

Some characteristics of snow-cover in upper Beas catchment

D.S. UPADHYAY, RAJNI KANT, J.N. CHOWDHURY and K.N. KATYAL

Meteorological Office, New Delhi

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सार — ऊपरी व्यास जल संस्तर में 1981 के हिम सर्वेक्षण में संग्रहीत हिमाच्छादन आंकड़ों को वर्तमान हिमाच्छादन की तापीय गुणवत्ता का अनुमान लगाने तथा सोलांग और कोठी (2630 मी. लगभग) से ऊपर, ऊपरी व्यास उपजलग्रहण क्षेत्र की हिम गलन मात्रा निकालने के लिए उपयोग में लाया गया है। मनाली से ऊपर, ऊपरी व्यास बेसिन में हिमाच्छादन का संक्षिप्त सक्षरण दिया गया है।

ABSTRACT. The snow cover data collected during snow-survey 1981 in upper Beas watershed have been utilized to assess the thermal quality of existing snow-cover and to compute snow-melt quantities for the sub-catchments of Solang and upper Beas above Kothi (2680 m approx.). A brief survey of snow-cover in upper Beas basin above Manali has also been described.

1. Introduction

A seasonal snow-cover is formed when the snow fall is sufficient to persist on the ground till next spell. In Beas and Sutlej catchments seasonal snow-cover is normally formed by early December and last till June ends in glaciated area. The glacier-melt contribution to river runoff starts only after seasonal snow-cover has melted (July-October). Thus for water management a reliable prediction of snow-melt hydrograph is very important.

The first task involved in this process is to accurately assess the quantity of water that has accumulated in upper catchment in the form of seasonal snow-cover. There are three independent parameters involved

- (i) Area under snow,
- (ii) Mean depth of standing snow and
- (iii) Mean density of snow-pack.

Even though some remote sensing techniques have become technically possible, it is necessary to collect ground truths in respect of snow and met. parameters such as snow line, snow lay, density, depths, temperature of the cover, air temperature, radiation, wind, water equivalent etc. which are essential inputs for a prediction model.

Glaciology unit of India Met. Dep. conducted a snow survey on a small scale during March-April 1981 over limited area of 425 km² in the sub-catchment of upper Beas and Parbati river.

2. Topography of river Beas

River Beas originates from the southern slopes of Rohtang Pass (3977 m) in Pirpanjal range. It flows southward for about 120 km upto Larji, here it crosses through Dhola-Dhar range and turns its course westward through Kangra valley and finally joins river Sutlej near Harika. The total course of the river is about 440 km. Recently river Beas has been artificially diverted near Pandoh through two tunnels 13 km and 9 km long and is linked with Sutlej at Salapar to feed the Gobind Sagar reservoir of Bhakra Dam.

About 5% of the area lies under permanent glacier. The elevation of glacier field is generally about 5500 m a.s.l.

The catchment of river Beas lies between latitude 31 deg. 29' N to 32 deg. 27' N and longitude 75 deg. 54' E to 77 deg. 54' E and has an area of about 12509 km² upto Pong dam site. The analysis of elevation field shows that the catchment is characterised by a mean altitude to 1725 m a.s.l. with a high variation in it and plays a very significant role in the climatic features of the catchment.

Northern boundary consists of high mountains (above 4000 m) which separate Beas catchment those of Ravi and Chenab. In the south and east, there exists a vast area of Sutlej basin. Considering the variations in elevation fields, the watershed can be divided into two distinct parts:

- (i) where the precipitation occurs as snow during winter and
- (ii) where the precipitation occurs in the form of rainfall.

TABLE 1
Quality technique

Date (April '81)	Radiation received at the horizon- tal surface (ly/day) (<i>R</i>)	Mean density (gm/cc)	Mean albedo (<i>r</i>)	Absorbed <i>R</i> (1- <i>r</i>) (ly/day)	Thermal quality	Snow melt (cm)	Observed discharge at Palchan (cusec)	Precipitation (mm)
(a) Sub-catchment — Kothi								
4	776	0.50	0.67	256	0.80	4.00	84	43.0
5	904	0.57	0.65	316	0.70	5.64	71	
6	858	0.43	0.60	343	0.90	4.76	67	
7	669	0.50	0.55	301	0.80	4.70	77	
8	679	0.58	0.50	340	0.70	6.06	86	
9	737	0.52	0.45	405	0.78	6.50	100	
10	847	0.56	0.40	508	0.70	9.08	100	
11	858	0.56	0.36	549	0.70	9.80	119	
12	866	0.52	0.40	520	0.78	8.32	168	
13	811	0.51	0.42	470	0.80	7.34	188	
14	743	0.46	0.44	416	0.84	6.18	227	
15	136	0.44	0.46	73	0.85	1.08	226	Tr
16	—	—	—	—	—	—	321	11.8
17	979	0.47	0.66	333	0.82	5.08	170	30.2
18	919	0.47	0.60	368	0.82	5.60	145	
19	954	0.52	0.58	401	0.80	6.26	169	
20	889	0.56	0.50	445	0.70	7.94	187	
21	226	0.38	0.47	120	0.75	2.00	296	4.4
22	213	0.40	0.43	121	0.75	2.02	217	20.8
23	983	0.47	0.38	609	0.80	9.52	164	0.5
24	966	0.54	0.35	628	0.75	10.46	—	—
25	931	0.60	0.35	605	0.65	11.64	—	—
(b) Sub-catchment — Solang								
4	776	0.50	0.60	310	0.80	4.9	236	43.0
5	904	0.57	0.53	425	0.70	7.6	208	
6	858	0.59	0.50	429	0.66	8.1	187	
7	669	0.60	0.50	334	0.65	6.4	226	
8	679	0.58	0.48	353	0.70	6.3	258	
9	737	0.58	0.45	405	0.70	7.2	289	
10	847	0.55	0.40	508	0.71	8.9	296	
11	858	0.54	0.30	549	0.75	9.1	447	
12	866	0.53	0.35	563	0.77	9.1	412	
13	811	0.51	0.35	527	0.80	8.2	475	
14	743	0.52	0.34	490	0.80	7.7	526	

These parts have an area of 5412 km² and 7079 km² respectively. The seasonal snow cover, however, is restricted to about 2000 to 4800 m a.s.l. during January to June. Snow bounded area of Parbati sub-catchment lies mainly beyond Manikaran above 1700-1800 m of altitude. This valley is narrow and densely forested by pine trees. When the snow party surveyed this area on 7 & 8 April, snow line has shifted to 2700-2800 m a.s.l. beyond Pulga.

Bhuntar is the confluence point of river *Beas* and *Parbati*. The total area of sub-catchment of these two

ivers upto Bhuntar is about 1060 km² (*Beas* — 435 km² & *Parbati* — 625 km²).

3. Physical processes of snowmelt

Snow-cover gains heat from various sources such as insolation, long wave radiation from atmosphere and clouds, advection of warm air, conduction from the ground under neath, latent heat released by formation of surface hoar and rainfall occurring over snow surface. On the other hand snow pack is loosing heat

to its environment by radiation, by sublimation evaporation and conductivity. Also the transfer of sensible heat takes place through the pores of the pack from one part to the other due to various metamorphic process. The net heat gained is applied to the melting of snow. The combine effects are too complex to allow accurate evaluation of snowmelt quantities. Broadly, the following three melting processes may be taken into consideration:

- (a) Snowmelt due to radiation,
- (b) Snowmelt due to latent heat of condensation & sublimation and
- (c) Snowmelt due to convective transfer of heat.

The other processes such as occurrence of rainfall over snow-cover & avalanches also become significant in particular cases.

A snow-cover is a porous material, porosity depending on mean density of the snow pack. Porosity (p) is defined as :

$$p = \frac{\rho_i - \rho_s}{\rho_i} \quad (1)$$

where ρ_i is the density of hard ice normally taken as 0.917 gm/cc and ρ_s is the density of snow.

Thus a snow-cover with mean density of 0.5 gm/cc will have about 45% of porous space. The melt water percolates down through the pores. No melt water appears as surface run off unless the voids are entirely filled with. In this state the snow-cover is said to be ripe. In a ripe snow-cover if the rate of melting is more than rate of infiltration of melt water under ground, the surface run off starts. This condition usually commences not before the first week of April.

4. Thermal quality of snow-cover

It is defined as the ratio of heat required to melt a snow sample to produce certain volume of water to the heat required to melt the ice at 0 deg. C to produce same volume of water. If

- h = depth of standing snow (cm)
- ρ = mean density of pack (gm/cc)
- w = relative mass of free water content present in the pack (Mass of free water/total mass of the snow).
- L_f = latent heat of fusion (79.7 cal/cm)
- s = specific heat of snow (0.5)
- t = mean temperature of snow pack (0°C)

Then heat required to melt the snow column standing on a unit area is given by

$$q_1 = h\rho (1 - w) (st + L_f) \quad (2)$$

The quantity of heat required to produce a volume of $h\rho$ (cm³) of water from melting the ice is given by

$$q_2 = h\rho L_f \quad (3)$$

Thermal quality Q_t is

$$Q_t = \frac{q_1}{q_2} = \frac{(1-w)(st + L_f)}{L_f} = (1+0.00627t)(1-w) \quad (4)$$

e.g., a snow-cover with $t=0^\circ\text{C}$ and $w=20\%$ has $Q_t=0.8$.

5. Degree day factor

A degree day is taken as the arithmetic mean of all positive temperatures recorded during a day(24 hours), the negative temperatures are neglected. Thus if hourly temperatures are T_i ($i=1,2, \dots, 24$)

then

$$\text{degree day } (T_\theta) = \sum_{i=1}^{24} \frac{T_i}{24} \text{ if } T_i \geq 0 \quad (5)$$

For practical purposes, the mean of daily maximum and minimum temperatures may be regarded as degree days.

The quantity of snow melt, S_M is directly proportional to T_θ

$$\therefore S_M = a.T_\theta \quad (6)$$

where 'a' is called degree day factor

'a' depends on density of snow (ρ). As suggested by Rodda (Facets of Hydrology—1970) if ρ is in gm/cc and 'a' in cm/°C/day, then

$$a = (1.1)\rho \quad (7)$$

6. Computation of snow melt

(i) Thermal quality technique

If 'R' is the observed incident global radiation (Langley/day) on surface of snow, then $R(1-r)$ will be absorbed, where 'r' is albedo of snow surface.

The range of penetration follows an exponential law and hence, the quantity of radiation reaching at depth 'Z' will be

$$R(1-r)e^{-\epsilon Z} \quad (8)$$

whereas, the extinction coefficient ϵ may have any value between 0.017 & 1.7 cm⁻¹ (de Quervain, Banff Symposium 1972, p. 215)

Thus if $\epsilon=0.1$, it can be seen that the incident radiation does not penetrate deeper than 10 cm.

Snowmelt quantity in cm due to radiation is given by

$$S_M = \frac{R(1-r)}{80 Q_t} \quad (9)$$

TABLE 2
Degree days technique

Date (Apr '81)	Degree days (T_{θ}) (°C)	Density (gm/cc)	Degree day factor $a =$ (1.1) ρ	Snow melt $S_M =$ $a \cdot T_{\theta}$ (cm)	Obs. dis- charge (cusec)	Pptn. (mm)
(a) Sub-catchment — Kothi						
4	1.8	0.50	0.55	1.0	84	43.0
5	7.2	0.57	0.63	4.5	71	
6	8.6	0.43	0.47	4.0	67	
7	9.4	0.50	0.55	5.2	77	
8	11.7	0.58	0.64	7.5	86	
9	12.7	0.52	0.57	7.2	100	
10	14.2	0.56	0.62	8.8	100	
11	14.0	0.56	0.62	8.7	119	
12	15.5	0.62	0.57	8.8	168	
13	15.0	0.51	0.56	8.4	188	
14	15.2	0.46	0.51	7.7	227	
15	13.8	0.44	0.48	6.6	266	Tr
16	10.2	0.46	0.51	5.1	321	11.8
17	9.2	0.47	0.52	4.8	170	30.2
18	13.6	0.47	0.52	7.2	145	
19	15.0	0.52	0.57	8.5	169	
20	15.6	0.56	0.62	9.7	187	
21	13.4	0.38	0.42	5.6	296	4.4
22	11.1	0.40	0.44	4.8	217	20.8
23	12.0	0.47	0.52	6.2	164	0.6
24	12.8	0.54	0.60	7.7	—	
25	13.4	0.60	0.66	8.8	—	
(b) Sub-catchment — Solang						
4	1.8	0.50	0.55	1.0	236	43.0
5	7.2	0.57	0.63	4.5	208	
6	8.6	0.59	0.65	5.6	187	
7	9.4	0.60	0.66	6.2	226	
8	11.7	0.58	0.64	7.5	258	
9	12.7	0.58	0.64	8.1	289	
10	14.2	0.55	0.61	8.7	296	
11	14.0	0.54	0.59	8.3	447	
12	15.5	0.53	0.58	9.0	412	
13	15.0	0.51	0.56	8.4	475	
14	15.2	0.52	0.57	8.7	526	

where Q_t is thermal quality of snow.

Computed values of S_M are given in Table 1.

The exchange of energy at snow-air interface under radiation process may be neglected as compared to the incident short wave solar radiation. As an example, if the temperature of snow surface and that of adjacent air are T_1 and T_2 respectively, the energy flux (considering emissivity=1) may be given as

$$E = \sigma (T_1^4 - T_2^4) \quad (10)$$

Where, $\sigma = 82 \times 10^{-12}$ cal cm⁻² min⁻¹ deg. K⁻⁴

Usually the difference $T_1 - T_2$ is very small (ΔT)

$$\therefore E = 4 \sigma \bar{T}^3 \Delta T \quad (11)$$

$$\text{where, } \bar{T} = \frac{T_1 + T_2}{2}$$

e.g., if $\bar{T} = 270^\circ\text{K}$ and $\Delta T = 4^\circ$ then

$$E \approx 37$$

This magnitude is about 1/20th of the incident short wave radiation. Hence may be safely neglected.

(ii) Degree day factor technique

With the observed mean density of snow pack degree days factors have been worked out using relation (7). The degree day, T_{θ} has been worked out as the mean of daily maximum and minimum temperature.

$$S_M = a \cdot T_{\theta} \quad (\text{from Eqn. 6})$$

The computed results of snow melt have been presented in Table 2.

7. Discussions

One of the major problems in developing snowmelt prediction model is the consideration of lag factor which affects the quantity of snow melt run off and the respective meteorological conditions. Glacier melt run off on n^{th} day may be correlated to the meteorological factors such as temperature recorded on n^{th} , $(n-1)^{\text{th}}$, $(n-2)^{\text{th}}$ days and so on, by introducing recession coefficient, K .

The time lag before the run off commences from a snow pack has three components :

(i) The time required to raise the temperature of snow pack to 0°C (t_A),

(ii) The time required to fill the storage capacity of the pack, i.e., the time lags for ripening the snow-cover (t_B),

(iii) The time of transition of melt water through snow-cover before it appears as surface run-off (t_C).

After the time $T = t_A + t_B + t_C$

The surface run-off commences. Its routing from the point of commencement of observations should also be considered to determine the exact time lag.

However, the cross correlation analysis between snow melt quantities and observed run-off shows that these variables have higher degree of agreement with a lag of two days.

According to Mathews (*Handbook of applied Hydrology by Ven-te chow*, pp. 16-21), the daily mean stream flow is given by

$$Q_n = e + f(T_n + KT_{n-1} + K^2T_{n-2} + \dots) \quad (12)$$

where 'e' and 'f' are the regression coefficients. K is recession coefficient < 1.

The computation of theoretical discharge in Beas and Solang at Palchan is being carried out and will be presented later on separately. Here, while studying the correlation coefficient (r) between computed snowmelt quantity and observed discharge show the following results :

Sub-catchment	r		
	Zero lag	One day lag	Two days lag (Technique)
(a) Kothi	0.30	0.50	0.62 (Thermal quality)
	0.66	0.77	0.79 (Degree days factor)
(b) Solang	0.46	0.82	0.61 (Thermal quality)
	0.76	0.87	0.90 (Degree days factor)

While computing the correlation coefficient, those days have been omitted when the run off was markedly high due to rainfall spell on preceding days. In both the catchments, it is seen that observed discharge on n^{th} day has a better correlation with the snowmelt quantity on $(n-2)^{th}$ day.

7.1. The significant of difference between snow-melt quantities

The snowmelt quantities as computed by thermal quality approach and degree days factor technique were subjected to paired t-test in order to find the significant differences between the computed values. The results are as under :

$$t = 1.89$$

$$d.f. = 12$$

$$t_{0.025} = 2.18$$

$$t_{0.01} = 2.68$$

The difference is insignificant at 2.5% and 1% levels for the sub-catchment — Kothi.

$$t = 0.79$$

$$d.f. = 9$$

$$t_{0.05} = 1.83$$

$$t_{0.01} = 2.82$$

The difference is insignificant at 5% and 1% levels for the sub-catchment — Solang.

8. Conclusions

(1) Snowmelt caused by incoming solar radiation is predominant over other physical processes such as long wave energy transfer at snow air interface the convective heat exchange and latent heat released by condensation.

(2) The degree day approach for snow melt computation does not exhibit significant difference from the result obtained by thermal quality approach. Since it is easier to compute degree day factor (based on ambient temperature) this approach may be preferable for operational use.

(3) In both the catchments, viz., Solang and Kothi, it is seen that the discharge of the n^{th} day (Q_n) has highest correlation with Q_{n-2} . This information may be useful in deriving regressive models for run-off prediction.

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