 1993).

The storage of precipitation in the form of snow and glaciers in the mountains over a long period can provide a large amount of water potentially available and also can regulate the annual distribution of the water. The release of the water from these reservoirs provide valuable natural resource in the form of rivers, streams, springs and lakes. These natural resources are not only necessary for the survival of the people living in low lying areas but also for their prosperity. It is an important source of runoff in many parts of the world. In most of the high mountainous areas snow and glaciers are considered the major source of water yield. However, hydrological studies are considered complex in the mountain environment. They become more complicated when mountains with areas covered by snow and glaciers are dealt.

All the major rivers in south Asia originate in the Himalayas. The Indus, Ganga and Brahmaputra which receive substantial amount of melt water from the Himalayas are considered as the life-line of the Indian sub-continent. Majority of the rivers have their upper catchments in the snow coveredareas and flow through steep mountains. The perennial nature of these rivers and appropriate topographic setting provide excellent conditions for the development of hydropower resources. These rivers have substantial exploitable hydropower potential. Rainfall during the monsoon season further adds to the potential of the resources.

An estimation of the volume of water released from the snow and glaciers, therefore, is needed for efficient management of water resources which include flood forecasting, reservoir operation, design of hydraulic structures etc. The plans for new hydroelectric projects on Himalayan rivers in the country further emphasizes the need for reliable estimate of snow and glacier runoff. In the present study efforts have been made to estimate contribution from snow and glaciers in the annual flows of Chenab river at Akhnoor. The extent of maximum and minimum (permanent) snow covered areas have been assessed using satellite information.

2.0 Himalayas

The Himalayas are a system of huge and lofty mountain ranges bordering our country on the north and containing some of the highest peaks in the world. They are an extensive mountain system of 2400 km from Nanga Parbat (8126 m) in the west to Namcha Barua (7756 m) in the east in the shape of a convex with its convexity toward the south. The Himalayas further may be subdivided laterally into western, central and eastern Himalayas. The western Himalayas extend right from Nanga Parbat to Nanda Devi and are the origin of Indus and Ganga river. The central Himalayas stretch from Ghaghra and Gandak to Kosi river system, whereas the eastern Himalayas range from east of Kosi to Namcha Barua in the bend of Brahmaputra river.

As described above the Himalayas are not a single chain of mountains. They consist of three west to east running parallel ranges and between these ranges there are numerous narrow valleys. The three parallel ranges or geographical zones are described below:

The outer Himalayas is the southernmost range of Himalayas and is known as Siwalik ranges also. Their average height varies from 900 to 1200 m asl and average width varies from 10 to 50 km. The middle Himalayas consists of higher mountains. These are a series of broken mountain ranges whose mean elevation varies from 2000 m to 3300 m asl. Their width varies from 60 to 80 km. These ranges have different names in the different sections of the Himalayas such as Lesser Himalayas or Pir-panjal ranges in the western Himalayas. The middle Himalayas lie between the outer Himalayas and the perpetual snow covered ranges of greater Himalayas.

The greater Himalayas are the most northern range of the Himalayas. They are lofty, rugged chain reaching high above the perpetual snowline. The average height of this range is about 6000 m asl. In this great Himalayan range as many as 13 peaks exceed 6000m elevation. A still large number of peaks range from 4500 m to 6000 m. Beyond the main ranges of Himalaya, there are continual series of somewhat lower Trans-Himalayan zone (average altitude varying between 5000 m and 6000m) adjoining the Tibetan plateau.

3.0 STUDY BASIN AND ITS HYDROLOGICAL CHARACTERISTICS

3.1 The Chenab river

The Chenab river is one of the main five constituent of the great Indus system. The Chenab river has its major part of course through India and the lower reach including its outfall into the main Indus river in Pakistan. In India the Chenab basin is located in western Himalayas between latitudes 30°to 34° North and longitudes 74°to 78° East (Figure 1). It spreads over the two states of Himachal Pradesh and Jammu & Kashmir which comprises of the extreme western sector of Himalayas. Upper half of this basin is located between the Zanskar and the Pir-panjal ranges whereas the lower half is located between the Pir-panjal and the Dhauladhar ranges. In this way this basin covers outer, middle and greater Himalayas.

The Chandra and the Bhaga rivers constitute the Chandrabhaga or the Chenab. The Chandra starts from a large snowbed on the south-eastern side of Baralacha Pass at an elevation of 5639 m asl and after flowing (south-east) through snow clad barren area for about 90 kms, it sweeps round the basin of mid Himalayas and joins the Bhaga at Tandi after a course of about 185 kms. The Bhaga rises in the north-western slopes of Baralacha pass the elevation of 8477 m. The length of the Bhaga up to the confluence with the Chandra is about 105 kms. The combined streams then known as Chandrabhaga or the Chenab, flows in north-west direction through the Pangi valley of Himachal Pradesh and enters Kishtwar area in Jammu & Kashmir. At Benjawar near Kishtwar it turns south and flows through a gorge across Pir-Panjal range and then enters the valley between the Pir-Panjal and theDhauladhar ranges. It receives its major tributary, the

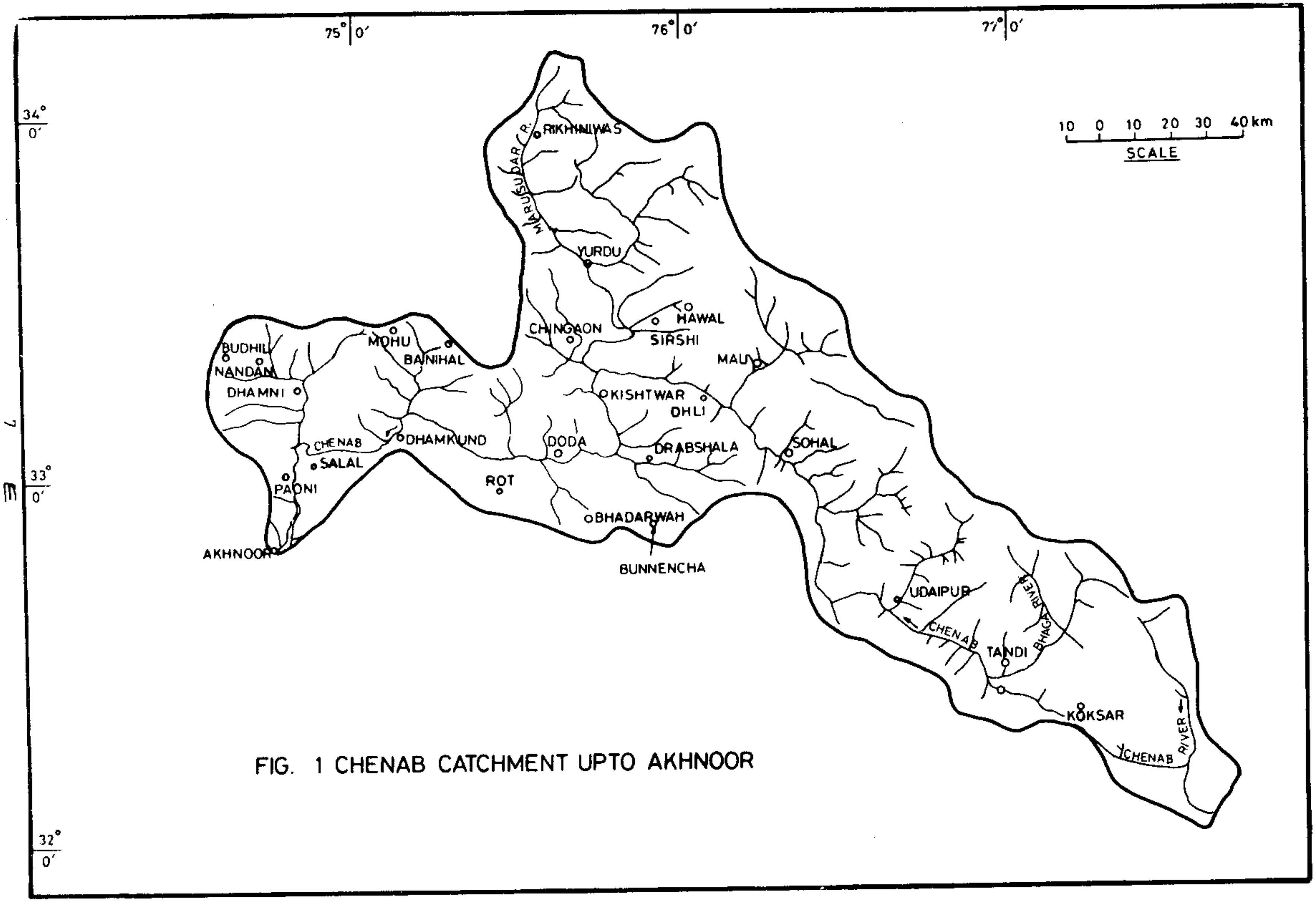

FIG. 1 CHENAB CATCHMENT UPTO AKHNOOR

Marusudar river and then flows in southern direction for about 25 km. Thereafter, it flows almost in westerly direction up to the Salal Dam site and then takes a southerly turn and emerges out into plains near Akhnoor. The total length of the Chenab river up to Akhnoor is about 535 km.

The Chenab basin consists of separate valleys which act as sub-basins, contributing considerable amount of runoff as the tributaries of the Chenab river. The main tributaries in its passage up to Kishtwar are, Thirot, Shedi, Sohal, Lidder and Marusudar. Marusudar is the biggest tributary of the Chenab and meets Chenab atBandalkot. Between Kishatwar and Akhnoor, it receives the water of Neeru, Pugal, Bagi, Bachleri and Ans tributaries.

The catchment of Chenab is elongated in shape and covers an area of about 22200 Km^2 up to Akhnoor. The elevation of the catchment varies widely from about 305 m to 7500 m. Mean elevation of the basin is about 3600 m asl. The hydropower potential of Chenab river is very high. The gradient is very steep at its source and gradually reduces down stream. The Chenab river has the general character of torrent with a gradient of 10m/km in the higher reaches and 3-4m/km in the lower reaches.

3.2 Precipitation characteristics in the Chenab basin

The great contrast in the geographical relief results in variety of climate in the Himalayas. Such regions are characterized by numerous small climatic differences over short horizontal distances. Principal controls producing such differences are those of altitude, local relief and mountain barrier effect. The strongest systematic dependence of climate on physiography is its relation to elevation, but the actual distribution of elements is greatly determined by the patterns of landscape and other physiographical contrasts in slopes, valleys etc creating climatic differences over short distances.

The most important factors controlling the weather and climate in the Himalayas are the altitude and aspect. Largely due to variations in altitude, the climate varies from hot and moist tropical climate in lower valleys, to cool temperate climate at about 2000 m and tends toward polar as the altitude increases beyond 2000 m. Altitude controls not only temperature but rainfall also. The second factor controlling the climate is aspect. Usually the south facing slopes are more sunny and also get more rain. Further, in each individual range the snowline is higher or southern aspect as these slopes have more sunshine. Also, the snow line in the eastern Himalayas is higher than in the western Himalayas.

Knowledge of precipitation distribution during individual months, seasons and the year is of vital importance both for planning water resources projects and agricultural operation ina given basin/region. The precipitation distribution over this basin in months, season and year have been studied for each Himalayan range separately. For this purpose a year has been divided into the following four seasons depending upon broad climatic conditions prevailing over the basin.

(i) Winter season (December-March)
(ii) Premonsoon season (April-June)
(iii) Monsoon season (July-September)
(iv) Post monsoon (October-November)

The precipitation during winter season is caused by extra-tropical weather system of mid latitude region originating from Caspian sea and moving eastward. They approach India from the west through Iran, Afghanistan and Pakistan. With the setting of the winter season these disturbances have the tendency to move along lower latitudes. Ordinarily these disturbances remain at high latitudes and do not influence the Himalayas. But, as the season advances they come lower and lower and by the end of December they cover more or less whole Himalaya. After the close of season they recede to their original position beyond the Himalayan mountains.

The precipitation in the winter season is generally in the form of snow in the greater Himalayas , snow and rain in the middle Himalayas, and only rain over the outer Himalayas and the adjoining north Indian plains. Precipitation occurs at intervals throughout the winter season. It is found that average frequency of occurrences of these disturbances is about 3 to 5 each month and reduces as the season advances. The higher precipitation in the western Himalayas during these months is the combined effect of the nearly east-west configuration of the Himalayas and eastward movement of the winter weather system. The precipitation associated with this weather system decreases considerably as they move eastwards along the Himalaya because of increasing distance from the source of moisture.

Generally premonsoon seasons lasts for about a period of 3 months from April to June and is considered as transit period between winter and southwest monsoon. Light to moderate rain is essentially caused by air mass convective storms. Convection increases as the season advances because of increasing trend of temperature in the Himalayan region.

Normally precipitation over the Himalayas is caused by the moist air currents from Bay of Bengal in this season. Sometimes, in association with certain weather situations both branches of monsoon (i.e., the Bay of Bengal and Arabian sea) arrive simultaneously in this region heralding the onset of monsoon. These currents after striking the Burma and eastern Himalayas are deflected westwards and travel along the Himalayas. Rainfall decreases westward because of increasing distance from the source of moisture i.e. Bay of Bengal or Arabian Sea, which results in less amount of moisture content in the air currents. Consequently lesser precipitation is observed as one moves further and further to the west. This is the season of abundant rain and rivers are generally flooded. Snow and glaciers at very high altitudes continue melting during this season. The monsoon normally starts withdrawing from this region towards the end of September. It was observed that while the monsoon currents give copious rainfall over the Indian plains, after they cross the Himalayan ranges and move over trans-Himalayan regions become practically dry as most of the moisture they initially carried is precipitated during their passage over the plains and mountain ranges of the Himalayas.

During post monsoon season clear autumn weather sets in and there is generally little rainfall. This is the driest season in the entire Himalaya as well as in the plain areas. There is no specific detail available for the climatic conditions of the Chenab basin, but this basin is inside the Himalayan ranges and general information available for Himalayan catchments can be drawn. The maximum and the minimum temperatures rise steadily from February and attain peak values in June/July. Thereafter, they decline steadily to their minimum values in December/January. In the summer due to increase in temperature, the atmospheric pressure falls over the heated land and humidity also drops.

Precipitation distribution with elevation has been studied in the Chenab basin.This basin comprises parts of outer, middle and greater Himalayan ranges and results could, therefore, be compared for different ranges of Himalayas. Because precipitation experienced in different seasons is derived from different weather systems which are influenced by different ranges of Himalayas differently. Grouping of stations with respectto the particular range and aspect has been done before making precipitation analysis. Analysis of the rainfall and snowfall distribution were carried out separately for each range and season. Efforts have also been made to explain whether variation in precipitation is due to changes in precipitation intensity or number of precipitation days or a combination of both.

Rainfall and snowfall exhibited different trends with elevation on the windward and leeward slopes of the three ranges of Himalayas. Seasonal characteristics of rainfall have shown a spill over effect on the leeward side during winter, premonsoon and postmonsoon seasons in the outer Himalayas. For these three seasons rainfall increases linearly with elevation, but in the monsoon season rainfall on the windward side initially increases reaching to its maximum at about 600m and thereafter it decreases. Annual rainfall trends are guided by monsoon season rainfall and show similar pattern of distribution with elevation. Second order polynomials fitted well for rainfall distribution of monsoon and annual rainfall.

The role of orography in the middle Himalayas was found to be more pronounced for both rainfall and snowfall in comparison to other ranges of Himalayas. Snowfall has shown more significant variation with elevation in comparison to rainfall. Rainfall follows similar type of distribution with elevation on both windward and leeward sides i.e. first it increases with elevation and then starts decreasing and distribution of rainfall fitted well with second order polynomials on both sides. The region of maximum rainfall on windward and leeward sides was found to be between 1600 and 2200 m. Snowfall distribution has shown a trend of linear increasing with elevation on the windward side whereas on the leeward side it followed the trend of rainfall in the middle Himalayas i.e. initially increases with elevation and then decreases. In this range maximum snowfall was found at about 2500m on the windward and at 1800 m on the leeward side. An increase in rainfall and snowfall intensities was found responsible for higher amount of rainfall and snowfall on the windward side in the middle Himalayan range.

In the greater Himalayan range it was found that rainfall decreases exponentially with elevation and snowfall increases linearly. Rainfall becomes negligible at elevations beyond 4000m on the windward side of great Himalayan range. Also, greater Himalayas experience lower snowfall in comparison to the middle Himalayas. Average number of snowfall days increases with elevation, but the intensity decreases.

Outer and middle Himalayas experience moderate rainfall whereas greater Himalayan range receives less rainfall. In the outer and middle Himalayas, average of all stations on a particular range indicates that monsoon rainfall exhibits maximum contribution, more than 40%, in annual rainfall followed by winter rainfall which is more than 26%. In the greater Himalayas, premonsoon rainfall was found to be relatively more prominent than the monsoon rainfall. Post-monsoon rainfall contribution was in general negligible over all Himalayan ranges. Generally, maximum rainfall is observed in the month of July over outer Himalayas, in March and July over middle Himalayas and in May over the greater Himalayas. Maximum snowfall is generally experienced in themonths of January and February in the middle and in March in the greater Himalayas.

3.3 Flow Characteristics of the Chenab river at Akhnoor

Temporal variability in discharge is another outstanding feature of the Himalayan rivers. The flow can be distributed in well marked four seasons. In the winter season flow is basically from surface flow due to seasonal rains, sub-surface flow and ground water contribution. In the premonsoon season, snowmelt and glacier produce high flows in the mid or late summer. Sometimes, rainfall also contributes to the flows in this season. During monsoon season, the flow is augmented by monsoon rains to produce higher discharges and occasional peak floods. In the postmonsoon season, flow is believed to be from the glaciers and occasional rain events in the basin. Generally glacier contribution starts in the month of July when snow accumulated on the glaciers in the preceding winter season is ablated and continues till September/October. Glacier melt runoff in the streams coincides with the monsoon period. Snow and glacier melt runoff make these rivers perennial in nature. As mentioned above flooding in these areas results from excessive or heavy rainfall. Sometimes combination of rainfall and excessive snowmelt also cause floods.

In the present study, the average seasonal distribution of the flow volumes at Akhnoor using 10 years data was found as follows:

S. No.	Season	Percent of annual flow volume
1.	October - December	7.6
2.	January - March	8.7
3.	April - June	32.6
4.	July - September	51.1

4.0 DATA USED

Rainfall, evapotranspiration, flow and remote sensing data is used in this study. Rainfall data of 25 stations has been used in Chenab basin up to Akhnoor to compute volume of rainfall over the basin. The total rainfall depth at each station over a period of 10 years (Oct. 1982 - Sept. 1992) isobtained by making cumulative sum of daily rainfall. Total volume of rainfall over the basin is computed using cumulative depth of rainfall. The period from October to September is chosen so that complete snow accumulation and snowmelt period may be taken into account in a year. Similarly flow volume for the same period (10years) are calculated at the Akhnoor gauging site with the help of daily flow values.

To find out maximum and minimum (permanent) snow covered area, remote sensing data for the months of March/April and September/October, respectively, have been used. For this purpose Landsat (MSS) and IRS (LISS-I) data were procured from National Remote Sensing Agency (NRSA) for the study period. Landsat data have been used for a period of 5 years (1983-87) whereas IRS data used for the remaining 5 years (1988-92). For both satellites remote sensing information of band 3/4 was used. Details of the satellite coverage of this basin are as follows;

Year	Satellite	Path/Row
1983-1987	Landsat(MSS)	147/37
		147/38
		148/37
		149/37
1988-1992	IRS(LISS-I)	29/45
		30/44
		30/45
		31/44
		32/44

5.0 METHODOLOGY

The snow and glacier melt contribution has been estimated using water balance approach. It is well known that all the Himalayan rivers originate from the glaciers and experience snowfall in the upper part of basin during winter (December-March) and rainfall in the lower part of the basin in the monsoon season (June-September). Generally a poor network is found in these basins for snow measurements at high altitudes where heavy snowfall is experienced. Therefore assessment of snow input to these basins becomes very difficult in such basins. However in some mountainous basins network for rainfall measurement is better than snowfall measurement and can be considered reasonable to assess rainfall input to the basin. In such conditions rain contribution can be estimated and used to determine the snow and glacier contribution using water balance approach. In the present study latter approach is used which considers rainfall, flow and evapotranspiration volumes. The various factors considered for this approach are described below.

5.1 Soil moisture status

In the water balance analysis volumes of rain and flow are used for a period of 10 years. The period length of 10 years has been chosen so that one can assume that soil moisture status of the basin is same after 10 years period. However, there may be changes on the annual basis but moisture status can be considered of same order after 10 years period. Moreover this length of period is more than sufficient to assume that all the losses from the rain and snowmelt in the form of infiltration and percolation, except evapotranspiration, will be reflected at the outlet of the basin within 10 years time. It is considered as very safe assumption specially for the mountainous catchments with very high relief variation from the outlet to upper most part of the basin. In such watersheds because time taken by the infiltrated and percolated water will be very less than in the flat watershed. As such the amount of water which is percolated very deep and not contributing at the outlet of the basin within a period considered for this study, is assumed negligible.

5.2 Rainfall

Rain input to the basin over a period of 10 years period has been estimated using isohyetal technique. Cumulative isohyetal pattern of the Chenab basin up to Akhnoor is shown in Figure 2. This method is considered more reliable for the mountainous area where topography of the basin influences the precipitation due to high relief and different orientations. Such effects can be observed from the rainfall distribution in the basin shown by the isohyets. The range of the isohyets varies from 300 cm to 2200 cm. Such high variation in rainfall are very well taken into account by isohyetal technique when calculating mean rainfall depth over the basin.

The isohyets show that lower catchment experiences very heavy rainfall at few locations. The general trend of rainfall exhibits that lower and middle part of the basin experience good rainfall whereas upper part of the basin experiences less rainfall. At very high elevations where observations are not available, isohyets are extended using the information from IMD annual normal rainfall maps over India.

5.3 Evapotranspiration

The net rain input to the basin can be obtained by

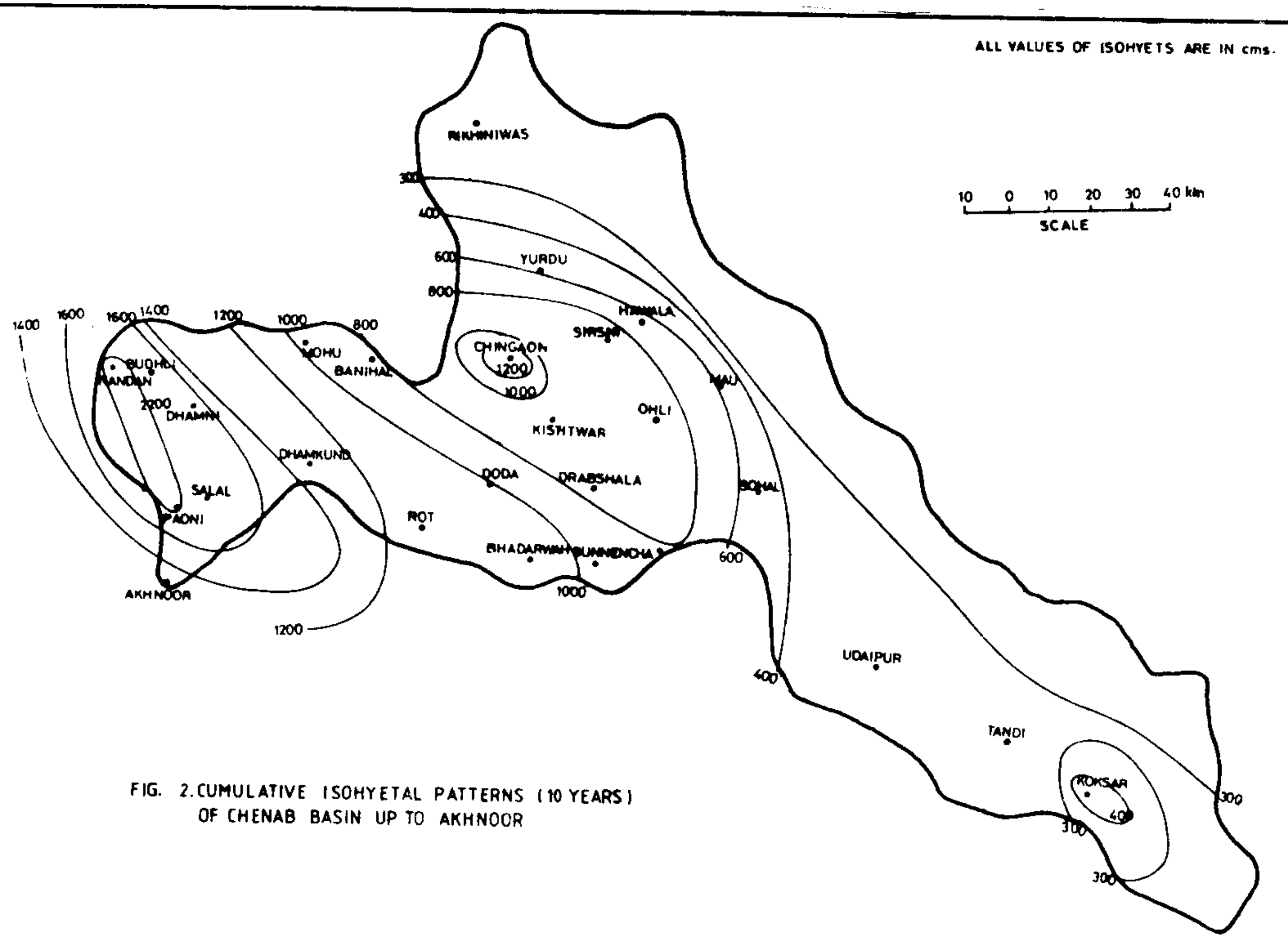

FIG. 2. CUMULATIVE ISOHYETAL PATTERNS (10 YEARS) OF CHENAB BASIN UP TO AKHNOOR

subtracting cumulated volume of evapotranspiration losses from the cumulated rainfall volume over 10 years period. For the catchments which are partly snow covered, the information on the snow free and snow covered area is needed to estimate losses through evapotranspiration from the basin. This is because evapotranspiration losses from the snow covered area are very less (Bengtsson, 1980) whereas those from the snow free area are significant. It is assumed that rainfall occurring over the snow covered area contributes about in totality to the flow within 10 years period whereas the contribution from the rain falling on the snow free area is reduced in accordance with the evapotranspiration occurred from snow free area.

Snow covered and snow free area in the basin are determined from the satellite imageries. The details of the satellite imageries and method used to extract this information are described elsewhere in this report. The snow free area in the basin is obtained by simply subtracting snow covered area from the total drainage area of the basin. The information on snow covered area was available for the months of March/April and September/October. It was linearly interpolated for the remaining months. The linear interpolation is made based on the following concept. It is obvious that depletion of snow covered area in the basin or receding of snowline depends upon the depth of snow and atmospheric temperature causing snowmelt. In the spring months snow disappears from the lower elevation where snow depth is less, and temperatures are not very high during these months. While in the summer months at higher elevations temperatures are high in comparison to the spring period, but snow depth is also much at higher elevations. These trends of temperature and snow depth support linear interpolation of the snow cover area. In this way information on snow covered area and snow free area was obtained on the monthly basis. This information in conjunction with potential evapotranspiration (PET) was used to get total volume of evapotranspiration losses occurred in the basin.

There was no data available on PET in the Chenab basin. The pan evaporation data was available only for Jammu which lies on the lower catchment boundary of the basin and experiences hot weather in the summer when most of the evapotranspiration losses occur in the basin. Monthly PET values at Jammu are computed by simply multiplying pan evaporation values by 0.7. For Chenab basin representative PET values have been computed using Jammu data. Keeping in view elevation of the Tillar station (2130 m) and location of the this station, Tillar is considered as representative station for the evapotranspiration losses has been selected. Normal monthly mean temperature available at Jammu and Tillar are used in modifying Jammu PET to Tillar PET values (National Commission on Agriculture, 1976, Rao and Madan, 1989). Ratios of the normal monthly mean temperature at Jammu and Tillar are computed and monthly PET values at Jammu are multiplied by these monthly ratios to get monthly PET vales at Tillar for further use.

In evapotranspiration calculations, snow free area and actual evapotranspitration values are required on monthly basis. In the present study actual evapotranspiration (AET) for the Tillar which is considered as representative station is computed from PET at this station. No study has been reported for this region which can give AET and PET ratio. Therefore, few studies carried out in other basins wherein such estimates have been made, were reviewed. In a study carried out in the Ganjal sub-basin of

Narmada basin applying Systeme Hydrologique European (SHE model), an average AET/PET value was estimated to be 0.40 (NIH, 1990). It is to be pointed out that Ganjal sub-basin experiences moderate rainfall. Therefore, keeping in view the rainfall in the Chenab basin, annual AET and PET ratio is assumed to be 0.30 for this study. The cold climate which prevails in the upper part of the basin further support this lower AET/PET value.

These annual AET values are distributed over a period of 12 months to give seasonality in the AET on the monthly basis. During distribution, AET and PET are considered closer in the months of July and August when sufficient moisture in available in the soil to evaporate and AET it is kept minimum in the months of January and February when temperatures are very low causing very less evapotranspiration losses. Snow free area and AET values are used on the monthly basis to estimate evapotranspiration losses from the basin and has been cumulated over a period of 10 years to give total evapotranspiration volume from the basin. Based on this approach evapotranspiration losses were estimated for the years for which snow covered/snow free data was available and an average yearly value of evapotranspiration is obtained. Using this value evapotranspiration losses for the 10 years period were computed and used in water balance analysis.

5.4 Maximum and minimum snow cover

Snow cover serves as the vast store-house of the water for the great rivers which take their birth in the Himalayas. Conventional methods have limitations in the monitoring of snow covered area in the Himalayan basins because of inaccessibility. Satellite data is considered a very prominent means of attempting snow related studies and for snow cover mapping in particular.

This technique finds increased importance and wide application for difficult terrain and inaccessible areas and is considered most suitable means of detailed survey. Also, the advantage of satellite remote sensing like multispectral, synoptic and repetitive coverage is ideally suited to monitor snow and deciphering meaningful information. The usual problems like location, recognition and measurement encountered in remote sensing are virtually not found when the target is snow. Snow has the unique physical property of a high albedo in the visible/near infrared portion of the spectrum. This makes snow easily identifiable from the darker background associated with other natural terrain.

Since very little information on snow is collected regularly in the Himalayas, remote sensing remains the only practical way of obtaining information of the snow cover in the large number of basins in the Himalayas. At present the visible, near infra-red (IR) and thermal IR data from various satellites (Landsat, IRS and NOAA) are being used operationally for mapping the areal extent of snow cover in the Himalayan basins. In the present study snow covered area for a period of 10 years (1983-92) have been carried out using visual interpretation technique of IRS and Landsat data. First of all a base map of basin under study was prepared using available maps. These base maps were overlayed on the positive prints (imageries) devepoled from the film negatives of band 3/4. The scales of base map and positive prints were matched. The whole study area was not covered in a single imagery, therefore the data of the closest date of adjoining imagery was used to find out the snow covered area in the basin.

When mapping snow cover there are several possible features of the imagery which are considered in order to prevent misidentification of snow or snow free areas. For example, cloud tops exhibit a very bright reflectance in the visible/infrared bands that is often indistinguishable from snow. These aspects have been kept in view when delineating snow covered area. Small portions in snow covered area, which are under shadow (either from terrain features or clouds) have been considered as snow bound. The maps depicting snow covered areas for March/April and September/October have been prepared for the period for which data was available. After preparation of final maps, these were digitized using DIGITIZE module of ILWIS (Integrated Land and Water Information System) - a PC based system developed by International Institute for Aerospace Survey and Earth Sciences (ITC), Enschede, the Netherlands. After digitization the snow covered area also has been computed using the same DIGITIZE module. The snow covered areas obtained for March/April and September/October for different years are given in Table 1 and are also illustrated in Figure 3. The results indicate that a major portion of the basin is covered by snow in the month of March/April. For few years remote sensing data could not be supplied by NRSA either due to poor data quality or high percentage of cloud cover (>50%) in the basin under consideration.

The range snow covered area in the month of March/April for different years varied from 14731 to 16645 km^2 i.e. 67.6 to 74.9 %. Similarly the range of minimum snow covered area in the month of September/October for different years varied from 4023 km^2 to 7018 km^2 i.e. 18.3 to 31.6 %.

TABLE 1 : Snow covered area (SCA) and permanent snow covered area (PSCA) in the Chenab basin up to Akhnoor

(Total Area of Chenab basin up to Akhnoor = 22200 Km^2)

Year	Month	SCA (km^2)	%	Month	PSCA (km^2)	%
1983	March/April	N.A.	N.A.	Sept.	4023	18.1
1984	March/April	N.A.	N.A.	Sept.	5045	22.7
1985	March/April	N.A.	N.A.	Sept./Oct.	N.A.	N.A.
1986	March/April	N.A.	N.A.	Sept./Oct.	N.A.	N.A.
1987	March	15979	71.9	Sept./Oct.	N.A.	N.A.
1988	March/April	N.A.	N.A.	Sept./Oct.	N.A.	N.A.
1989	March	15001	67.6	Oct.	5170	23.3
1990	March	14731	66.4	Sept.	5972	26.9
1991	March	16645	74.9	Oct.	5146	23.2
1992	March/April	N.A.	N.A.	Oct.	7018	31.6
	Average =	15589	70.2		5396	24.3

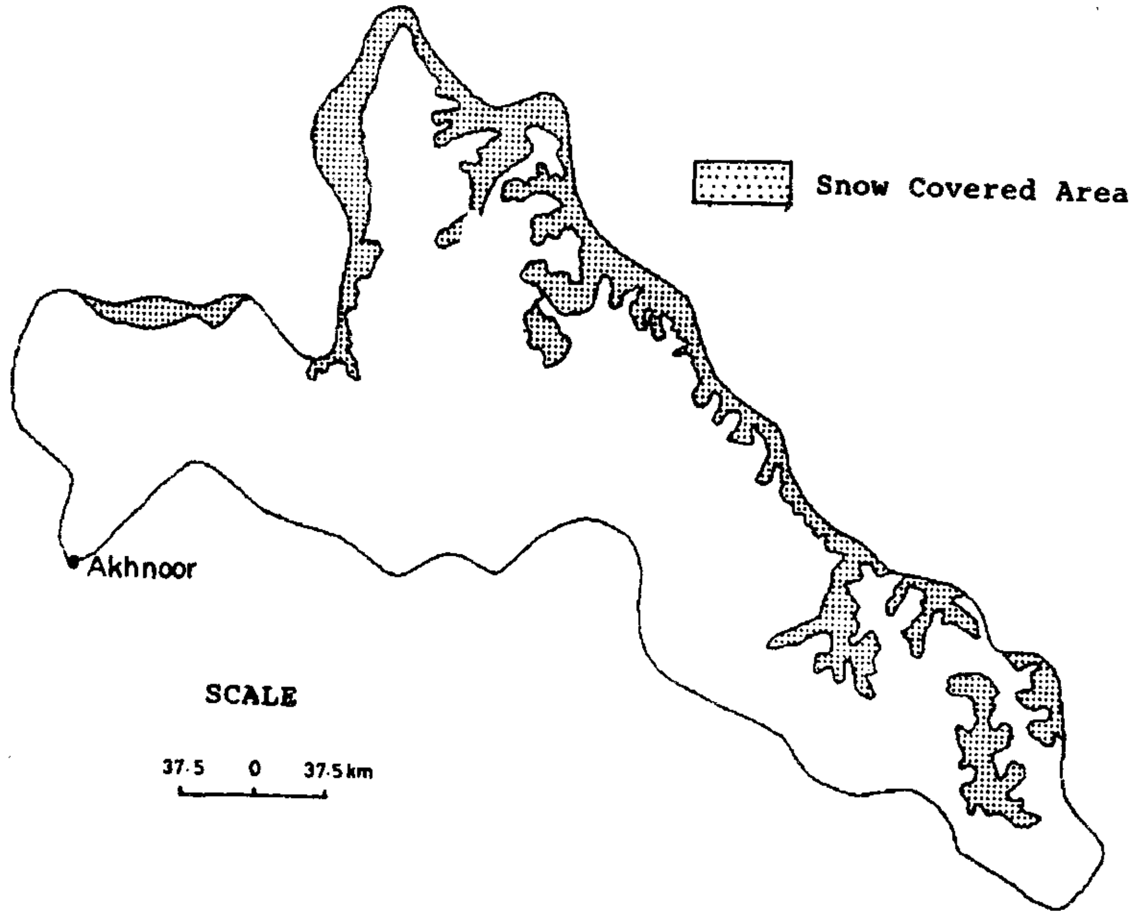

Fig. 3(a) : Snow coverd area in Chenab catchment (upto Akhnoor) in the month of September , 1983.

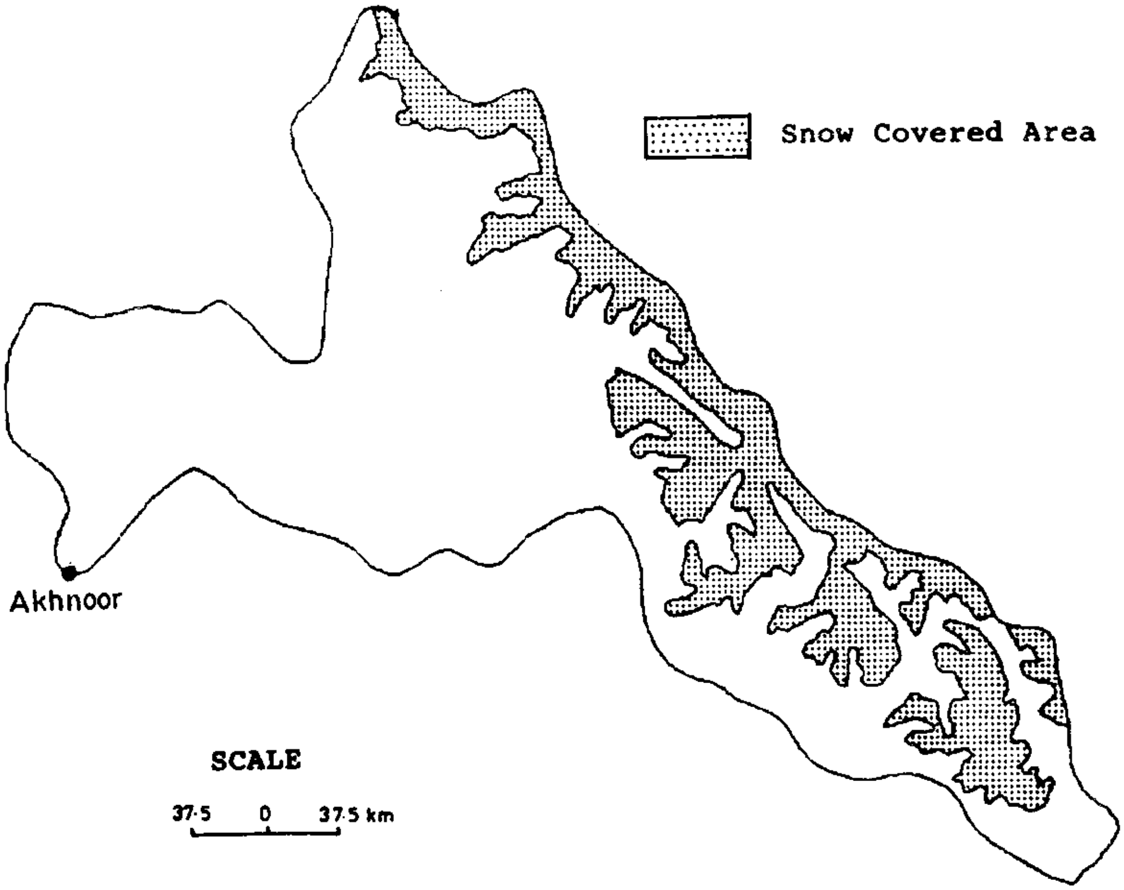

Fig. 3(b) : Snow coverd area in Chenab catchment (upto Akhnoor) in the month of September , 1984.

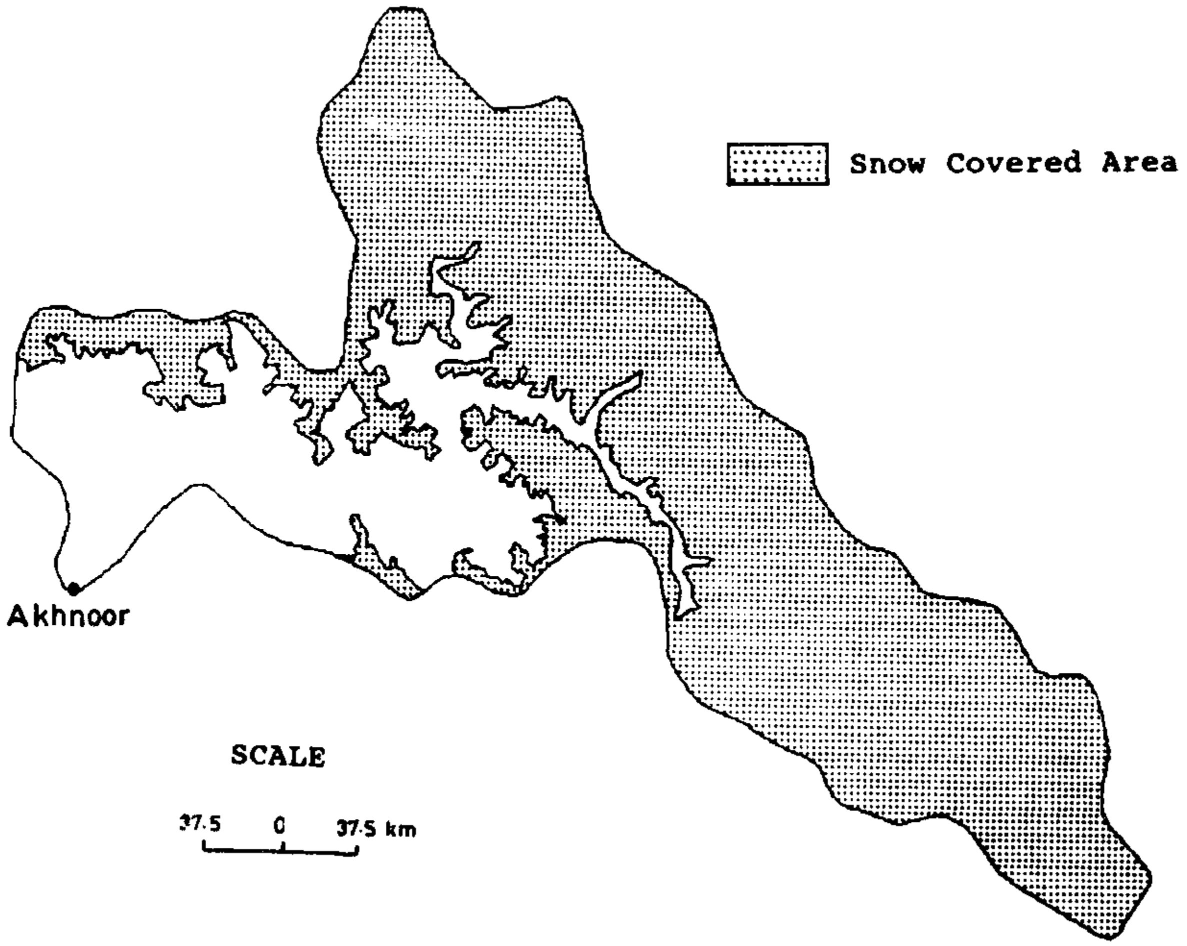

Fig. 3(c) : Snow coverd area in Chenab catchment (upto Akhnoor) in the month of March , 1987.

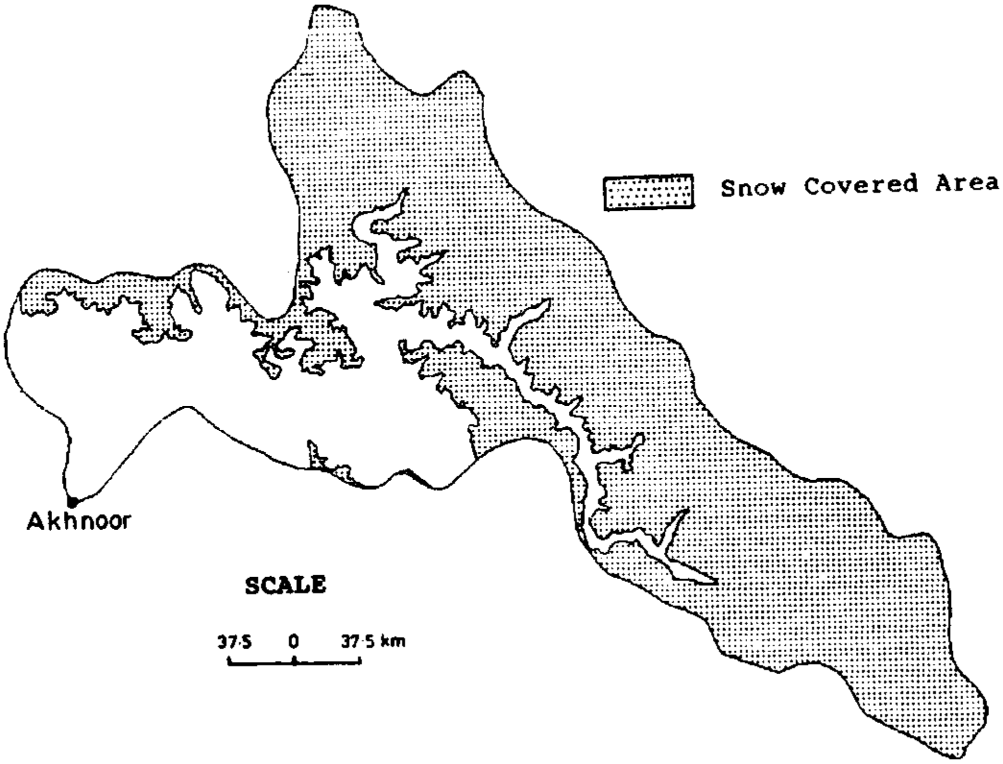

Fig. 3(d) : Snow coverd area in Chenab catchment (upto Akhnoor) in the month of March , 1989.

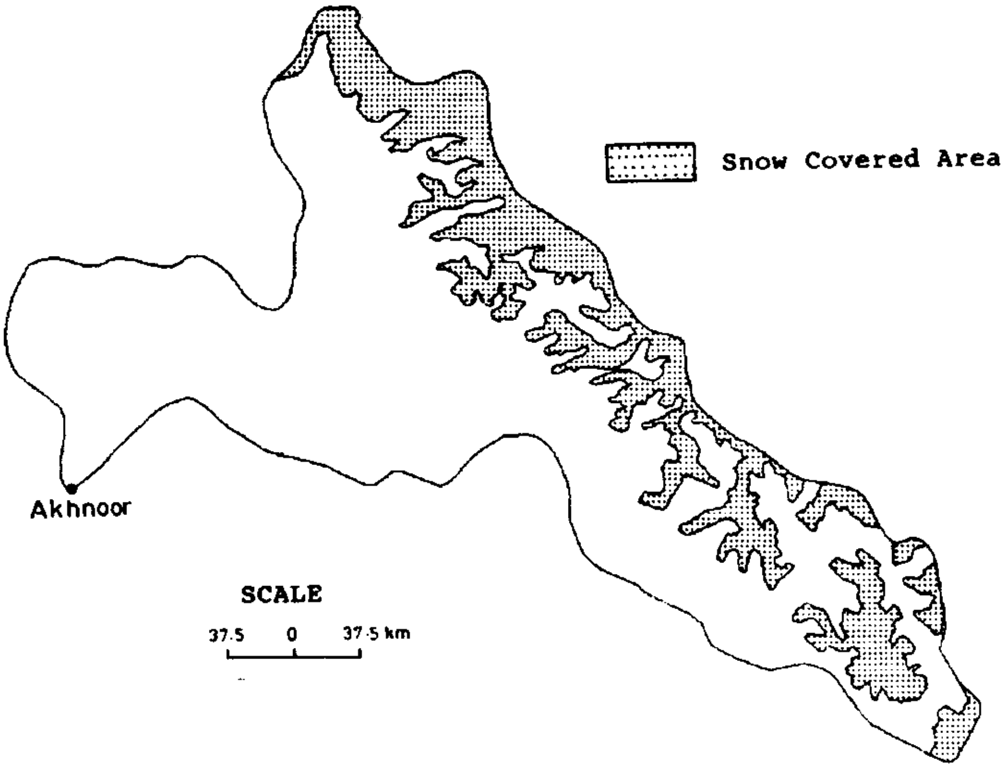

Fig. 3(e) : Snow coverd area in Chenab catchment (upto Akhnoor) in the month of October , 1989.

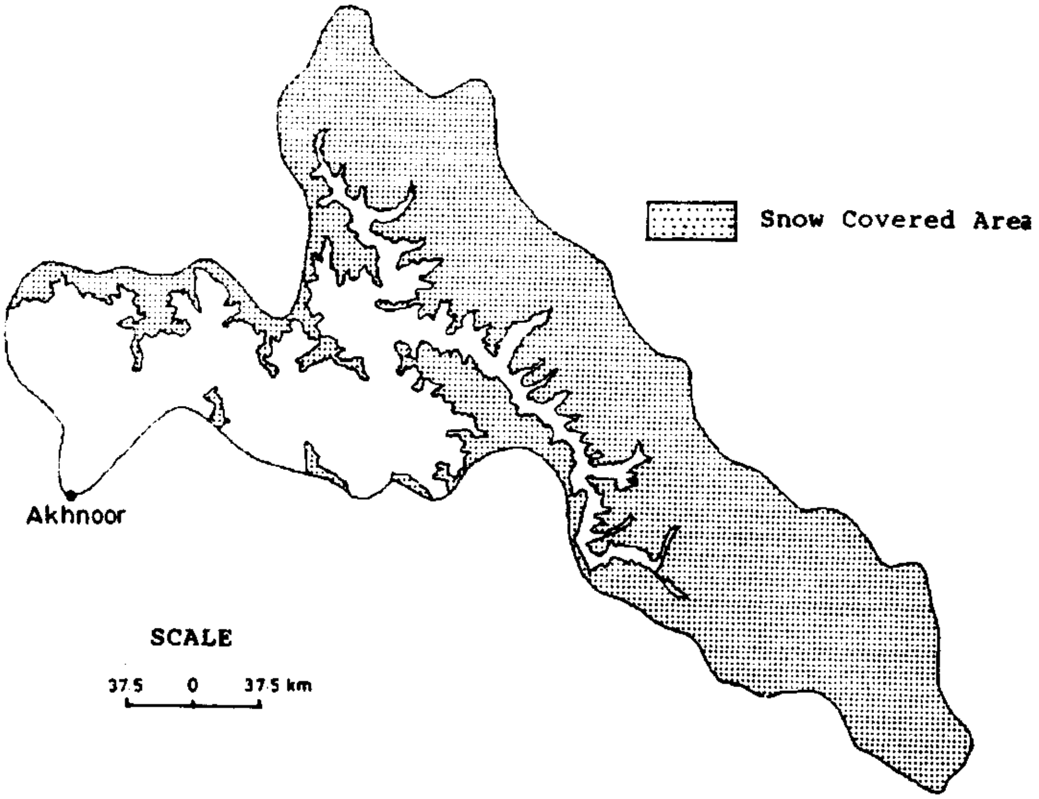

Fig. 3(f) : Snow coverd area in Chenab catchment (upto Akhnoor) in the month of March , 1990.

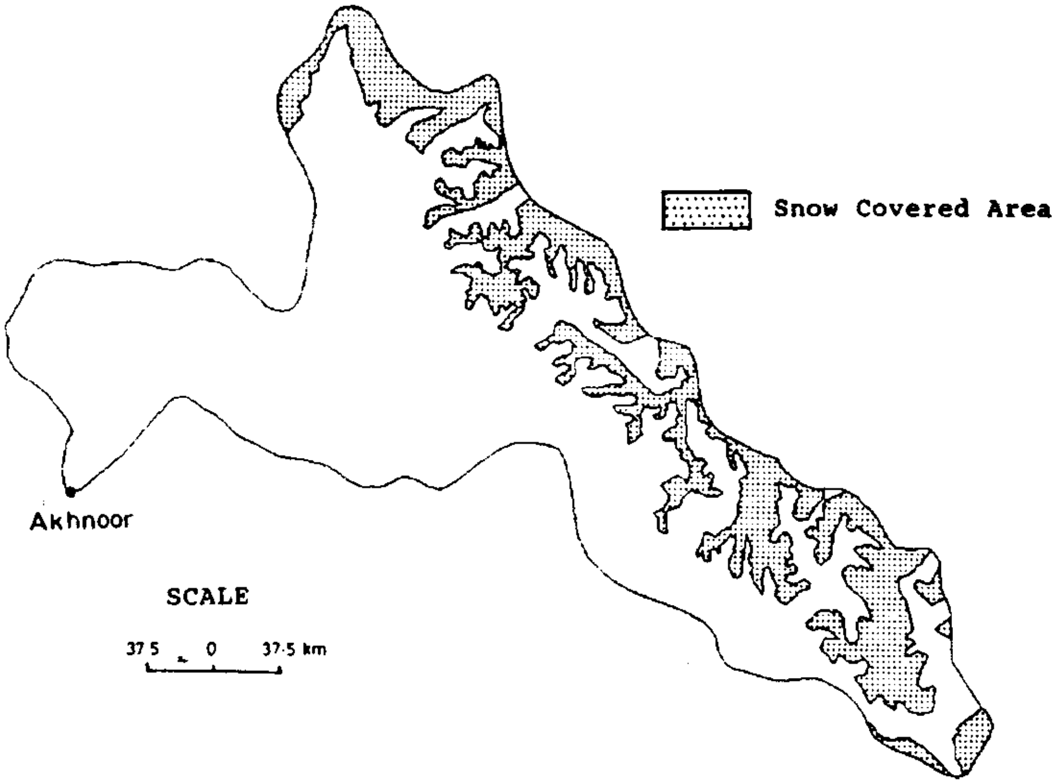

Fig. 3(g) : Snow coverd area in Chenab catchment (upto Akhnoor) in the month of September , 1990.

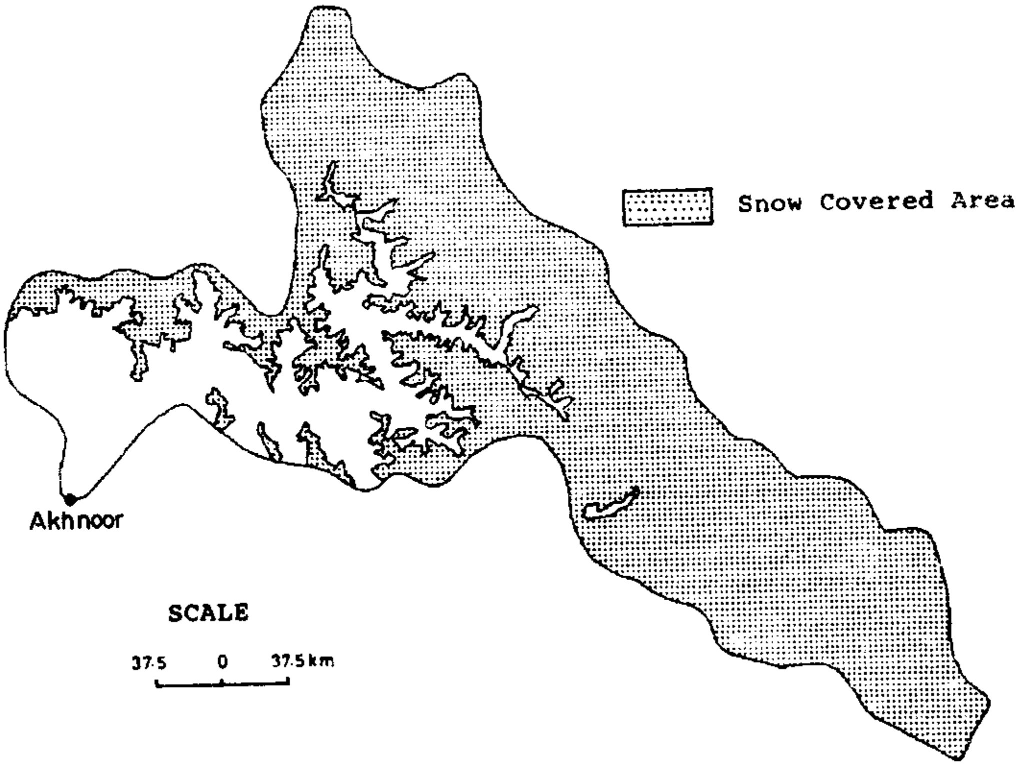

Fig. 3(h) : Snow coverd area in Chenab catchment (upto Akhnoor) in the month of March , 1991.

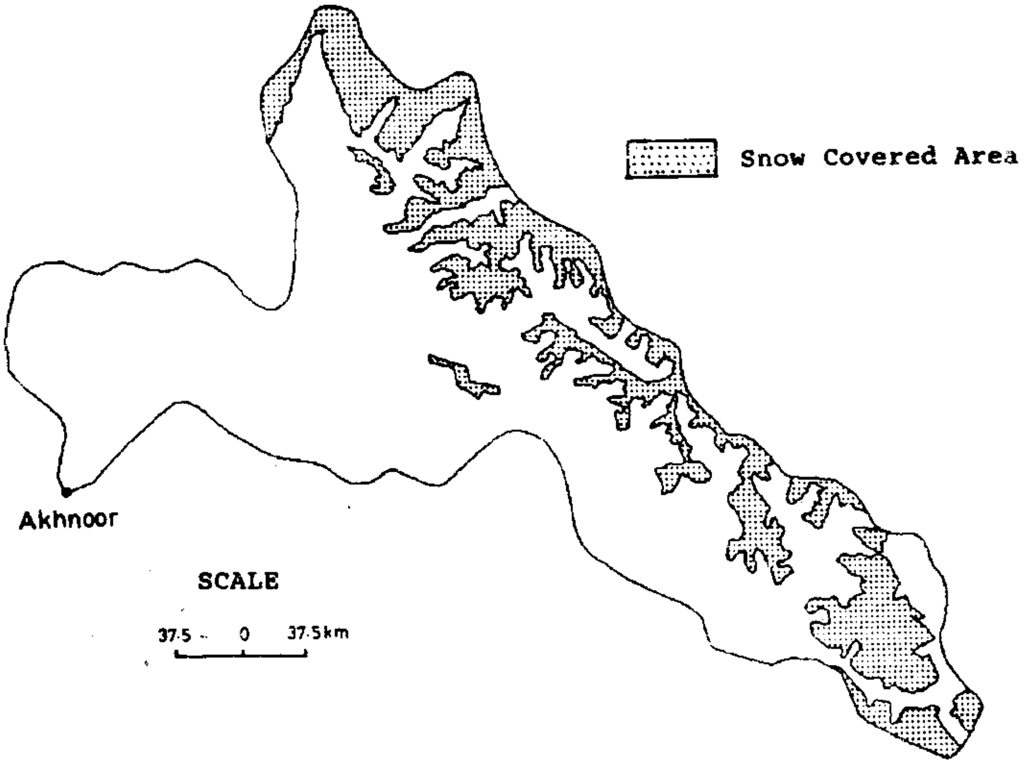

Fig. 3(i) : Snow coverd area in Chenab catchment (upto Akhnoor) in the month of October , 1991.

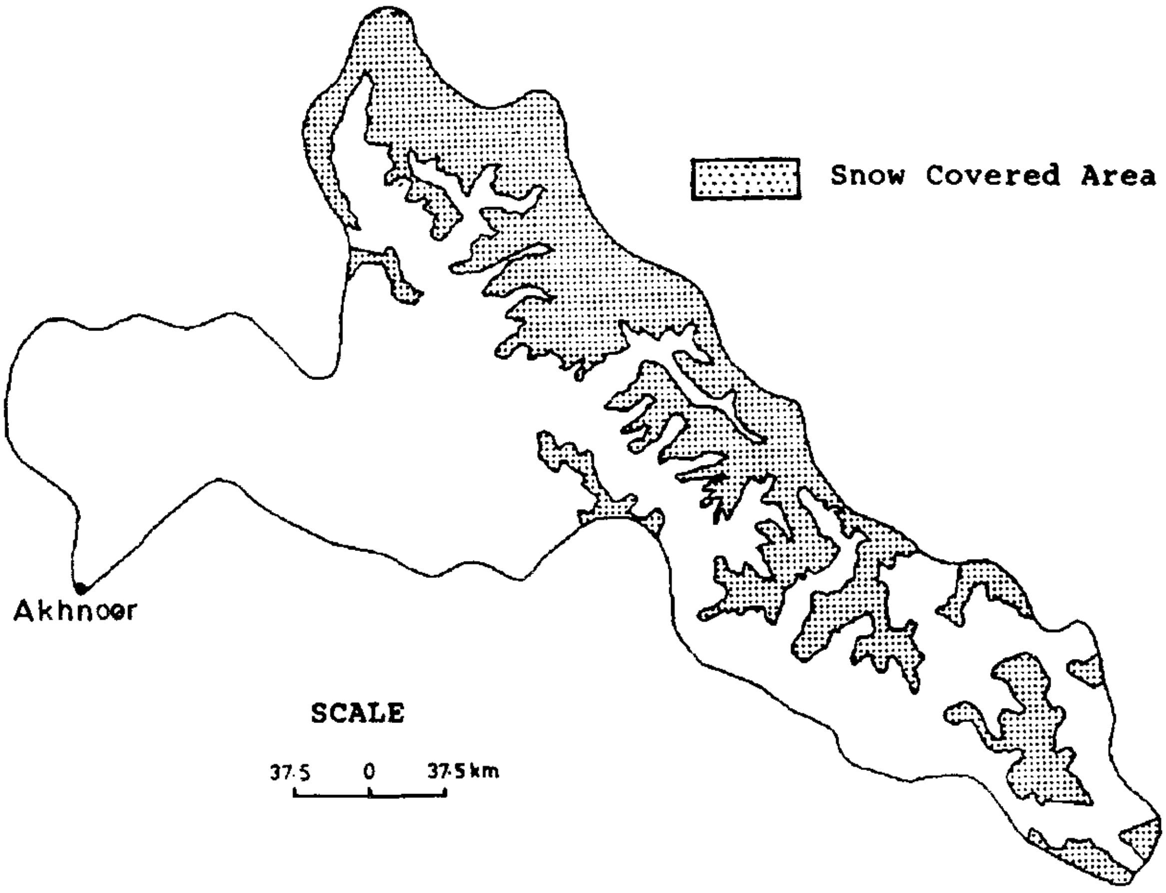

Fig. 3(j) : Snow coverd area in Chenab catchment (upto Akhnoor) in the month of October , 1992.

6.0 SNOW AND GLACIER CONTRIBUTION

The location of gauging site where snow and glacier contribution is to be computed is very important for such studies. The percentage of contribution of the snow and glacier melt runoff increases in all the rivers originating from the Himalayas in the head catchment region. In the downstream contribution of snow and glacier melt decreases. Obviously, this is because of decrease in ratio of snow covered area and total drainage area in the downstream.

Snow and glacier contribution in the 10 years volume of flow in Chenab river at Akhnoor has been estimated using water following water balance approach;

Snow & glacier runoff volume = Observed flow volume - (Rainfall volume - evapotranspiration)

As explained earlier it is assumed that all the losses from the rain and snowmelt in the form of infiltration and percolation will be reflected within a period of 10 years considered for this study for volume computation. Therefore, base flow is not considered separately in the above equation. Based on the water balance approach it is found that on average snow and glacier contribution in the annual flow of Chenab basin at Akhnoor is 49.10%. Details of other parameters are shown in Table 2.

TABLE 2: Rainfall and Snow & Glacier contribution in Chenab river at Akhnoor. The volumes of rainfall, evapotranspiration, runoff and snow & glacier melt are given for a period of 10 years (1982/83-91/92).

Total Rainfall volume (km^3)	Total evapotranspiration losses (km^3)	Total runoff volume (km^3)	Rain contribution		snow & glacier contribution	
			Vol.(km^3)	%	Vol.(km^3)	%
162.42	14.22	291.15	148.20	50.90	142.95	49.10

7.0 CONCLUSIONS

The following conclusions could be drawn from this study:

1. On average about 15590 km^2 area which is 70.2% of the total drainage area of the Chenab basin up to Akhnoor is covered by snow in the month of March/April and about 5400 km^2 (24.3%) remains covered by perpetual snow and glaciers.

2. On the average (based on 10 years) snow and glacier melt contribution in flow volume of Chenab river at Akhnoor is found to be 49.10%. and rest from the rain.

Acknowledgements

Authors are thankful to Dr Satish Chandra, Former Director, NIH, Dr S M Seth, Director, NIH,Shri K S Ramasastri, Scientist F , NIH, Roorkee and Prof. Subhash Chander, Deputy Director, IIT, New Delhi for their valuable discussions during study period. Thanks are due to Dr P V Seethapathi, Scientist F forarranging remote sensing data. The help extended by Indus Commission and Central Water Commission in supplying the data is also acknowledged. This study was part of the project supported by Ministry of Water Resources, Govt. of India, New Delhi.

REFERENCES

Bengtsson, L (1980), Evaporation from a snow cover, Nordic Hydrology, Vol.11, pp.221-234.

Flint, R F (1971), Glacial Quaternary Geology, Wiley, New York.

International Association of Hydrological Sciences (IAHS) (1993), Snow and Glacier Hydrology, IAHS Publication No. 218.

India Meteorological Dept. (1971), Potential Evapotranspiration (PE) over India, Scientific Report No.136.

National Commission Agriculture (1976), Rainfall and cropping patterns in Jammu and Kashmir, Vol. VII, Ministry of Agriculture and Irrigation, New Delhi.

National Institute of Hydrology (NIH), Application of SHE model to the Ganjal sub-basin of river Narmada, CS-28, 1980.

Rao, P R and D S Madan (1989), Review of design storm and flood studies for Salal dam in Chenab basin, 55th R&D Session of CBIP, July, 1989, Srinagar (J&K)

Report on Irrigation Commission, Volume III (Part-1), (1972), Ministry of Irrigation and Power, New Delhi

Singh, R L (1971), India - A Regional Geography, Silver Jubilee Publication, Varansi.

Director	Dr S M Seth

STUDY GROUP

Dr Pratap Singh	Scientist C
Shri S K Jain	Scientist C
Shri Naresh Kumar	SRA
Shri U K Singh	RA