International Conference "Water, Environment, Energy and Society" (WEES–2009)
New Delhi, 12–16 January 2009

Snow Harvesting for Drinking and Irrigation Water: A Case Study

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ABSTRACT: In the recent past due to global warming and change in climate, the snow fall pattern has changed considerably. The late snow fall, frequent avalanche activity and fast snow melting reduces the frequency of contact time and availability of water for recharging to the ground resulting in scarcity of drinking and irrigation water in snow bound regions. Therefore, an attempt has been made to carry out the investigation, design and implementation of low cost structures and their effectiveness for snow harvesting. In this paper a case study of the various techniques used for snow harvesting which is a means to retain snow mass in the formation zone, collect avalanche debris in the middle zone and trap snow melt water are presented.The observation made during winter of 2003–2004 and 2006–2007 are presented here. The snow was successfully retained in a slope of 34°–38°. Studies reveal that the standing snow at harvesting site is more than the general slope and remained for longer duration approximately by 20 days. The mean snow thickness was observed 66 cm for general slope and 77 cm for harvesting site. The snow pit profile of general slope and harvesting site was compared and found that the harvesting site has larger snow layer thickness with higher density than the general slope. The mean standing snow during measurement period of catch dam was observed 275 cm and ablation/week was observed 10 cm for general slope and 23.3 cm for catch dam. The evaluation carried out shows that the measures are very effective.

Keywords: Snow Harvesting, Formation Zone, Avalanche, Global Warming, Melt Water, Ambient Temperature, Avalanche Debris, Spring.

INTRODUCTION

Mountains store large quantity of fresh water in the form of ice and snow. World's large rivers, lakes, ponds and wet lands have their origins in mountains. In India the Himalayas are one of the largest sources of fresh water for Northern parts. Earlier in late September there used to be snow fall in Indian Himalaya but now usually there is no snow fall up to the month of December and some time even January. Whenever there is heavy snowfall, the snow mass in the formation zone comes down due to avalanche and takes away the snow in middle zone. The melting rate has also increased due to rise in ambient temperature which restricts melt water availability for longer periods. The non availability of snow mass in the formation zone due to frequent avalanche activity, or less snow fall or fast melting of snow, has caused many springs vanished resulting in the acute shortage of drinking and irrigation water in Himachal Pradesh, Jammu-Kashmir and Uttrakhand in India. Also the increasing world population, deforestation and land utilisation day by day is making great concern for increasing water consumption especially in Hilly and mountainous terrain.

Considering the above problems Snow and Avalanche Study Establishment has started a pilot project on snow harvesting entitled "Snow harvesting for Drinking and Irrigation water in Snow bound regions". To carry out this study, a site near Patsio research station (3800 msl) in greater Himalayan Range in North-West Himalaya located at 32° 45′ N, 77° 16′ E has been selected as study site (Figure 1).

Various techniques are being tried to retain snow mass, collect avalanche debris, trap snow melt water and comparison of standing snow at harvesting site and general slopes is being done. The creeping and gliding snow pack exert pressure on terraces which in turn give backward pressure and change the snow cover properties. To asses the stability of snow pack, the knowledge of snow pit profile and the snow properties are very important. It is the basis for predicting the rate and intensity of the transformation processes and thus of future alterations, which affect, for example, the propensity of fracture initiation and propagation (Sigrist *et al.*, 2006). Avalanche debris was trapped in the middle zone which remained for longer duration. The snow was successfully retained in a slope of 34°–38°. A case study of various methods

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for snow harvesting has been presented in detail in this paper.

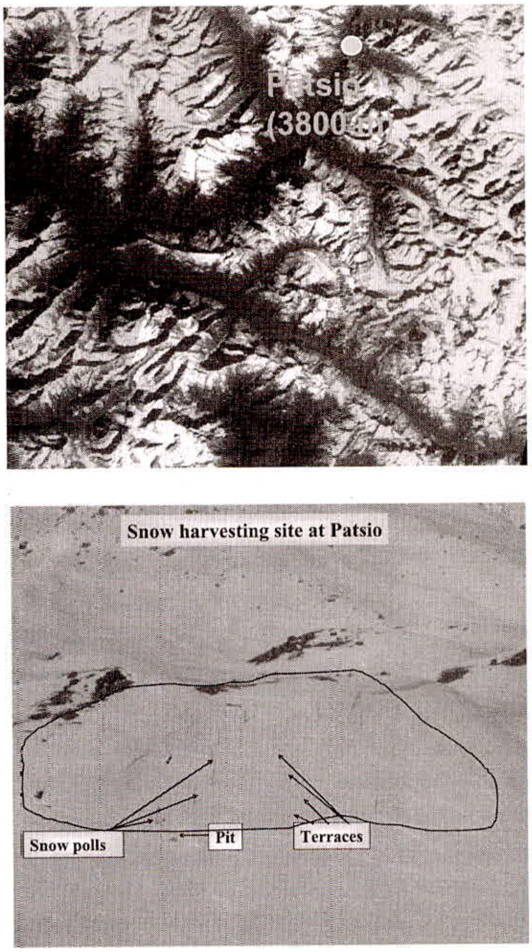

Fig. 1: Location of study site

STUDY AREA AND CLIMATE

A representative site of avalanche formation zone, where frequent avalanche activity was observed in winter, was selected for the study purpose. This site is located at 4220 meter from msl close to SASE research station at Patsio (3800 m) latitude is 32° 45′ and longitude 77° 16′ in Greater Himalaya range.

The climate of greater Himalaya is best described as polar with dry summer and very cold winter. Precipitation is moderate with low density snow and temperature decreases very fast. The annual accumulation generally amounts to depth of 1 m to 2.5 m with a highly variable stratigraphy and low mechanical strength. The snow being dry and low density most of the radiation is reflected back to atmosphere. That is why the recrystalisation process is also slow at this location than the Pirpanjal range. The wind speed generally remains high and humidity remains low.

METHODOLOGY

Snow can be harvested by making terraces in the formation zone to avoid fracture of snow slab and, trenches and catch dams in the middle zone. Once snow mass is retained in the formation zone then the snow mass in down below slope also remains there, which subsequently fetch more snow melt water for drinking and irrigation. Also avalanche debris which is high density snow, when trapped in the catch dam in middle zone fetch more water for longer duration due to reduced surface area, which further reduces the snow melt rate. Then by making Ponds in the middle or run out zone depending upon the location of the village and their agricultural land, the snow melt water can be harvested.

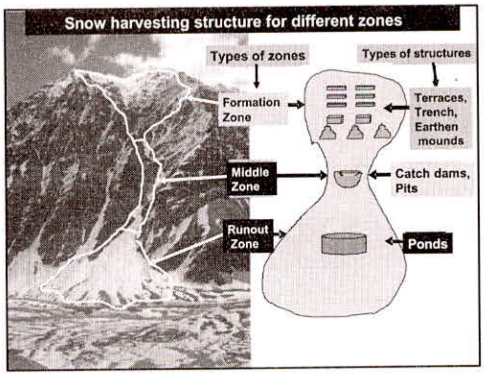

Fig. 2: Schematic diagram of different zones and harvesting structure

Figure 2 shows the schematic diagram of various zones with actual photograph. Also the various methods of snow and snow melt water harvesting in various zones. Before selection of harvesting structure for different zones it is necessary to carry out the initial study which includes the following parameters:

Type of Zones	*Surface Conditions*	*Structure Recommended*
Formation zone	Rocky or smooth	Trench, terraces
Middle zone	Smooth	Pits, Terraces
Run out zone	Smooth	Ponds
Type of slope	Open or Channel	Terraces, pits, catch dams
Angle of formation and middle zone		
(i) If > 50 deg	Trench in upper middle zone	
(ii) 25 to 45 deg	Terraces, small earthen mounds	

CONSTRUCTION OF TERRACES

A site representative of formation zone was selected for the study. The terraces were constructed to retain

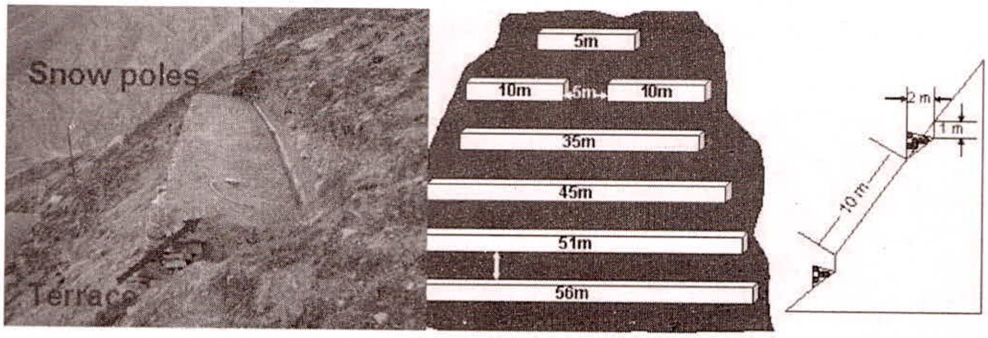

Fig. 3: Schematic diagram of construction of Traces at study site

snow in the formation and upper middle zone in the open slope. These terraces had stoped the occurrence of full depth avalanche. The Figure 3 explains the schematic diagram of terraces constructed at the study site. The average slope of the study site is 35°. Soil was excavated one meter deep and one meter in width from the slope. The width of the terrace was increased further to two meter by constructing wall on the slope. The wall was constructed using the local material available there i.e. stone and soil. The surface of the terrace was made of 6 inches thick concrete structure. The length of the terrace varies from 5 meter to 57 meter. The gap between the two rows of terrace is 10 meter. The terraces give back pressure to the creeping and gliding snow pack due to which densification takes place and snow pack becomes harder than the non-terraced slope. This densified snow pack gives more water than non densified snow pack. Once snow in the formation zone is retained then snow in the middle and run out zones is also retained there. Once snow remains in the slope, melting starts slowly and water starts percolating into the soil which travels very slowly than the surface run off water. Thus charges up the springs down below for longer duration.

Trench

The size of trench was kept 2 meter deep and 2 meter wide and length depending upon the site. It is constructed just below the steep formation zone. The snow, which slides from steep angle, falls in the trench and gets compacted due to pressure of overburden weight of snow and densification takes place. The ratio of surface area to mass of snow is also reduced, resulting in reduced melting rate. The snow melt water of trench as well as of formation zones during the late winter charges up the springs down below.

Pits

The pits size was 3 meter in diameter and 3 metre deep. These pits were constructed in the lower middle zone. Pits are useful in trapping high density avalanche debris and snow melt water during late winter. The contact time for snow melt water is more in pits and percolation rate is better. In pits also the snow remains for longer duration. The evaporation rate is less for snow melt water which gets accumulated into the pits. This is because the ratio of surface area to volume is lesser as compared to general slope.

Catch Dams

Catch dams are constructed between upper and middle zone and in run out zones. These catch dams trap the avalanche debris which are high density snow debris. This avalanche debris remains for longer duration in the catch dams due to reduced surface area and more debris depth. Due to less surface area the energy received for melting is less. Therefore, the snow melts very slowly and water is available for longer duration.

Ponds

Ponds are constructed in the lower middle and upper run out zone. These are constructed to collect snow melt water. The snow melt water collected in the ponds percolates into the soil and water starts flowing with its own gravity. The water flowing through the subsurface and the soil travels very slowly than the water flowing at the ground surface. The loss of water mass by evaporation is also reduced in subsurface flow. Therefore, the snow melt water during late winter should be collected in ponds. By collecting snow melt water into ponds the contact time and contact area is increased. With this process, the artificial ground water recharging is done so that the springs in down streams can be recharged.

Data

After construction of snow harvesting structures, the following parameters were observed during winter of 2003–2004 and 2006–2007:

1. Initiation of snow slab fracture from the formation zone of snow harvesting site
2. Standing snow in general slope, harvesting site, pit and catch dam
3. Ablation of standing snow in pits, general slope, harvesting site and catch dam
4. Density profile of snow pack of general slope, harvesting site and catch dam
5. Snow pit profile of general slope and harvesting site
6. Frequency of snow thickness in general slope and harvesting site.

RESULTS AND DISCUSSIONS

Retention of Snow Mass in the Formation Zone

The study site was selected, based on past observations, from where avalanche used to release every winter. The objective of selecting this site was for investigation, design and implementation of low cost structures to retain snow mass in the formation zone and compare the effectiveness of structures in retaining snow mass. From Figure 4 it is observed that avalanche has triggered from the general slope whereas in the harvesting site, the snow mass is retained. Once the snow mass in the formation zone is retained the snow mass in the middle and run out zone is also retained. This phenomenon has resulted in slow melting and more ground water recharge.

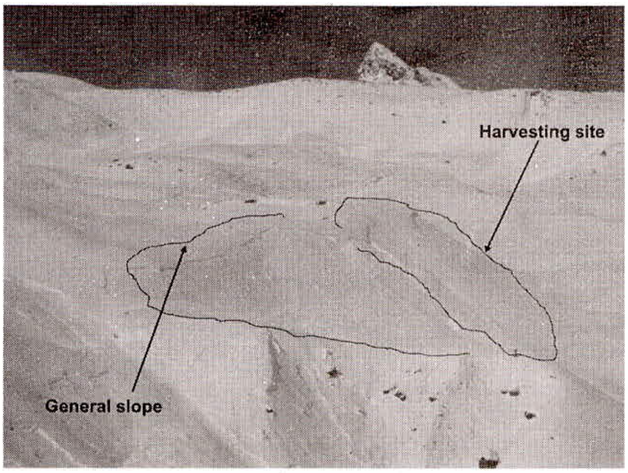

Fig. 4: Retention of snow mass in harvesting site

Comparison of Standing Snow at General Slope and Harvesting Site

The site selected for snow harvesting is in the same formation zone, aspect and slope with general slope. After construction of the harvesting structures the standing snow of general slope was compared with harvesting site. It was observed that the snow was retained in the harvesting site for longer duration. Figure 5 shows the standing snow was observed in the harvesting site till 9th June whereas in general slope it was observed till 19th May only.

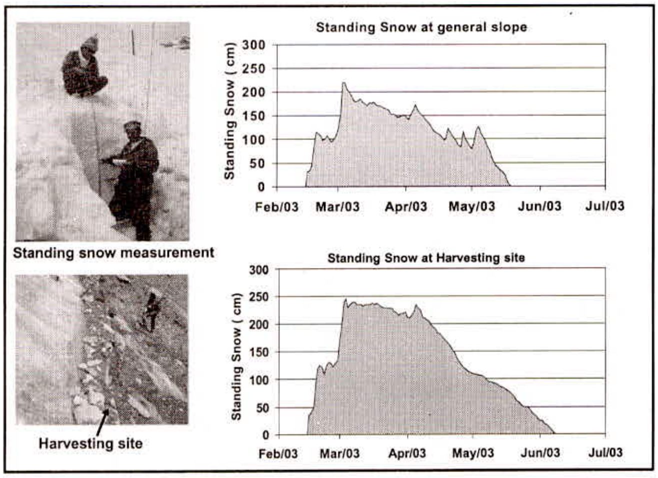

Fig. 5: Comparison of standing snow of general slope and harvesting site

Frequency of Snow Pack Thickness

Due to variation in ground surface condition, erosion and deposition of snow by wind activity, we need to take measurements at a number of points to get true information of standing snow. Therefore, to have a sufficient confidence level in measurement of standing snow, observations were made in general slope as well as harvesting site. Figure 6 shows the frequency of snow thickness in general slope and harvesting site. The y-axis shows the frequency and x-axis shows the population of the snow thickness. In total 75 measurements for standing snow was carried out both for general slope and snow harvesting site. The observation shows that snow thickness in the range of 81–90 cm was observed 20 times for general slope and 20 times in the range of 101–110 cm for snow harvesting site. The mean snow thickness was observed 76.16 cm for general slope and 92.41 cm for the harvesting site. Snow depth measured perpendicular to the slope is called thickness of snow (T_s),

$$T_s = H_s * \cos\theta \qquad \dots (1)$$

Where H_s are snow depth measured vertically and θ is slope angle. The average slope of harvesting site is 33° and the mean snow depth measured for general slope was 76.16 cm and harvesting site was 92.41cm. Substituting these values in equation (i) the mean Ts for general slope was found 63 cm and 77 cm for harvesting site.

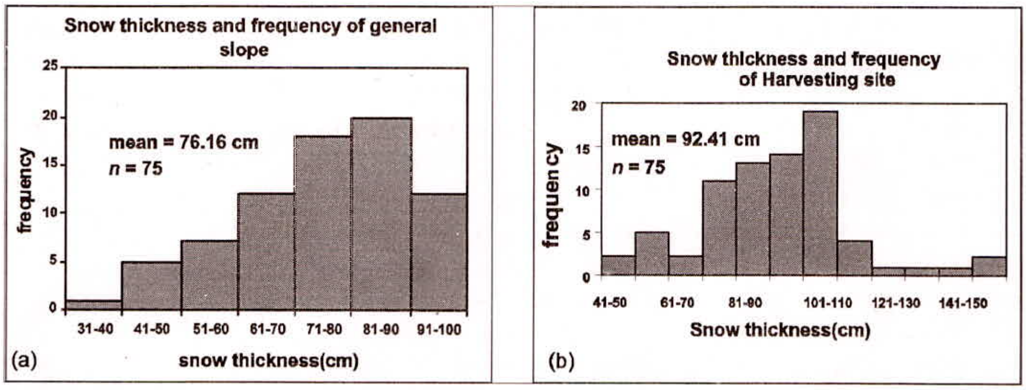

Fig. 6(a)&(b): Frequency of snow thickness in the general slope and harvesting site

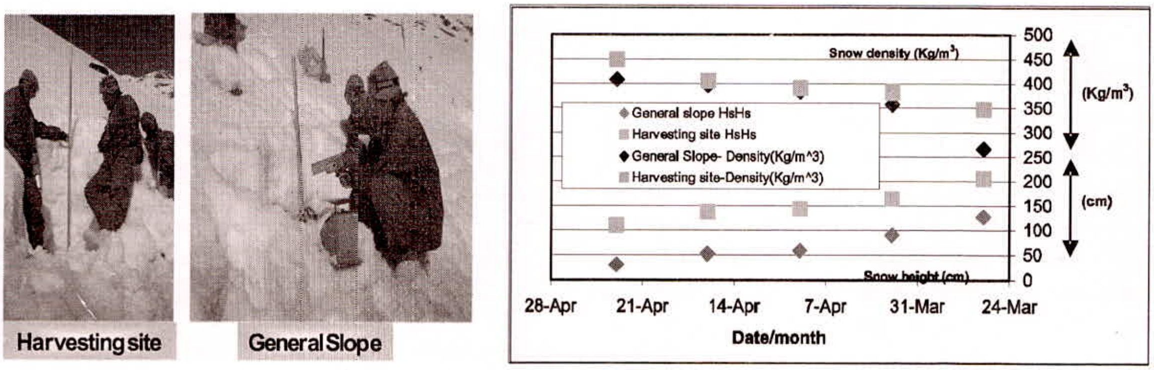

Fig. 7: Comparison of standing snow and average density of general slope and harvesting site

Figure 7 depicts the comparison of average density and standing snow of general slope and harvesting site measured during 2003–2004. The mean density was observed 362 Kg/m^3 for general slope and 395 Kg/m^3 for harvesting site. The mean standing snow was observed 72 cm for as general slope and 150 cm for harvesting site.

Snow Pit Properties Study

The snow pack in the slope gets altered to a large extent depending on the boundary conditions at snow surface such as radiation, temperature, wind speed and ground surface conditions. To investigate the difference between the snow cover properties of snow harvestingsite with terraces and general slope without terraces, the snow pit profile was conducted at altitude of 4220 mtr. The studies were conducted by digging the pits of approximately 1.5 × 1.5 meter and depth ranging from .7 to 1.20 meter. Several layers were identified on the pit walls. The following parameters were collected through stratigraphy study:

(i) Density, (ii) Temperature at interval of 10 cm, depth, (iii) grain size, grain type, (iv) ram hardness and layer thickness.

Figure 8 depicts that the average density was observed 246 Kg/m^3 for general slope and 256 Kg/m^3 for harvesting site. There is not much variation in the temperature within the snow cover. The harvesting site has larger layer thickness with higher density than the general slope. The density value at bottom layer for harvesting site is more than the general slope. Comparatively the ram value close to ground is more for harvesting site then the general slope. The higher value of ram at top surface of both the site indicates that a layer of crust which is found due to prolong melt freeze processes.

Comparison of Standing Snow and Average Density of General Slope and Catch Dam Near Avalanche Site 114

Figure 9 depicts the measurement carried out for comparison of standing snow and average density profile of general slope and catch dam were at avalanche site 114 near Patsio field station. The measurements were carried out on weekly basis. The graph in Figure 10 shows the snow height and density of General slope and catch dam measured on weekly basis. The mean standing snow of general slope and catch dam

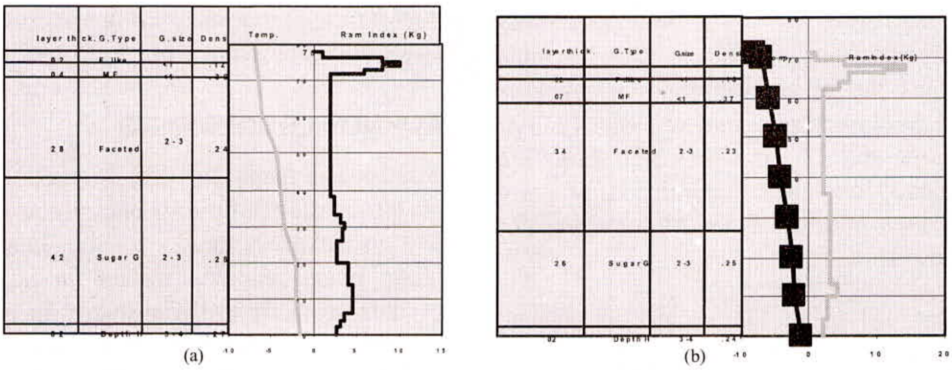

Fig. 8(a)&(b): Snow pit profile study of General slope and harvesting site

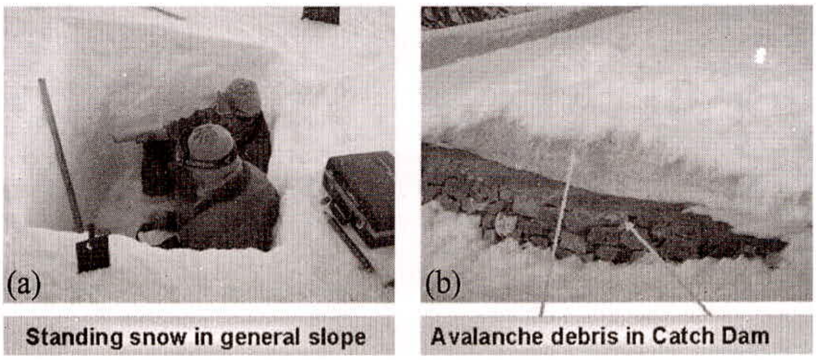

Fig. 9(a)&(b): Measurement of standing snow and density of General slope and catch dam

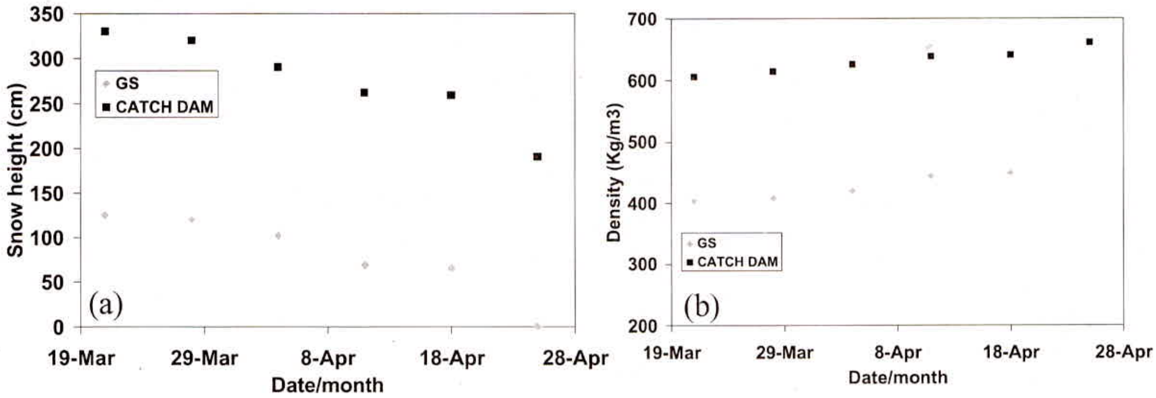

Fig. 10(a)&(b): Comparison of standing snow and density profile of general slope and catch dam

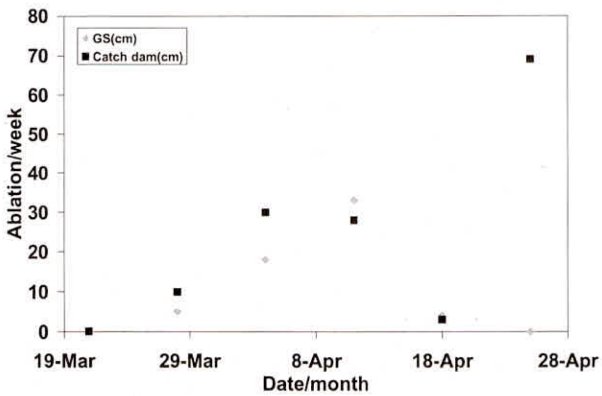

Fig. 11: Weekly ablation of snow cover of general slope and catch dam

during measurement period was observed 96.2 cm and 275 cm respectively.

Figure 11 shows the mean ablation per week of general slope and catchment area and was observed 10 cm for general slope and 23.3 cm for catch dam. The ablation rate depends on surface condition of snow pack, density of snow at surface and cloud cover and aspect of the slope.

CONCLUSIONS

The various methodologies to retain snow mass and avalanche debris have been presented in this paper. The limited trials carried out for snow harvesting have revealed that these structures can serve as an effective control measures in retaining snow mass in the formation zone, avalanche debris in the middle zone and snow melt water in the ponds. The effectiveness of the methods were studied and the result are presented and compared. Snow pit profile of general slope and harvesting site was also compared. The frequency of snow thickness gives a very good representation of standing snow in the slope. Also the ablation rate of standing snow at general slope and avalanche debris was compared. The density comparison of snow at general slope and catch dam were measured and compared.

ACKNOWLEDGEMENTS

The authors thank Dr. R.N. Sarvade Director, SASE for giving us the continuous encouragement and guidance. We also express thanks to Sh. Gulshan Sood and Sh. Uttam chand technical officer for assisting in collection of data in such a difficult terrain and harsh weather conditions and also to all the technical assistants of cold lab group for their sincere effort in data observation.

REFERENCES

Jairell, Robert L. and Schmidt, R.A. (1992). "Harvesting Snow When water levels are low." *Proceedings, 60th Western Snow Conference,* April 14–16, 1992, Jackson, Wyoming.

Schiled, Andreas (2007). "The mountain perspective as an Emerging element in the international development agenda." Sustainable mountain development, Vol. 53, winter 2007.

Beninson, M. (2003). "Climatic change in Mountain Regions: A Review of Possible Impacts." *In Climatic Changes*, 59: 5–31.