MELTWATER MODELLING OF DOKRIANI BAMAK GLACIER, GARHWAL HIMALAYAS, UTTARKASHI DISTRICT, UTTAR PRADESH

Dissertation Submitted to the Jawaharlal Nehru University
in partial fulfilment of the requirements for the award of the degree of

MASTER OF PHILOSOPHY

BHARMINDER SINGH GILL

SCHOOL OF ENVIRONMENTAL SCIENCES
JAWAHARLAL NEHRU UNIVERSITY
NEW DELHI - 110 067, INDIA

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CERTIFICATE

The research work, “Meltwater Modelling of Dokriani Bamak Glacier, Garhwal Himalayas, Uttarkashi District, Uttar Pradesh” has been done in the School of Environmental Sciences, Jawaharlal Nehru University, New Delhi. This work is original and has not been submitted in part or full for any other degree or diploma for any University.

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Bharminder

Bharminder Singh Gill

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CHAPTER 1

INTRODUCTION

The Himalayan mountain ranges which separate India, along its north central and north eastern frontier, from China (Tibet) and extend between latitudes 26°20' and 35°40' North and between longitudes 74°50' and 95° 40' East (Ives and Messerli, 1989) are home to some of the largest mountain glaciers outside the polar and sub-polar regions. The vast glacier coverage included in two of the longest components of the high Asia glacier complex, the Himalayas and Trans-Himalayas comprise by area 50% of all glaciers outside of the polar regions (Mayewski and Jeshke, 1979). There are nearly, 15,000 glaciers in the Himalayas lying between the two syntaxial bends of the Hindukush-Karakoram ranges and the Eastern Himalaya - Patkai Bum ranges. The length of the glacier varies from small (3-5 km) to large glaciers like Siachen (75 km). Glaciers in the Indian Himalayas cover an area of 3.8×10^4 km^2 (Agarwal and Narain, 1987), 17% of the Himalayas is snow and ice clad, of which the Karakoram ranges alone account for 16,000 km^2. In contrast only 2.2% of mountain area in the Alps is covered by snow and ice. the Himalayan glaciers occur at much greater altitude than mountain glaciers elsewhere and the snowline varies considerably in the different sections of the Himalayas depending upon the latitude.

The Himalayan glaciers are broadly classified as belonging to the three major river systems, the Indus, Ganga and Brahmaputra. The Indus basin accounts for the largest number of glaciers (3358) followed by Ganga (1020), and the Brahmaputra (662). The major river systems of North India are perennial in nature, and majority of water production comes from snow and ice melt in the high mountains. Power generation, irrigation and water supply in North India also depends on the runoff from catchments of these rivers. The flow during summers in these river systems is maintained by melting of the glaciers .

The importance of snowfall and seasonal snow cover on Himalayan mountain during the winter month was recognised as early as 1875 for a proper understanding of the meteorology of India. Reports received from district officers, forest officers, officer incharge of mountain passes, travellers etc. usually contains information on the number of days on which snow fell and a rough estimate of quantity of snow fallen during a month, the thickness of snow cover on certain passes and stations at the end of a month; the lowest altitude to which snowfall reached during the month and a qualitative comparison of the snowfall in the month with that of the normal year . The data supplied are in the nature of estimates and often incomplete because the people who supply the information as well as those who record them are not trained personnel. Even this fragmentary data for a long series of years has been found to be quite useful. In early 1947, the services of an American expert, Dr. J.E Church were obtained by the Government of India to survey the snow fields in the Himalayas to assess the contribution of seasonal snows to the Himalayan rivers. Dr. Church led three snow survey expeditions in the Teeasta basin in Sikkim and Kosi basin in eastern Nepal Himalayas in March-May, 1947. This snow survey expeditions and subsequent studies in Himalayan snows showed that in the central and eastern Himalayas snow contribution to the river flow is comparatively very small when compared to the Himalayan rivers of western Himalayas, such as Jhelum, Ravi , Beas and Sutlaj.

Systematic studies on snow precipitation and seasonal snow cover are of recent origin and have commenced from 1969 onwards with the establishment of Snow and Avalanche Study Establishment at Manali by the Defence Research Development Organisation.

In recent years detailed study of a number of glaciers in Himachal Pradesh , Kashmir and Uttar Pradesh has been taken up. A number of glaciers having an area more than 0.6 km^2 have also been mapped in these areas (Current Science vol. 61 Aug. 1991). With the advent of weather satellite (April 1960) and the earth resource satellite Landsat (1972) a new dimension was added in the study of snow and ice. By using the data from these satellites it is possible to estimate the snow bound area. In March 1988 the first Indian Resource Satellite (IRS-IA) was launched. Its data are being used for preparing a systematic inventory of the Himalayan glaciers.

The glaciers are also a perennial source of 19 rivers which flow though the subcontinent and any excessive meltdown could have serious repercussions for life on the plains. Glaciers are bodies of ice with cyrstallised snow accumulated on the surface. The prime requisite for the formation of a glacier is that a residual layer of snow which represents the excess of accumulation over wastage, remains in place each year and is incorporated into the ice mass.

The annual mass balance of a glacier is defined as the difference in water equivalent between accumulation and ablation at the surface, summed over the area of the glacier. Accumulation is a result of snow which is transformed into ice however, avalanches, rime formation and freezing of rain within the snowpack also contributes to the mass. Melting followed by runoff, evaporation and removal of snow by wind sublimation are primary ablation processes .

The glacier, is thus , a stable entity and its location is fixed. But the snow which covers the ice and ice free areas in winter months is transiting and variable in spatial extent.
The annual contribution to the streamflow from the snow and glacier melt water in all the 19 rivers is about 70%. Therefore the storage of precipitation in the form of glacier ice

over several decades can make a large amount of water potentially available and can change the distribution of these rivers.

Glaciers mass balance, although complicated by local climatic effects, is considered sensitive to climate (temperature, albedo, precipitation, cloudiness etc.) and thus an effective indicator of climatic change. It is because of these factors that glaciers act as buffers and regulate the runoff. For example, in contrast to basin fed by rainfall, the run off of some glaciers in any year can be much less and more than that years precipitation. This is caused by the heat balance at ice surface, given the amount of solar radiation and the reflectivity at the surface.

AREA OF STUDY

The Dokriani Bamak glacier is located in the upper Ganga catchment, Garhwal Himalaya (Lat 31° 49' to 31° 52' N, Long 78° 47' to 78° 51' E). The Din Gad (meltwater stream) joins the Bhagirathi proglacial river (Fig. 1.1) . The confluence of Bhagirathi proglacial river with Alaknanda proglacial river at Devaprayag from the Ganga river . The Dokriani glacier drainage basin area is 23 km^2 and 45 per cent of the total catchment area is covered by perennial ice, glacier descends from 5800 to 3800 m asl and is 5.5 km long (Fig 1.2). Glacier area with respect to altitude is shown in figure 1.3. Geology of the glacierised region of Bhagirathi valley consists mainly of crystallines with occurrences of carbonates and pyritous shales and phyllities (Sarin et al. 1992).

Some of the climatological parameters observed during the 1994 glacier expedition were as follows .

Temperature :-

At the base camp mean average temperature shows a rise as expects from May to July, when average temperature is 12°C. It fall thereafter and in November the average is -

0.5°C. Monthly average dry bulb temperature at the Base Camp is tabulated below which shows the seasonal much.

Table 1.1.

Month	May	June	July	August	September	October	November
°C	7.9	11.3	12.0	10.7	8.4	3.1	-0.5

The temperature reaches maximum at noon.

Wind -: Winds are mainly calm or variable. At occasions in varied from 2 to 10 kmph. In general, the wind is light to moderate during day times and calm at night. The wind is mostly from N.E. direction in the morning and S.W. in the afternoon. The winds are stronger in the month of November.

Precipitation:- The rainfall amount increases from May to August. Highest monthly rainfall is recorded in the month of August at the snowfall is observed for few days in May and November.

Clouds :- In May clear sky is noticed till about 8 'o' clock and later clouds are seen to occupy three okta of the sky . In the afternoon rain bearing clouds of stratus genre cover the sky. Average cloud cover during May maybe taken as six okta, June six okta, and July seven okta over the valley region of the glacier. Mist and very low stratus clouds are frequently observed during July and August.

Sunshine :- Average duration of bright sunshine in August is two and a half hours mainly due to monsoon clouds, whereas is September, October and November the values are five hours, six hours, and four and a half hours respectively at the Base Camp. Main sunshine hours are 0900-1200hrs in the glacier valley.

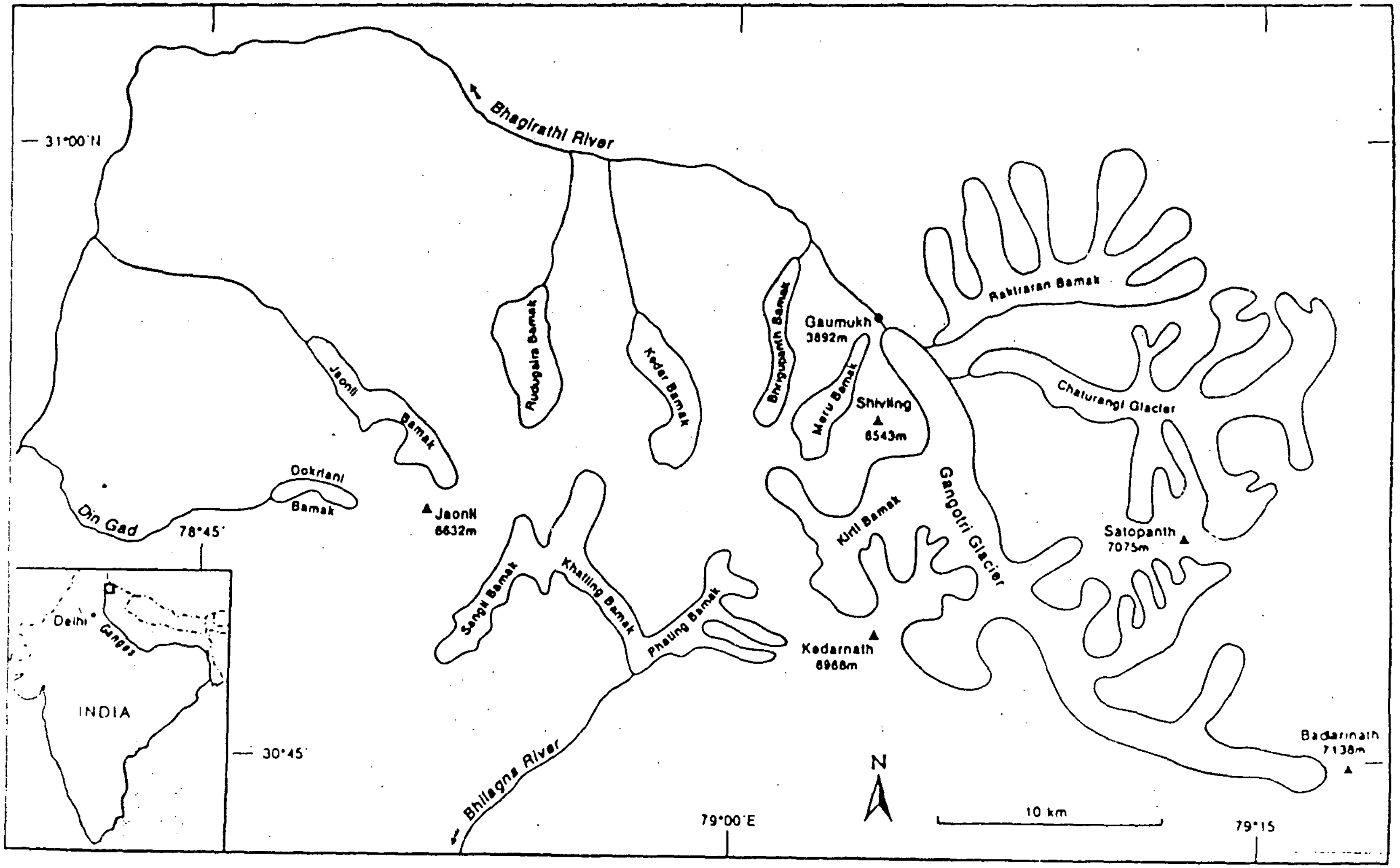
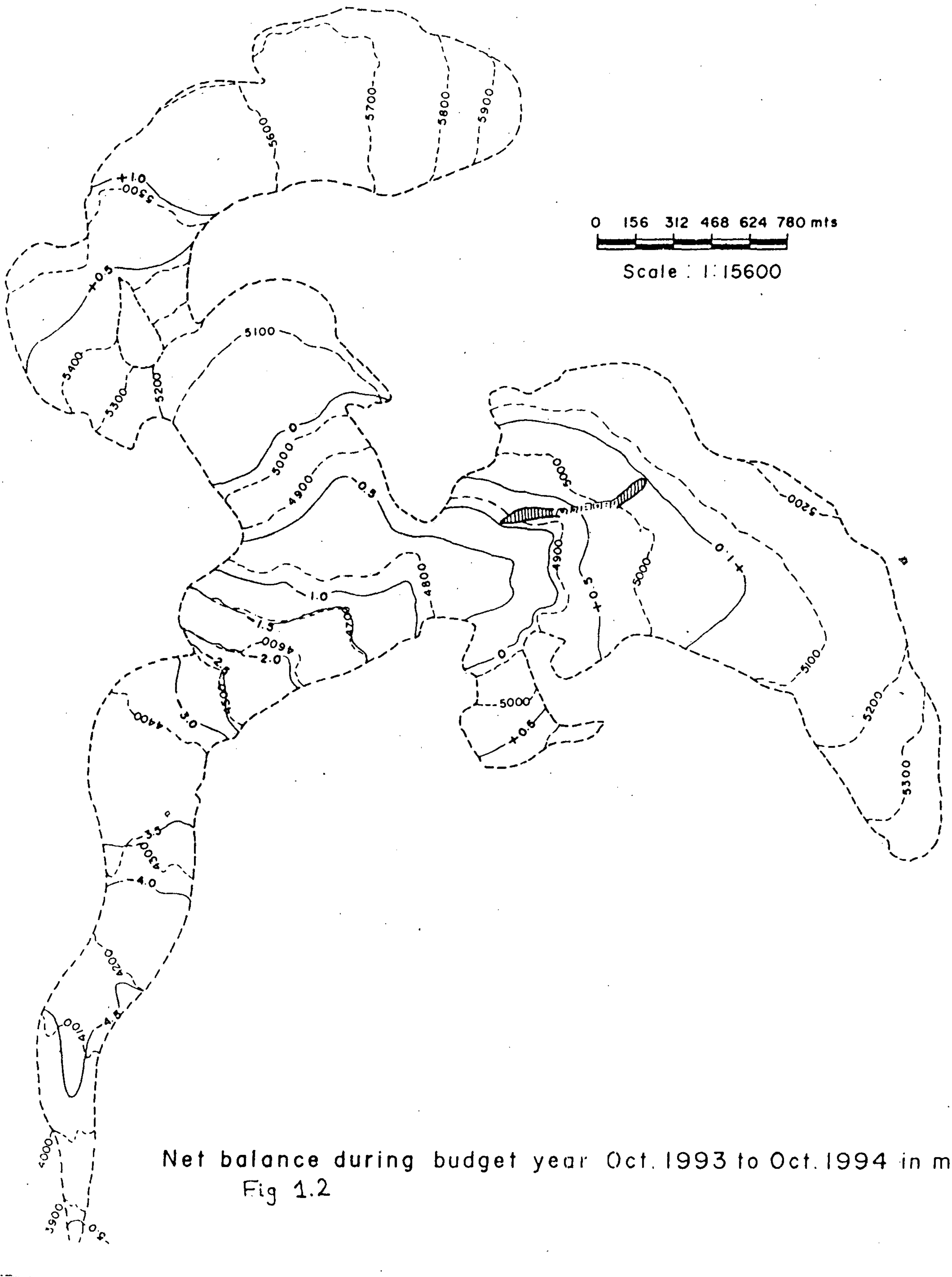
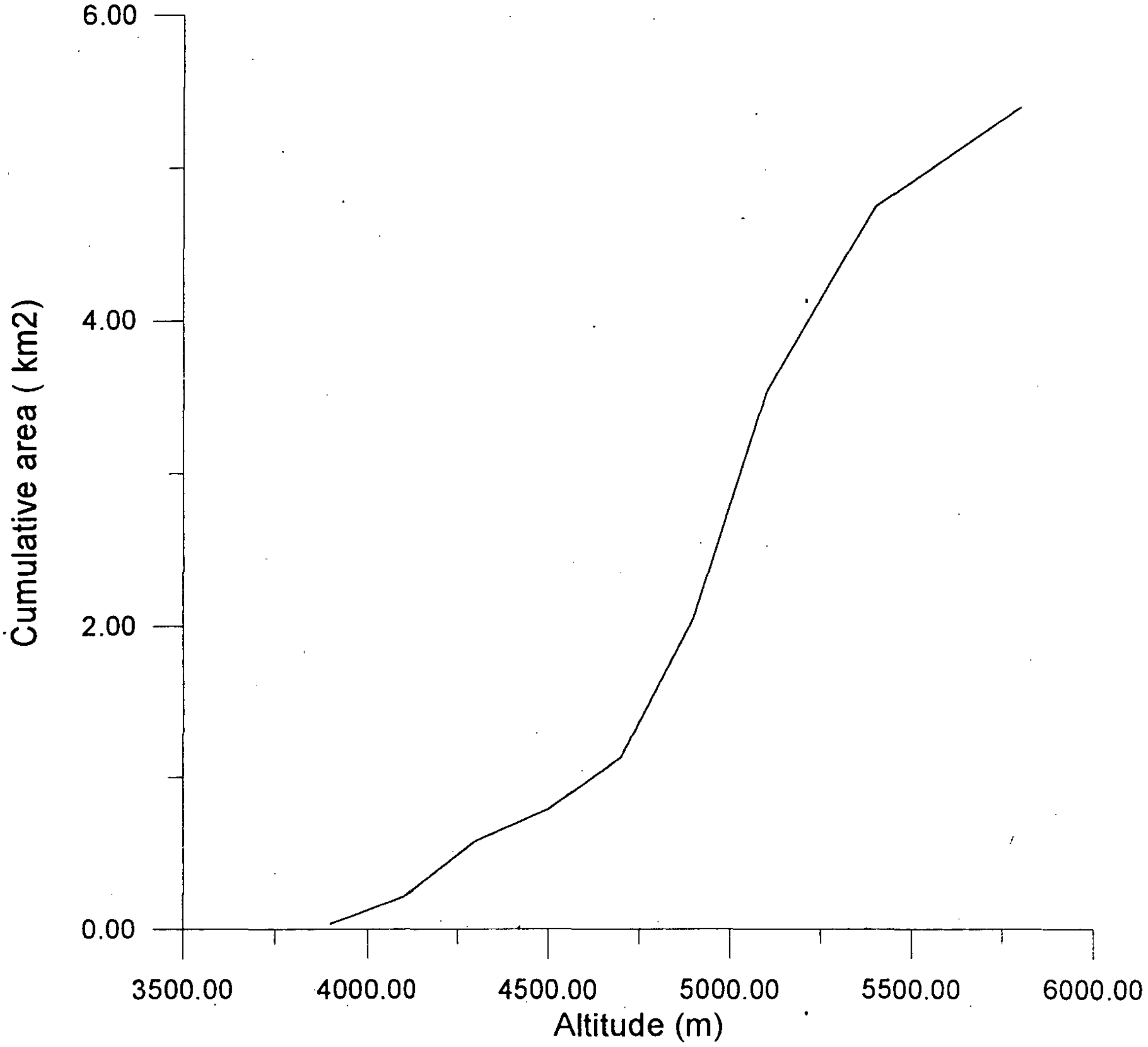


Figure 1.1Drainage Map of Ganga basin



Net balance during budget year Oct. 1993 to Oct. 1994 in m
Fig 1.2

Figure. 1.3 Plot of Altitude Vs Glaciarised area



Visibility :- Visibility in the area in good in the morning and deterioration stratus after 1130 IST. In the month of June and July poor visibility is noticed even at 1130 IST due to mist.

Snow Density :- The measurement of old snow values between 0.6 to 0.7 gm/cc in June. The snow melting rate in iron pipe is found between 4 to 8 cm/day in June and July.

Condition over high reaches of glacier :- Temperature, wind and other parameters are also taken at a very high altitude temperature of snow was recorded as 0°C and additional reading at the glacier lake gave a reading of 0.1 °C. Wind was 0-6 kmph in this zone. Hard ice is littered around in the area possibly by avalanches crevices are seen all round . The sound of avalanches crashing are frequently heard in the base camp.

Hydrological process in The Garhwal Himalaya

There are seasonal variations in discharge of the Bhagirathi river and its numerous tributaries. The basin has permanent ice cover, and also receives abundant winter snowfall from Westerlies. Regional climatic conditions are influencing energy availability for melting and rainfall, and having an impact on the temporal pattern and quantity of runoff. Length and intensity of monsoon season with topographic microclimates. Incoming radiation, with a stronger seasonality at 38° N, is intercepted by cloud cover to give periodic depression in the curve of irradiance. Thus the reduced energy availability for melting but also leads to precipitation. Flows are generally lower in July and August than in June, suggesting that runoff arising from monsoon rainfall compensates the icemelt during the period. Runoff is more evenly distributed during the pre-monsoon summer time, after the initial rise of the transient snowline, reflecting limits to aerial extent over which ice ablation can occur as a result of summer snowfall events.

The quantity and timing of discharge in the Bhagirathi and Alaknanda rivers above Devaprayag with Snow and Ice-melt components of runoff depend therefore on amount, incidence and form (Liquid or Solid) of precipitation, and on thermal regime which determines the pattern of melting in spring. The amount of Winter Snow pack and perennial Ice throughout Summer sustain flows in those basins which are glacierised. The timing and intensity of monsoonal rain storm inputs also determine the shape of the hydrograph, and lead to extensive flooding particularly in the basins of the right hand side of Alaknanda river and Bhagirathi rivers.

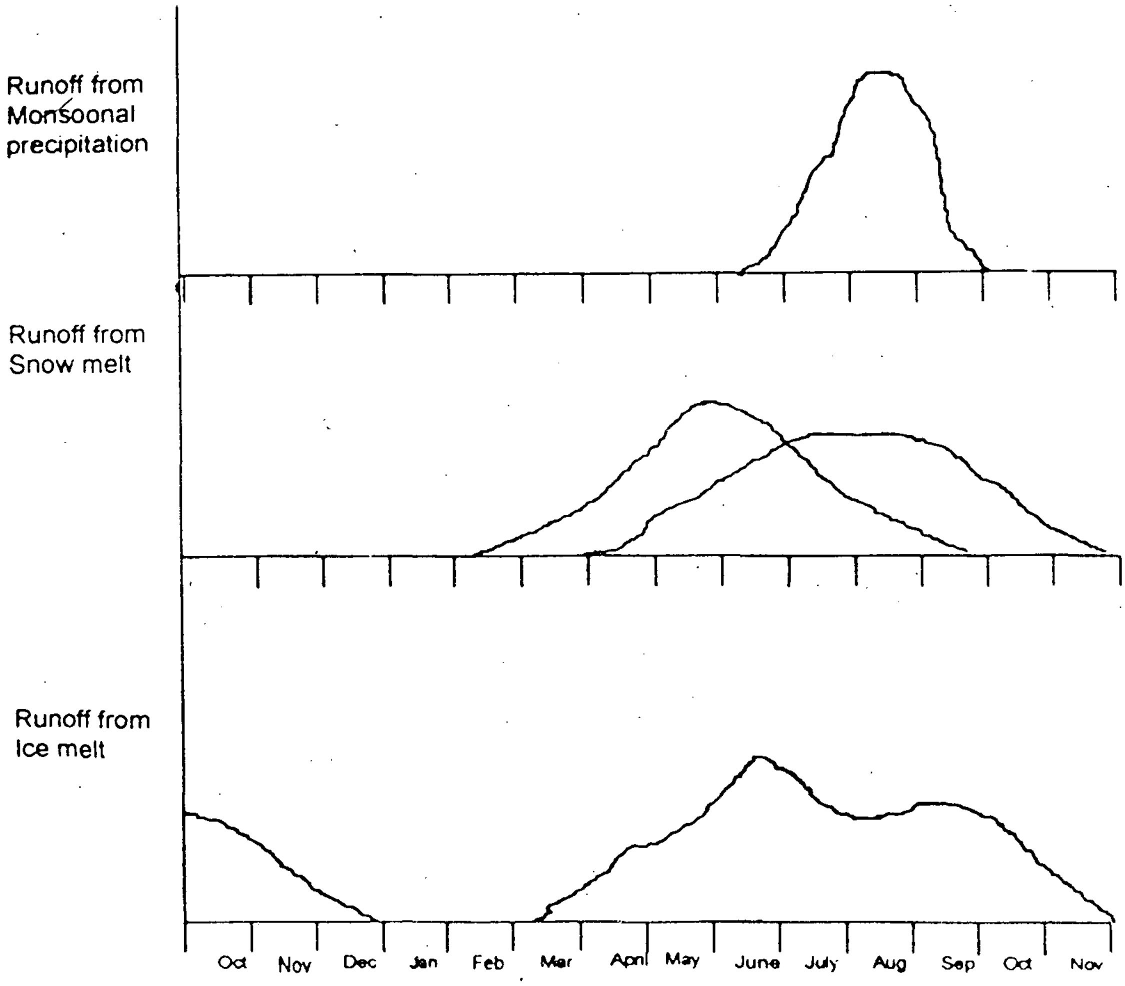
Conceptual model of the hydrological regime of Garhwal rivers.

Seasonal Variations of the components of runoff

Seasonal fluctuations in components of the basin hydrological cycle under various conditions in Garhwal Himalaya are shown schematically in figure1.4. Water equivalent held in the winter snow pack will be greater and remain longer in spring at higher elevations which corresponds also to the area maintaining glacierisation. Both the quantities of water stored and the elevation at which the storage occurs affect the pattern of melt and the timing and volume of release of meltwater from snow. Precipitation during the monsoon season is quite substantial with an daily average of 40.0 mm. The rainfall contributions to runoff is visible between July and early September.

The pattern of runoff derived from ablation of ice depends on the rate of removal of the winter snow cover a function of thermal conditions and the quantity of water snow-both of which have an altitudnal components. Essentially the rise of the runoff hydrograph in spring is controlled by the rate at which the transient snowline rises, before decline takes over accompanying the reduction cloud cover over Garhwal interacts with the availability of heat energy, such that in area subject to the monsoon ice-melt will be reduced.

Fig 14. Schematic diagram of hydrograph components



The overall runoff from Bhagirathi basin is made up of the some of values of each of the individual components at each point in time. Actually, the runoff curve reflect the specific effect of each process (per m^2) multiplied by the proportion of the basin area involved. This might be for example, a declining snow-covered area, decreasing in size but with enhancing melt-rate as the area of exposed ice and ice-melt rate increases in early summer. During monsoon season, the ice-melt rate reduces but with increased precipitation higher discharge rate is unstained. The proportion of a basin area involved is important in determining quantitatively-differing responses to the same thermal and precipitation inputs in catchments of differing percentage glacierisation.

FOCUS OF STUDY

The Himalayas contain the largest glaciated surface area outside the polar region. But the research work so far available for understanding its melt processes and temporal distribution of water yield is very inadequate.

The present work proposes to model the entire glaciers surface into different temperature zones and to estimate net melt rate during June-July. The modelling has been done by two different methods i.e. Degree Day and Energy balance in order to make a comparison of results.

The technique involved has been illustrated for Dokriani Bamak glacier by utilising the Hydrometeorological data collected in a glacier expedition during 1994.

The following aspects have been highlighted.

1) Computation of melt rate from different parts of the glacier by Degree Day and Energy Balance methods.
2) Comparison of melt rates obtained by the two different methods.
3) Comparison of the average melt rates with the observed discharge.

4) Derivation of spatial temperature distribution area glacier surface.

CHAPTER 2

LITERATURE REVIEW

The mountains of India which cradle the many glaciers, present a very fragile and highly sensitive hydrological regime. Being a tropical area, the Indian part of the Himalayas are subject to various meteorological phenomenon. Over the mountainous surface the meteorological conditions influence temperature variations besides orographic orientations and prevailing environmental conditions. Meteorological data (air temperature, air humidity, wind speed) are valuable for calculating the discharge from a particular altitude. Several other factors which affect the melt rate is the density of the snow pack, ablation area of the total glaciated mass and snow albedo.

Difficulties in measurement of high altitude precipitation, particularly when it occurs as snow have long been recognised. the most significant source of measurement error appears to be catch deficiency caused by wind (Larsen and Peck, 1974). Although snow water equivalent measurement are less affected by instantaneous wind effects, snow redistribution may have a substantial effect on these measures, which consequently may not provide a good indication of mean area of snow water storage. As a result, low altitude precipitation gauges which tent to be less affected by wind often provide a better index of high altitude mean area precipitation than do high altitude gauges themselves.

Tangborn (1977) has proposed a hydrometeorological model (HM) for forecasting stream flow runoff. volumes which utilize only low altitude precipitation data to estimate a basin water balance from which summer runoff is forecasted. Several models of the energy balance of a snow cover have been developed (Anderson, 1968, 1976; O'Neill, 1972;

Outcalt et al., 1975; Gottlieb, 1980; Baker et al., 1982; Tangborn, 1983; and Owens, 1984; Hay and Fitzharris, 1988). The testing and development of these models require accurate experimental data, which at present are insufficient. The insufficient data have been the result of inadequate instrumentation for measuring comparatively small heat transfer values in extreme meteorological conditions . The information of the magnitudes of various heat budget components using the most modern instrumentation for measuring comparatively small heat transfer values in extreme meteorological conditions. The information of the magnitudes of various heat budget components using the most moderm instrumentation in conjunction with eddy correlation techniques would provide a logical basis for the further testing and development of these models.

The energy balance for a snow cover can be expressed as

$$Q_{le}+Q_{rs} + Q_e+ Q_c + Q_p + Q_g = Q_m \qquad \_\_\_\_\_\_ \quad (1)$$

where

Q_{rs} is the short wave radiation input

Q_{le} is the long wave radiation input

$Q_c$is the sensible heat transfer.

Q_e is the latent heat transfer.

Q_p is the gain of energy by all vertical advective processes (e.g. rain)

Q_g is the heat transfer across the snow soil interface.

Q_m is the energy stored in the snowpack or utilised in the fusion process.

Equation (1) has been applied with increasing sophistication and has been found to be generally satisfactory for modelling at a point (US Corps of engineers, 1956; Gold and Williams, 1960; Muller and Keeler, 1969; Anderson, 1968, 1976). The energy balance of a snowpack in an environment determines its meltrate. The rate of water release resulting from their energy be easily determined . Water released is available for transformation into streamflow by a number of pathways as discussed by Price et. al, (1978). Water movement in the snowpack commences once storage is satisfied, with dominantly vertical flow except in the presence of impermeable ice layers.

Air temperature (ambient) is an adequate index to surface energy exchange in most cases. Several elements are needed in mathematical expressions need to compute snow cover energy exchange from air temperature.

A seasonal variation in the melt factor is essential primarily because of the variation in the net available solar energy. The use of a different meltrate during rain or snow period is important in areas where rain or snow frequently occurs because different mechanism dominate the energy exchange process during rain period than during non rain periods than during non rain periods.

A method to compute energy exchange during non-melt period is especially needed in areas where significant heat deficits can exist just prior to a melt period. The mathematical representation should recognise that energy during non-melt period is not just as loss of heat but also can be a gain.

Even though air is generally a good index a snow cover energy exchange, it is not always adequate . In general air temperature is an inadequate index when meteorological factors affecting the energy balance deviate significantly from normal. Some specific cases when air temperature is not an adequate index to snow cover energy exchange (Anderson, 1976) are days with:

a) very warm temperature and little wind

b) high dew-points and high winds

c) clear skies, but abnormally cold temperatures during the melt season after the snow is ripe .

It is still unclear as to whether and energy balance method of computing surface energy exchange will give improved results for a temperature index procedure even if the minimum data for the energy balance method are available. Some of the reasons why an energy balance method may not give improved overall results are:

a) wind data are hard to extra polate especially in mountainous areas.

b) incoming solar radiation data is also hard to extrapolate in mountainous area from low to high elevations

c) incoming longwave radiation and albedo are not measured.

d) methods to estimate radiation exchange in the forest are approximate, plus the needed data on cover density are not available on a wide scale and

e) turbulent transfer over irregular terrain with some vegetation cover, and a dynamic snow surface (roughness varies)is not completely understood.

Thus because of modelling simplifications and data inadequacies an energy balance method of computing energy exchange may contain much as overall error as temperature index procedure.

Some investigators have used model calibration error as a measure of forecast accuracy. A sequence of summer runoff and associated model input sequences are used to estimate the parameters of a forecast model, then the model is used to 'forecast" flow for the same runoff sequence . The model parameters are estimated to minimise the error and some measure of these errors are used as the basis for model comparison. It is well known in statistics that when an efficient parameter estimation procedure is used, the apparent model 'fit" or calibration error is always improved as the number of parameters is increased, even though the additional parameter may not be either statistically significant or physically meaningful. Inclusion of an excessive number of parameters effectively results in incorporation of additive noise components in model forecasts, so that while calibration error are decreased forecast errors are increased.

Forecasting of snowmelt runoff is somewhat unique in hydrology in that the economic consequences of model improvement, at least for some water users, can be assessed in a relatively straight forward manner.

The degree day method which uses air temperature observations have been need to estimate snowmelt for streamflow . Forecasting for several decades (Linsley, 1945; Corps of Engineer, 1960; Anderson, 1976).

Mass balance data from glaciers and ice sheets contain implicit information about the dependence of glacier mass balance on climate. The measured mass balance varies with elevation and from year to year, mainly as a consequence of variations in temperature and precipitation. It should , therefore be possible to use measured variations in the mass balance together with meteorological data to parameterize the relation between glacier mass balance and climate using a suitable glacier mass balance model (Tomas Johannesson et al; 1995). The mass-balance model may than be used to estimate likely glacier mass-balance changes resulting from hypothetical climatic changes.

Some Energy Balance and Degree Day studies in India

1) Daco and Shirvaikar presented an energy balance model of snow melt for use with routinely collected meteorological data and produced nomograms based on this model. The authors have also tried to establish delay periods for snowmelt water to reach the gauging point and it is claimed that their estimates using the nomograms compare fortunately with the observed data for the catchment for clear or partly covered sky conditions. However the nomograms underestimate by a factor of three for overcast condition.

2) Abbi et al., have presented an approach for estimation of maximum water equivalent of snow cover in the catchments and time distribution of snow melt from April to June using features like area elevation relationships. freezing level, surface temperature and

snow day factor monthly snow melt have been compared using degree day concept and compared with actual discharge .

3) Seth presented model results of daily snowmelt runoff during pre-monsoon months . His model uses information regarding the aerial extent of permanent and temporary snow cover obtained by comparison of a few available satellite imageries and considers altitude effect on temperature, orographic effect on precipitation melt due to rain, losses from meltwater and effect of rain falling on snow cover area.

4) Upadhyay et al (1983) have worked out the monthly budget for net energy available for snowmelt for a number of stations in Himalayas. Estimation of Q_{rs} , Q_{rl}, Q_c, Q_e have been made by indirect approach using meteorological data on temperature, vapour pressure, wind and cloudiness.

In another model Upadhyay et al (1989) have used the Degree Day approach to model the glacier melt of Chota Shigri glacier during 1986-88.

CHAPTER 3

THERMAL CLASSIFICATION OF GLACIER

The thermal classification is better applied to parts of glaciers rather than entire valley glaciers or ice caps because the thermal status of one part of a glacier maybe different from that of another part. A discussion of the thermal condition of glaciers on parts of glaciers has a very important bearing on both their form and their ability to shape landscapes.

1) Cold, Polar or Dry Base glaciers : They are so called because the basal ice must be firmly bonded to the rock beneath . The surface bonds between silicate minerals and ice is considerably strongly held than the yield strength of ice, so that any motion of a cold glacier must be by internal plastic flow. Most of the motion is considered to concentrated in the basal, relatively warm ice, however differential shear in the basal zone might break off rock projection or fracture them, for e.g. glaciers in Greenland with temperatures of 25°C below zero.

2) Temperate or Wet-Base Glaciers: Here the mean annual temperature is close to 0 °C Than with progressive burial pressure melts a minute amount of ice, and the ice and water phases co-exist at lower temperature with depth. Here the flow rates would be twice as fast as those in polar areas.

The temperature at the base is less than at the surface. No geothermal heat can flow upwards as in a polar glacier. The geothermal heat that reaches the base of a temperate glacier cannot be conducted upward but must melt ice. This heat, plus an increment of heat generated by sliding friction that is also trapped at the base of the ice, assume that a temperate glacier must move on a wet base (Weertman, 1966).

3) Intermediate categories : (Lagally, 1932) in a classification proposed an intermediate type that would be cold or polar at the top but which experiences pressure melting at the

base. It was accepted more as theoretical possibility than a practical one. Some glaciologist include the glaciers of New Zealand and Antarctica in this category.

ENERGY FLOW IN GLACIAL SYSTEMS

All physical phenomena maybe conceived as being organised into systems, a system being defined as a collection of objects and the relationships between those objects. Closed systems are those that have boundaries across which no energy or matter moves. Open systems have a flow of energy and matter through their boundaries .

A closed system must change toward a time independent equilibrium state, according to the second law of thermodynamics, in which the rates of various physical phases remain constant , the amount of free energy (such as chemical potential energy of position etc.) is minimal, and the entropy (unavailable energy, often visualised as the diffuse heat of random molecular motion) is maximal. An open system, on the other hand, may achieve a steady state, wherein the system and its phases remain in a constant condition even though matter and energy enter and leave it (Von Bertalanffy, 1950).

The entire subaerial portion of the earth's surface can be profitably regarded as an open system (Chorley. 1962). Matter is supplied to processes such as volcanism, diastrophism and even glaciation with additional trivial net increase of mass. Energy is derived from solar radiation gravitational, rotational inertia, and internal heat. Surface processes erode the rock structure, and the eroded debris is deposited elsewhere usually below sea level.
It is conceivable that a steady state could be reached in such a complex open system such that the form of the landscape would not change even though the mass that composes it was constantly changing and energy was being constantly expended .

The energy balance in the geomorphic system is becoming quite well known owing to related research is meteorology astronomy and geophysics. The earth's surface has not grown significantly colder or warmer in geologic times, so it must dissipate in to space as much heat as it receives from various sources. In the system as a whole, gravity is the dominant form of energy (Dyson, 1971). Within the geomorphic system under consideration, solar radiation (in itself a result of gravitational force that sustains thermonuclear fusion in the Sun) dominates all other energy sources.

THE ENERGY AVAILABLE FOR GEOMORPHIC CHANGE

Solar radiation, mostly in visible and near infrared wavelength supplies about 99.98 per cent of the energy entering the geomorphic system. About 30 per cent of the solar radiation is directly reflected, mostly by clouds (the planetary albedo, or brightness, is the measure of this reflected energy). Most of the non reflected energy is converted to thermal vibration of air, water and mineral molecules are sensible heat, activating chemical and physical reactions and possibly even giving an incremental heat to the glaciated terrain. A very significant fraction is absorbed as latent heat of vaporisation by abundant water on the surface of the earth and is transported by water vapour in the atmosphere until it is released by condensation in clouds . Much smaller fractions of the energy are converted directly to kinetic motion of air and water masses, driving connective and adjective currents in atmosphere and oceans or are absorbed by photosynthetic plants. A very small amounts of the energy drives the geomorphic process. All of this energy is ultimately returned outer space by re-radiation from the moderately warmed earth.

Solar radiation provides energy for geomorphic change at a rate of 4000 times faster than all other energy sources combined, yet these other sources cannot be ignored. They include the gravitational and inertial forces associated with the mass and motion of the earth, moon, sun and other objects of the solar system, expressed at the earth's surface by tides in both the lithosphere and hydrosphere. Also included is the heat that flows outward through the surface from the interior of the earth. Only about 1-10 per cent of the earth's internal heat is released by volcanic heat the heat is conducted to the surface along the geothermal gradient from the hotter interior to the colder surface rocks, which is a world wide phenomena. In ways not yet understood, heat energy and geothermal gradients in the interior of the earth, aided by kinetic rotational forces and gravity drive all of the diastrophic activity in the lithosphere.

In addition to reflecting nearly one third of the total incoming energy, the atmosphere acts as a selective filter to further restrict the wavelengths of solar radiation that reach the earth's surface. In the lower atmosphere, water vapour (H_2O) and carbon dioxide (CO_2) strongly absorb incoming solar radiation in specific longer infrared wavelength. It is one of the remarkable balance of nature that the earth is warmed by the Sun to just the right temperature so that it re-radiates energy out through the atmosphere into space at wavelengths that are in spectral "windows" between the incoming wavelengths that are so strongly absorbed by water and by carbon dioxide. The mean terrestrial surface temperature of 288°K is a result of the balance between both the wavelengths and the intensity of incoming and outgoing radiation.

TERRESTRIAL THERMAL GRADIENTS

Solar energy is absorbed and radiated unequally by the lower atmosphere, hydrosphere and lithosphere. The result is a complex thermal gradients that cause atmospheric and oceanic circulation and produce climatic regions on the earth's surface. As climate is an important aspect of geomorphic processes, the major thermal energy gradients need specific discussion.

LATITUDINAL GRADIENTS

Most of the solar radiation is received by earth within the tropics. The sun is high in the tropical sky at all seasons, and the reflectance is least and incoming re-radiation is at a high angle to the surface . The atmosphere is cloudy and humid absorbing re-radiated earth heat. Almost 40 per cent of earth's surface is within the tropics . That is why more energy is received from the sun than is radiated back into space. (Vonder Haar and Suomi, 1969).

The Polar regions receive very little of the total solar radiation. The low incident angle of sun light , promotes reflection. For a considerable part of the year the energy input at the polar is far lower than the output.

ALTITUDINAL GRADIENT

The atmosphere is reasonably transparent to incoming solar radiation of visible and near infra-red wavelengths but is strongly absorbent in certain wavelengths of outgoing longer wave infrared radiation and leaves the solid earth. Thus the atmosphere is heated from beneath, at a normal temperature lapse rate of about - 6.4°C 1000m is recorded during ascent from sea level with increasing altitude the mean annual temperature on a mountain side steadily decreases until it is below freezing point.

If precipitation is adequate, a permanent snowline is reached. The altitude of regional snowline varies from nearly 6000 m above sea level in the sub tropical dry belts to sea level in the polar regions. Near the equator, the snowline dips to about 5000 m because of the greater cloudiness and precipitation there than in the adjacent clear, dry sub tropical belts.

If a mountain is high enough to intersect the regional snowline it will carry a year round snowcap and possibly glaciers. The sediment loads in streams draining glaciated and non glaciated mountain peaks suggests that the presence of glaciers in its headwaters increase a streams erosion by a factor of 4 to 25. Thus altitude alone can be a powerful factor in determining the effectiveness and even the kind of geomorphic process acting on a landform . Although mountain peaks are cold, they are nevertheless subject to very high energy flux. Unimpeded by most clouds, haze and atmospheric dust, the incoming radiations intensity on a mountain greatly exceeds the average at sea level. Reradiation is also rapid. Sunlit rock surfaces at high altitude maybe much warmer than the air only a few centimeters away, but as soon as the sun sets, the rocks reradiate into cold, day space and cool rapidly .

THE HYDROLOGIC CYCLE

A very large proportion of solar radiation intercepted by the earth is isothermally absorbed as latent heat of vaporisation by water . Almost 2.4 KJ are required to evaporate 1 gm. of water at 20°C. The heat absorbed by the oceans are not in the form of sensible heat, but heat in the latent (hidden) form which changes the state of water from liquid to vapour. When the water vapour condenses to form clouds or droplets the latent heat is liberated to the surrounding atmosphere . The largest single largest component of the horizontal transfer of heat over the surface of the earth from equitorial to polar regions is undoubtedly this latent heat of vapourisation and condensation.

In a hydrologic cycle the annual exchange of water takes place in between the various reservoirs. The energy inflow equals the outflow, and with negligible exceptions, the amount of water in the system is constant . In order of importance the resources of water are : (1) oceans (2) glaciers (3) ground water, (4) lakes and rivers (5) atmosphere and (6) biomass. About 33 per cent of the fresh water is present in the streams and the rest in glaciers . A large amount of water is also contained in the interior of the earth, chemically combined or dissolved in solid or molten rocks. Only a small amount of new water might be added annually by condensation of volcanic gases, and an equally small amount of water is probably lost from the earth annually by the photochemical dissociation of water vapour be solar radiation . Glaciers store large amounts of water on land temporarily removing it from the hydrologic cycle. If the present glaciers wave to melt, sea land would rise by about 72 m and submerge the most heavily populated areas of the earth .

INTERNAL HEAT

Heat Flow : The energies of geomorphic processes are better understood in terms of the energy that flows to the surface from the interior of the earth rather than the temperature gradient of earth. This also acts as a heating factor which is conducted in increments to the base of a glaciers. Heat flow, is the product of the geothermal gradient and the conductivity of the rocks. The rate of energy receipt at the earth's surface from internal heat is about 30 x 10^{12} watts, calculated from the measured average heat flow on continents and in ocean sediments.

Also there is some energy which is entrapped in the lattice structure of ice. When exposed to chemical reactions such as oxidation and hydrolysis they contribute to the latent heat of snowfall. The reactions proceed exothermically and produce new heat components that are more stable under surface conditions. Thus the free energy of the original crystal lattice is degraded and lost into the ice pack, thereby stimulating discharge of snow. And where the ice is buried into the depths internal heat is absorbed from adjacent areas. Radiogenic sources of energy, from the half lines of radioactive isotopes, also supplies internal heat to a glaciated mass.

CHAPTER 4

MODELLING OF SNOWMELT PROCESSES

The snow covered area of the glacier is divided into different altitude zones.By using the lapse rate the temperature of the i^{th} zone can be calculated.

If the temperature of the base camp is t_o then the daily mean temperatures recorded at various altitude for different months are plotted on a graph. The slope of the lines represents the lapse rate for different months.

$$t_i=t_o+(H-h_i)r \qquad -(4.1)$$

where

r is the lapse rate
h_i is the average height of the i^{th} zone
H is the height of the base camp

COMPUTATION OF MELT RATE

I . DEGREE DAY APPROACH

Many authors including U.S. Army Corps of Engineers(1956) have worked out temperature indices which provide empirical methods of computing melt rate. I propose to utilise degree day method for computation of snow melt. But instead of taking the usual degree day ie the arithmetical mean of all positive temperatures recorded during the day a modified degree day

$$T_\phi = 0.6(T_Q)_n+0.3(T_Q)_{n-1}+0.1(T_Q)_{n-2} \qquad -(4.2)$$

has been utilised where T is usual degree day defined as

$$T_Q= \Sigma T_i/24 \text{ if } \quad T_i>0 \qquad -(4.3)$$

in which T_i are the hourly temperatures during a day. For practical purpose, T_Q has been taken as mean of daily maximum and minimum temperatures.(Upadhyay et al, 1989) the concept behind modifying the degree day is that the quantity of snowmelt for a particular day also depends upon the temperatures of the previous two days

The quantity of snow melt SM maybe given by the relation

$$SM=aT_{\phi} \qquad -(4.4)$$

where 'a' is called the degree day factor expressed as

$$a=(1.1)\,\rho \qquad -(4.5)$$

and ρ is the density of snow in gm/cc. From equations 4.2 , 4.4 and 4.5

$$SM=\{0.6(T_Q)_n+0.3(T_Q)_{n-1}+0.1(T_Q)_{n-2}\}1.1\,\rho \qquad -(4.6)$$

Here the quantity of snow melt SM is in cm/day.

For the purpose of snow melt computations the whole glacier surface extending from snout to peak was divided into zones and the modified degree day method was applied to each zone.

II ENERGY BALANCE METHOD

For the calculation of snow melt the components which are more relevant are shortwave(Q_{rs}),longwave(Q_{le}),convective(Q_c)and and latent heat flux (Q_e) which are described in the equation

$$Q_m=Q_{rs}+Q_{le}+Q_c+Q_e+Q_p+Q_g \qquad -(4.7)$$

Q_{rs}=net short wave radiation received by the earth.
Q_{le}=longwave radiation input to the snow surface
Q_c=heat transfer at ice-air interface by conduction (sensible heat,+ive if air temperature $T_a>T_s$, snow surface temperature and -ive if ($T_a<T_s$)

Q_e=Latent heat flux due to evaporation or sublimation (-ive) or condensation/ sublimation (+ive)
Q_g=heat exchange at snow-ground interface(+ive but very little)
Q_p=Advected heat flow (mass transfer of vapour or meltwater or rainwater)(+ive or - ive)

(a) **Estimation of Q_{rs}**

Insolation at the top of the atmosphere depends on
(i) time of the year (declination),
(ii)time of the day (hour angle),
(iii)latitude of the place

there is no interannual variation in these values. For practical use the daily values (R_o)have been computed at standard latitude for different months and provided in form of nomograms and tables (Fig. 4.1)

The value of R_o maybe also computed with the help of the following equations

$$W_S=\cos^{-1}[-\tan(\phi)\tan(\delta)] \qquad -(4.8)$$

$$R_o = (24/\pi)I_{sc}E_o[(\pi/180)W_s\sin(\phi)\sin(\delta)+\cos(\phi)\cos(\delta)\sin(Ws)] \qquad -(4.9)$$

$$E_o=(r_o/r)^2=1+0.033\cos[2\pi d_n/365] \qquad -(4.10)$$

where

ϕ is the latitude of the place

δ is the declination of the Sun,

I_{sc} is the solar constant,

r is the instantaneous Sun-Earth distance

r_o is the mean Sun -Earth distance,

d_n is the number of days elapsed since 1st January

On a cloudless day the incident radiation on a snow surface is reduced due to atmospheric transparency (optical air masses).According to U.S Army Corps of Engrs(1956)

$R=0.80R_o$ during winter and

$R=0.85R_o$ during summer

If N is the amount of cloudiness; the net radiation (ly day^{-1}) reaching on a surface maybe given as :

$$Q_{si} = [1 - (0.82 - 0.000073\,Z)\,N]\,R \qquad -(4.11)$$

where N is cloudiness in decimal fraction and Z is cloud height in m.

If r is the albedo of snow then short wave radiation absorbed

$$Q_{rs} = Q_{si}\,(1-r) \qquad -(4.12)$$

Albedo which is defined as the fraction of incident radiation reflected back is highly variable and depends on free water content, crystal size, and shape and inpurities. For fresh and dry snow it maybe 0.95, for ripe snow 0.5 to 0.6 and for glacier surface covered with debris it maybe less than 0.2 . The corps of Engrs, US Army (Snow Hydrology 1956) tried to relate albedo with the age of snow. Some of their experimental values are given in Table.4.1

Table 4.1

Age of Snow Days	Accumulation period (Dec - Feb)	Melt - period (March - May)
0	85	78
2	77	65
4	72	57
6	68	53
8	66	50
10	65	48
12	64	46
14	63	44

(b) Estimation of Q_{le} :

Longwaves are received by snow surface as back radiation from all levels of atmosphere. Back radiation depends on the distribution of moisture, pollutants, cloudiness and temperature in the entire atmosphere. The downward long wave radiation Q_q from the atmosphere can be estimated from surface air temperature (T_a) and vapour pressure (e_a) alone. Empirically (Brunt (1952) Phys & Dynamic Met)

$$Q_a = \sigma T_a^4 (a + b \sqrt{e_a}) \qquad -(4.13)$$

Some scientist have suggested exponential or linear functions of e_a to be used.

The values of a and b have been experimentally determined by various researchers some of which are given below:

Region	a	b	e_a (hpa)	
India	0.47	0.061	8-18	Ramnathan and Desai
England	0.52	0.065	7-14	Dines
Algeria	0.48	0.058	5-15	Angstrom

The value $\varepsilon = (a+b \sqrt{e_a})$ for India ranges from 0.64 to 0.73 depending on the value of e_a.

Thus on a cloudfree day net long wave radiation input to snow cover is

$$Q_{le} = \sigma (\varepsilon T_a^4 - T_o^4) \qquad -(4.14)$$

Taking $\varepsilon = 0.7$ and $T_o = 273$ k

Q_{le} is +ve if $T_a \geq 300$ k

clouds, being composed of liquid water droplets, absorb much more longwave radiation than water vapour and hence act as near perfect black body. In overcast sky condition if T_c is cloud base temerature, then net long wave radiation input to snow cover will be $\sigma (T_c^4 - T_0^4)$. There will be given of heat to snow cover if $T_c > T_o$. However main role of cloudiness (fraction of sky covered) then

$$Q_{le} = \sigma(\varepsilon T_a^4 - T_o^4)(1-KN) \qquad -(4.15)$$

then K depends on type and height of clouds. Experimental values reported by Army Corps of Engrs (1956) are:

K= 0.76 for low and thick clouds
= 0.52 for medium clouds
= 0.26 for high clouds

An empirical relationship between K and height of cloud base Z (m) as suggested by Phillips quoted in snow Hydrology (1956) is

$$K = (1 - 0.73 \times 10^{-4} Z) \qquad -(4.16)$$

(c) Latent and Sensible Heat Exchange between Snowcover and Atmosphere.

If V_a (ms^{-1}) is the wind speed observed at height Z_a (m) then

Latent Heat

$$Q_e = \{0.622\, \rho L K_t (e_a - e_o) v_a\}/p \text{ and } \qquad -(4.17)$$

Sensible Heat

$$Q_c = \rho C_p K_t (T_a - T_o) v_a \qquad -(4.18)$$

where

ρ= air desity (gm cm^{-3})

C_p = Specific heat of dry air (=0.24 cal gm^{-1} K^{-1})

L = latent heat (= 677 cal gm^{-1}) for snow vapour system and.

p is Atmospheric pressure (mb)

v_a = average velocity of wind

e_a , e_o and T_a , T_o are vapour pressure (hPa) and temperature (°C) at levels Z_a and Z_o (snow surface) respectively.

Vapour pressure Computation

The relation $e = mp/ 0.622$ shows that the vapour pressure falls faster than air pressure (p) due to the condensation of vapour as a consequence of falling temperature.
An empirical relation which gives the variation of vapour pressure with altitude is

$$e=e_o\, 10^{-kz} \qquad -(4.19)$$

where z is the altitude of the point where vapour pressure is being calculated
e_o is the vapour pressure at the point of observation.

K is a empirical constant which depends on the local climatic factor

Kuzmin gives a value of 1/5 for free atmosphere and a = 1/6.3 for mountain regions. He also gives the results of seperate study which found that the measured vertical humidity gradient, averaged over a large number of mountain regions agreed closely to the results obtained using equation 4.19 with

$a=1/6.3$

K_t is the transfer co-efficient given as :

$K_t = k^2 / \ln^2 (Z_a / Z_o) \ [1- R_i / R_c]^2$

$K_n = N^2 / \ln^2 (Z_a / Z_o)$

k = Karmans constant (=0.4)

R_i = Bulk Richardson number

$$= \{2g\, Z_a (T_a - T_o)\} / \{v_a^2 (T_a + T_o)\} \qquad -(4.20)$$

R_c = critical Richardson number beyond which turbulent conditions do not exist (R_c = 0.2 to 0.5)

(d) Heat Transfer at Snow-soil interface Q_g

Due to poor thermal conductivity of soil conduction of heat from the ground beneath is comparatively negligible (a few ly day $^{-1}$)

(e) Advected Heat from Rain water falling on snow Q_p.

Mass transfer in a snow pack may occur due to movement of melt water and rainwater faliing on snow of these the heat transfered to snow cover rain while cooling itself to 0 ° C is important . If p is the rainfall (cm) amount for the day and ^tw (°C) the wet bulb temperature (representing temperature of rain water) then

$$Q_p = pt_w \text{ ly day}^{-1} \qquad \text{-(4.21)}$$

Snow Melt

If Q (langley) is the net energy available to snow pack from all the processes described above the consequent snow melt quantity SM (cm) is given by

$$SM = Q/80\,\theta \qquad \text{-(4.22)}$$

where θ is called the thermal quality of snow.

(III) Temperature Based Indices:-

Several Snow melt run off watershed models use empirical relationship.

$$SM = C\,(T_a - T_b) \text{ or } SM = C\,(T_a - T_b)^n \qquad \text{-(4.23)}$$

For evaluating snowmelt. T_a is air temperature, T_b is base value or critical temperature usually freezing point condensation-convection melt is also expressed in term of T_a, T_b (dew point) and wind velocity,v

$$SM = K(AT_a + BT_d - T_b)v. \qquad -(4.24)$$

The co-effecients K, A, B are basin specific and have to be empirically evaluated. Experimental values suggested in US Army Corp of Engrs (1956) pubication 'Snow Hydrology' for (SSI 7200 ft above level)

$$SM = 0.0084\,(0.2\,T_a + 0.8\,T_d - 32)v \qquad -(4.25)$$

where SM (inches /day) T_a and T_d (at 10 ft level) are in °F, v is wind speed (miles per hour) at 50 ft level.

Under the similar conditions of measurements general equations of total melt rate for an experimental area has been given as.

(i) for open or partly forested basin,

$$SM = (0.029 + 0.0084Kv + 0.007P_r)(T_a - 32) + 0.09. \quad -(4.26)$$

(ii) for heavily forested areas.

$$SM = (0.074 + 0.007\,P_r)(T_a - 32) + 0.05. \qquad -(4.27)$$

Where SM is total melt rate (inches / day) P_r is the rate of precipitation (inches / day) and K is the basin constant which varies from 0.2 for density forested area to 1.0 for exposed ridges.

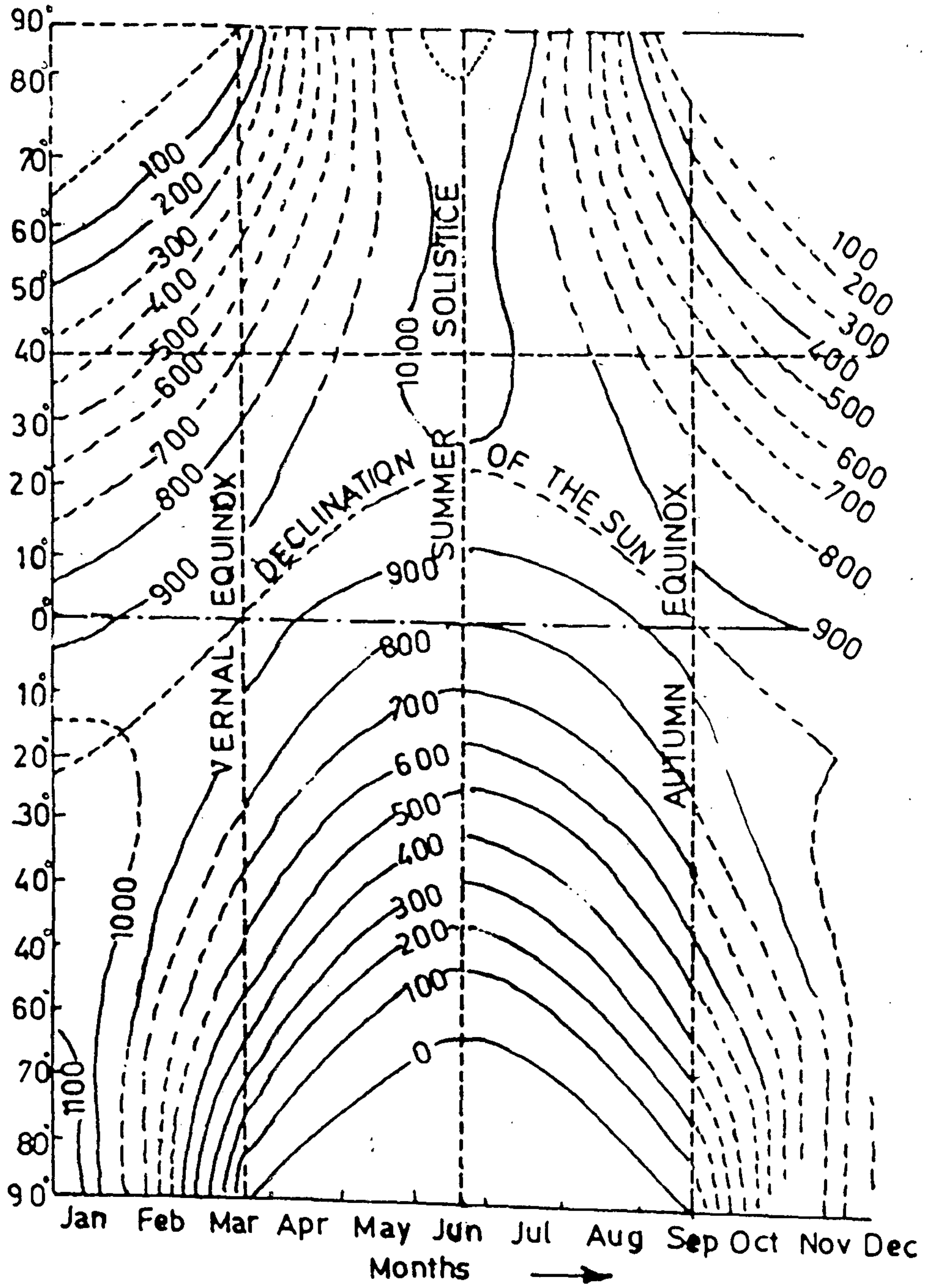
Jackson (1978) (Journal IWFS 32 pp 495-508) indicated the following equation for snowmelt SM (mm/day)

$$SM = (1.32 + 0.305\, v)\ T - 0.236\, v\Delta \qquad -(4.28)$$

Where

v = mean wind velocity (Kts), T is air temperature (°C)

Δ = Dew point of depression.



DISTRIBUTION OF SOLAR RADIATION AT THE TOP OF ATMOSPHERE

Fig.4.1

CHAPTER 5

CALCULATIONS AND ASSUMPTIONS

LAPSE RATE

The mean monthly temperature plots given in the Dokriani Bamak Glacier Expedition-1994 Meteorological Report were used to compute the lapse rate for different months.

Table 5.1

Month	May	June	July
L.R (°C/km)	6.5	5.7	7.5

ZONING OF GLACIER SURFACE :-

The glacier surface was divided into 9 zones. The areas for each zone were calculated using the graphical method.

Table 5.2

Zone	Altitude Range (m)	Mean Altitude (m)	Area of each Zone (km^2)
1	3900-4000	3950	0.030
2	4000-4200	4100	0.180
3	4200-4400	4300	0.370
4	4400-4600	4500	0.21
5	4600-4800	4700	0.34
6	4800-5000	4900	0.91
7	5000-5200	5100	1.49
8	5200-5600	5400	1.21
9	5600-6000	5800	0.65
Total			5.39 km^2

Using the lapse rate and the mean. Base camp temperature the mean temperature at the mean altitude for each zone was computed.

Equation 4.6 was used to compute the snow melt for each day in each zone the average densities assumed were as follows:

Table 5.3

Month	Density for zone 1 to zone 6 (gm/cc)	Density for zone 7 to zone 9 (gm/cc)
May	0.4	0.3
June	0.5	0.4
July	0.7	0.5

The ablation zone was assumed to extent upto a altitude of 5000 m. The region beyond 5000 m was considered as the accumulation zone. The mean snow melt was computed by using the area as weights.

ENERGY BALANCE CALCULATIONS :-

(i) Shortwave Radiation Input (Q_{rs}).

The incoming solar radiation at the top of the atmosphere was computed for each day by using equations 4.8, 4.9 and 4.10 and the shortwave radiation absorbed by the earths surface was computed using equation 4.11 and 4.12. The various parameters used in the above computtations were as follows.

Table 5.4

MONTH	MAY	JUNE	JULY
Albedo of ablation zone	0.5	0.5	0.4
Albedo of accumulation zone	0.6	0.6	0.5
Cloudiness (N)	0.75	0.75	0.875
Cloud Height Z (m)	3000	2000	1000

The solar constant was taken as Isc = 2ly min^{-1}

(ii) Longwave Radiation Input (Q_{le})

Equation 4.15 gives the long wave radiation input . The constant k was taken as 0.52 for May June while for July it was taken as 0.76.

(iii) Latent Heat Input .

For smooth snow on land the roughness height $Z_0 = 0.7 \times 10^{-3}$m and $Z_a = 1.25$ m above ground level. The critical Richardson number was taken as 0.3

K = Karmans constant = 0.4

Average wind velocity used in calculation ..

Table 5.5

Month	May	June	July
Velocity m/sec	2.0	2.0	2.0

The values for various quantities used in equation.

P = density of air = 1.1×10^{-3} gm/cm^3

E_o = SVP at 273° K = 6.1 mb

C_p = specific heat of dry air = 0.24 cal gm^{-1} K^{-1}

L = latent heat for snow vapour system = 677 cal gm^{-1}

p = atmospheric pressure = 1000 mb:

To compute the vapour pressure the equation (4.19) was used.

Taking logarithmn on both sides of the equation

$$e = e_o\, 10^{-kz}$$

$$\log_{10} e = \log_{10} e_{01} - kz_1 \quad - (5.1)$$

$$\log_{10} e = \log_{10} e_{02} - kz_2 \quad - (5.2)$$

Subtracting (2) from (1)

$$0 = \log_{10} e_{01} - \log_{10} e_{02} - kz_1 + kz_2$$

$$\Rightarrow k = \log_{10} \frac{[e_{01}/e_{02}]}{[z_1 - z_2]} \qquad (5.3)$$

where

e_{01} and e_{02} are the vapour pressure at station 1 and 2

z_1 z_2 are the altitudes of the third station with respect to station 1 and station 2 respectively.

Table 5.6 Mean of observed monthly vapour pressure of various observatories

Station	Base Camp(3750)			Snout(3835)			AdvanceBaseCamp (4270)		
Month Time	May	June	July	May	June	July	May	June	July
0830	5.6	7.6	11.0	-	5.6	-	-	-	
1130	5.8	9.5	12.3	3.2	5.4	-	-	6.7	9.0
1430	6.2	9.8	12.6	5.0	7.4	-	-	6.92	8.8
1730	8.6	10.0	11.6	6.0	7.7	-	-	6.92	-
Mean monthly V.pressure	6.6	9.2	11.9	4.7	6.5	-	-	6.9	8.9

For May

$$k = \frac{\log_{10}[4.7/6.6]}{(2165 - 2250)} \times 10^3 = 1.735.\ \text{km}^{-1}$$

For June

$$k = \frac{\log_{10}[6.9/9.2]}{1730 - 2250} \times 10^3 = 0.204\ \text{km}^{-1}$$

$$k = \frac{\log_{10}[6.5/9.2]}{2165 - 2250} \times 10^3 = 1.77\ \text{km}^{-1}$$

For July

$$k = \frac{\log_{10}[8.9/11.9]}{1730 - 2250} \times 10^3 = 0.242\ \text{km}^{-1}$$

As the values 0.204 and 0.242 are closer to the value 0.16 km^{-1} (Kuzmin 1961), the mean of the two values ($k = 0.223\ \text{km}^{-1}$) is taken for the purpose of calculations.

Using the equations 4.17 and 4.18 the sensible heat and latent heat fluxes were calculated and the net energy balance and snow melt was computed using the equations 4.7 and 4.22 . Average snow melt was computed using area as weight.

CHAPTER - 6

RESULTS AND DISCUSSION

The modelling of the snow melt was carried out using meteorological data (temperature, vapour pressure, wind speed cloud cover, precipitation, albedo) for the period from 27 May to 28 July 1994. The data used for modelling was obtained from the Meteorological report of Dokriani Bamak glacier expedition 1994 . Using the mean daily temperature of the Base Camp and monthly lapse rate the mean daily temperature of the nine glacier zones were calculated . The snow melt rate is comprately by energy balance and degree day methods.

The results of the calcultion have been presented in Tables 6.1, 6.2 and 6.3. The calculated components have been presented according to major sources of energy input .

The temperature distribution shows sub-zero temperature for a few days in zone 7 (5100m) and for a large number of days in zone 8 (5400m) and zone 9 (11) . These negative temperatures have been taken as zero for the purpose of degree day calculations. The snow melt rate calculated by the Degree Day method varies from 12.5 cm/day to 0 cm/day.

The short wave energy input varies from 232.84 ly/day to 143.12 ly/day while the longwave energy input varies from -145.09 ly/day to -37.79 ly/day. Varation in latent heat is from 59.99 ly/day to -138.18 ly/day .Sensible heat varies between 52.39 ly/day to -101.13 ly/day . The snow melt rate calculated by energy balance method varies between 3.01 cm/day to 0 cm/day. The snow melt calculated by the two methods shows a large difference . Energy balance gives lower values because all the energy components have been indirectly estimated by empirical relations . The meteorological inputs like temperature, vapour pressure, albedo have been extrapolated from base camp observations by using empirical relations . This may not give a accurate value of the meteorological variables .

More over only four major energy inputs have been considered. The heat exchange at snow-ground interface which is positive has been neglected. Advected heat flow due rainwater falling on snow has been neglected. This component becomes particularly important in month July when rainfall is very high. Many of meteorological inputs like albedo and density have been estimated and not measured accurately. This could contribute significatly to the error in snow melt.

There all broadly three sources of water which contribute to the discharge viz.

(i) Melting of seasonal snow cover and

(ii) Rainfall

(iii) Glacier melt due to precipitation.

Then there are losses due to infiltration and evaporation.

Due to these reasons the process of runoff prediction becomes complex (Upadhyay et.al 1983). During the early pacts albedo seasonal when the precipitation is very little, approxmiately the entire runoff is from melting of seasonal snow cover. Even during the monsoon months the glacier and snow pack resting in high reaches contribute quite significantly to river discharge.

In such catchments floods occur when the wide spread rainstorms combine with snow and ice melt. Futher more, when rain water falles on the surface of snow ice the meltrate is multiplied manyfold owing to the large scale release of latent heat of condensation . Therefore it may not be possible to estimate the discharge by converting the snow melt into the corresponding water equivalent.

In order to test the results obtained the co-efficient of correlation between the observed discharge (corrected for rainfall) and the snow melt rate obtained by Energy Balance and Degree Day was calculated and found to be 0.75 and 0.54 respectively.

The correlation for degree day is not very high which implies that the densities assumed would have to be modified . As for the energy balance method the corelation is quite high indicating that the method can be used to develop working model for estimating runoff from glacier basins. However further improvement of the model is possible by incorporating data of number of years and more statistical analysis.. The data on mass balance also can be used effectivelly to modify the method.

As snowline recession has not been considred for the calculations it may lead to large error in calculating the effective snow covered area..

Figure.6.1 Temporal variations of snowmelt rate by Degree day and Energy balance methods (Zone 1-3)

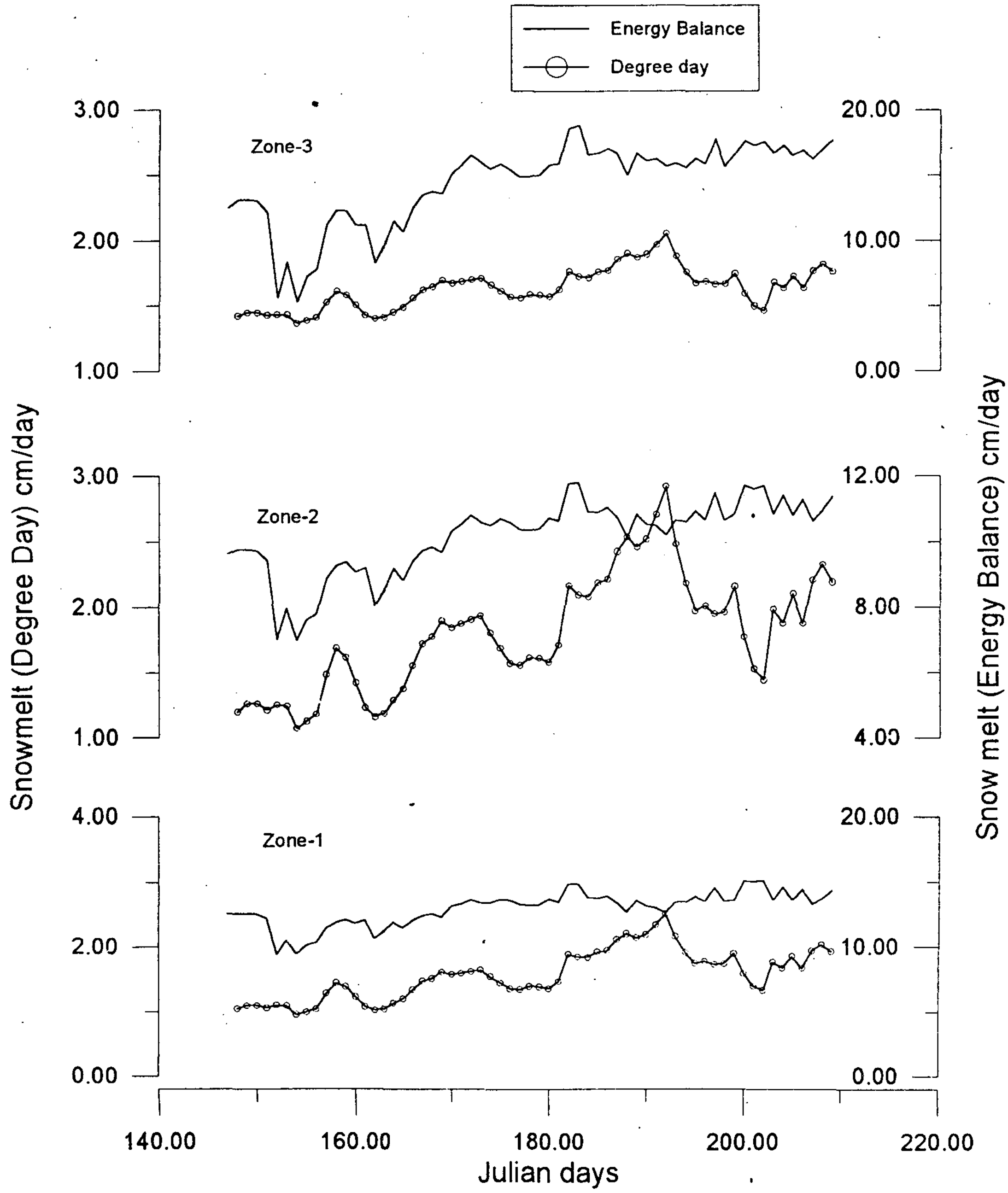


Figure 6.2 Temporal variations of snowmelt rate by Degree day and Energy balance method (Zone 4-6)

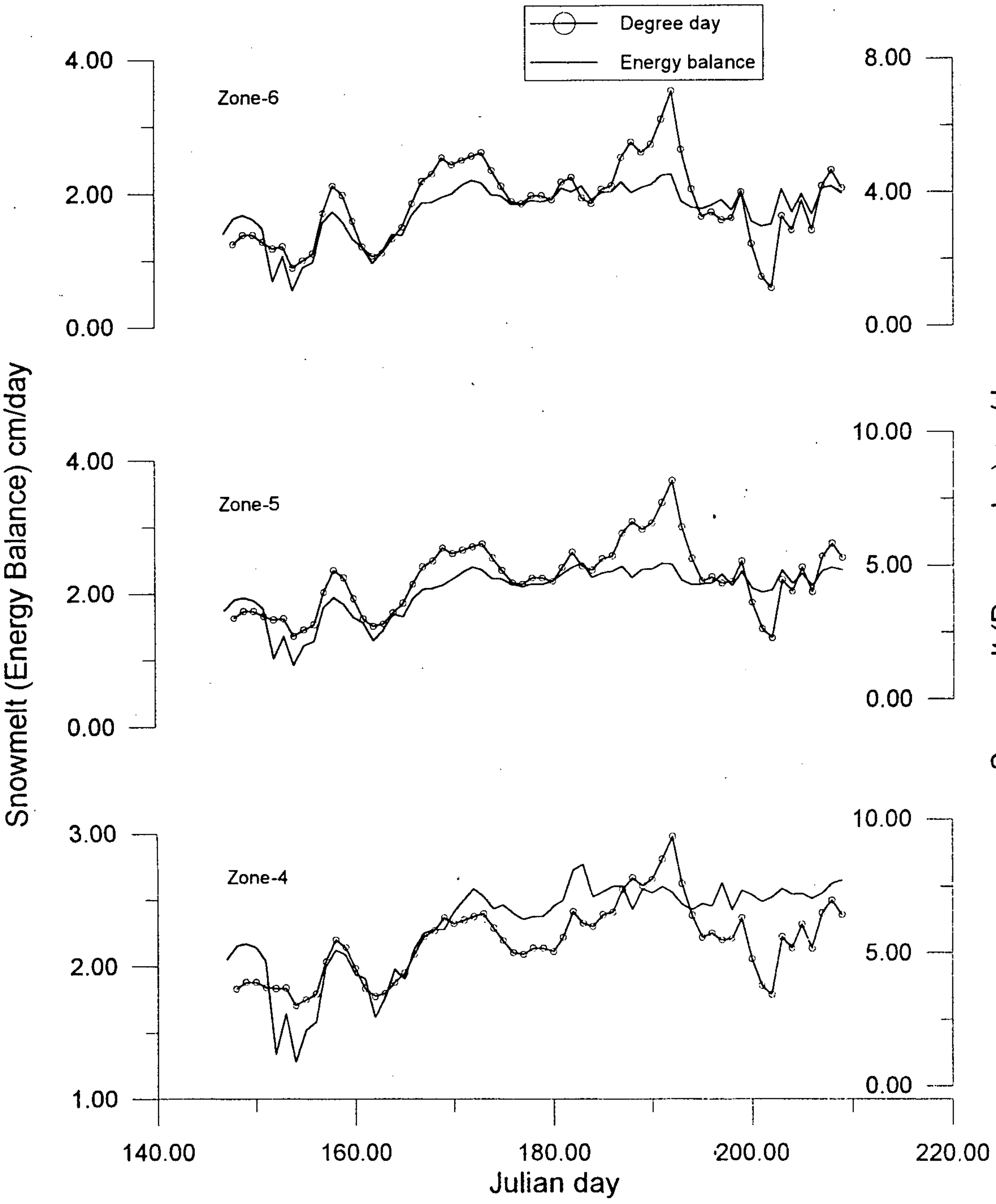


Figure - 6.3 Temporal variations of snowmelt rate by Degree day and Energy balance methods (Zone 7-9)

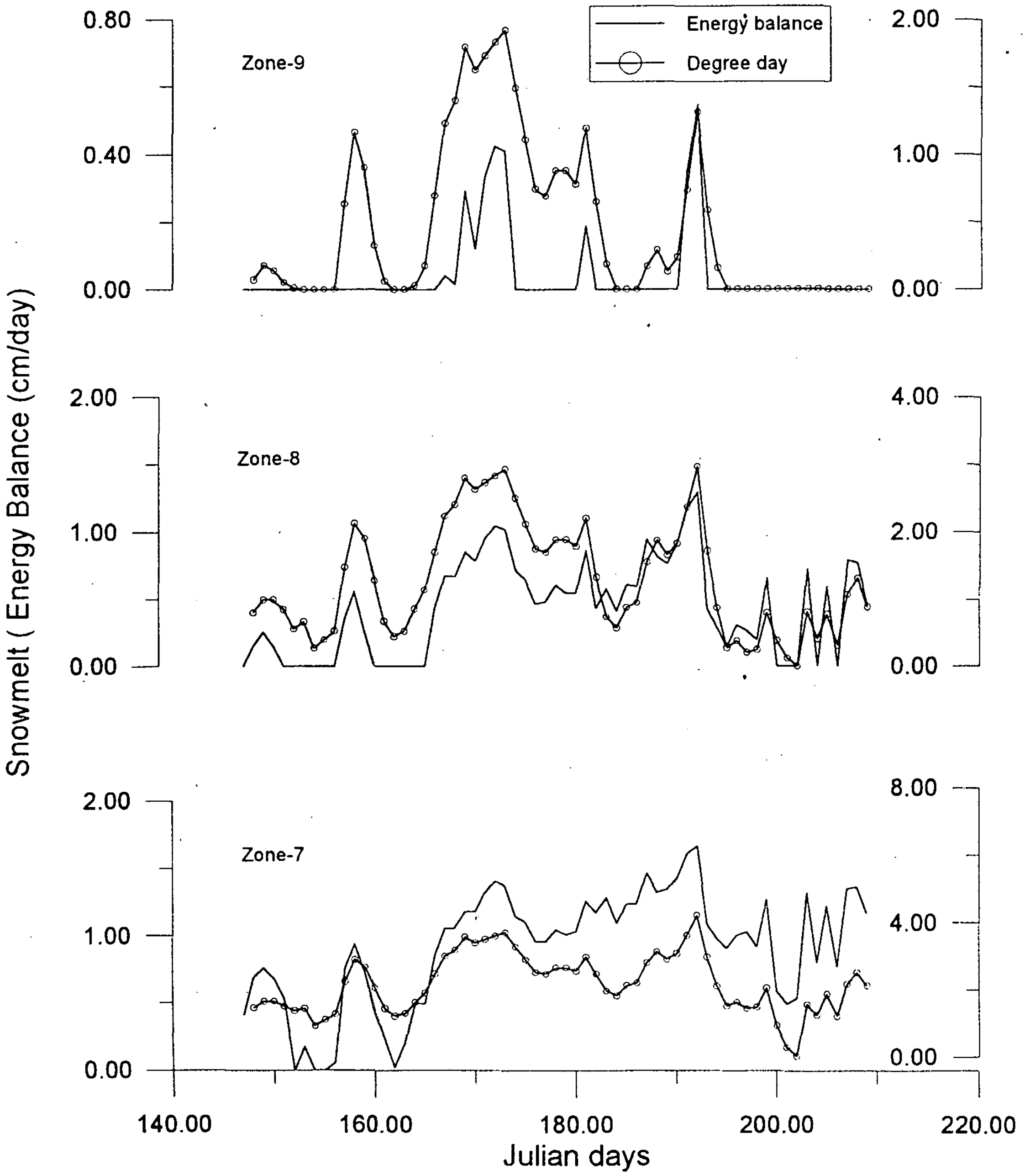


Figure. 6.4 Temporal variation of (a) observed discharge corrected for rain component (b) Average daily temperature at base camp (c) Calculated daily average snow melt rate

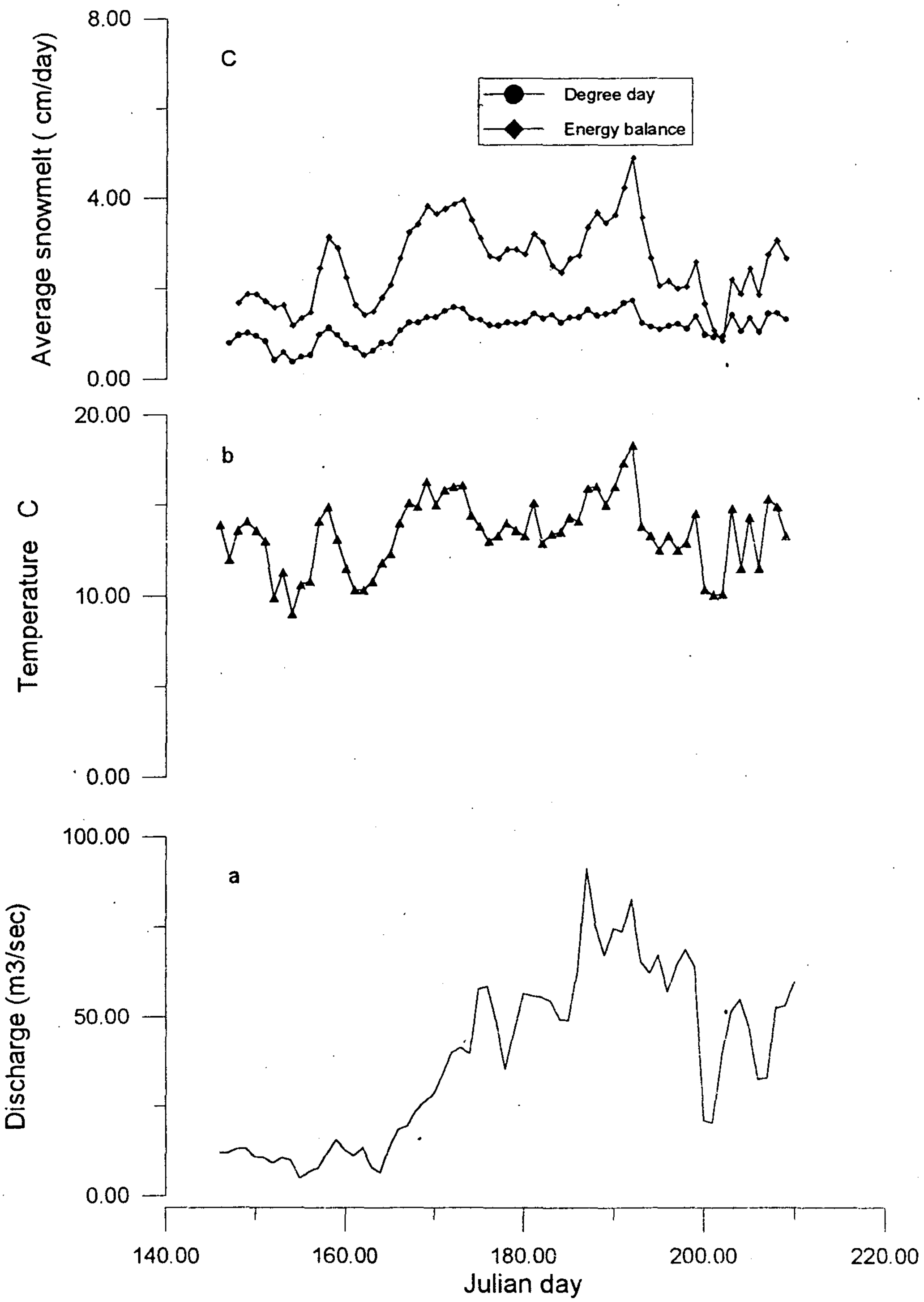


Table :6.1 Degree day calculations

Julian.d	Base camp temp:	TZ1	TZ2	TZ 3	TZ 4	TZ 5	TZ6	TZ7	TZ8	TZ9
146	13.9	12.6	11.63	10.33	9.03	7.73	6.43	5.13	3.18	0.58
147	12	10.7	9.73	8.43	7.13	5.83	4.53	3.23	1.28	0
148	13.6	12.3	11.33	10.03	8.73	7.43	6.13	4.83	2.88	0.28
149	14.1	12.8	11.83	10.53	9.23	7.93	6.63	5.33	3.38	0.78
150	13.6	12.3	11.33	10.03	8.73	7.43	6.13	4.83	2.88	0.28
151	13	11.7	10.73	9.43	8.13	6.83	5.53	4.23	2.28	0
152	9.9	8.76	7.91	6.77	5.63	4.49	3.35	2.21	0.5	0
153	11.3	10.16	9.31	8.17	7.03	5.89	4.75	3.61	1.9	0
154	9	7.86	7.01	5.87	4.73	3.59	2.45	1.31	0	0
155	10.6	9.46	8.61	7.47	6.33	5.19	4.05	2.91	1.2	0
156	10.8	9.66	8.81	7.67	6.53	5.39	4.25	3.11	1.4	0
157	14.1	12.96	12.11	10.97	9.83	8.69	7.55	6.41	4.7	2.42
158	14.9	13.76	12.91	11.77	10.63	9.49	8.35	7.21	5.5	3.22
159	13.1	11.96	11.11	9.97	8.83	7.69	6.55	5.41	3.7	1.42
160	11.5	10.36	9.51	8.37	7.23	6.09	4.95	3.81	2.1	0
161	10.3	9.16	8.31	7.17	6.03	4.89	3.75	2.61	0.9	0
162	10.3	9.16	8.31	7.17	6.03	4.89	3.75	2.61	0.9	0
163	10.8	9.66	8.81	7.67	6.53	5.39	4.25	3.11	1.4	0
164	11.8	10.66	9.81	8.67	7.53	6.39	5.25	4.11	2.4	0.12
165	12.3	11.16	10.31	9.17	8.03	6.89	5.75	4.61	2.9	0.62
166	14	12.86	12.01	10.87	9.73	8.59	7.45	6.31	4.6	2.32
167	15.1	13.96	13.11	11.97	10.83	9.69	8.55	7.41	5.7	3.42
168	14.9	13.76	12.91	11.77	10.63	9.49	8.35	7.21	5.5	3.22
169	16.3	15.16	14.31	13.17	12.03	10.89	9.75	8.61	6.9	4.62
170	15	13.86	13.01	11.87	10.73	9.59	8.45	7.31	5.6	3.32
171	15.8	14.66	13.81	12.67	11.53	10.39	9.25	8.11	6.4	4.12
172	16	14.86	14.01	12.87	11.73	10.59	9.45	8.31	6.6	4.32
173	16.1	14.96	14.11	12.97	11.83	10.69	9.55	8.41	6.7	4.42
174	14.4	13.26	12.41	11.27	10.13	8.99	7.85	6.71	5	2.72
175	13.8	12.66	11.81	10.67	9.53	8.39	7.25	6.11	4.4	2.12

TZ - Temperature of zones MRZ - Melt rate of zones ASM - Average daily snowmelt rate

Julian.d	Base temp:	TZ1	TZ2	TZ 3	TZ 4	TZ 5	TZ6	TZ7	TZ8	TZ9
176	13	11.86	11.01	9.87	8.73	7.59	6.45	5.31	3.6	1.32
177	13.3	12.16	11.31	10.17	9.03	7.89	6.75	5.61	3.9	1.62
178	14	12.86	12.01	10.87	9.73	8.59	7.45	6.31	4.6	2.32
179	13.6	12.46	11.61	10.47	9.33	8.19	7.05	5.91	4.2	1.92
180	13.3	12.16	11.31	10.17	9.03	7.89	6.75	5.61	3.9	1.62
181	15.1	13.96	13.11	11.97	10.83	9.69	8.55	7.41	5.7	3.42
182	12.9	11.4	10.28	8.78	7.28	5.78	4.28	2.78	0.53	0
183	13.4	11.9	10.78	9.28	7.78	6.28	4.78	3.28	1.03	0
184	13.5	12	10.88	9.38	7.88	6.38	4.88	3.38	1.13	0
185	14.3	12.8	11.68	10.18	8.68	7.18	5.68	4.18	1.93	0
186	14.1	12.6	11.48	9.98	8.48	6.98	5.48	3.98	1.73	0
187	15.9	14.4	13.28	11.78	10.28	8.78	7.28	5.78	3.53	0.53
188	16	14.5	13.38	11.88	10.38	8.88	7.38	5.88	3.63	0.63
189	15	13.5	12.38	10.88	9.38	7.88	6.38	4.88	2.63	0
190	16	14.5	13.38	11.88	10.38	8.88	7.38	5.88	3.63	0.63
191	17.3	15.8	14.68	13.18	11.68	10.18	8.68	7.18	4.93	1.93
192	18.3	16.8	15.68	14.18	12.68	11.18	9.68	8.18	5.93	2.93
193	13.8	12.3	11.18	9.68	8.18	6.68	5.18	3.68	1.43	0
194	13.3	11.8	10.68	9.18	7.68	6.18	4.68	3.18	0.93	0
195	12.5	11	9.88	8.38	6.88	5.38	3.88	2.38	0.13	0
196	13.3	11.8	10.68	9.18	7.68	6.18	4.68	3.18	0.93	0
197	12.5	11	9.88	8.38	6.88	5.38	3.88	2.38	0.13	0
198	12.9	11.4	10.28	8.78	7.28	5.78	4.28	2.78	0.53	0
199	14.5	13	11.88	10.38	8.88	7.38	5.88	4.38	2.13	0
200	10.3	8.8	7.68	6.18	4.68	3.18	1.68	0.18	0	0
201	10	8.5	7.38	5.88	4.38	2.88	1.38	0	0	0
202	10.1	8.6	7.48	5.98	4.48	2.98	1.48	0	0	0
203	14.8	13.3	12.18	10.68	9.18	7.68	6.18	4.68	2.43	0
204	11.5	10	8.88	7.38	5.88	4.38	2.88	1.38	0	0
205	14.3	12.8	11.68	10.18	8.68	7.18	5.68	4.18	1.93	0
206	11.5	10	8.88	7.38	5.88	4.38	2.88	1.38	0	0
207	15.3	13.8	12.68	11.18	9.68	8.18	6.68	5.18	2.93	0

208	14.9	13.4	12.28	10.78	9.28	7.78	6.28	4.78	2.53	0
209	13.3	11.82	10.68	9.18	7.68	6.18	4.68	3.18	0.93	0

MRZ1	MRZ	MRZ3	MRZ4	MRZ5	MRZ6	MRZ7	MRZ8	MRZ9
5.21	4.79	4.21	3.64	3.07	2.5	1.44	0.8	0.07
5.47	5.04	4.47	3.9	3.33	2.76	1.64	0.99	0.18
5.48	5.05	4.48	3.91	3.33	2.76	1.64	1	0.14
5.28	4.85	4.27	3.7	3.13	2.56	1.49	0.85	0.05
5.5	5	4.34	3.68	3.01	2.35	1.35	0.56	0.01
5.44	4.96	4.33	3.69	3.06	2.42	1.43	0.67	0
4.75	4.28	3.65	3.03	2.4	1.77	0.92	0.27	0
4.98	4.51	3.88	3.25	2.63	2	1.1	0.4	0
5.18	4.71	4.08	3.46	2.83	2.2	1.26	0.53	0
6.39	5.92	5.29	4.67	4.04	3.41	2.23	1.48	0.64
7.21	6.74	6.11	5.49	4.86	4.23	2.88	2.13	1.17
6.93	6.46	5.83	5.21	4.58	3.95	2.66	1.91	0.9
6.15	5.68	5.05	4.42	3.8	3.17	2.04	1.28	0.33
5.39	4.92	4.29	3.67	3.04	2.41	1.43	0.68	0.06
5.1	4.63	4.01	3.38	2.75	2.13	1.2	0.45	0
5.2	4.73	4.11	3.48	2.85	2.22	1.28	0.53	0
5.62	5.15	4.52	3.89	3.26	2.64	1.61	0.86	0.03
5.97	5.5	4.88	4.25	3.62	2.99	1.89	1.14	0.18
6.67	6.2	5.57	4.95	4.32	3.69	2.45	1.7	0.7
7.34	6.87	6.25	5.62	4.99	4.36	2.99	2.24	1.23
7.55	7.08	6.45	5.83	5.2	4.57	3.16	2.4	1.4
8.04	7.57	6.94	6.32	5.69	5.06	3.55	2.8	1.79
7.83	7.36	6.73	6.11	5.48	4.85	3.38	2.63	1.63
7.96	7.49	6.86	6.23	5.61	4.98	3.48	2.73	1.73
8.09	7.61	6.99	6.36	5.73	5.11	3.58	2.83	1.83
8.2	7.72	7.1	6.47	5.84	5.22	3.67	2.92	1.92
7.66	7.19	6.56	5.94	5.31	4.68	3.25	2.49	1.49
7.19	6.72	6.09	5.46	4.84	4.21	2.87	2.11	1.11

MRZ1	MRZ2	MRZ3	MRZ4	MRZ5	MRZ6	MRZ7	MRZ8	MRZ9
6.73	6.26	5.63	5.01	4.38	3.75	2.5	1.75	0.75
6.67	6.2	5.57	4.94	4.31	3.69	2.45	1.7	0.69
6.9	6.43	5.81	5.18	4.55	3.92	2.64	1.89	0.88
6.9	6.43	5.81	5.18	4.55	3.92	2.64	1.89	0.88
6.78	6.31	5.68	5.05	4.42	3.8	2.54	1.78	0.78
7.3	6.83	6.2	5.57	4.95	4.32	2.95	2.2	1.2
9.43	8.64	7.6	6.56	5.51	4.47	2.45	1.33	0.65
9.21	8.36	7.23	6.11	4.98	3.85	1.95	0.74	0.19
9.17	8.3	7.15	5.99	4.84	3.68	1.81	0.57	0
9.6	8.74	7.58	6.43	5.27	4.12	2.11	0.88	0
9.7	8.84	7.68	6.53	5.37	4.22	2.19	0.95	0
10.55	9.68	8.53	7.37	6.22	5.06	2.79	1.55	0.17
11	10.13	8.97	7.82	6.66	5.51	3.11	1.87	0.29
10.7	9.83	8.67	7.52	6.36	5.21	2.9	1.66	0.13
10.93	10.07	8.91	7.76	6.6	5.45	3.07	1.83	0.24
11.69	10.82	9.67	8.51	7.36	6.2	3.61	2.37	0.74
12.53	11.66	10.51	9.35	8.2	7.04	4.2	2.97	1.32
10.78	9.91	8.76	7.6	6.45	5.29	2.96	1.72	0.59
9.59	8.72	7.57	6.41	5.26	4.1	2.1	0.87	0.16
8.75	7.89	6.73	5.58	4.42	3.27	1.51	0.27	0
8.9	8.03	6.88	5.72	4.57	3.41	1.61	0.38	0
8.65	7.79	6.63	5.48	4.32	3.17	1.44	0.2	0
8.72	7.85	6.7	5.54	4.39	3.23	1.48	0.24	0
9.49	8.62	7.47	6.31	5.16	4	2.03	0.79	0
7.95	7.08	5.93	4.77	3.62	2.46	0.93	0.38	0
6.96	6.09	4.94	3.78	2.63	1.47	0.27	0.12	0
6.61	5.75	4.59	3.44	2.28	1.13	0.01	0	0
8.79	7.92	6.76	5.61	4.45	3.3	1.54	0.8	0
8.35	7.49	6.33	5.18	4.02	2.87	1.23	0.4	0
9.25	8.38	7.23	6.07	4.92	3.76	1.86	0.77	0
8.35	7.48	6.33	5.17	4.02	2.86	1.22	0.32	0
9.67	8.8	7.65	6.49	5.34	4.18	2.16	1.07	0

10.15	9.28	8.13	6.97	5.82	4.66	2.51	1.32	0
9.62	8.74	7.59	6.43	5.28	4.12	2.12	0.88	0

ASM
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41m

Table : 6.2 Components of Energy Balance Computations

julian.d	R0	QRS1	QRS2	QC1	QC2	QC3	QC4	QC5	QC6	QC7	QC8
147.00	996.47	232.58	186.14	51.35	52.23	52.11	50.32	46.61	40.74	32.48	15.04
148.00	997.60	232.84	186.35	48.41	50.41	52.04	52.28	50.89	47.65	42.30	29.81
149.00	998.54	233.06	186.53	47.16	49.46	51.57	52.37	51.63	49.13	44.62	33.56
150.00	1000.71	233.57	186.93	48.41	50.41	52.04	52.28	50.89	47.65	42.30	29.81
151.00	1001.68	233.79	187.11	49.71	51.32	52.34	51.86	49.64	45.45	39.06	24.78
152.00	1002.88	210.81	168.58	52.29	51.61	49.49	45.85	40.53	33.35	24.15	6.20
153.00	1003.91	211.02	168.76	51.93	52.36	51.89	50.10	46.82	41.90	35.16	21.28
154.00	1005.02	211.26	168.94	51.55	50.06	46.75	41.79	35.02	26.27	15.36	-5.43
155.00	1005.86	211.43	169.09	52.33	52.22	50.96	48.28	44.00	37.98	30.05	14.18
156.00	1006.73	211.61	169.23	52.26	52.31	51.28	48.86	44.88	39.17	31.59	16.30
157.00	1007.74	211.83	169.40	46.73	48.86	50.99	52.18	52.26	51.09	48.51	41.64
158.00	1008.55	212.00	169.54	44.39	46.88	49.58	51.45	52.32	52.05	50.48	45.33
159.00	1009.04	212.10	169.62	49.18	50.77	52.09	52.32	51.31	48.91	44.96	35.76
160.00	1009.66	212.23	169.72	51.75	52.32	52.07	50.52	47.51	42.89	36.48	23.15
161.00	1010.35	212.38	169.84	52.37	52.02	50.40	47.31	42.60	36.09	27.62	10.87
162.00	1011.01	212.51	169.95	52.37	52.02	50.40	47.31	42.60	36.09	27.62	10.87
163.00	1011.48	212.61	170.03	52.26	52.31	51.28	48.86	44.88	39.17	31.59	16.30
164.00	1011.95	212.71	170.11	51.41	52.19	52.25	51.06	48.46	44.27	38.35	25.83
165.00	1012.27	212.78	170.16	50.69	51.80	52.37	51.75	49.78	46.31	41.17	29.97
166.00	1012.59	212.85	170.22	47.00	49.08	51.13	52.23	52.21	50.93	48.21	41.12
167.00	1012.46	212.82	170.19	43.76	46.33	49.16	51.19	52.25	52.19	50.86	46.12
168.00	1012.94	212.92	170.28	44.39	46.88	49.58	51.45	52.32	52.05	50.48	45.33
169.00	1013.18	212.97	170.32	39.63	42.63	46.16	49.03	51.10	52.22	52.22	49.81
170.00	1013.22	212.98	170.32	44.07	46.61	49.38	51.32	52.29	52.13	50.67	45.73
171.00	1013.31	213.00	170.34	41.42	44.25	47.51	50.05	51.72	52.37	51.84	48.48
172.00	1013.40	213.02	170.35	40.71	43.61	46.99	49.66	51.50	52.33	52.02	49.05
173.00	1013.30	213.00	170.34	40.36	43.29	46.71	49.46	51.37	52.30	52.10	49.31
174.00	1013.19	212.97	170.32	45.89	48.16	50.51	51.96	52.35	51.53	49.34	43.13
175.00	1012.71	212.87	170.24	47.52	49.50	51.40	52.31	52.08	50.56	47.58	40.03
176.00	1012.62	212.85	170.22	49.39	50.93	52.15	52.28	51.16	48.63	44.53	35.09
177.00	1012.49	212.83	170.20	48.73	50.45	51.93	52.36	51.58	49.44	45.77	37.05
178.00	1012.02	212.73	170.12	47.00	49.08	51.13	52.23	52.21	50.93	48.21	41.12

179.00	1011.48	212.61	170.03	48.02	49.90	51.63	52.36	51.91	50.15	46.90	38.88
180.00	1010.84	212.48	169.92	48.73	50.45	51.93	52.36	51.58	49.44	45.77	37.05
julian.d	R0	QRS1	QRS2	QC1	QC2	QC3	QC4	QC5	QC6	QC7	QC8
181.00	1010.53	212.41	169.87	43.76	46.33	49.16	51.19	52.25	52.19	50.86	46.12
182.00	1010.04	178.47	148.68	50.28	51.83	52.30	50.62	46.42	39.35	29.01	6.56
183.00	1009.36	178.35	148.58	49.30	51.26	52.36	51.44	48.12	42.05	32.84	12.33
184.00	1008.47	178.20	148.45	49.09	51.12	52.35	51.57	48.43	42.55	33.56	13.42
185.00	1007.81	178.08	148.35	47.16	49.76	51.92	52.26	50.42	46.05	38.76	21.57
186.00	1006.86	177.91	148.21	47.68	50.14	52.08	52.15	49.99	45.25	37.55	19.64
187.00	1006.02	177.76	148.09	42.31	45.84	49.56	51.83	52.30	50.62	46.42	34.61
188.00	1004.99	177.58	147.93	41.97	45.55	49.36	51.73	52.33	50.80	46.79	35.29
189.00	1004.99	177.58	147.93	45.18	48.23	51.12	52.35	51.57	48.43	42.55	27.79
190.00	1003.02	177.23	147.64	41.97	45.55	49.36	51.73	52.33	50.80	46.79	35.29
191.00	1001.84	177.03	147.47	37.24	41.36	46.13	49.76	51.92	52.26	50.42	42.79
192.00	1000.82	176.84	147.32	33.31	37.72	43.06	47.48	50.66	52.25	51.90	46.97
193.00	999.60	176.63	147.14	48.41	50.66	52.25	51.90	49.26	43.96	35.63	16.61
194.00	998.16	176.37	146.93	49.51	51.39	52.37	51.30	47.81	41.54	32.11	11.21
195.00	996.79	176.13	146.73	50.94	52.14	52.08	49.76	44.83	36.93	25.66	1.61
196.00	995.52	175.91	146.54	49.51	51.39	52.37	51.30	47.81	41.54	32.11	11.21
197.00	993.96	175.63	146.31	50.94	52.14	52.08	49.76	44.83	36.93	25.66	1.61
198.00	992.65	175.40	146.12	50.28	51.83	52.30	50.62	46.42	39.35	29.01	6.56
199.00	990.92	175.10	145.86	46.62	49.36	51.73	52.33	50.80	46.79	39.92	23.43
200.00	989.50	174.84	145.65	52.31	51.30	47.81	41.54	32.11	19.14	2.25	-31.34
201.00	987.51	174.49	145.36	52.16	50.80	46.79	39.92	29.81	16.09	-1.64	-36.63
202.00	986.28	174.28	145.18	52.22	50.98	47.14	40.47	30.59	17.13	-0.33	-34.85
203.00	984.11	173.89	144.86	45.77	48.70	51.39	52.37	51.30	47.81	41.54	26.09
204.00	982.48	173.60	144.62	52.06	52.33	50.80	46.79	39.92	29.81	16.09	-12.13
205.00	980.61	173.27	144.35	47.16	49.76	51.92	52.26	50.42	46.05	38.76	21.57
206.00	978.53	172.91	144.04	52.06	52.33	50.80	46.79	39.92	29.81	16.09	-12.13
207.00	976.56	172.56	143.75	44.26	47.48	50.66	52.25	51.90	49.26	43.96	30.20
208.00	974.71	172.23	143.48	45.48	48.47	51.26	52.36	51.44	48.12	42.05	26.95
209.00	972.29	171.80	143.12	49.47	51.39	52.37	51.30	47.81	41.54	32.11	11.21

QRS1 - Short wave energy component (ablation zone)(ly/day)

1-9 - Glacier zones

QRS2 - Short wave energy component (accumulation zone) (ly/day)

QL - Long wave energy component (ly/day

QC - Sensible heat component (ly/day)

QE - Latent heat component (ly/day)

SM - Snow melt rate in, cm/day

ASM - Average snow melt, cm/day

QC9	julian.d	QE1	QE2	QE3	QE4	QE5	QE6	QE7	QE8
-18.98	147.00	2.59	-1.58	-8.11	-15.73	-30.41	-44.44	-60.49	-83.39
3.50	148.00	-1.00	-4.57	-10.24	-16.92	-29.38	-41.56	-55.56	-75.97
9.50	149.00	-2.68	-6.14	-11.61	-18.06	-29.83	-41.42	-54.77	-74.38
3.50	150.00	-2.24	-5.88	-11.61	-18.35	-30.72	-42.82	-56.72	-77.03
-4.33	151.00	-5.78	-9.83	-16.09	-23.36	-36.13	-48.63	-62.87	-83.69
-26.42	152.00	-15.69	-21.06	-28.94	-37.62	-51.91	-65.41	-80.29	-101.37
-5.15	153.00	-5.34	-9.91	-16.74	-24.40	-37.98	-50.76	-65.03	-85.14
-42.31	154.00	-11.00	-16.77	-25.21	-34.48	-50.42	-65.24	-81.57	-104.33
-15.28	155.00	-9.28	-14.24	-21.59	-29.75	-43.81	-57.03	-71.71	-92.41
-12.28	156.00	-6.51	-11.33	-18.50	-26.51	-40.58	-53.80	-68.51	-89.18
26.01	157.00	1.37	-1.78	-6.71	-12.46	-23.46	-33.98	-46.00	-63.16
32.41	158.00	6.33	3.72	-0.51	-5.58	-16.14	-26.23	-37.91	-54.53
16.51	159.00	12.63	9.38	4.21	-1.88	-14.99	-27.18	-41.16	-60.50
-2.44	160.00	12.97	8.87	2.55	-4.72	-19.81	-33.65	-49.34	-70.78
-19.93	161.00	21.18	16.52	9.39	1.26	-16.19	-31.91	-49.66	-73.45
-19.93	162.00	-0.54	-5.52	-12.94	-21.24	-36.53	-50.70	-66.49	-88.37
-12.28	163.00	5.48	0.86	-6.11	-13.99	-29.24	-43.30	-59.09	-80.81
1.48	164.00	13.29	9.36	3.27	-3.77	-18.52	-32.07	-47.46	-68.53
7.63	165.00	4.60	0.73	-5.22	-12.05	-25.37	-37.83	-51.93	-71.60
25.13	166.00	10.07	7.19	2.55	-2.99	-14.84	-25.99	-38.85	-56.86
33.85	167.00	13.10	10.88	7.12	2.45	-8.44	-18.74	-30.81	-47.73
32.41	168.00	15.53	13.31	9.53	4.82	-6.49	-17.11	-29.57	-46.93
41.22	169.00	10.10	8.30	5.15	1.14	-8.26	-17.31	-28.03	-43.31
33.13	170.00	24.37	22.58	19.32	15.05	3.13	-7.91	-21.02	-38.97
38.41	171.00	26.57	25.37	22.87	19.36	8.18	-2.20	-14.73	-31.88
39.58	172.00	30.97	30.12	28.07	24.95	13.67	3.25	-9.45	-26.71
40.14	173.00	27.08	26.09	23.88	20.64	9.77	-0.34	-12.63	-29.46
28.53	174.00	28.71	26.74	23.19	18.59	5.61	-6.28	-20.35	-39.40
23.34	175.00	34.12	31.96	28.11	23.17	9.00	-3.84	-18.98	-39.23
15.46	176.00	34.55	31.88	27.34	21.70	6.49	-7.22	-23.22	-44.54
18.54	177.00	29.44	26.81	22.37	16.86	2.48	-10.58	-25.83	-46.33
25.13	178.00	26.85	24.57	20.60	15.61	2.31	-9.88	-24.19	-43.58

21.47	179.00	29.54	27.10	22.91	17.66	3.64	-9.12	-24.07	-44.19
18.54	180.00	36.42	34.01	29.80	24.48	9.48	-4.03	-19.89	-40.97
QC9	julian.d	QE1	QE2	QE3	QE4	QE5	QE6	QE7	QE8
33.85	181.00	29.98	28.50	25.60	21.65	9.39	-1.87	-15.36	-33.64
-38.44	182.00	47.77	46.58	43.44	38.49	20.24	3.16	-17.85	-46.79
-29.63	183.00	47.50	46.72	44.13	39.76	22.29	5.88	-14.47	-42.57
-27.93	184.00	32.00	30.31	26.66	21.38	5.10	-10.47	-29.48	-56.28
-15.13	185.00	30.57	29.36	26.39	21.82	6.76	-7.76	-25.68	-51.12
-18.20	186.00	33.79	32.66	29.76	25.23	9.69	-5.22	-23.63	-49.61
6.56	187.00	27.17	26.83	25.11	21.88	9.21	-3.26	-19.04	-41.79
7.75	188.00	16.68	15.47	12.70	8.54	-3.50	-15.54	-30.46	-52.39
-5.01	189.00	29.36	28.56	26.18	22.23	8.21	-5.41	-22.41	-46.68
7.75	190.00	24.01	23.46	21.49	18.06	5.68	-6.59	-22.03	-44.42
21.57	191.00	23.66	23.96	23.20	21.04	10.37	-0.38	-14.32	-34.76
30.20	192.00	19.28	19.75	19.33	17.60	8.33	-1.22	-13.78	-32.52
-22.97	193.00	28.29	26.58	22.93	17.69	2.08	-12.95	-31.30	-57.36
-31.34	194.00	28.17	26.10	21.97	16.23	-0.07	-15.71	-34.66	-61.50
-45.90	195.00	36.22	34.05	29.69	23.63	5.60	-11.43	-32.03	-60.75
-31.34	196.00	30.16	28.22	24.23	18.63	2.18	-13.55	-32.65	-59.64
-45.90	197.00	46.49	44.89	41.21	35.72	16.95	-0.60	-22.02	-51.52
-38.44	198.00	31.01	28.83	24.52	18.56	1.49	-14.78	-34.45	-62.14
-12.13	199.00	32.59	31.68	29.08	24.88	9.98	-4.38	-22.22	-47.49
-93.68	200.00	58.73	55.84	50.28	42.79	19.57	-1.65	-27.01	-61.20
-101.13	201.00	58.69	55.53	49.62	41.76	18.05	-3.59	-29.35	-64.07
-98.62	202.00	59.99	56.98	51.24	43.56	19.90	-1.67	-27.41	-62.06
-7.80	203.00	32.91	32.24	29.99	26.13	11.63	-2.37	-19.87	-44.69
-66.16	204.00	49.79	47.53	42.92	36.45	15.88	-3.18	-26.18	-57.60
-15.13	205.00	33.48	32.49	29.76	25.42	10.18	-4.46	-22.61	-48.25
-66.16	206.00	48.14	45.80	41.09	34.55	14.10	-4.86	-27.72	-59.02
-0.98	207.00	30.17	29.65	27.64	24.08	10.43	-2.86	-19.56	-43.42
-6.40	208.00	36.22	35.88	34.04	30.56	16.02	2.01	-15.62	-40.51
-31.34	209.00	45.99	45.16	42.36	37.77	20.25	3.77	-16.60	-44.76

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QE9	julian.d	QL1	QL2	QL3	QL4	QL5	QL6	QL7
-118.81	147.00	-96.06	-100.26	-105.79	-111.24	-116.61	-121.91	-127.14
-107.79	148.00	-89.08	-93.35	-98.97	-104.52	-109.99	-115.38	-120.70
-105.01	149.00	-86.88	-91.17	-96.82	-102.39	-107.89	-113.31	-118.66
-108.65	150.00	-89.08	-93.35	-98.97	-104.52	-109.99	-115.38	-120.70
-115.89	151.00	-91.71	-95.95	-101.54	-107.05	-112.48	-117.84	-123.13
-132.80	152.00	-104.37	-107.98	-112.73	-117.43	-122.08	-126.66	-131.19
-115.50	153.00	-98.39	-102.05	-106.88	-111.65	-116.37	-121.02	-125.62
-138.18	154.00	-108.16	-111.74	-116.45	-121.10	-125.70	-130.24	-134.73
-123.47	155.00	-101.39	-105.03	-109.82	-114.55	-119.23	-123.85	-128.42
-120.28	156.00	-100.54	-104.18	-108.98	-113.73	-118.42	-123.05	-127.62
-89.68	157.00	-86.17	-89.94	-94.91	-99.83	-104.69	-109.48	-114.22
-80.52	158.00	-82.61	-86.41	-91.43	-96.39	-101.28	-106.12	-110.90
-90.42	159.00	-90.58	-94.31	-99.23	-104.09	-108.90	-113.65	-118.33
-103.52	160.00	-97.53	-101.20	-106.04	-110.82	-115.54	-120.21	-124.82
-109.56	161.00	-102.67	-106.29	-111.07	-115.79	-120.45	-125.06	-129.61
-121.27	162.00	-102.67	-106.29	-111.07	-115.79	-120.45	-125.06	-129.61
-113.69	163.00	-100.54	-104.18	-108.98	-113.73	-118.42	-123.05	-127.62
-100.78	164.00	-96.24	-99.92	-104.77	-109.57	-114.31	-118.99	-123.61
-101.67	165.00	-94.07	-97.77	-102.65	-107.47	-112.24	-116.94	-121.59
-84.89	166.00	-86.61	-90.38	-95.35	-100.26	-105.11	-109.90	-114.64
-74.47	167.00	-81.72	-85.53	-90.55	-95.52	-100.43	-105.28	-110.07
-74.36	168.00	-82.61	-86.41	-91.43	-96.39	-101.28	-106.12	-110.90
-67.72	169.00	-76.31	-80.17	-85.26	-90.29	-95.26	-100.17	-105.03
-67.64	170.00	-82.16	-85.97	-90.99	-95.95	-100.86	-105.70	-110.49
-59.68	171.00	-78.57	-82.41	-87.47	-92.48	-97.42	-102.31	-107.13
-54.91	172.00	-77.67	-81.51	-86.59	-91.60	-96.56	-101.46	-106.29
-56.90	173.00	-77.22	-81.07	-86.15	-91.17	-96.13	-101.03	-105.87
-69.68	174.00	-84.84	-88.62	-93.61	-98.54	-103.41	-108.23	-112.98
-71.30	175.00	-87.50	-91.25	-96.21	-101.11	-105.95	-110.74	-115.46
-77.97	176.00	-91.01	-94.74	-99.66	-104.52	-109.32	-114.06	-118.74
-78.48	177.00	-89.70	-93.44	-98.37	-103.24	-108.06	-112.82	-117.52
-74.20	178.00	-86.61	-90.38	-95.35	-100.26	-105.11	-109.90	-114.64

-75.87	179.00	-88.38	-92.13	-97.08	-101.97	-106.80	-111.57	-116.28
-74.20	180.00	-89.70	-93.44	-98.37	-103.24	-108.06	-112.82	-117.52

QE9	julian.d	QL1	QL2	QL3	QL4	QL5	QL6	QL7
-63.03	181.00	-81.72	-85.53	-90.55	-95.52	-100.43	-105.28	-110.07
-94.56	182.00	-51.09	-53.76	-57.28	-60.75	-64.16	-67.51	-70.81
-89.29	183.00	-49.89	-52.58	-56.12	-59.60	-63.03	-66.40	-69.72
-100.29	184.00	-49.65	-52.34	-55.88	-59.37	-62.80	-66.17	-69.50
-93.30	185.00	-47.71	-50.43	-54.00	-57.52	-60.98	-64.38	-67.73
-92.72	186.00	-48.20	-50.91	-54.47	-57.98	-61.43	-64.83	-68.17
-80.32	187.00	-43.79	-46.56	-50.19	-53.76	-57.28	-60.75	-64.16
-88.97	188.00	-43.55	-46.31	-49.95	-53.53	-57.05	-60.52	-63.93
-87.29	189.00	-46.01	-48.74	-52.34	-55.88	-59.37	-62.80	-66.17
-82.24	190.00	-43.55	-46.31	-49.95	-53.53	-57.05	-60.52	-63.93
-70.11	191.00	-40.31	-43.11	-46.80	-50.43	-54.00	-57.52	-60.98
-65.32	192.00	-37.79	-40.62	-44.35	-48.02	-51.63	-55.18	-58.68
-100.17	193.00	-48.92	-51.63	-55.18	-58.68	-62.12	-65.50	-68.84
-105.30	194.00	-50.13	-52.82	-56.35	-59.83	-63.25	-66.62	-69.93
-107.49	195.00	-52.04	-54.71	-58.21	-61.66	-65.06	-68.39	-71.68
-103.76	196.00	-50.13	-52.82	-56.35	-59.83	-63.25	-66.62	-69.93
-99.90	197.00	-52.04	-54.71	-58.21	-61.66	-65.06	-68.39	-71.68
-107.21	198.00	-51.09	-53.76	-57.28	-60.75	-64.16	-67.51	-70.81
-89.61	199.00	-47.23	-49.95	-53.53	-57.05	-60.52	-63.93	-67.29
-116.15	200.00	-57.23	-59.83	-63.25	-66.62	-69.93	-73.20	-76.40
-119.67	201.00	-57.92	-60.52	-63.93	-67.29	-70.59	-73.84	-77.04
-117.64	202.00	-57.69	-60.29	-63.70	-67.07	-70.37	-73.63	-76.83
-86.29	203.00	-46.49	-49.22	-52.82	-56.35	-59.83	-63.25	-66.62
-108.58	204.00	-54.41	-57.05	-60.52	-63.93	-67.29	-70.59	-73.84
-90.92	205.00	-47.71	-50.43	-54.00	-57.52	-60.98	-64.38	-67.73
-109.74	206.00	-54.41	-57.05	-60.52	-63.93	-67.29	-70.59	-73.84
-83.60	207.00	-45.27	-48.02	-51.63	-55.18	-58.68	-62.12	-65.50
-82.46	208.00	-46.25	-48.98	-52.58	-56.12	-59.60	-63.03	-66.40
-91.46	209.00	-50.08	-52.82	-56.35	-59.83	-63.25	-66.62	-69.93

QL8	QL9	julian.d	SM1	SM2	SM3	SM4	SM5	SM6
-134.85	-144.87	147.00	2.51	2.41	2.25	2.05	1.74	1.41
-128.54	-138.73	148.00	2.52	2.44	2.31	2.15	1.90	1.63
-126.54	-136.80	149.00	2.51	2.44	2.32	2.17	1.93	1.68
-128.54	-138.73	150.00	2.51	2.43	2.30	2.14	1.89	1.62
-130.92	-141.05	151.00	2.45	2.36	2.22	2.04	1.77	1.48
-137.88	-146.61	152.00	1.88	1.75	1.56	1.34	1.02	0.69
-132.41	-141.28	153.00	2.10	1.99	1.83	1.65	1.36	1.07
-141.35	-149.99	154.00	1.89	1.75	1.53	1.28	0.92	0.55
-135.16	-143.95	155.00	2.01	1.90	1.72	1.52	1.22	0.90
-134.38	-143.19	156.00	2.06	1.95	1.78	1.58	1.28	0.97
-121.23	-130.36	157.00	2.29	2.22	2.12	2.00	1.79	1.57
-117.97	-127.18	158.00	2.37	2.32	2.23	2.12	1.93	1.73
-125.26	-134.30	159.00	2.41	2.34	2.23	2.08	1.84	1.58
-131.63	-140.51	160.00	2.36	2.27	2.12	1.94	1.64	1.33
-136.33	-145.09	161.00	2.41	2.30	2.12	1.91	1.56	1.20
-136.33	-145.09	162.00	2.13	2.01	1.83	1.62	1.29	0.96
-134.38	-143.19	163.00	2.23	2.13	1.96	1.76	1.45	1.12
-130.44	-139.35	164.00	2.38	2.29	2.15	1.98	1.69	1.39
-128.46	-137.42	165.00	2.29	2.20	2.07	1.91	1.64	1.37
-121.63	-130.76	166.00	2.41	2.35	2.25	2.13	1.91	1.68
-117.15	-126.38	167.00	2.47	2.43	2.35	2.25	2.06	1.86
-117.97	-127.18	168.00	2.50	2.46	2.38	2.27	2.07	1.86
-112.19	-121.55	169.00	2.45	2.42	2.36	2.27	2.11	1.94
-117.56	-126.78	170.00	2.62	2.58	2.51	2.41	2.20	1.99
-114.27	-123.57	171.00	2.66	2.63	2.58	2.50	2.31	2.12
-113.44	-122.76	172.00	2.72	2.70	2.65	2.58	2.39	2.20
-113.02	-122.36	173.00	2.67	2.65	2.60	2.53	2.34	2.16
-120.01	-129.17	174.00	2.67	2.62	2.54	2.43	2.20	1.97
-122.44	-131.55	175.00	2.72	2.67	2.58	2.46	2.21	1.96
-125.66	-134.69	176.00	2.71	2.64	2.54	2.40	2.12	1.84
-124.46	-133.51	177.00	2.65	2.59	2.48	2.35	2.09	1.83
-121.63	-130.76	178.00	2.63	2.58	2.49	2.37	2.13	1.89

QL8	QL9	julian.d	SM1	SM2	SM3	SM4	SM5	SM6
-134.85	-144.87	147.00	2.51	2.41	2.25	2.05	1.74	1.41
-128.54	-138.73	148.00	2.52	2.44	2.31	2.15	1.90	1.63
-126.54	-136.80	149.00	2.51	2.44	2.32	2.17	1.93	1.68
-128.54	-138.73	150.00	2.51	2.43	2.30	2.14	1.89	1.62
-130.92	-141.05	151.00	2.45	2.36	2.22	2.04	1.77	1.48
-137.88	-146.61	152.00	1.88	1.75	1.56	1.34	1.02	0.69
-132.41	-141.28	153.00	2.10	1.99	1.83	1.65	1.36	1.07
-141.35	-149.99	154.00	1.89	1.75	1.53	1.28	0.92	0.55
-135.16	-143.95	155.00	2.01	1.90	1.72	1.52	1.22	0.90
-134.38	-143.19	156.00	2.06	1.95	1.78	1.58	1.28	0.97
-121.23	-130.36	157.00	2.29	2.22	2.12	2.00	1.79	1.57
-117.97	-127.18	158.00	2.37	2.32	2.23	2.12	1.93	1.73
-125.26	-134.30	159.00	2.41	2.34	2.23	2.08	1.84	1.58
-131.63	-140.51	160.00	2.36	2.27	2.12	1.94	1.64	1.33
-136.33	-145.09	161.00	2.41	2.30	2.12	1.91	1.56	1.20
-136.33	-145.09	162.00	2.13	2.01	1.83	1.62	1.29	0.96
-134.38	-143.19	163.00	2.23	2.13	1.96	1.76	1.45	1.12
-130.44	-139.35	164.00	2.38	2.29	2.15	1.98	1.69	1.39
-128.46	-137.42	165.00	2.29	2.20	2.07	1.91	1.64	1.37
-121.63	-130.76	166.00	2.41	2.35	2.25	2.13	1.91	1.68
-117.15	-126.38	167.00	2.47	2.43	2.35	2.25	2.06	1.86
-117.97	-127.18	168.00	2.50	2.46	2.38	2.27	2.07	1.86
-112.19	-121.55	169.00	2.45	2.42	2.36	2.27	2.11	1.94
-117.56	-126.78	170.00	2.62	2.58	2.51	2.41	2.20	1.99
-114.27	-123.57	171.00	2.66	2.63	2.58	2.50	2.31	2.12
-113.44	-122.76	172.00	2.72	2.70	2.65	2.58	2.39	2.20
-113.02	-122.36	173.00	2.67	2.65	2.60	2.53	2.34	2.16
-120.01	-129.17	174.00	2.67	2.62	2.54	2.43	2.20	1.97
-122.44	-131.55	175.00	2.72	2.67	2.58	2.46	2.21	1.96
-125.66	-134.69	176.00	2.71	2.64	2.54	2.40	2.12	1.84
-124.46	-133.51	177.00	2.65	2.59	2.48	2.35	2.09	1.83
-121.63	-130.76	178.00	2.63	2.58	2.49	2.37	2.13	1.89

SM7	SM8	SM9	ASM
0.41	0.00	0.00	0.79
0.69	0.15	0.00	0.96
0.76	0.25	0.00	1.01
0.68	0.15	0.00	0.95
0.53	0.00	0.00	0.83
0.00	0.00	0.00	0.41
0.17	0.00	0.00	0.58
0.00	0.00	0.00	0.38
0.00	0.00	0.00	0.48
0.06	0.00	0.00	0.52
0.76	0.35	0.00	0.98
0.94	0.56	0.00	1.13
0.72	0.26	0.00	0.97
0.42	0.00	0.00	0.75
0.24	0.00	0.00	0.68
0.02	0.00	0.00	0.52
0.20	0.00	0.00	0.62
0.49	0.00	0.00	0.79
0.50	0.00	0.00	0.78
0.85	0.43	0.00	1.07
1.05	0.68	0.04	1.24
1.06	0.67	0.01	1.24
1.18	0.85	0.29	1.36
1.18	0.78	0.12	1.36
1.32	0.96	0.34	1.50
1.40	1.04	0.42	1.58
1.37	1.02	0.41	1.55
1.14	0.71	0.00	1.32
1.10	0.64	0.00	1.29
0.96	0.46	0.00	1.18
0.96	0.48	0.00	1.18
1.05	0.61	0.00	1.24

1.01	0.55	0.00	1.22
1.03	0.55	0.00	1.24

SM7	SM8	SM9	ASM
1.25	0.86	0.19	1.43
1.17	0.43	0.00	1.33
1.28	0.58	0.00	1.41
1.09	0.41	0.00	1.24
1.23	0.61	0.00	1.35
1.24	0.59	0.00	1.36
1.46	0.94	0.00	1.52
1.32	0.81	0.00	1.39
1.34	0.76	0.00	1.43
1.43	0.92	0.00	1.49
1.61	1.18	0.35	1.67
1.67	1.29	0.55	1.73
1.09	0.43	0.00	1.23
0.98	0.29	0.00	1.14
0.90	0.15	0.00	1.10
1.00	0.31	0.00	1.16
1.03	0.26	0.00	1.21
0.92	0.20	0.00	1.10
1.27	0.65	0.00	1.37
0.59	0.00	0.00	0.96
0.49	0.00	0.00	0.91
0.53	0.00	0.00	0.93
1.31	0.72	0.00	1.41
0.80	0.00	0.00	1.04
1.22	0.59	0.00	1.33
0.77	0.00	0.00	1.02
1.35	0.79	0.00	1.43
1.36	0.77	0.00	1.45
1.17	0.46	0.00	1.31

Table : 6.3 Comparison of Corrected discharge and

Melt rate by Energy balance and Degree day methods

Date	J.Day	Corrected Discharge 10^4 m3	Melt rate	
			Energy Balance cm/day	Degree Day cm/day
26/5/94	146	12.01		
27	147	12.18	0.79	
28	148	13.14	0.96	1.6788
29	149	13.13	1.01	1.8797
30	150	10.84	0.95	1.8781
31	151	10.66	0.83	1.721
1/6/94	152	9.11	0.41	1.5761
2	153	10.59	0.58	1.634
3	154	9.88	0.38	1.1751
4	155	4.87	0.48	1.3321
5	156	6.71	0.52	1.4765
6	157	7.73	0.98	2.4559
7	158	11.75	1.13	3.1338
8	159	15.72	0.97	2.8919
9	160	12.63	0.75	2.2373
10	161	11.02	0.68	1.6366
11	162	13.48	0.52	1.4148
12	163	7.99	0.62	1.489
13	164	6.35	0.79	1.8017
14	165	13.22	0.78	2.0873
15	166	18.49	1.07	2.6733
16	167	19.53	1.24	3.2407
17	168	23.59	1.24	3.4174
18	169	26.24	1.36	3.8314
19	170	28.68	1.36	3.6546
20	171	33.96	1.5	3.7616
21	172	40.00	1.58	3.8686
22	173	41.39	1.55	3.9616
23	174	39.71	1.32	3.5105
24	175	57.80	1.29	3.1105
25	176	58.50	1.18	2.7244
26	177	47.93	1.18	2.6686
27	178	35.46	1.24	2.8686
28	179	46.28	1.22	2.8686
29	180	56.36	1.24	2.7616
30	181	55.73	1.43	3.2035
1/7/94	182	55.39	1.33	3.0134
2	183	54.54	1.41	2.5042
3	184	49.23	1.24	2.3577
4	185	48.86	1.35	2.6622
5	186	62.93	1.36	2.7329
6	187	91.17	1.52	3.352
7	188	75.49	1.39	3.6818
8	189	67.08	1.43	3.4503
9	190	74.63	1.49	3.632
10	191	73.61	1.67	4.2249
11	192	82.51	1.73	4.8875
12	193	65.30	1.23	3.5652
13	194	62.07	1.14	2.6707
14	195	67.26	1.1	2.064
15	196	56.85	1.16	2.1673
16	197	64.47	1.21	1.9933
17	198	68.58	1.1	2.0368
18	199	63.95	1.37	2.5806
19	200	20.99	0.96	1.6468
20	201	20.30	0.91	1.0612
21	202	38.72	0.93	0.8424
22	203	51.34	1.41	2.2024
23	204	54.76	1.04	1.8745

24	205	47.28	1.33	2.4445
25	206	32.52	1.02	1.8514
26	207	33.01	1.43	2.7435
27	208	52.37	1.45	3.0591
28	209	53.09	1.31	2.6677

CHAPTER 7

CONCLUSION

1) The average snow melt rate by the degree day method varies from 0.84 cm/day to 4.88 cm/day while the snow melt rate by the energy balance method varies from 0.38 cm/day to 1.73 cm/day. The energy balance method is found to be better correlated with corrected observed discharge.

2) Day to day variability in snow melt rate is a consequence of variation due to meteorlogical factors.

3) The meltrate decreases with altitude .

4) The modelling maybe extended to develop a working model on basis of statistical analysis and by using mass balance data.

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