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Snow cover monitoring in Baspa basin using IRS WiFS data

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सार – आइ.आर.एस. 1 सी., 1 डी. और पी. 3 डब्ल्यू. आई.एफ.एस. से प्राप्त आँकड़ों का उपयोग करके बासपा नदी बेसिन में मौसमी हिमाच्छादन का मानीटरन किया गया है। इस अध्ययन में, 1996–97 से 2001–2002 तक के वर्षों की अक्तूबर और जून के बीच की अवधि का उपयोग किया गया है। कुल 57 स्थानों का विश्लेषण किया गया। हिमाच्छादन में परिवर्तनों के क्रमबद्ध विश्लेषण से पता चला है कि वर्ष 1997–98 और 1998–99 की तुलना में शीतऋतु के आरंभ में अर्थात्, अक्तूबर से जनवरी 2001–2002 तथा मध्य दिसम्बर से मध्य फरवरी 2000–2001 में, हिमाच्छादन का विस्तार वास्तविकता में कम रहा। शीतऋतु के आरंभ में हुए कम हिमपात तथा असामान्य रूप से अधिक तापमान के कारण हिमाच्छादन कम रहा। इसके विपरीत वर्ष 2000–2001 में हिमपात का पैटर्न बिलकुल अलग रहा है। नवम्बर–दिसम्बर माह में कुल हिमाच्छादन बहुत अधिक रहता है। तथापि, दिसंबर के आरंभ से हिमाच्छादन कम होने लगा और यही प्रवृत्ति फरवरी के मध्य तक जारी रही। शीतऋतु के चढ़ाव पर अर्थात् जनवरी और फरवरी में बर्फ का पिघलना बहुत असामान्य घटना है। इसके अलावा, हिमाच्छादन का कुल विस्तार चार वर्षों के औसत से लगभग 30 प्रतिशत कम रहा। इससे हिम अवक्षय पैटर्न भी प्रभावित हुआ, उदाहरणार्थ, मई 1998 के आरंभ में लगभग 85 प्रतिशत बेसिन हिमाच्छादित था जबकि वर्ष 1999 में केवल 74 प्रतिशत बेसिन हिमाच्छादित था। अवक्षय वक्रों का उपयोग करके हिमाच्छादन के पिघलने और वापस बनने का विश्लेषण किया गया। हिम अवक्षय वक्र से यह पता चला है कि 3000 से 3600 मीटर की उँचाई वाले क्षेत्र में मई के आरंभ में बर्फ खत्म हो जाती हे और 3600 से 4200 मी. की उँचाई वाले क्षेत्र में जून के आरंभ तक तथा इससे अधिक 4200 से 4800 मी. की उँचाई वाले क्षेत्र में जून के मध्य तक बर्फ पिघल जाती है।

ABSTRACT. Seasonal snow cover monitoring was carried out in the Baspa river basin using IRS 1C, 1D and P3 WiFS data. In the study, a period between October and June for years starting from 1996-97 to 2001-2002 was used. A total of 57 scenes were analyzed. Systematic analysis of changes in snow cover suggests that extent of snow cover in early winter, *i.e.* October to January of 2001-2002 and mid December to mid February 2000-2001 is substantially lower than year 1997-98 and 1998-99. This low snow cover is caused due to lower snowfall in the early part of winter and abnormally high temperature. On the other hand snow accumulation pattern in year 2000-2001 is completely different. Overall snow cover is very high in the month of November-December. However, from the beginning of December snow cover started to reduce and this trend continues up to middle of February. The melting of snow cover in the peak of winter, *i.e*. January and February is very unusual observation. In addition, overall snow extent is almost 30 % less than average of four years. This has also affected snow depletion pattern, for example, at the beginning of May 1998 approximately 85 percent basin was covered by snow and in the year 1999 only 74 % of basin was covered by snow. Melting and retreat of snow cover was analyzed using depletion curves. Snow depletion curve suggests an altitude zone between 3000 to 3600 m is free of snow by beginning of May and altitude between 3600 and 4200 m is cleared by beginning of June and higher attitude zone between 4200 to 4800 m is cleared by middle of June.

Key words –Snow cover, IRS, WIFS, Satellite monitoring, Baspa basin Himalayas, Remote sensing.

1. Introduction

Snow covers almost 40 per cent of the Earth's land surface during Northern Hemisphere winter. This makes snow albedo and areal extent an important component of the Earth's radiation balance (Foster and Chang, 1993). In addition, large areas in the Himalayas are also covered by snow during wintertime. Area of snow can change significantly during winter and spring. This can affect stream flow during spring and summer for rivers originating in the Higher Himalayas. In addition, snow pack ablation is highly sensitive to climatic variations. Increase in atmospheric temperature can influence snowmelt and stream runoff pattern (Kulkarni, *et al*., 2002a). Therefore, mapping of areal extent and reflectance of snow is an important parameter for various

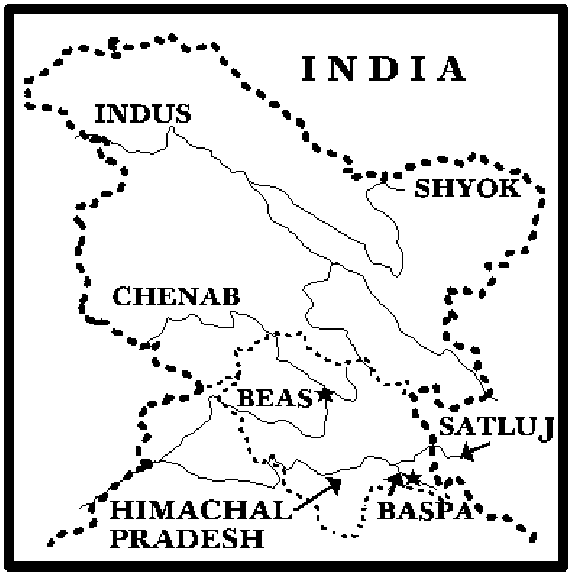

Fig. 1. Location map of Baspa basin, Himachal Pradesh, India

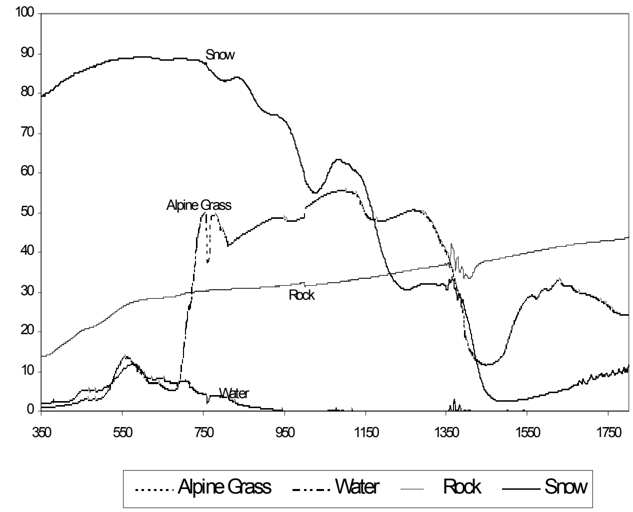

Fig. 2. Showing spectral reflectance of snow, rock, grass and water in visible and near IR region. The observations were carried out near Manali, Himachal Pradesh

climatological and hydrological applications. In addition, extent of snow cover can also be used as an input for avalanche investigations.

Snow was first observed by satellite in eastern Canada from the TIROS-1 satellite in April 1960. Since then, the potential for operational satellite-based mapping has been enhanced by the development of higher temporal-frequency satellites and sensors such as WiFS on IRS 1C and P3 satellites and satellite sensors with higher spatial resolution, such as Landsat TM, IRS LISS-II and III. In addition, satellites with better radiometric resolutions, such as NOAA have been used successfully for snow mapping (Hall *et al*., 1995). This is possibly due to distinct spectral reflectance characteristics of snow in visible and near infrared region. Reflectance of snow is explained in detail in the following section. Information generated from satellite observations has been extensively used for snowmelt runoff modeling (Kulkarni *et al*., 1997). In this investigation snow monitoring was carried out from November to June in Baspa basin. Baspa basin is located in Kullu district of Himachal Pradesh and location map of Baspa basin is given in Fig. 1.

2. Spectral reflectance characteristics of snow

One of the important concepts in determination of various objects through remote sensing is that different objects reflect energy differently in various parts of the spectrum. This depends upon physical property of the object and it can vary depending upon wavelength. The reflectance curve is given in Fig. 2. This investigation was carried out using spectral radiometer with a range from 300 to 1800 nm, near Manali, Himachal Pradesh. In general, the reflectance of snow is high at the red end of the visible spectrum. It tends to decline in the near-infrared region until 1090 nm, where slight gain in reflectance occurs and gives a minor peak at approximately 1090 to 1100 nm (O'Brian and Munis, 1975). The reflectance also shows minor peak around 1830 and 2240 nm with a strong depression of reflectance around 1950 and 2050 nm.

In optical region snow reflectance is higher as compared to other land features as grass, rock and water (Fig. 2). However, in SWIR region snow reflectance is lower than rock and vegetation. Therefore, snow on satellite images appears white in visible and black in SWIR region (Fig. 3). This characteristic can be effectively used to develop Normalized Difference Snow Index (NDSI) for snow cover mapping. It can be useful technique in the Himalayan region, as it can be applied under mountain shadow conditions (Kulkarni *etal*., 2002b; Hall *et al*., 1995). This is possibly due to reflectance from diffuse radiation in shadow areas. This technique will be useful to monitor snow cover in the Himalayas, when data of Advance WiFS is available form Resoursesat in near future. The utilization of middle infrared has additional advantage, as cloud reflectance is high in this band. This helps in discriminating between snow and cloud. Therefore, NDSI is also useful for snow-cloud

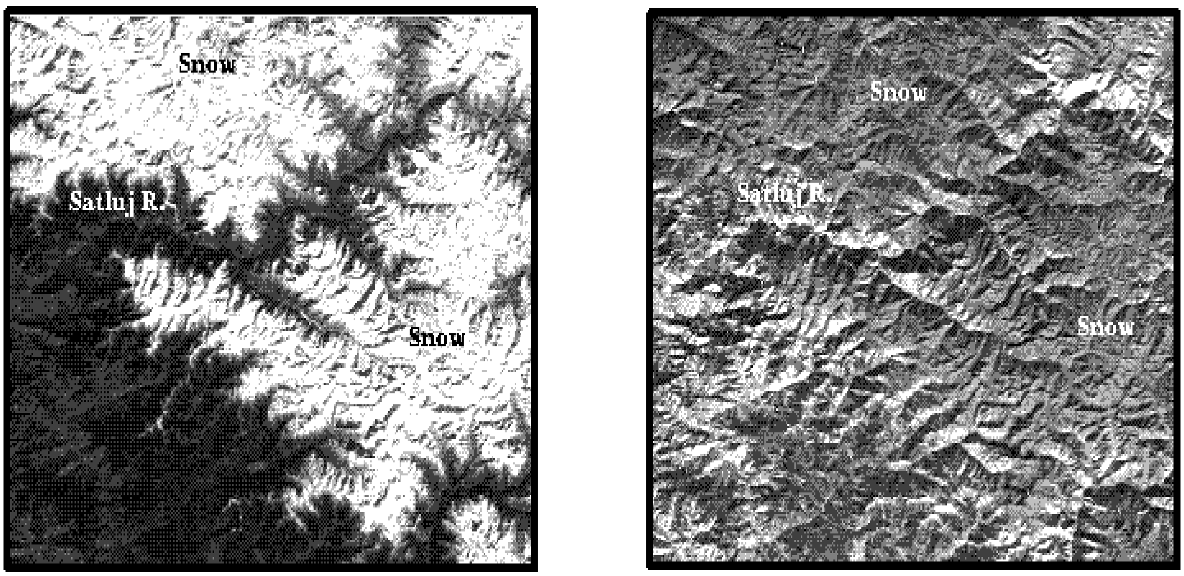

Fig. 3. Showing IRS P3 WiFS images in visible and SWIR region. Note difference in tone of snow due to different reflectance characteristics

discrimination. NDSI can be estimated using following relationship.

$$\text{NDSI} = \frac{(\text{Green Reflectance} - \text{SWIR Reflectance})}{(\text{Green Reflectance} + \text{SWIR Reflectance})}$$

3. Methods of investigation

In this investigation WiFS sensor of IRS-1C, 1D and P3 was used. WiFS sensor is ideally suited for snow cover monitoring due to 5-day repetitive coverage and 188 m ground resolution. WiFS sensor has two spectral bands, one in visible (0.62-0.68 μm) and another in near infrared spectrum (0.77-0.86 μm). WiFS of IRS-P3 has additional SWIR (1.55 to 1.75 μm) band, which can be used for snow-cloud discrimination. A total of 57 scenes were analyzed in this investigation.

In this investigation digital analysis technique and geographic information system was used. Initially WiFS data is geocoded using ground control points and then sub image of Baspa basin was extracted. For a period between November to February, due to mountain shadow, snow delineation was carried out by interactive mode. In this method all shadows above snow line were considered as snow covered. From March onward-unsupervised classification was used for estimation of seasonal snow cover. Similar procedure was used to delineate snow cover under individual altitude zones. A total of six altitude zones from 1800 m at an interval of 600 m were used.

One of the major difficulties in operational snow cover mapping is cloud cover. It is further compounded due to similar reflectance characteristics of snow and cloud. The discrimination between snow and cloud can be done by using various techniques such as textural analysis, association with shadow and by using multi temporal analysis. In Himalayas and in present investigation, snow/cloud discrimination was done by using texture, where snow shows characteristic mountainous pattern and it can not be seen, when area is covered by cloud cover. In addition, geostationary satellites can be used for multi temporal analysis, where cloud may alter in form and position over time where as temporal variations in snow cover is less extreme.

In visible and near infrared region reflectance of snow and cloud is very high. Therefore discrimination between snow and cloud is not possible. This is because of similar reflectance characteristics in this region. In spectral range between 1.55-1.75 m, 2.1-2.35 m and 3.55-3.93 m have shown potential for snow/cloud discrimination. In these bands snow shows lower reflectance than cloud. Presently, data in spectral range between 1.55-1.75 m is available from LISS-III and WiFS sensors of Indian Remote Sensing Satellite. Snow/cloud differentiation is possible in these bands.

4. Results and discussion

A systematic analysis of changes in snow cover was carried out in the Baspa basin. The period was selected

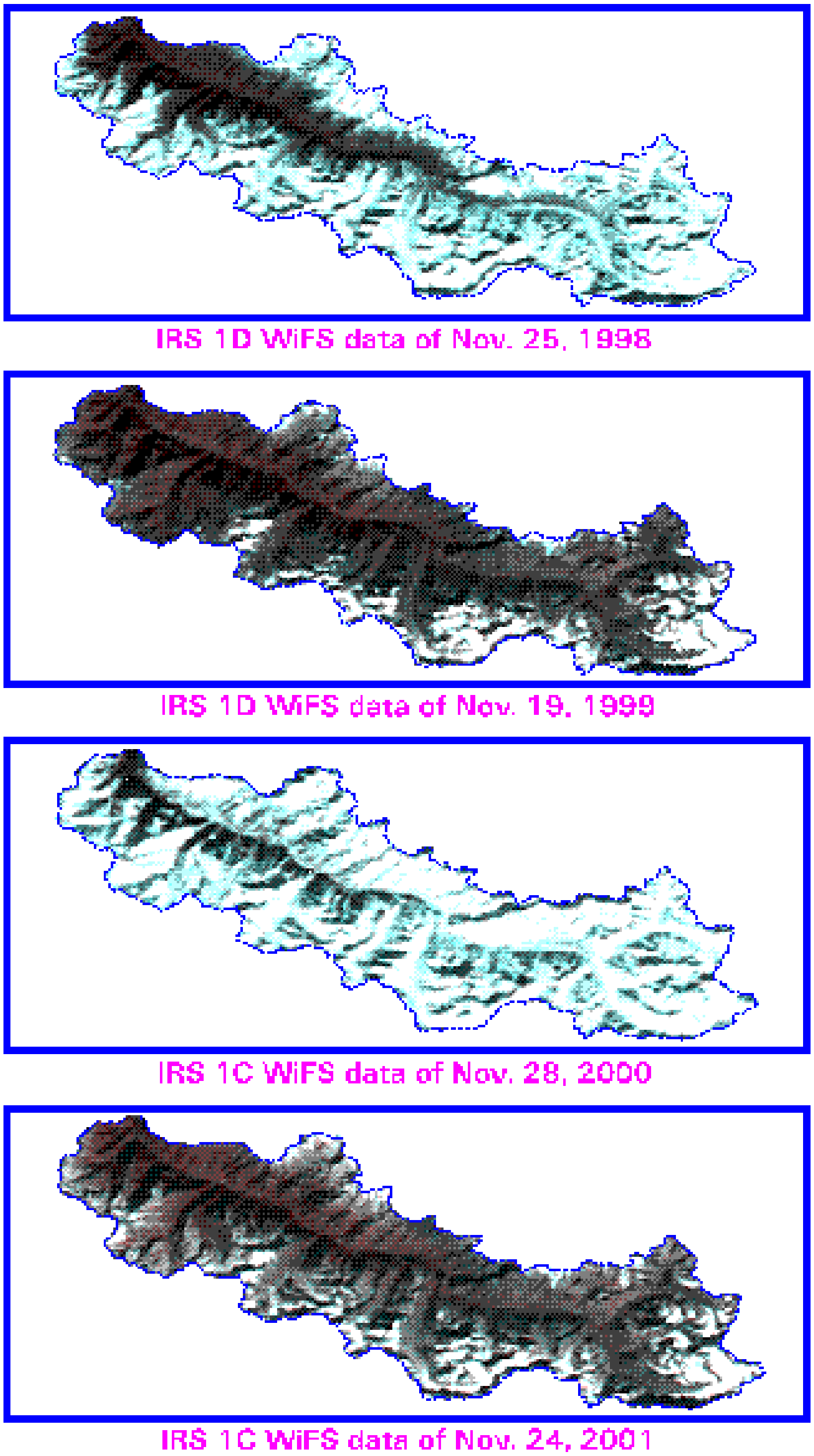

Fig. 4. Satellite images showing snow cover from 1998-99 to 2001-2002

from October to June and the investigation was carried out between 1996-97 and 2001-2002. Satellite images showing snow cover for various years are given in Fig. 4 and graphs showing changes in snow extent are given in Fig. 5. We find that the accumulation of snow cover in early winter, *i.e*. October to January of 2001-02 and

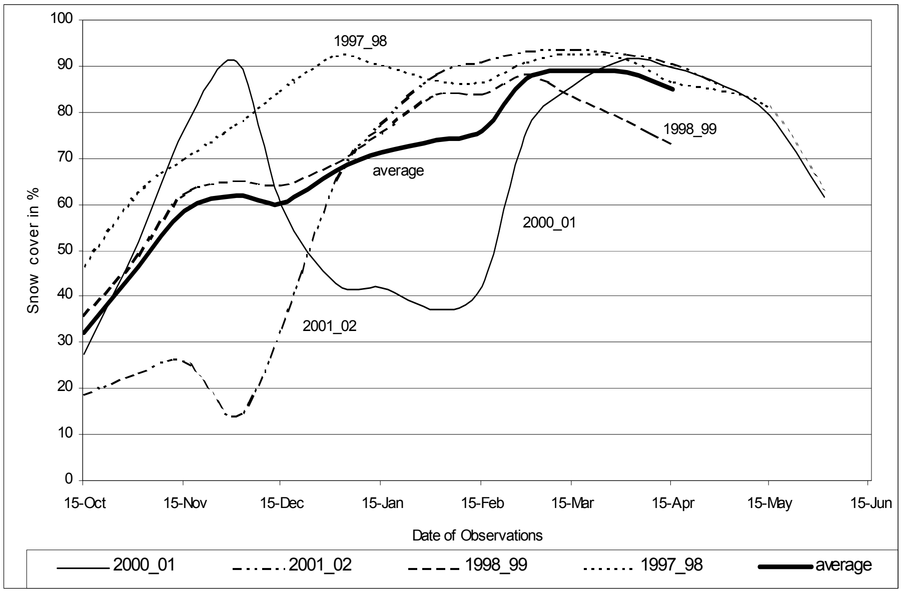

Fig. 5. A graph showing changes in snow extent between October and June from 1997-98, 1998-99, 2000-2001, 2001-2002 and average of four year

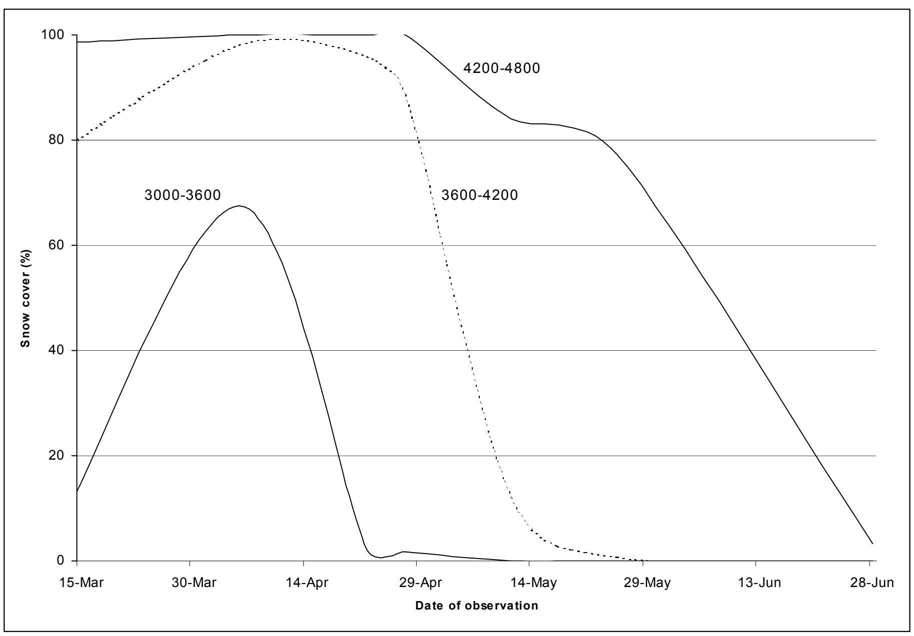

Fig. 6. Depletion curves for the Baspa basin in three altitude zones between 3000 and 4800 m

December to February of 2000-01 is substantially lower than year 1997-98 and 1998-99. This low snow cover is caused due to lower snowfall in the early part of winter and abnormally high temperature. The average maximum temperature for a period between November and December is substantially higher in year 1998 and 1999 as compared to year 1997. On the other hand snow accumulation pattern in year 2000-01 is completely different. Overall snow cover is very high in the month of November-December. However, from the beginning of December snow cover started to reduce and this trend continues up to middle of February. The melting of snow cover in the peak of winter, *i.e.* January and February is very unusual observation. In addition, overall snow extent is almost 20 % less than year 1997-98. This has also affected snow depletion pattern, for example, at the beginning of May 1998 approximately 85 percent basin was covered by snow and in year 1999 only 55 % of basin was covered by snow. Average extent of snow cover was estimated and plotted in Fig. 5. Average extent of snow

TABLE 1

Mean monthly altitude of snow line in the Baspa basin between September and June for years 2000-2001 and 2001-2002

Month of Observation	Altitude of snow line (m)		
	Year 2000-2001	Year 2001-2002	Mean
September	5050	4887	4969
October	5100	5050	5075
November	2500	4650	3575
December	4100	5050	4575
January	4300	3433	3867
February	4350	2800	3575
March	3700	2900	3300
April	3200	3500	3350
May	4325	4300	4313
June	4900	4600	4750

cover is for 4-years. The data suggests that snow accumulation was above normal for year 97-98 and very low for 1998-99. This is also reflected in snow ablation pattern. Snow ablation in 1998-99 is very fast as compared to 1997-98. At the middle of May snow cover was almost 70 % in 1998 as compared to 30 % in 1999.

The aspects of snow melt and snow cover depletion can be well studied by using depletion curves. The depletion curves were developed for various altitudes zones and for different years. At present suitable satellite data is available for year 2001. This is used to estimate annual depletion curve. An average depletion curve of snow in altitude range from 3000-3600, 3600-4200 and 4200-4800 m are given in Fig. 6. In addition, monthly altitude of snow line from September to June was also estimated from year 2000. This is varying between 2900 and 5100 m (Table 1).

The depletion curve suggests that snow melting in the altitude zone between 3000-3600 m begins from beginning of April and region is free on snow by beginning of May. In the same graph, depletion curve for altitude range between 3600 and 4200 m is also given. This suggests that snowmelt completes in this zone by end of May and it is almost one month later of lower altitude zone. In the same graph, depletion curve for altitude range between 4200 and 4800 m is also given. This suggests that snowmelt completes in this zone by middle of June. Depletion curve also suggests that for a period earlier than end April no change is snow extent is observed in altitude zone 3600-4200 m and higher altitude zone. Snow cover was reduced in altitude zone 3000-3600 m. This suggests that most of the stream runoff generated during mid March to mid April is due to snow melt from altitude zone of 3000-3600 m. Around end of April very little snow cover was observed in lower altitude zone and most of the runoff is coming from altitude zone of 3600-4200 m. This continues up to middle of June. Snow depletion curves are being prepared for higher altitude zones. However, most of the glaciers in the Baspa basin are located in regions above 4000 m altitude zones. Average glacier snout altitude in the Baspa basin was measured as 4200 m (Kulkarni *et al*., 1999). Therefore, runoff after middle of June may be dominated by glacier melts and monsoon rainfall. This is useful information for runoff modeling and to assess future changes in runoff due to global warming (Martinec and Rango, 2001). It is now proposed for develop depletion curves for all altitude zones in the basin.

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