ANALYSIS FOR SNOWMELT RUNOFF DURING PREMONSOON MONTHS IN BEAS BASIN USING SATELLITE IMAGERIES

A DISSERTATION

submitted in partial fulfilment of
the requirements for the award of the degree
of

MASTER IN HYDROLOGY

By
K. B. THAPA
(Nepal)

UNESCO SPONSORED
INTERNATIONAL HYDROLOGY COURSE
UNIVERSITY OF ROORKEE
ROORKEE (INDIA)

April, 1980

CERTIFICATE

This is to certify that the dissertation entitled 'ANALYSIS FOR SNOWMELT RUNOFF DURING PREDICTION MONTHS IN DRAS BASIN USING CATCHMENT PARAMETERS' being submitted by Col K. S. Thapa in partial fulfilment of the requirements for award of the degree of Master in Hydrology of the University of Roorkee, is a record of the candidate's own work carried out by him under our supervision and guidance. The material embodied in this dissertation has not been submitted for the award of any other degree or diploma.

This is further to certify that Col K. S. Thapa has worked for a period of 6 months since 1st October to 31st March 1990 in the preparation of this dissertation under our guidance at this university.

(K. G. Sharma)
Reader in Civil Engg.
[redacted] Survey and
Photogrammetry
Section, University
of Roorkee, Roorkee.

(S. M. Seth)
Associate Professor of Hydrology,
School of Hydrology,
University of Roorkee, Roorkee,
(On deputation to National Institute of Hydrology, Roorkee)

Roorkee:
Dated April 18, 1990.

ACKNOWLEDGEMENTS

It is a great pleasure for me to express my deep sense of gratitude to Dr. S.M. Seth, Associate Professor, School of Hydrology, presently on deputation to the National Institute of Hydrology, Roorkee and Shri K.P. Sharma, Reader in Civil Engineering, [redacted] Survey and Photogrammetry Section for their keen interest, valuable guidance and encouragement throughout the course of this study.

I am also highly grateful to Dr. Satish Chandra, Professor, Dr. B.S. Mathur, Coordinator, and all other faculty staff members of the International Hydrology course, University of Roorkee, for their keen interest and encouragement given to me throughout the period of my stay in Roorkee.

I am also thankful to Mr. D.P. Goyal, Executive Engineer, H.P.S.E.B. for his cooperation in collection of various data required for this study.

Thanks are also due to the Government of Nepal for deputing me to undergo this training at the University of Roorkee. I am also highly thankful to UNESCO and the Government of India for providing me all the necessary facilities and financial assistance for undergoing training at the University of Roorkee, Roorkee.

Roorkee
Dated April 18, 1980.

(KHADGA BAHADUR THAPA)
TRAINEE OFFICER FROM NEPAL
7TH HYDROLOGY COURSE

ABSTRACT

The increase in demand for water coupled with the construction of multipurpose reservoirs to control and regulate snowmelt runoff, requires accurate stream flow forecast. Forecasts are needed to determine allowable releases from reservoirs for power, irrigation, municipal use, recreation, pollution abatement, flood control, etc.

Information on the extent of snow accumulation during the winter months is necessary for making accurate prediction of spring runoff. An important index of runoff during the snowmelt season is the areal extent of the snow cover, which is achieved with the remote sensing techniques. The conventional methods for obtaining such data from remote areas are not only time consuming and expensive but by the time the results could be compiled, they would certainly be out-dated. Thus the application of phototechnique is gaining popularity in the hydrological studies.

The water of Beas river is being utilized for operation of different water resources projects amongst which the Beas - Sutlej Link Project is the most important. The water supply during the premonsoon period for the Beas river comes from the snowmelt. The gradual melting of the snow accumulated over the catchment during the winter months is responsible for the perennial character of the Beas river.

Photo-hydrological investigation of the Beas catchment, upstream of Manali, and the estimation of the snowmelt runoff during the premonsoon period have been studied. An attempt has been made to study the relationship between the snow cover, acquired with the help of the satellite imageries, and the cumulative discharges of the months of March, April and May of the years 1973, 1975, 1976 and 1977. An exponential trend has been observed in plotting. The snow covered areas in Band 5 and Band 7 of the LANDSAT imageries on the same day have been compared. A linear trend has been observed in plotting. An attempt has also been made to identify and delineate the vegetal cover and land use features using visual interpretation techniques.

Due to the availability of the limited meteorological and hydrological data the study for the estimation of snowmelt runoff has been confined to the sub-basin upstream of Manali. The sub-basin has been divided into permanent and temporary snow covered zones, provided that it is completely covered by snow. The Degree-Day method and the melt due to rainfall on snow have been used to estimate the snowmelt runoff. The calculated snowmelt runoff and the gauged discharges give a reasonable agreement. With several trials the degree-day factor of 0.00[illegible] cm $°C^{-1} d^{-1}$ for March and April and 0.00319 cm $°C^{-1} d^{-1}$ for May have been assigned for the years 1977, 1978 and 1979. The routing of snowmelt after accounting for losses as well as the excess rainfall runoff from the permanent & temporary snow covered area has been done with the recession coefficient of 0.90 and the excess rain from the non snow covered area has been as directly contributing for runoff on that same day as the time of concentration [illegible]

Lastly, the runoff coefficients of 0.999 for the rainfall on the snow covered area and 0.270 for rainfall on the non snow covered area have been calculated. Since the time of concentration in the catchment is less than a day, the runoff due to rainfall on the non snow covered area is superimposed on the same day on the calculated hydrograph obtained from the snowmelt and the runoff from the rain falling on the snow covered area. There is an improvement in the result.

More hydrometeorological data, regular satellite imageries, and snow survey for determining the Degree -Day Factor, the water equivalent, snow depth etc. are essential for a better estimation of snowmelt runoff.

LIST OF FIGURES

LIST OF TABLES

CONTENTS

CONTENTS

Page

Page

Page

LIST OF APPENDIX

Page

CHAPTER I

INTRODUCTION

1.1 General:

Water is one of the most essential requirements for the sustenance of all living beings. The total quantity of water available in the earth does not vary, but it merely goes through a gigantic hydrologic cycle of conversion into gaseous state by evaporation and reaching the earth again as precipitation. The hydrologic cycle comprises of four basic phases of interest. They are precipitation, evaporation and transpiration, runoff, and recharge or ground water.

Snow is an important part of the hydrologic cycle. Accurate estimation of the volume of water stored in the snow cover pack and the release of that water are essential to predict the flow during the lean period. For a rational snowmelt yield information on snow cover depth and water equivalent is a pre-requisite besides the energy transfer to the snowpack. The hydrologists face many intricate problems especially in the mountainous watersheds, since very limited information relating to the meteorological and physical factors affecting the runoff is available. In contrast to rainfall, snowmelt is not generally measured quantitatively but must be estimated indirectly from meteorological parameters and information about the terrain, vegetative cover etc. An important index of runoff during the snowmelt season is the areal extent of the snow cover.

Remote sensing has paved an efficient and easy methodology to assess snow cover in areas which are relatively inaccessible and hazardous.

The Beas catchment upstream of Larji has been selected for the study, since it has a moderate size and above 50 per cent of the catchment is covered by snow before the melting period. Snow is the dominant source of Beas river during the lean period.

The present study can be broken down into two components:

a) the analysis of LANDSAT imageries for the Beas catchment

and b) the estimation of snowmelt runoff in the sub-basin of MANALI during the premonsoon period.

The photoanalysis section touches the general criteria for evaluating the different physiographic parameters of the sub-basins of the Beas catchment upstream of Larji. Perhaps the areal extent of the snow cover is the most reliable easily measurable parameter than the others like the snowpack density and snow depth in the remote areas. The areal snow coverage is measured here in with the help of LANDSAT (MSS) imageries. The relationship between the snow cover and the cumulative discharge of the melting season has been studied. The snow covered areas from the imageries in Band 5 and Band 7 taken on the same day have been studied also.

Due to the limited data a small sub-catchment upstream of Manali has been selected for estimating the snowmelt runoff during the premonsoon period. This section deals with the assessment of runoff due to snowmelt in Beas river originating from the Himalayas. The hydrological condition of the Himalayan catchments is very complex since they are partly snow covered at higher altitudes and rainfed at the lower altitudes. The year in Beas catchment is divided into the accumulation season , the snowmelt season, the monsoon season and the groundwater season.

The objective of the runoff from snowmelt computation is to forecast seasonal water yield and the rate of runoff forecasting. Both of these objectives may require snowmelt computation in partly snow covered catchment either for the operation of existing projects or for the use of designing future projects.

CHAPTER II

SNOW AND ITS CONTRIBUTION TO STREAM FLOW

2.1 INTRODUCTION :

In many areas snow is the dominant source of stream flow. Goodell (1966) has indicated that about 90 per cent of the yearly water supply in the high elevations of the Colorado Rokies is derived from snowmelt. The generation of snowmelt and sequential stream flow from the snowpack that accumulates in winter, forms one of the most important phases of the hydrologic cycle in the northern region of India. In India and many other countries snowmelt runoff estimations are vitally important in

a) forecasting seasonal water yields for a diversity of water supply purposes.

b) implementing flood control programmes.

c) regulating rivers and storage works.

and d) selecting design floods for particular watersheds.

Therefore, any programme for the effective control, conservation, and optimum development of water resources in these northern regions must take into account the vital contribution of snowmelt to the spring season runoff, or its potential for storage and subsequent utilization.

Despite the importance of snow hydrology, it is only in the last decades that intensive research has led to the formation of theory which yields a partly satisfactory understanding of the complex hydrodynamics processes producing snowmelt and subsequent stream flow. The new techniques are being widely used for predicting design estimates and seasonal yield. However, for short range forecasting of peak flow rates, the agreement between prediction and actual observations has been found to be uncertain, and leaves room for much improvement.

2.2 ROLE OF SNOW AND ICE IN THE GLOBAL WATER BALANCE :

The quantitative assessment of the world water balance is still in the process of revision and refinement. Even so, reasonable estimates can be attempted in order to illustrate the relative importance of the different components.

The total volume of water present in the whole hydrosphere amounts , according to Lvovitch (1970), to approximately 1.45 x 10^9 km^3. Ice and snow represent about 28 x 10^6 km^3 of water (Hoinkes 1967). Other estimates put these values rather lower but, at any rate, ice and snow constitutes 2 per cent of the water in all its forms. Of course, the seas and oceans contain about 97.4 per cent of the world water, but if this saline water is discarded ice and snow become the major component (Volker 1970).

2.3 PHYSICAL PROPERTIES OF SNOW AND ICE :

Snow is defined as falling or deposited ice particles formed mainly by sublimation (UNESCO / IASH / WMO 1970). It can also be described as the solid form of water which grown while floating, rising or falling in the free air of the atmosphere (Carstin 1964), or simply as a porous, permeable aggregate of ice grains (Bader 1962). Snow is formed when crystals nucleate, grow, and begin their descent to earth. While falling through atmospheric layers of varying temperature and humidity, the crystals can change in form and size. When windy conditions prevail, snow crystals are carried along while held in suspension so that further modification by a thermodynamic and mechanical processes is possible, especially near the ground.

The density of the newly fallen snow is very frequently around 0.1. The density of 0.5 is very seldom exceeded even by wet old snow. Snow can eventually reach a density at which air permeability drops to zero, either by refreezing of pore water or by compaction during progressive burial. By convention the material is then considered to have made the transition from 'snow to ice'. Snow density is the mass per unit volume given in grams (g) per cm^3 or $kg\ m^{-3}$. Since porosity is the volume ratio of voids to snow it is related to density as follows:

$$n = \frac{\rho_i - \rho}{\rho_i} = 1 - \frac{\rho}{0.917} = 1 - 1.09\rho$$

where n is the porosity as dimensionless ratio

ρ is the snow density in $g\ cm^{-3}$

ρ_i is the density of ice in $g\ cm^{-3}$.

snow behaves in a very complicated manner near the melting point temperature. It is also a very highly variable material, with some properties that change by several orders of magnitude as bulk density varies over a typical range for deposited snow. However, the general properties of snow are fairly known and the only problem lies in locating the relevant data.

2.4 THE SNOWLINE :

The snowline, the lower limit of the perennial snow, is an irregular an line located along the ground surface where the accumulation of the snowfall equals ablation (melting and evaporation).

This line varies greatly in altitude and depends on several factors. On wind warm slopes and those facing the afternoon sun, the snowline may be as much as a kilometer higher than on opposite slopes. Over larger areas summer temperatures and amount of snowfall determine the position of the snowline. The snowline near the poles are lower than that near the equator. In moist coastal area with much snowfall the snowline is lower than in the area of dry continental climates because of differential ablation. The snowline in dry horse latitude is higher than at the equator where there is more snowfall for the same reason. The average altitudes of snowline taken over large areas can be used to derive a climatic snowline. This rises and falls in altitude in response to world wide climatic change. During the glacial periods, the climatic snowline was from 600 to 1200 metres lower than at present.

2.5 SNOW SURVEY :

A great variety of methods and instruments has been developed for snow surveys in order to meet different demands and conditions. The snow data of primary importance for hydrological purpose are

1) snow depth
2) density and water equivalent

and 3) areal extent.

All measurements related to snow accumulation and ablation depend greatly on the characteristics of the site, and in particular on the exposure to wind and sun and on the frequency and velocity of the wind. Unless there is some particular motive in choosing a special exposure, a site for measuring snow should be

1) horizontal
2) open to snowfall and insolation
3) sheltered against strong wind and drifting snow
4) distant from any objects which could cause excessive snow deposit.

These conditions partly contradict each other, and in most cases a compromise has to be found.

(1) Snow depth :

Snow depth is the vertical distance from the snow surface to the ground. It is measured by fixed graduated stakes which are part of the standard equipment of snow gauging stations.

If the true average snow depth over a large area with locally variable snow conditions is to be obtained, a great many observations must be taken. A network of observation sites a so called snow course is established.

There are three kinds of arrangements :

1) a number of sites are chosen each of which is representative for certain terrain conditions. On each sites several measuring points are selected in triangular paths.

2) A large number of single measuring points are installed along the path which can be easily followed.

3) The single measuring points are disposed along paths in a dense rectangular grid.

(2) Snow density and water equivalent :

Snow density is the mass per unit volume given in g cm^{-3} or kg m^{-3}. It can also be considered as a dimensionless ratio called specific gravity, which is the snow density relative to density of water at 4 °C.

Water equivalent of snow cover is thus the product of snow depth and density. It is the vertical depth of water layer which would be obtained by melting the snow cover over a given area (UNESCO / IASH / WMO 1970).

Conventional measuring instruments are based on weighing snow samples which are taken by tubes of different lengths and diameters. The variability of snow depth is generally greater than that of snow density.

Considerable variations of densities in different layers may be encountered, especially in cold climate. The average density of a snow cover may also become more variable in localities with different slopes and exposures. Daily falls of new snow, in terms of water equivalent, are measured by rain gauges. In fact, most rain gauges make bad snow gauges. Losses of catch is far greater for snow than rain. Comparative studies (U.S.Army Corps of Engineers,1956) have shown that for an average wind speed of 10 km/hr there was a catch deficit of 20 per cent for rain and 55 per cent for snow. Recording rain gauges with heated collectors are also affected by this error, although there is a reduction in the blowing out of snow caught in the funnel. Better values are obtained by measuring the depth of daily snowfall on a snow board and determining its water equivalent. The use of weighing gauges to record the intensity of snowfall is not entirely satisfactory.

(3) The areal extent of snow :

An areal extent is especially important in regions with a seasonal snow cover, since it can change from a 100 per cent coverage of a basin to zero in a relatively short time.

It is evident that the water production from a melting snow cover depend directly on its surface area and yet, systematic measurements of seasonal changes of the snow cover have been limited, until recently, to experimental areas. In the basin the snow cover is gradually decreasing from the start of the snowmelt season. As the summer progresses the snowline recede just from the lower altitude till it reaches the permanent snowline[8]. Leaf (1967) fitted the snow cover depletion curve to the equation

$$A = \frac{100}{1 - e^{-bt}}$$

where A is the percentage of area without snow

t is the time measured from an arbitrary origin

b is a constant

e is the base of natural logarithms which can be rearranged as

$$S = \frac{100}{1 - e^{b(t_{50}-t)}}$$

where S is the percentage of snow cover

t_{50} is the time at which $S = 50$.

2.6 FACTORS AFFECTING SNOWMELT AT A POINT :

The generation of snowmelt at a point location in a snowpack is essentially a thermodynamic process, the amount of melt produced being dependent on the net heat exchange between the snowpack and its environment. The travel of melt water to another point in the pack and its time distribution at that point depend on physiographic (gradient, depth, etc.) and hydrodynamic (porosity, structure, storage etc.) properties of the snowpack[23].

The various sources and processes influencing heat transfer to or from a snowpack shown in figure (2.1) are listed below:

1. Absorbed shortwave (solar) radiation, R_s.
2. Net longwave (terrestrial and atmospheric) radiation, R_b.
3. Condensation (or vaporization) from the air, R_c.
4. Convective heat transfer (by wind) R_h.
5. Heat content of rain water, H_r.
6. Conduction of heat from ground, H_g.

The melt water produced by the net transfer of heat from all sources to the snowpack may be obtained from

$$M = \frac{\sum H}{203\ B} \qquad (1)$$

where M = water equivalent of snowmelt (in.)

H = algebraic sum of all heat contributions (cal./cm^2), and

B = thermal quality of the snowpack, defined as the ratio of heat required to melt a unit weight of snow to that of ice at 0°C (averages from 0.95 to 0.97, for 3 to 5 per cent liquid water).

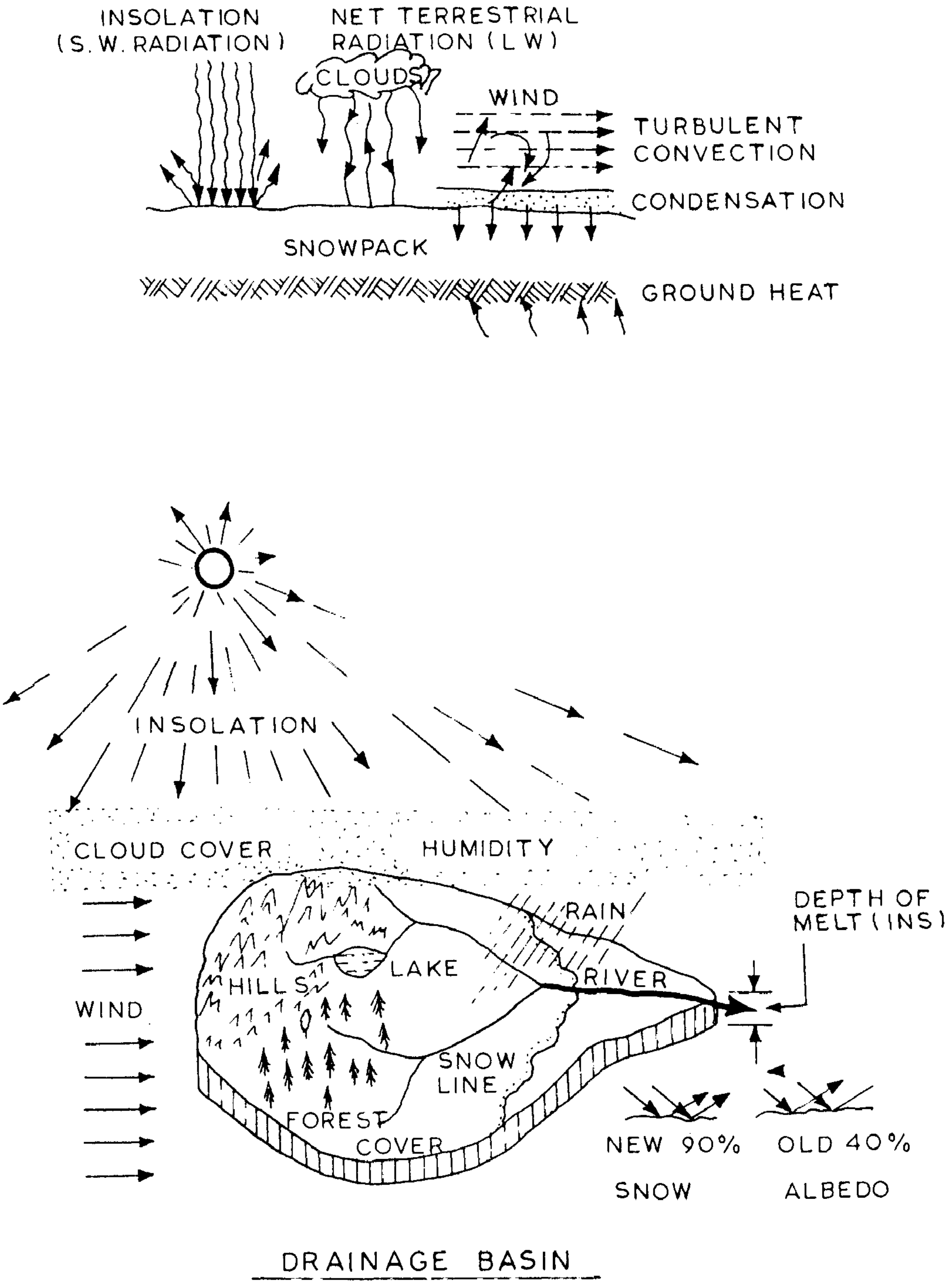


FIG. 2.1 SOURCES OF HEAT THAT GENERATE SNOWMELT

The constant 203 is the heat input in cal/sq.cm. required to produce one inch of water from ice at 0 °C, it has the dimensions (cals/cm^2/in).

3. Absorbed shortwave(solar) radiation :

Incoming solar (shortwave) radiation greatly influences the environmental microclimate above a snowpack; the amount absorbed by the snowpack forms an important component of total snowmelt. The net amount of heat absorbed by the snowpack depends on latitude, orientation and slope, season, time of day, atmospheric conditions (clouds, fog, rain), forest cover, and reflectivity of the snow (albedo).

The intensity of insolation or shortwave solar radiation is normally expressed in langleys (cal/sq.cm) per unit of time (min., hr., or day). The most simple and accurate measurement of net insolation is by solarimeters or pyrheliometers. These instruments are calibrated to give the shortwave radiation intensity in ly/hr or ly/day.

In those locations where net solar radiation measurements are not available, either of the two approaches may be employed. The net insolation is estimated by allowing for transmission efficiency of the atmosphere (cloud cover), forest cover, slope, orientation, and most important, the albedo of the snowpack. Of these , cloud cover and albedo are of major significance , and need careful evaluation. The cloud is considered to be the most significant for open areas , and when known is included in melt computations. The albedo is commonly taken as 80 per cent for fresh snow and assumed to decrease exponentially to about 40 per cent for melting late season snow. The melt component produced by shortwave radiation can be expressed as

$$M_{sw} = \frac{(1-a)\ R_{si}}{203\ B} = 0.00508\ R_{si}(1-a)\ \text{in/day}$$

where 'a' is the albedo written as a decimal fraction, R_{si} is the effective solar radiation in Ly/day and B is assumed to be 0.97 for a melting snowpack.

A second much simpler approach assumes a correlation between effective insolation and sunshine duration, and substitutes daily hours of sunshine in lieu with suitably modified coefficients to compute the melt. A recent study in New Brunswick by Pysklywec (1966) has demonstrated this approach to be only slightly less accurate than using measured net insolation in Ly/day.

2. Net Longwave (Terrestrial and atmosphere) Radiation

Snow is considered to be a near perfect black body with respect to longwave radiation and longwave radiation emitted by snow can be estimated by Stefan's law. However, computation of net longwave radiation involves estimation of back radiation from the atmosphere under clear or cloudy skies, and from under forest cover ; these evaluations are different and their use avoided in practical snow hydrology.

Instead the USCE Manual (1960) suggests the following simplified expressions using environmental temperatures :

Clear skies in open :

$$M_R = 0.0212 (T_a - 32) - 0.04 \qquad (2)$$

where M_R = the daily snowmelt in inches

and T_a = the air temperature over snow surface

Under forest canopy :

$$M_R = 0.029 (T_a - 32)$$

Complete cloud cover :

$$M_R = 0.029 (T_c - 32)$$

where T_c is the temperature of cloud base in °F.

When measured temperatures are available, the information can be used directly in these equations ; otherwise suitable correlations with temperature measurements taken at a nearby meteorological station need to be established.

3. Condensation and Convection Melt :

When water vapour from the atmosphere condenses on a snow surface, the heat of condensation of water is absorbed by snowpack. The vapour pressure gradient and wind speeds are considered to be the principal parameters influencing this process.

The snowmelt produced by condensation may be estimated from the experimentally derived relation (USCE experiments as given in their Manual Runoff from Snowmelt)

$$M_e = 0.054 \, (z_a \, z_b)^{-1/6} \, (e_a - e_o) \, u_b \qquad (1)$$

where M_e = snowmelt in in/day

z_a and z_b = the heights of measurement (ft) of the air vapour pressure and wind speed above the snow surface.

e_a = the air vapour pressure in mb

e_o = the snow surface vapour pressure in mb (6.11 mb at a melting snow surface).

and u_b = the wind speed in mph.

Melt produced by convection results mainly from heat transferred from warm air advected over the snow surface. The theory of turbulent transfer in the atmosphere is very complex, but experiments have indicated that simple approximation can be useful. The simplified expression considers chiefly the temperature gradient of the air above the snow surface, the wind speed, and the air density (taken as the function of the air pressure).

Convection melt may be estimated from the experimental equation

$$M_c = 0.00629 \, (p/p_o) \, (z_a \, z_b)^{-1/6} \, (T_a - T_s) \, u_b \qquad (2)$$

where M_c = snowmelt in ins/day

p and p_o = air pressure at the site and sea level, respectively

z_a and z_b = heights (ft) above the snow surface of air temperature and wind speed respectively

T_a and T_o = air and snow surface temperatures in °F, the snow surface temperature being normally taken as 32 °F.

The contribution from convection is usually small relative to other factors. The equation for condensation and convection can be conveniently combined into a single equation to give

$$M_{ce} = 0.00629\,(z_a\,z_b)^{-1/6}\,[(T_a - 32)p/p_o + 8.59(e_a - 6.11)]\,ub$$

the total condensation - convection melt in ins/day. For practical applications in hydrology this equation can be further simplified. The ratio p/p_o varies from 1.0 at sea level to 0.7 at an elevation of 10,000 ft. For areas with moderate topographic changes it may be assumed to have a constant value of approximately 0.8. Also the vapour pressure can be assumed to be adequately represented by dew point temperatures. By fixing the heights of measurement of T_a and T_d in °F at 10 ft. and that of wind speed at 50 ft. the preceding equation can be simplified to

$$M_{ce} = 0.0004\,[0.22\,(T_a - 32) + 0.78\,(T_d - 32)]\,ub$$

where T_a and T_d = the mean air and dew point temperature respectively at the 10 ft. height

and u_b = the mean wind speed in mph at the 50 ft. height.

In some regions a linear regression relation between T_a and T_d gives a high degree of correlation, permitting further simplification.

4. Melt Content of Rain :

Rain falling on the snow surface at temperature above 32 °F transfers heat to the snow thus producing melt. This can be stated directly by the equation

$$M_p = 0.007\,P(T_a - 32)$$

where M_p = the snowmelt in ins/day due to rain

P = the mean rainfall in ins/day

and T_a = the mean free air temperature in °F.

Ray K. Linsley Jr.[7] in his paper in June 1943 had also suggested this relation.

5. Heat conduction at ground :

Melt produced by heat conduction at the ground (M_g) is generally considered insignificant, unless there is a large underground source. A nominal value of 0.02 in/day is recommends for inclusion in design estimates.

In this subsection a semi-empirical theory developed mainly by the U.S. Corps of Engineers, has been given in outline; it is valid for very small plots of homogeneous character. Its chief purpose has been to provide an insight into the snowmelt process as influenced by various meteorological parameters, and to quantitate the effectiveness of each of these parameters in causing snowmelt.

The total snowmelt produced at a point location by the various factors will be

$$M = M_{rs} + M_{rl} + M_{ce} + M_{p} + M_{g}.$$

2.7 SNOWMELT RUNOFF DETERMINATION

The manner in which runoff from either rainfall or snowmelt is affected by conditions prevalent within the snow pack is of primary interest to the hydrologist. Various views on storage characteristics of a snow pack have been suggested. These range from the concept that a snowpack can retain large amounts of liquid water to the hypothesis that snow pack storage is negligible. There is no universally applicable relationship, and it is important to base any runoff consideration on a knowledge of the character of a snowpack at the time of study. Winter runoff is related to snowpack condition whereas in the spring, once active melt begins, little or no delay in the transport of melt or rainfall through the snowpack occurs.

For drainage basins in mountainous area, snowpack storage effects may be approximated by subdividing the water shed into relatively uniform areas. Normally, this will be x accomplished by using elevation zones. Snowpack at the lowest levels may be conditioned readily transmit rain or meltwater, whereas in higher elevations a liquid water deficit may prevail. At upper most elevations, the snowpack may be very dry and cold and thus in a condition for the optimum storage of water. The storage potential of the watershed zones must be based on representative measurements of the snow depth, density, temperature, water equivalent, moisture content, and snowpack character. The snowpack character relates to the physical structure of the pack. Unfortunately, adequate measure of all these factors are not always available or easily obtained. Estimates of changes between sampling periods are usually indexed to readily observed meteorologic variables.

The formulation of snowpack storage and time delay characteristics can be fashioned by assuming a homogeneous pack. In this case storage is related directly to the liquid water deficit and cold content of the pack. Time delay is a function of inflow rate. It is considered that the snowpack storage potential must be entirely satisfied before runoff begins. This is not so in reality, but the assumption permits an analysis to be made. As melt proceeds, the storage potential of any snowpack diminishes.

Storage of a snowpack before runoff commences is considered to be the sum of the equivalent water requirement to raise the temperature of the snowpack to 0 °C (cold content W) and the liquid water holding capacity of the snowpack. If the water needed to bring a snowpack temperature to 0°C, it may be represented by

$$W_c = \frac{W_o T_s}{160}$$

where T_s = the mean snowpack temperature below zero.

W_o = the initial water equivalent of the snowpack in inches for an assumed specific heat of the ice of 0.5.

The time t_c in hour needed to raise the snowpack temperature to zero is thus given by

$$t_c = \frac{W_o T_s}{160(i+m)}$$

where i = the rainfall intensity (in/hr)

and m = rate of melt (in/hr)

Storage required to meet the liquid water deficit of the snowpack is given by

$$S_f = \frac{f_p}{100}(W_o+W_c)$$

where S_f = the amount of water stored (in)

f_p = the per cent deficiency in liquid water of the snowpack.

The time in hours t_f needed to fill the storage S_f is given by

$$t_f = \frac{f_p (W_e + W_o)}{100 (i + m)}$$

It has been specified that the total storage potential S_p to be met prior to the runoff is given as

$$S_p = W_o + S_f$$

This is also known as 'permanent' storage since it is not available to the runoff untill the snowpack has finally melted. An additional storage component transitory storage S_t is that water stored in the snowpack while moving through it to become runoff till initiation of runoff, the transitory storage in inches can be expressed as

$$S_t = \frac{D (i + m)}{V}$$

where D = the depth of the snowpack (ft)

V = the rate of transmission through the snowpack (ft/hr)

The delay time of water in passing through the snowpack t_t is thus

$$t_t = D/V$$

for t_t in hours.

Assuming that W_e is very small compared to W_o, the depth of the snowpack is given by

$$D = \frac{W_e}{P_s}$$

with P_s the density of the snowpack.

then $t_t = W_e/(P_s V)$

Before the runoff commences, the total water S stored in the snowpack, in inches, is given by

$$S = W_e + S_f + S_t$$

which can also be written as

$$S = W_e \left(\frac{T_s}{160} + \frac{f_s}{100} + \frac{(1 + m)}{P_s V} \right)$$

The total time in hours which passes before runoff is produced is thus

$$t = t_e + t_f + t_t$$

or

$$t = W_o \; \frac{T_s}{160(1+m)} + \frac{Y f_s}{100(1+m)} + \frac{1}{P_s V}$$

After establishing the active runoff from the snowpack, the only significant term in equation $t = t_o + t_f + t_t$ is t_t, and this is usually small compared with the overall basin lag and can be neglected. With increased snowmelt and runoff, additional increments of water previously withheld by snow blockage to drainage outlets and other factors are released. Adequate quantification of this cannot be accomplished at present. A deep snowpack say 15 ft having a mean temperature of -5 °C , could store about 4 in. of liquid water before the onset of runoff[2].

2.7.1 Hydrograph Recessions :

Recession curves have the general form

$$Q = Q_0 e^{-kt}$$

where Q = the discharge at time t

Q_0 = the initial rate of flow

k = a recession constant.

Studies of daily stream flow by hydrographs permit evaluating the amount of runoff derived from snowmelt[2]. The technique is essentially one of separation of the daily hydrographs. Fig.(2.2) illustrates the procedure. Assume that the first, second and succeeding peaks, respectively, fit snowmelt days. If the ultimate recession curve is extended backward in time, at a point-A, the recession curve from hydrograph 2 will intersect it. The area between recession from hydrograph 1 and hydrograph 2 (shown cross-hatched) is the melt attributed to day 1. In like manner, a series of snowmelt hydrographs can be studied to determine their individual melt components. By observing such hydrograph features as the height to peak X, the height to trough Y, and the form of the recession volumetric and rate forecasts of snowmelt runoff can be made. A more comprehensive treatment of this subject can be found in [5].

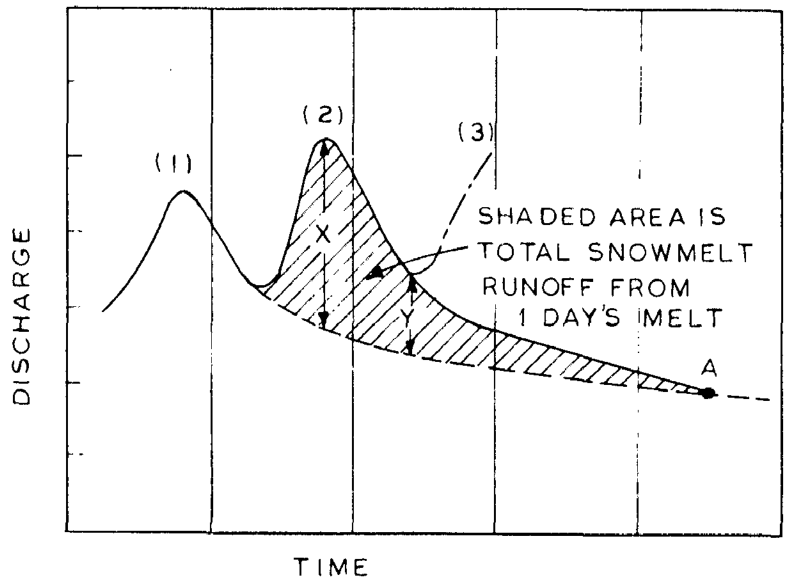


FIG. 2·2 SEPARATION OF A SNOWMELT HYDROGRAPH.

2.7.2 THE DEGREE - DAY METHOD :

This method was first suggested by W.T.Wilson[6] As used in the U.S. a degree day in its broadest sense, is a unit expressing the amount of heat in terms of the persistence of a temperature for a 24 hr period of one degree - Fahrenheit departure from a reference temperature. As often applied in snowmelt studies, the degree day is computed by subtracting the average of the daily maximum and daily minimum temperature from 32°F. For example, if the daily mean thus computed were 32°F, there would be zero degree day. A daily mean of 37 °F would yield 5 degree-days. Degree days above 32 °F and degree days above reference temperature have been used in point-snowmelt and in runoff-snowmelt computation. Accordingly, Garstka, Love, Goodell, and Bertle [4] used the commonly available maximum and minimum temperatures to estimate the degree days in a detailed interpretive study. The ratio of the water equivalent of the snowmelt away in 24 hrs to the number of degree days in the same period is called degree-day factor [5]. The relation reads

$$M = a\,T_d \qquad (1)$$

where M = the daily snowmelt depth (cm)

a = the degree-day factor (cm $^{\circ}C^{-1}\ d^{-1}$)

T_d = the number of degree-days (°Cd)

Degree days ratios given in inches and degree days Fahrenheit can be converted to values in cm. and deg. celsius by a coefficient of 4.57. It is pertinent at this point to deal with the degree day factors. Numerous determinations of the dry bulb degree day factor (watershed constant) have been made.

Ray K. Linsley, Jr. has determined values of the watershed constant by dividing the total runoff from the basin for a short period by concurrent unit melt. (The term, unit melt is defined as the depth of runoff in inches over the entire drainage basin if 0.01 inch of runoff occurs in the melting zone for each degree day above 32 °F. It is determined simply by dividing average degree days over the basin by 100). He said that the observed runoff should be corrected for runoff from rainfall. This may be done by the means of a rainfall runoff relation for the basin, but because of the possible error in such a procedure, it is usually best determined, the watershed constant from periods when little or no rain occurred. Correction of the observed runoff for baseflow will undoubtedly improve the results.

Clyde [10] found the watershed constant for Gooseberry Creek, Utah, was about 0.09 in. per degree day. He also exposed snow samples in a laboratory and found the value of constant as 0.05 in/degree-day, he supposed that the difference probably represents heat supplied to the snow in the basin from radiation and from the soil which is not reflected in the air temperature.

Studies by U.S.Weather Bureau and others indicate that the dry bulb degree day factor varies between 0.05 and 0.15 in/degree day.

Studies have shown that the apparent degree day factor computed during flood tends to increase with time after a freezing spell. This effect is probably largely due to the retention of early melt water in the snow and soil. In studies of basins in Western Pennsylvania, Horton [11] found the degree day factor to be slightly lower on heavily forested basins with values ranging from 0.09 on basins with thin cover to 0.06 where cover was heavy.

The U.S. Soil Conservation Service [12] found certain values of degree day factor (watershed constant) for different conditions and stated that the watershed constant value include the infiltration rate of watershed also.

TABLE 2·1

Watershed Condition	Value of degree day factor
1. Low runoff potential	0.02
2. Average heavily forested area north facing slopes of open country	0.04 – 0.06
3. Average runoff potential	0.05
4. South-facing slopes of forested area average open country	0.06 – 0.08
5. High runoff potential	0.10

The WMO 'A guide for hydrological practices'[15] has given a table containing values of the degree day factor on monthly basis shown below :

TABLE 2.2

	Month	Degree day factor (mm/°C)		
		Moderately forested	Partly forested	Non-forested
1.	April	2	3	4
2.	May	3	4	6
3.	June	4	6	7

In the same publication, the value of the degree factor found by a Russian scientist have been given as

TABLE 2.3

	Watershed condition	Degree-day factor (mm/°C)
1.	Nonforested area	5
2.	Sparse coniferous and average density of hard wood	3 to 4
3.	Average density of coniferous woods and dense mixed	1.7 to 1.9
4.	Dense coniferous woods	1.4 to 1.5

The conclusion which can be drawn from earlier studies by different persons mentioned above, could be summarized as follows :

1) Watershed constant is including the infiltration loss at snow spot site.
2) Watershed constant is varying for different periods of the melting season.
3) The study so far established the watershed constant value the effect of temperature, on snowmelting process.
4) Watershed constant may be varying as the catchment is not uniform in its pattern.

Since the air is not the only source of heat and in view of the varying conditions in the snowpack, the degree-day factor cannot be expected to be constant. Values in the range from 0.07 to 0.9 have been reported (Garstka,(1964). Using a nuclear snow gauge it is possible to measure degree day ratios in different conditions without disturbing the snow cover (Bertiness,1960). Snow density appeared to be a useful parameter to which variations of the degree-day factor could be attributed by the relation

$$a = 1.1 \ \rho_r \qquad (2)$$

where ρ_r = the snow density relative to water (sp. gravity)

Equation (2) has been derived for average wind conditions. Substantial deviations must be expected in periods with extremely high or low wind speeds. However in larger basins, it might be necessary to take into account further possible causes of deviations in calculating areal runoff.

(i) In forested areas degree day ratios are affected by changed radiation balance as compared with open areas.

(ii) The difference in the exposure of slopes can influence the heat gain from the radiation which is included in the degree-day factor.

(iii) On a slope the atmospheric effects on snowmelt are increased since the exposed area is greater than its horizontal projection (i.e. a snow layer of a given thickness on a slope represents more melt water than a horizontal layer of equal thickness, although carto-graphically both areas would be equal). 8

In equation (2) the snow density seems to represent other factors affecting the snowmelt: a greater density means in many cases older snow with a low albedo, which promotes the heat gain radiation. Furthermore, high densities are frequently connected with the increased free water content and the low thermal quality of snow. Independent experimental work has also shown that density is a generally satisfactory index of the thermal properties of snowpack (Riley and co-workers, 1972).

According to a study by the U.S. Army Corps of Engineers the daily spring time snowmelt M in inches may be estimated by the following correlation equations as a function individual observations or groups of observations to replace watershed values in time and space. The adequacy of an index is based on (1) the ability of the index to adequately describe the physical process it represents, (2) the random variability of the observation (3) the degree to which the point observation is typical of actual conditions and (4) the nature of variability between the point measurement and the basin means. Indexes may be equations or simple coefficients, and variable or constant.

The type of data required to make comprehensive thermal budget studies are normally unavailable in whole or part for watersheds other than those which themselves are experimental areas. As a result, hydrologist must make the best use of information at hand. The most commonly available data are daily maximum and minimum temperature humidity, and wind velocity. Less prevalent are continuous measurements of these data, and few stations record solar radiation or the duration of the sunshine. Hourly cloudiness data can be sometimes obtained from local airport weather stations.

A complete general index for reliably describing snowmelt-runoff relationships for all basins has not been established. Most indexes include coefficients valid only for specific topographic, meteorologic, hydrologic, and seasonal conditions and are therefore limited in applicability to other watersheds. The snowmelt runoff equation stated in terms of thermal budget indexes is of the mean daily temperature T_{mean}, the max. daily temperature T_{max} and the relative forest cover.

1. For open sites

$$M = 0.06 \, (T_{mean} - 24)$$

$$M = 0.04 \, (T_{max} - 27)$$

2. For forest sites

$$M = 0.05 \, (T_{mean} - 32)$$

$$M = 0.04 \, (T_{max} - 42)$$

These equations are applicable for T_{mean} in the range of 34 to 60°F and for T_{max} in the range of 44 to 75 °F. The point melt rate in inches (in) per degree-day above 32°F may vary from as little as 0.015 to as much as 0.2 in. per degree-day. For a spring snowmelt period an average of 0.05 in/degree-day may be used but with discretion.

2.7.3 INDEXES :

Hydrologic indexes are made up of hydrologic or meteorologic variables to describe their functioning. The index variable is more easily measured or handled than element it represents. When near fixed relationships are known to exist between point measurements and watershed values, indexes can be used to record both areal and temporal aspects of basin values. Indexes serve to permit (1) readily obtainable observations to depict hydrologic variables or processes which themselves cannot be easily measured, and (2) simplification of computational methods by allowing individual observations or groups of observations to replace watershed values in time and space. The adequacy of an index is based on (1) the ability of the index to adequately describe the physical process it represents, (2) the random variability of the observation (3) the degree to which the point observation is typical of actual conditions and (4) the nature of variability between the point measurement and the basin mean. Indexes may be equations or simple coefficients, and variable or constant.

The type of data required to make comprehensive thermal budget studies are normally unavailable in whole or part for watersheds other than ones which themselves are experimental areas. As a result, hydrologist must make the best use of information at hand. The most commonly available data are daily maximum and minimum temperature humidity, and wind velocity. Less prevalent are continuous measurements of these data, and few stations record solar radiation or the duration of the sunshine. Hourly cloudiness data can be sometimes obtained from local airport weather stations.

A complete general index for reliably describing snowmelt-runoff relationships for all basins has not been established. Most indexes include coefficients valid only for specific topographic, meteorologic, hydrologic, and seasonal conditions and are therefore limited in applicability to other watersheds. The general runoff equation stated in terms of thermal budget indexes is

$$Y = a + \sum_{i=1}^{n} b_i X_i$$

where Y = the snowmelt runoff

a = a regression constant

the b_i's = the regression coefficient

the X_i's = individual indices.

The table below shows some types of indices that have been successfully used in snowmelt investigations.

TABLE 2-4

Some indices used to describe thermal budget variables.

Thermal budget component	Index
Absorbed shortwave radiation	Duration of sunshine Diurnal temperature range
Longwave radiation	Air temperature for heavy forested areas For open areas longwave radiation should be estimated.
Convective heat exchange	$(T_a - T_b)$ V, where T_a is the air temp., T_b the snow surface temp. or base temp., and the V wind-velocity.
Heat of condensation	$(e_a - e_b)$ V, where e_a and e_b are vapor pressures of air and snow surface or a base value, and V is the wind speed.

It should be noted that every term in the heat budget equation is not always significant for a particular analysis, and thus the number of X's will vary for different basins and conditions. A final melt equation developed by the Corps of Engineers for the partly forested Boise River Basin above Twin Springs, Idaho, was

$$Q = 0.00253\,\theta + 0.0239\,(T_{max} - 77)$$

where

Q = daily snowmelt runoff (in.) over the snow covered area

θ = an estimated value of the daily all-wave radiation exchange in the snow (langleys)

T_{max} = the daily maximum temperature at Boise (^{o}F)

2.7.4 GENERALIZED BASIN SNOWMELT EQUATIONS:

Extensive studies by the U.S. Army Corps of Engrs at various laboratories in the West have produced several general equations for snowmelt during (1) rainfree periods and (2) periods of rain.

When rain is falling, heat transfer by convection and condensation is of prime importance. Solar radiation is slight, and longwave radiation can be readily determined from theoretical considerations. When rainfree periods prevail, both solar and terrestrial radiation become significant and may require direct evaluation. Convection and condensation are usually less critical during rainless intervals. The equations are summarized as follows :

1. Equations for periods with rainfall :

a) For open (cover below 10 per cent) or partly forested (cover from 10 to 60 per cent) watersheds.

$$M = (0.029 + 0.0084\,kV + 0.007\,P_r)(T_a - 32) + 0.09$$

b) For heavily forested areas (over 80 per cent cover).

$$M = (0.074 + 0.007\,P_r)(T_a - 32) + 0.05$$

where M = the daily snowmelt (in/day)

P_r = the rainfall intensity (in/day)

T_a = the temperature of the saturated air at 10 ft. level (°F)

V = the average wind velocity at 50 ft. level (mph)

k = the basin constant, which includes forest and topographic effects, and represents average exposure of the area to wind.

Values decrease from 1.0 for clear plain areas to about 0.3 for dense forests.

2. Equations for rainfree periods :

a) For heavy forested areas,

$$M = 0.074\,(0.53\,T'_a + 0.47\,T'_d)$$

b) For forested areas (cover of 60 to 80 per cent)

$$M = k\,(0.0084\,V)(0.22\,T'_a + 0.78\,T'_d) + 0.029\,T'_a$$

c) For partly forested areas,

$$M = k'(1-F)(0.0040\ I_i)(1-a) + k(0.0084\ V)(0.22\ T'_a + 0.78\ T'_d) + F(0.029\ T'_a)$$

d) For open areas

$$M = k'(0.00508\ I_i)(1-a) + (1-N)(0.0212\ T'_a - 0.84) + N(0.029\ T'_c) + k(0.0084\ V)(0.22\ T'_a + 0.78\ T'_d)$$

where M, V, and k = as previously described

T'_a = the difference between the 10 ft. air and the snow surface (°F) temperatures

T'_d = the difference between the 10 ft dewpoint and the snow surface temperature (°F)

I_i = the observed or estimated insolation (langleys)

a = the observed or estimated mean snow surface albedo.

k' = the basin shortwave radiation melt factor (varies from 0.9 to 1.1) which is related to mean exposure of open areas compared to an unshielded horizontal surface

F = the mean basin forest - canopy cover (decimal fraction)

T'_c = the difference between the cloud base and snow surface temperature (°F).

N = the estimated cloud cover (decimal fraction).

Note that the use of equations of the type given must be related to the areal extent of the snow cover if realistic values are to be obtained. Present methods of determining this are not totally adequate.

2.7.3 THE WATER BUDGET :

The water budget can be used to estimate the snowmelt runoff from a water shed[2]. Such an approach has particular merit for areas where hydrometeorological records are short. Difficulty with the method is the usual lack of satisfactory data to properly quantify the various components. A hydrologic budget equation for the earth's surface can be written as

$$R = P - L - \Delta S \qquad (1)$$

where P = the gross precipitation

R = the runoff

L = the losses

ΔS = the change in storage.

For snowmelt computations this equation is modified somewhat. Gross precipitation for a given period P will now be defined as the sum of precipitation in the form of snow P_s and rain P_r, or

$$P = P_r + P_s \qquad (2)$$

This also may be written as

$$P = P_r + P_s = P_n + L_i \qquad (3)$$

where P_n = net precipitation

L_i = interception loss

A further refinement yields

$$P = P_{rn} + L_{ri} + P_{sn} + L_{si} \qquad (4)$$

where

P_{rn} and P_{sn} = net rainfall and snowfall

L_{ri} and L_{si} = the rain and snow interception.

The total loss L will be

$$L = L_{si} + L_{ri} + L_e + Q_{sm} \qquad (5)$$

where

L_e = the evapotranspiration loss

Q_{sm} = change in available soil moisture. The storage term ΔS is then given as

$$\Delta S = (W_2 - W_1) + Q_g \qquad (6)$$

where

W_2 and W_1 = final and initial water equivalents of the snowpack

Q_g = the ground and channel storage.

Inserting values for P, L, and ΔS from eqns. (4, 5 and 6) in equation (1)

$$R = P_{rn} + L_{ri} + P_{sn} + L_{si} - L_{si} - L_{ri} - L_e - Q_{sm} - (W_2 - W_1) - Q_g \qquad ..(7)$$

and cancelling positive and negative values of L_{ri} and L_{si} produces

$$R = P_{rn} + P_{sn} - (W_2 - W_1) - Q_{sm} - Q_g - L_e \qquad (8)$$

The expression $P_{nn} - (U_2 - U_1)$ represents the amount E_g therefore,

$$R = P_{nn} + M - Q_{nn} - Q_g - E_c \qquad (9)$$

If reliable estimates of the terms in eqn.(9) can be secured, the basin discharge R is computable.

– 00 –

CHAPTER III

APPLICATION OF REMOTE SENSING TECHNIQUES FOR HYDROLOGICAL ANALYSIS

3.0 INTRODUCTION :

The use of aerial photograph for mapping was realised in the late 19th century, while some experiments were made by mapping from balloon photography. The impact of the two world wars accelerated the modern trends of aerial photographic mapping. Aerial photo-mapping and photo-analysis are very useful as they provide the latest, complete and sequential information of the area under investigation as compared to the conventional ground survey mapping and investigation method.

Aerial photographs also aid in preparation of thematic maps of all types of natural resources and in supplying quantitative and qualitative information about the ground conditions. This aspect of aerial photo-analysis has further vastly improved during the last decade or so by the introduction of Remote Sensing Techniques and computer aided photo-interpretation system.

Remote sensing has already an outstanding impact on hydrology and other environmental sciences. Broadly defined, remote sensing technique is any methodology employed to study the physical and other characteristics of objects without coming into physical contact with them. Conventional survey methods are time consuming and cannot be easily updated due to adverse terrain and weather conditions.

As such, updating information at reasonably frequent intervals calls for a strategy involving remote sensing techniques.

3.1 THE SATELLITES, SENSORS AND IMAGERY FOR PHOTO-ANALYSIS:

Artificial earth satellites can be used for research and analysis of hydrological aspects of water resources in two applications :

(i) as a platform for remote sensors
and (ii) as a data relay device.

Whether the spacecrafts are manned or not, two types of orbits are generally the most useful (i) the sun synchronous, which are relatively low altitude and have near polar inclination, and (ii) earth synchronous, which are relatively high and near equatorial.

The current United States satellites with sun synchronous orbits are from NOAA, TIROS, Nimbus and ERTS series. For NOAA series satellites the orbit permits the sensors from a single satellite to view any particular point on the earth twice each day, once during day light and once at night. Sensors carried on these satellites are generally vidicon cameras and radiometric scanners. Vidicon camera systems such as on ESSA and 9, are useful only during the daylight portion of the orbit. These cameras are sensitive to broad bands of electromagnetic spectrum, 0.5 μm to 0.7 μm. The automatic picture cameras transmit their information continuously whereas the advanced vidicon camera system stores its data on magnetic tape, transmitting them upon command to a ground station.

The TIROS series satellites system observes the earth's surface by automatic picture camera and advanced vidicon camera system, as well as by means of a scanning radiometer. The scanning radiometer data can be stored and transmitted upon command of a ground station's signal. This sensor, which is sensitive to infrared radiation in the 10.5 - 12.5 μm region, has night as well as day time capabilities.

During 1969 a successful testing was made from Nimbus III of a satellite born infrared spectrometer. Smith and Wolf showed that atmospheric temperature profiles made from such data was quite comparable with those obtained by standard meteorological instruments. Temperature and water vapour sounders, such as the satellite infrared spectrometer, hold much promise for improvement of quantitative precipitation forecasts.

These improvements will be realized through the increased number soundings for evaluating the mass and motion structure of the atmosphere. Improvement of the quantitative precipitation forecasts would be of great importance, since this should lead directly to improving the forecasts of watershed runoff.

The Geostationary Operational Environmental Satellites (GOES) are earth synchronous and will have day and night observation capability. Further, such a satellite is able to collect data from a variety of in situ automatic platforms and to broadcast specialised products to remote areas. Local users can to receive and display this information with relatively simple ground stations [14].

It is to be noted that there are relatively clear atmospheric windows in the range 0.3 μm to 1.3 μm, 3 μm to 5 μm, and 8μm to 1.3 μm where sensors can be used effectively. Band four operating in the range 0.5 to 0.6 μm is generally used for the study of sedimentation, turbidity and water quality and for the identification of geological information. Band five operating in the range 0.6 to 0.7 μm is usually used for the study of vegetation, road pattern, land use, snow cover, etc. Band six (0.7 to 0.8 μm) and Band seven (0.8 – 1.1 μm) are mostly used for the analysis of land use and water resources features. The composite chart showing the source energy, atmospheric transmission, and range of operation of various sensors is given in the figure (2.2).

Photo analysis of any area includes recognition of object and interpretation of imagery as well as making various relevant measurements. The process of identifying objects on the aerial photographs and collecting maximum information therefrom by analysis of the natural and cultural features are known as photo-interpretation. For remote areas this process a comparatively quicker and economical solution to the problem.

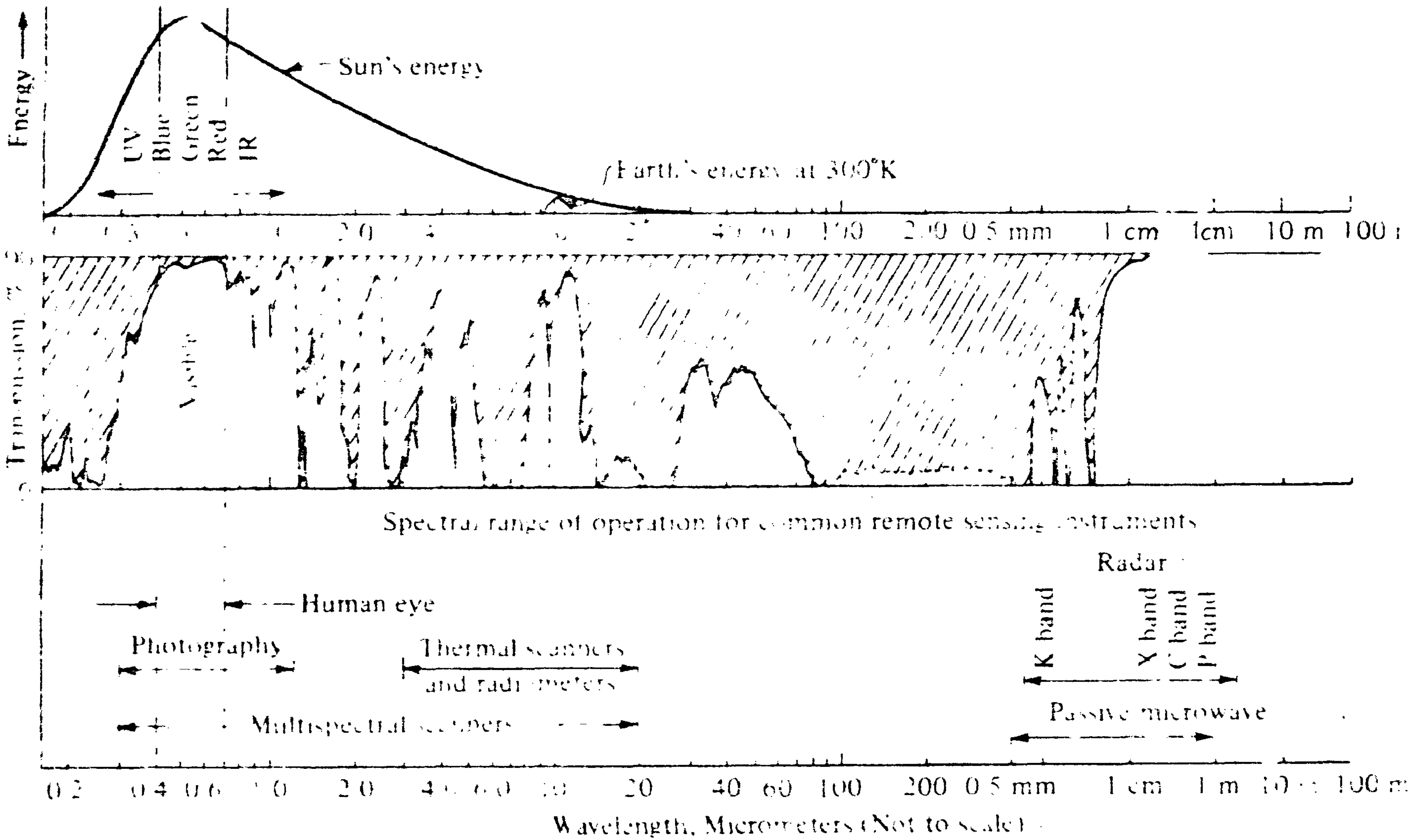


FIGURE 3·1
Composite chart showing source energy, atmospheric transmission, and rar_e of operation of various senors.

Due to the sensor's field view and resolution requirements on ERTS series the viewed areas do not overlap much on successive orbits. Furthermore, repetitive orbits of an ERTS are, in general, only once in eighteen days and contiguous viewing orbits are a day apart. [ ]. The ERTS data are more useful than the current meteorological satellites because of (a) increased resolution and (b) multispectral capability.

Multispectral capability is obtained by the use of three return - beam vidicons viewing, separately, 0.5 - 0.5, 0.5 - 0.6, 0.6 - 0.7 μm band widths. ERTS's scanning radiometer have the same capability in the visible bands and, in addition, in the near (about 1.0 μm) and far (10 - 14 μm) infrared.

Earth synchronous orbits are in the equatorial plane at a distance of 35,000 km above the earth's surface. The NASA Applications Technology Satellites (ATS) of hydrological interest observe the earth from such orbits. The disadvantages of this type of orbit are that it takes four satellites to view the entire earth and that the area near the poles is poorly observed. A good attribute of this type of orbit is that it permits the sensors to view about one-fourth of the globe constantly, or to monitor continuously any in situ measurements that are telemetered from the same portion of the globe. ATS spin cameras view the earth, from pole to pole, once every twenty minutes at the same wave length and resolution as the polar orbiting meteorological satellites.

9.2 SNOW COVER IN REMOTE SENSING :

9.2.1 Useful Spectral Bands -

Experience with multispectral scanner used in LANDSAT has indicated that the contrast between snowcover and snowfree terrain is maximum in the 0.6 to 0.7 μm band. The spectral band 10.5 to 12.5 μm in the infrared window region of the atmosphere is very useful for estimating the ground temperatures. Methods have been developed to utilise these data in conjunction with the visible data for the identification of snow covered area as well as the region of melting snow.

9.2.2 Distinguishing between Clouds and Snow -

Both clouds and snow have high reflectance. Hence mapping snow with cloud patches are very difficult. Aerial observation of snow cover distribution can provide valuable information during periods of cloud cover that preclude satellite snowcover observation.

The following procedure is normally adopted for distinguishing snow from cloud [19].

a) Recognition of Terrestrial features;

Recognition of terrestrial features like valleys, forested and non-forested areas etc., positively indicates absence of clouds.

b) Pattern recognition :

Snow cover on the mountains follow the same geological pattern, as the mountain ranges, which is different from the patterns of clouds viewed from space. Snow boundary is generally well defined.

c) Uniformity of reflectance :

Snow cover in areas that are not forested have more uniform reflectance than clouds. Even though the reflectance of clouds and snow is nearly same, snow covered areas are generally smooth textured - whereas clouds are often lumpy or rough in appearance.

d) Pattern stability :

Clouds do not retain the same shape for more than a few hours. Thus, stable pattern of high reflectivity viewed by satellite are indicative of snow cover. To use this technique, observations for a day or more apart, are required. The possible changes in snow extent due either to melting or additional snowfall must be taken into account.

e) Shadow :

Shadow cast by clouds at low sun angles and on the northern slopes of mountains are to be taken into account while mapping snow cover.

3.2.3 Procedure to Map Snow :

In non-forested areas which are identified to be cloud free, areas with continuous brightness distinctly greater than the dark background should be mapped as snow covered. Such areas represent the limit of snow accumulation of approximately 1 inch or more. Areas with mottled appearance (alternate grey and black) indicate snow of less than 1 inch.

In mountainous terrain the snowline is mapped at the edge of the brighter tone with regard to brightness variations due to forest and mountain shadows.

For snow mapping purposes it is essential to superimpose the satellite picture image over the base map. This is normally difficult as the VHRR image transmitted by the satellite has a non-uniform projection compared to the standard mercator projection for the base map. An optical device, 'Zoom Transferscope' is normally used for achieving proper superimposing of the picture and the base map. The instrument projects the satellite picture on the base map with different enlargement in the X and Y directions and the enlargement can be continuously changed to facilitate exact super imposition of the land-marks. The snow boundary is then marked out on the base map and a planimeter can be used to measure the area of snow cover. Different methods for estimating snowcover in forested mountainous basins have been given in reference [29]. Both manual and electronic-interactive analyses methods are used in such catchments.

LANDSAT Band 5 provides the best separation of snow from other materials and is used for manual methods like (1) snow line tracing and measurement with a planimeter. (2) Mean snowline altitude determined from many locations. (3) Estimation in 2.9 x 2.9 km boxes with reference to snow line image.

The machine tracing method is slow in execution and thus appreciably costly, but virtually no expensive equipment is required. The mean altitude method is fast and not much equipment is required, thus its cost is low. The 2.9x2.9 km box method, when used to obtain high precision is slow in execution but requires hardly any equipment.

The Standford Research Institute Electronic Satellite Image Analysis Console (ESIAC), is an interactive instrument that employs television scanning, storage and animation techniques in a manner intended to bridge the gap between traditional manual photointerpretation and completely objective digital processing. Three operating procedures are available for working with ESIAC. (1) single radiance - threshold level method (2) radiance threshold setting locally edited by reference to altitude contours and other images and (3) two-band colour-sensitive thematic extractions, locally edited as in method (2). The radiance threshold method using ESIAC is fast, but the machine is expensive. Edited Radiance-Threshold techniques need more operator and machine time and are therefore more expensive.

The digital spectral pattern recognition techniques are most convenient to apply when used in conjunction with an electronic console and standard pattern recognition techniques and programmes. Bands 4 to 5 versus band 7 LANDSAT imageries prove to be most useful to delineate snow, ice and rock mixed, snow and vegetation mixed, glacier ice, water, Snow can be clearly separated from rock, water, and vegetation but snow and vegetation mixed cannot always be clearly separated from rock.

The digital techniques are slow to average in speed depending on the equipment available for registering the image, of the drainage basin boundary. The cost of the magnetic tapes, the cost of machine and the labour for registering the image, and the computer time required for a four dimensional pattern recognition programs can be appreciable for a single measurement.

The following table 3.1 presents in summary form the qualitative comparision of the various methods for precision, cost, ability to recognize snow in trees, and supplemental data like finding the distribution of snow cover with altitude or in sub-basins, which can be used in energy balance snowmelt models.

TABLE 3.1

QUALITATIVE COMPARISON OF THE VARIOUS METHODS IN MEASURING SNOW COVER

	Manual			Electronic, interactive analyzer			Digital computer
	Planimeter	Mean altitude	Dot	Reflectance mask	Reflectance mask edited by altitude	Reflectance mask edited by colour altitude	Pixel by pixel analysis
Precision	poor	average	good	poor	good	good	excellent
Speed	average	fast	average to fast	fast	average to fast	average	slow to average
Cost	average	low	average	low to average	high	high	high
Recognize snow in forest or in shadows	fair	average	good	poor	good	excellent	good
Supplemental data produced	no	some	yes	yes	yes	yes	yes

3.2.4 Determination of snow depth from satellite :

It was shown by Mc.Ginnis et al. (1979) that estimation of snow depth is possible by relating the snow depth with its reflectivity as sensed by the satellite borne sensors in the visible band.

3.2.5 Water equivalent of snow measurement[16] :

Air borne technique, based on the attenuation by a snow layer of natural γ-radiation emitted from ground, has proved successful to determine the water equivalent. The aerial flight is made first in absence of snow and then next with snow coverage.

3.2.6 Snowpack density :

Mc Millan and Mc Ginnis studied the River Basins in U.S.A. for snow density using LANDSAT I imagery in 4 bands and CCTS (Computer Compatible Tapes). One of the difficulties in such studies is the low threshold of saturation. They have found a relation of the type

$$\text{Snow density} = 0.0125\,T + \text{[illegible]}\,D + \text{[illegible]}\times 10^{-6}\,H - \text{[illegible]}\times 10^{-6}\,R + \text{[illegible]}$$

where

T = Sum of the average daily temperature above freezing since snowfall (°F)

D = Solar declination.

H = Ground level in m.

R = Satellite measured radiance.

There is a strong feeling that radar or microwave techniques will come the break through for determining snow thickness, water equivalent and density of snow.

3.3 Use of snow cover data for seasonal stream flow forecasting

Snow cover data over the Himalaya has been used by Rango and Salomonson (1976) for forecast of stream flow in the Indus river. Early spring snow cover area measurements were obtained for the upper Indus river basin above Attock in Pakistan and compared to April-June total streamflow during the years 1967 to 1971. A linear regression equation quantitatively expressing the relationship had a regression coefficient of 0.92. Prediction of April June 1972 streamflow using the equation so derived produced an estimate that is within 3 per cent of the actual total. Similar work has been done in many catchments of the U.S.A.

Ødegaard and Østrem (1977) related snowcover and snowmelt runoff using satellite data in Norway. The relation theory obtained is as follows

$$Q = 15 (e^{0.0012A} - 1)$$

where Q = subsequent runoff (10^6 m^3)

A = snow covered area km^2.

3.4 Uses of aerial photos in Hydrological Investigations

It is possible to study a vast area in short time with the analysis of aerial photos, which is quite reliable and fast, and gives the latest information. Ground methods of investigations are not only time consuming and expensive but by the time results could be compiled, they could certainly be out-dated.

Photo hydrological investigations are carried out mainly for the following :

1) Preliminary evaluation of ground surface where no such information is available particularly for reconnaissance studies to indicate potential water resources.
2) Making maps for general purpose, revenue, planning welfare.
3) Inventory of natural resources, e.g. agriculture, forestry, water resources, mineral exploration, soil surveys, etc.
4) Delineation of watershed and their boundaries.
5) Topographic mapping for the study of the river basin characteristics, including morphometric features.
6) Division of catchment into suitable slope facets for estimation of precipitation.
7) Site selection for locating rain gauge stations.
8) Preparation of special purpose maps showing geological features, land use, soil characteristics, vegetal cover intensities, location of river valleys, and its flood plains etc.

9) Water balancing of river basins increases where no stream flood data is collected, qualitative, quantitative information may be obtained from the measurement of lengths, shape, width, and depth of the channels.

10) Preparation of hydrological models.

11) General Ground water studies.

12) Mapping and monitoring the snow field in order to predict runoff in streams, deriving part of their water from the snowfield.

13) Evaluation of intensity and frequency of floods and mapping flood inundated areas.

14) Property survey for submerged area for solving rehabilitation problem while planning any reservoir.

15) Flood control, and hydropower generation potential.

16) Mapping shore lines, erosion and setting of the sea-coasts and river banks.

However, the use of aerial photographs has got certain limitations. One cannot completely do away with the field work but saving in time may be 2-3 times and in cost up to 5 times by resorting to the use of aerial photography. It has been found that monitoring of snow cover by LANDSAT-imagery is 6 times faster than the high altitude aerial photograph survey, and the cost of mapping by LANDSAT is about 1/2000th times the cost of the simplest mapping from aircraft surveys.

3.3 PRINCIPLES OF PHOTO-ANALYSIS :

3.3.1 Procedural steps in photo-hydrological analysis

Photo-hydrologic studies are generally carried out in the following steps.

1) After proper selection of a watershed, the topographic map is required to be prepared by making measurements for distances directions, contours, elevations, etc. of the terrain features.

2) Identification of topographic features and other details (geomorphic features) with the aid of image characteristics like shape, size, pattern, shadow, tone, texture and sites.

3) Correlation of image characteristics of various ground features (physical feature of basin) to derive relevant information about geology, geomorphology, rock-soil type, vegetation, land use etc. of the given area.

3.3.2 Preparation of topographic map:

For an accurate investigation, the investigator requires an up-to-date map of the project area. Aerial photographs help to prepare topographic map with more accurate representation of true relief distribution including contours and other drainage details in lesser time and cheaper cost than that obtained by the ground surveys. The topographic map reveals physiographic features like

a) Drainage basin and channel characteristics, and

b) Drainage pattern and texture.

3.9.3 Characteristics of Basins :

Basin characteristics available from photo-analysis are

a) Area, size, and shape of the basin including the nature of water divide. b) Shape index. c) Time of concentration in the basin. d) Bifurcation ratio. e) Circulatory ratio. f) Elongation ratio. g) Slope of the water shed h) Relief condition.

These characteristics are described below:

3.9.3.1 The area, size and shape of the basin:-

A river, or drainage, basin is the entire area drained by a stream or system of connecting streams such that all streamflows originating in the area is discharged through a single outlet. In large basins, it is assumed that all groundwater runoff originating from precipitation on the area is ultimately discharge from the basin as streamflow with the exception of that moisture which is returned directly to the atmosphere by evapo-transpiration.

The drainage area which is the plain and horizontally projected area enclosed within its divide is determined by planimetry from large scale map [17].

The shape and size of the basin considering outline form may affect much the stream discharge character-istics.

Horton [4] described the outline of a normal basin (shape) as a pear-shaped void. The quantitative expression expression of drainage basin outline form was made by him through Form Factor.

3.5.3.2 Form Factor, R_f :

Form factor, R_f is the dimensionless ratio of the basin area A to the square of the basin length L.

$$R_f = \frac{A}{L^2}$$

3.5.3.3 Shape Index S_i :

In its inverted form, L^2/A, this ratio was used in unit hydrograph applications by the U.S.Army Corps of Engineers.

$$S_i = \frac{L^2}{A}$$

where A = area of the watershed

L = basin length along the main stream from the remotest point.

The plot of log L vs. log A gives linear relationship.

3.5.3.4 Circularity ratio R_c :

Miller defined circularity ratio as the ratio of basin area A to the area of a circle A_c, having the same perimeter as the basin.

$$R_c = A/A_c$$

3.5.3.5 Compactness Coefficient :

The compactness coefficient is given by the formula,

$$C_c = 0.28\, P_b / \sqrt{A}$$

where P_b = Perimeter of the basin or sub basin

A = Area of the basin or sub basin

3.3.3.6 Effective slope :

It is given by the formula

$$S_B = 1.5 \; D.N./A$$

where S_B = effective slope of the basin

D = contour interval

N = the total number of contour lines intersected by the grid line (when grid is adopted)

3.3.3.7 Bifurcation Ratio :

In linear aspect of the channel system the number of stream segments of any given order will be fewer than for the next lower order but more numerous than for the next higher order. The ratio of number of segments of a given order N_u to the number of segments of the higher N_{u+1} is termed as bifurcation ratio, R_b.

$$R_b = \frac{N_u}{N_{u+1}}$$

3.3.3.8 Stream order :

It is a classification reflecting the degree of branching, or bifurcation, within a basin. Horton assigned order 1 to small, unbranched , finger-tip tributaries, order 2 to those which have branches of the first order only, order 3 to streams with branches of 2nd, and lower orders etc. This classification is the inverse of the European system. Based on Horton law of stream number

$$N_u = R_b^{(k-u)}$$

3.3.3.9 Time of concentration :

Time of concentration, T_c, as per modified Kirpich formula is given as

$$T_c = \frac{L^{1.15}}{7700\ H^{0.38}} \text{ in hours.}$$

where, L = length in feet along the channel from the remotest point in the area.

3.3.3.10 Slope of the watershed :

It is the change in gradient per unit length. Sudden changes in gradient of a slope may indicate out-crops of strata of differentially resistant horizons or fault-line scarps. The break of slope is easily identified as a sudden change in the contour density.

3.3.4 Drainage Pattern :

The following drainage patterns which give some structural or lithological idea of a basin are easily identified on the aerial photograph.

i) Dendritic

ii) Trellis form

iii) Rectangular form

iv) Radial/Annular form

v) Parallel form

vi) Dichotomic form

vii) Braided form

viii) Pinnate form

3.9.5 Drainage Texture :

Drainage texture refers to the number and relative spacing of drainage courses per unit area in the drainage basin. The climate, amount and intensity of precipitations, etc. determine the drainage texture. Drainage texture is sometimes separated into

a) Drainage density

and b) Drainage frequency.

3.9.5.1 Drainage density :

An important indicator of the linear scale of landform elements in stream-eroded topography is drainage density, D, introduced by Horton

$$D = \frac{\sum L_u}{A} \text{ (in miles per sq. miles)}$$

where $\sum L_u$ = total channel segment lengths cumulated for all orders within a basin.

A = total area of basin

Generally low drainage density (meaning coarse texture) is favoured in regions of highly resistant or highly permeable sub-soil materials under dense vegetative cover and where relief is low. High drainage density (meaning fine texture) is favoured in regions of weak or impermeable sub-surface materials, sparse vegetation, and mountainous relief. All permanent stream channels in their upper reaches are to be carefully included while drainage density is determined by photo-analysis.

3.5.5.2 Drainage Frequency :

As per Horton, R.E., stream frequency or channel frequency, F is the number of stream segments per unit area of F = N/A .

3.5.6 Geomorphology :

Geomorphology analysis involves a systematic study of the relief and of drainage system. This is the landform study including the main feature of relief, local relief, fluvial forms, forms of mass transport , reaction to lithology and structure, glacial forms, coastal forms, arid forms etc.

3.5.7 Soil Study :

The rock-soil type, permeable or nonpermeable, porous or nonporous, fractured or nonfractural, and moist or dry can be easily recognised on the [illegible] aerial photographs from their tonal and textural variations. Certain species of trees also give good indication of soil type. The rocksoil type and the vegetative cover have direct effect on the infiltration capacity which itself, in turn has a bearing on the amount of runoff from the watershed.

3.5.8 Vegetation :

Photoanalysis is extensively used in delineating the areas having different natural vegetal cover densities, by correlating the tonal and texture variations these can be transferred on to the base map. The knowledge of the extent and type of vegetation, some important information regarding while dealing with imagery in the near IR (0.7-1.2μ) band from Nimbus 3. Some portions of times could indicate no snow in the Alps, while the visible band data, which was collected simultaneously, showed a considerable amount of snow. This phenomenon occurred during the melting conditions in spring. It is caused by a considerable decrease in the reflected near - IR. radiation which in turn is apparently the result of a thin film of water at or near the surface of the snow which tends to absorb the radiation in that band.

Investigations show that for a given area there appears to be a normal pattern of snow disappearance. The most significant finding of these studies was the establishment of a close relationship between snowcover depletion and accumulated stream flow.

Despite some indications that the reflectance of snow may, under certain circumstances, be related to the snow thickness, there is at present no viable method for determining snow thickness, or water equivalent, or density of snow.

infiltration, precipitation, surface runoff, evapotranspiration losses and ground water can be achieved.

3.5.9 Land Use :

Land use mainly consists of forestation, cultivation, irrigation, urbanisation and transportation which can be easily identified on the aerial photographs by their specific image characteristics. All these factors have a certain influence on the base flow which increase with the expanding land use.

3.5.10 Photoanalysis of the snow covered areas :

For the hydrologists the most frequent water levels, snow probably represents the most complicated and most difficult - to - measure hydrological variable. Snow extent, distribution, water equivalent, water content, ice, thickness and density all play a large part in the assessment of the snowpack's contribution to runoff.

The absence of information relating to contemporaneous extent and depth of snowcover is a common problem. Remote sensing has been looked upon by many as a promising means of attacking the snowpack problem.

Colour and infra-red techniques are currently being tried for distinguishing types of snow pack and the presence of the melting water. A potentially useful discovery in remote sensing was made by Strong and co-workers (1971) while dealing with imagery in the near IR (0.7-1.2μm) band from Nimbus 3. Some portions of these would indicate no snow in the Alps, while the visible band data, which was collected simultaneously, showed a considerable amount of snow. This phenomenon occurred during the melting conditions in spring. It is caused by a considerable decrease in the reflected near - IR. radiation which in turn is apparently the result of a thin film of water at or near the surface of the snow which tends to absorb the radiation in that band.

Investigations show that for a given area there appears to be a normal pattern of snow disappearance. The most significant finding of these studies was the establishment of a close relationship between snowcover depletion and accumulated stream flow.

Despite some indications that the reflectance of snow may, under certain circumstances, be related to the snow thickness, there is at present no viable method for determining snow thickness, or water equivalent, or density of snow.

CHAPTER-IV

ANALYSIS OF BEAS CATCHMENT FOR SNOW COVER AND SNOWMELT

4.1. THE BEAS CATCHMENT.

The source of Beas river is said to be Beas Kund a small spring near Rohtang pass. Unlike other major rivers of North India it is not fed by natural lakes. The catchment lies between longitude 76° 56' E to 77°52'E and latitude 31°30' N to 32° 25N' and occupies the area of about 4894 km^2, out of which about 1400 km^2 is permanently covered by snow. River Beas is the principal tributary of river Sutlej in the Indus river basin. Most of the catchment area comprises of precipititious slopes and the peaks are mainly bare. The river is mainly fed by snow and glacial melt besides the rainfall. The orographic pattern of the catchment is such that there are high mountains in the east as well as the north of the river valley. There is a high ridge on the West and a number of low hills ranging from 950 m to 1220 m in height. The river originating from Beas Kund takes a south-westerly direction upto Kulu and then takes a south-easterly direction upto its confluence with Tirthan and Saing rivers. It again flows in south-westerly direction, upto Pondoh, down stream of Larji.

The bed slope of river Beas in upper reaches is very steep, and the average value of the bed slope from Rohtang pass to Manali is about 78 m/km, from Manali to Kulu, about 15.6 m/km, and from Kulu to Larji, about 8 m/km.

The principal tributaries of Beas river upto Larji site are Allun Nallah near Manali, Sarvari khand, near kulu, Parvati river near Bhuntor, Thirthan and Sainj rivers near Larji (Appendix:I). All these tributaries have got perrennial flow which varies considerably during different months of the year. The catchment area at a scale of 1 inch to 4 miles (1: 253440), with contours at 2000 ft (611 m. approximately) interval is shown in the Appendix II.

4.2. COMPUTATION OF MORPHOMETRIC AND RELIEF FEATURES

4.2.1 MEASUREMENT OF BASIN AREA.

Area of Larji Basin and its subbasins were measured with the help of a planimeter and the average values are given in the table number (4.1).

4.2.2. NUMBER OF STREAMS

All the streams according to their order in each sub-catchment were counted and the total number is tabulated in the table number (4.1).

4.2.3. TOTAL LENGTH OF STREAMS

As arranged in orders, the respective lenths

Morphometric parameters and relief characteristics of Karji catchment

Sl.No.	Particulars	Symbols	Units	Values of the catchment				
				Mand II	[illegible]	[illegible]	[illegible]	Karji
1	2	3	4	5	6	7	8	9
1.	Area (Basin size)	A	km^2	339.41	699.42	795.8	1731.4	0024
2.	Basin Perimeter	P_b	km	75.02	175.70	155.16	217.54	339.02
3.	Area of circle of basin perimeter	A_c	km^2	459.49	1713.56	1052.79	3784.40	9105.63
4.	Diameter of circle of Basin Area	D_c	km	21.63	29.84	15.91	45.96	70.92
5.	Maximum Basin length	L	km	20.27	48.91	31.82	67.58	73.59
6.	Shape Index (Basin shape)	$S_i = L^2/A$	-	1.11	3.42	2.99	2.64	1.20
7	Form factor	$R_f = A/L^2$	-	0.90	0.29	0.340	[illegible]	0.89
8.	Compactness coefficient	$C_c = 0.28\ P_b/\sqrt{A}$	-	1.11	1.59	1.340	1.63	1.33
9.	Circularity	$R_c = A/A_c$	-	0.60	0.41	0.550	0.43	0.59
10.	Elongation ratio	$R_e = D_c/L$	-	1.07	0.61	0.66	0.69	1.00
11.	Total number of streams	N	-	59	105	114	194	724
12.	Total length of streams	L_u	km	144.49	257.10	205.24	337.01	1670.49
13.	Relief	H	m	4134.57	2370.03	4207.59	5549.43	5570.63

1	2	3	4	5	6	7	8	9
14.	Watershed slope	$S_s = H/L$	-	0.204	0.055	0.099	0.082	0.074
15.	Time of concentration	$T_c = \frac{L^{1.15}}{7700 H^{0.385}}$ hr.	-	2.24	6.19	6.42	10.79	11.56
16.	Maximum number of order of streams	U	-	3	5	5	5	6
17.	Bifurcation ratio	$R_b = N_u / N_{u+1}$	-	4.30	3.23	3.21	4.78	3.76
18.	Stream frequency	$F = N/A$	-	0.16	0.15	0.13	0.11	0.15
19.	Stream density	$D = \Sigma L/A$	-	0.39	0.37	0.26	0.21	0.30

of the streams were measured and these are given in table No. (4.1).

4.2.4. THE LOCAL RELIEF

It is generally found by selecting representative smaller sub-basins, finding the number of contours cut by a line and dividing it by the number of facets. Here the relief (H) is calculated by taking the elevation difference between basin mouth and the highest point on the basin perimeter. The values are given in table (4.1).

4.2.5. OTHER TYPICAL MORPHOMETRIC COMPUTATIONS

The other parameters like the stream density, stream frequency etc., have been calculated as according to the definition given in article (3.5.3) and tabulated in the table (4.1)

4.3. VEGETAL COVER AND LAND USE FEATURES

An attempt has been made to identify and delineate the vegetal cover and land use features using visual interpretation techniques, from 1:250,000 blow up of LANDSAT imagery dated 2nd December, 1972. Five distinct tonal variations could be recognised in the paper print. The interpretation includes the features like the snow covered area, Alphine pasture, thin forest, thick forest and bare-and- cultivated land which are shown in the appendix III. The areal coverage of the features are given below in table No. (4.2). The hydrologic behaviour of forest and range lands and relationship of land use to water yield and stream flow has been studied quite extensively. These studies have gradually lead to an understanding of some of the basic relationships between land use and run-off, debris deposition, the schooling of stream channels, silting of reservoirs, storm flows, and other phenomena that have followed excessive logging, cultivating, burning, and grazing of forest lands and range lands.

TABLE 4.2.

VEGETAL COVER AND LAND USE FEATURE IN LARJI CATCHMENT

Sl.No.	VEGETAL COVER & LAND USE FEATURES	AREA Km^2	PERCENTAGE OF CATCHMENT(%)
1	Snow cover	1451	29.66
2	Alpine pasture	552	11.29
3	Thin Forest	523	10.69
4	Thick Forest	1359	27.78
5	Bare and Cultivated land	1006	20.57
X			

4.4 SNOW COVERAGE IN LARJI CATCHMENT USING THE LAND SAT IMAGERIES.

4.4. SNOW COVERAGE IN LARJI CATCHMENT USING THE LAND-SAT IMAGERIES.

4.4.1. THE LANDSAT IMAGERIES

The Beas catchment upstream of Larji was studied with the help of the multi spectral LANDSAT imageries from Space Application Centre, Ahmedabad of the following dates as 22, Sept., 1972, 3 December, 1972, 3 March, 1973, 21 March, 1973, 2nd March, 1975, 1 April, 1976 and 27 March, 1977. These imageries were in Band 5 and 7 and at a scale of 1: 1000 000. These are shown in figures (4.1, 4.2, 4.3).

4.4.2. STUDY OF SNOW-COVERED REGIONS ON LANDSAT IMAGERIES

LANDSAT imageries as above of the Beas catchment up stream of Larji were analysed. The over lays were traced from the imageries and areal extent of the snow cover in each sub basin was measured. These are shown in figures (4.1, 4.2, 4.3).

The results are tabulated in table number (4.3)

From the LANDSAT imageries it is clearly discernible that the extent of snow cover gradually increases from the month of September to March. This can be observed from the data in the table No.(4.3). Snow coverage is maximum in the month of March after which it depletes due to melting. From similar observation it has also been found that the Sutlej and Beas catchments

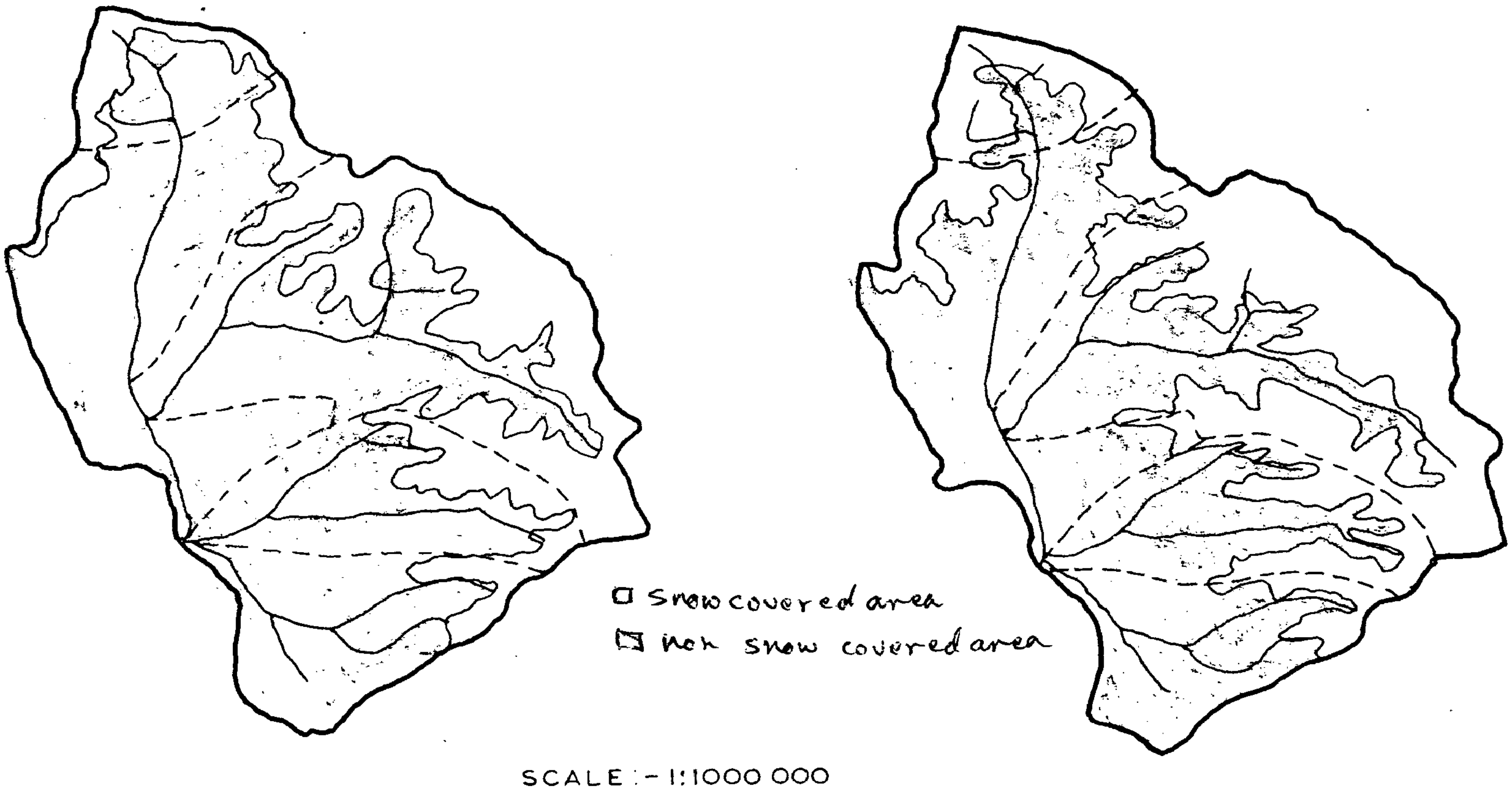


FIG. (i) LANDSAT IMAGE DATE 22 SEP. 1972
MSS 7

FIG.(ii) LANDSAT IMAGE DATE 3 DEC. 1972
MSS 7

FIG. 4·1 LANDSAT IMAGERIES OF BEAS CATCHMENT UP STREAM OF LARJI

FIG. (iii) LANDSAT IMAGE DATE 22 SEP 1972 MSS 5

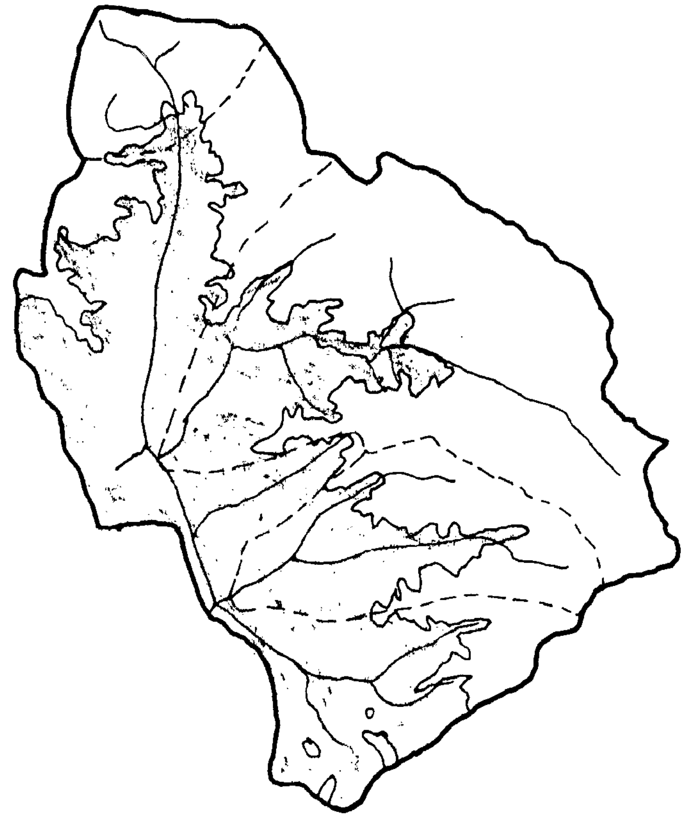


FIG. (iV) LANDSAT IMAGE DATE 3 DEC 1972 MSS 5

SCALE — 1:1000000

▨ Snow covered area
▩ non-snow covered area

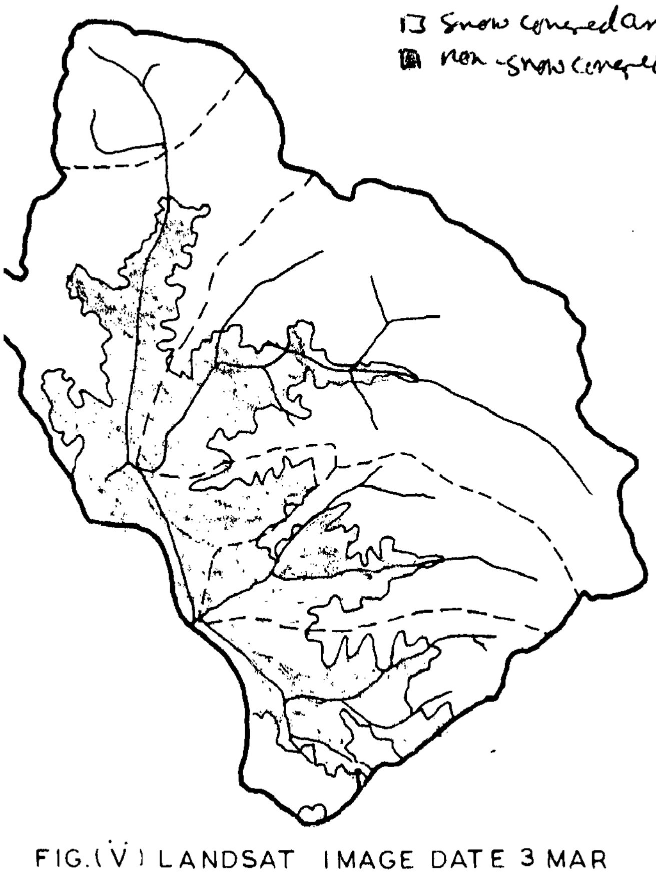


FIG. (V) LANDSAT IMAGE DATE 3 MAR 1973 MSS 5

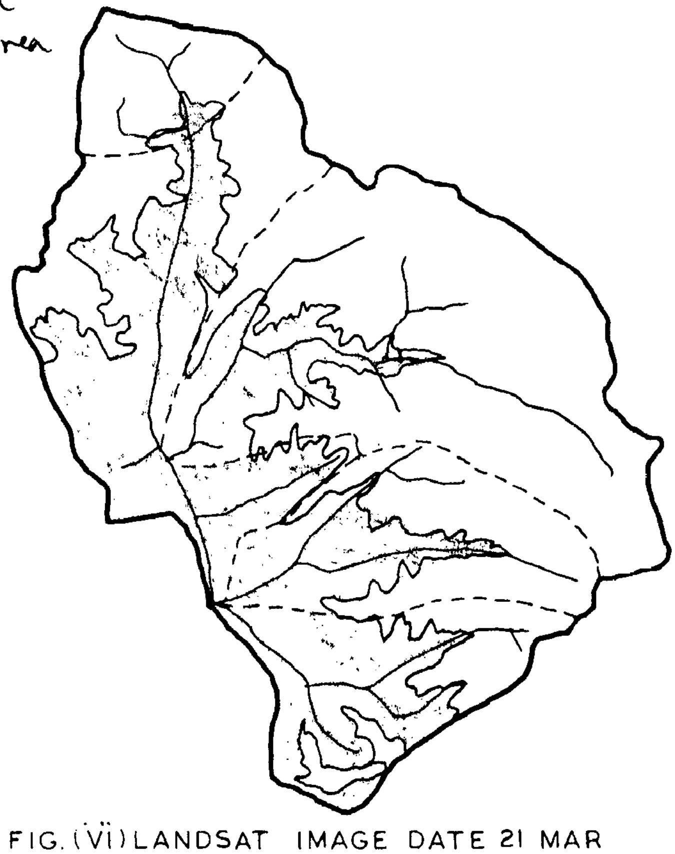
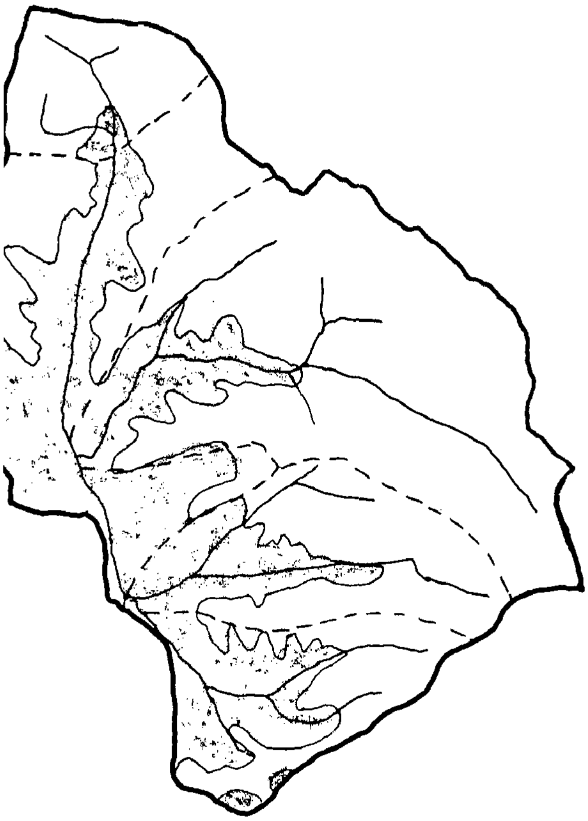


FIG. (Vi) LANDSAT IMAGE DATE 21 MAR 1973 MSS 7

FIG. 4·2 LANDSAT IMAGERIES OF BEAS CATCHMENT UP STREAM OF LARJI



.(Vii) LANDSAT IMAGE
DATE 21 MAR. 1973 MSS 5

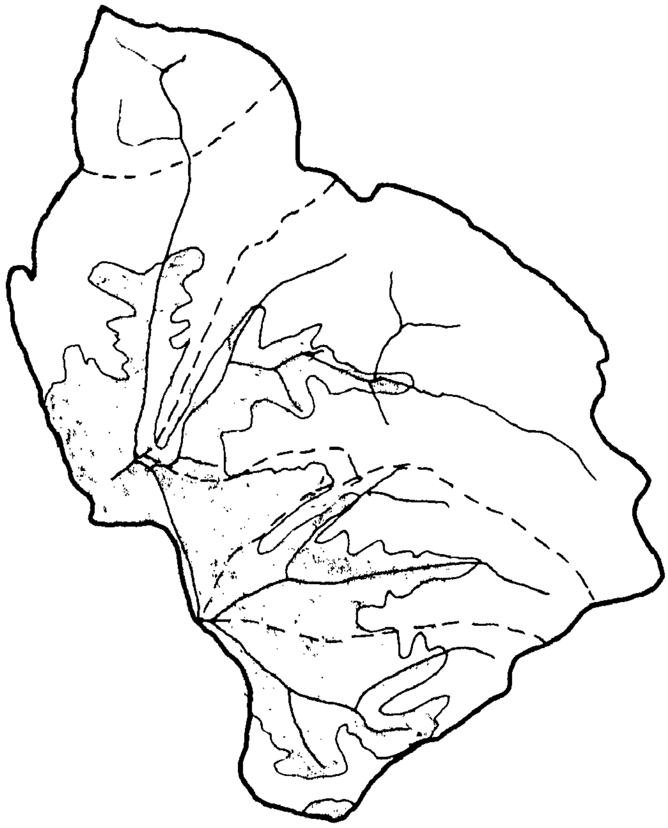


FIG.(Viii) LANDSAT IMAGE
DATE 2 MAR. 1975 MSS 7

SCALE:- 1: 1000,000

☐ snow covered area

▩ non snow covered area

(iX) LANDSAT IMAGE
TE 1 APR. 1976 MSS 5

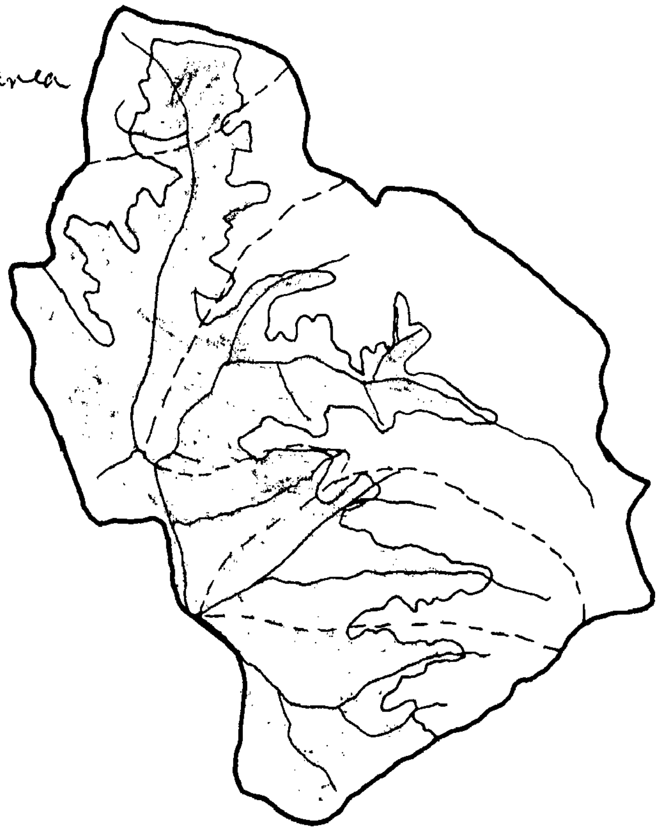


FIG. (X) LANDSAT IMAGE
DATE 27 MAR 1977 MSS 5

G. 4·3 LANDSAT IMAGERIES OF BEAS CATCHMENT UP STREAM OF LARJI

Areal Extent of snow-cover from LANDSAT Imageries

S.N.	Catchment	Area of catchment in km^2	Date: 22 Sept. 1972 (BAND MSS 5) snow-covered area in km^2	%	(BAND MSS 7) sno-covered area in km^2	%	Date: 3 Dec. 1972 (BAND MSS 5) snow-covered area in km^2	%	(BAND MSS 7) Snow-covered area in km^2	%	Date: 3 Mar. 1973 (BAND MSS5) snow-covered area in km^2	%
1.	Manali	369.41	207	56.04	116	31.40	359	97.18	212	57.39	360	97.45
2.	Parvati	1731.60	1100	63.53	724	41.81	1362	78.66	1080	62.37	1424	82.24
3.	Sainj	795.80	234	29.40	~~160~~ 167	20.99	340	42.72	208	26.14	336	42.22
4.	Tirthan	~~[illegible]~~ 699.40	~~[illegible]~~ 89	~~[illegible]~~ 12.73	71	10.15	119	17.01	95	13.88	265	37.89
5.	Larji	4894	1855	37.90	1216	24.85	2489	50.86	1832	37.43	3025	61.81

TABLE –4.3 Continued.

S.N.	Catchment	Area of catchment in km^2	Dates 21 March 1973 (BAND MSS 5) Snow-covered area in		(BAND MSS 7) Snow-covered area in		Date: 2 March 1975 (BAND MSS 7) Snow covered in area in		Date: 1 April 1976 BAND MSS5) Snow-covered area in		Date: 27 Mar. 19 (BAND MSS 5) Snow-covered area in	
			km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
1.	Manali	369.41	348	94.20	289	78.23	360	97.45	360	97.45	163	44.12
2.	Parvati	1731.60	1553	89.69	1450	83.74	1513	67.30	1430	02.58	1306	75.42
3.	Sainj	797.80	490	61.57	365	45.87	462	58.05	475	59.69	334	41.97
4.	Tirthan	699.40	273	39.03	219	31.31	191	27.31	310	44.32	174	24.88
5.	Larji	4894	3173	64.83	2912	59.50	3057	62.46	3050	62.32	2194	44.83

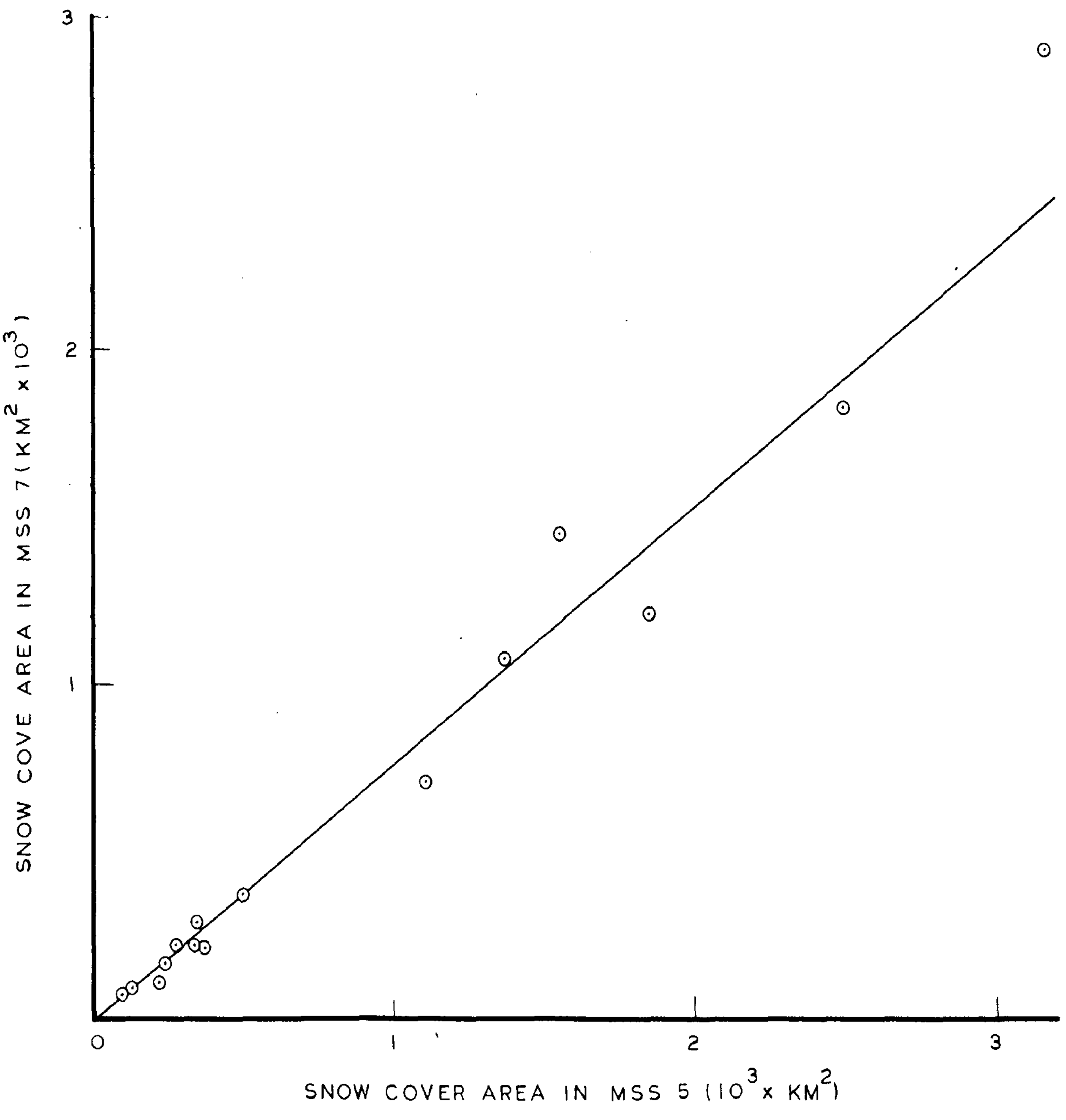


FIG. 4·4 SNOW COVER IN MSS 5 VS MSS 7 IN LARJI CATCHMENT have maximum snow coverage in the months of February and March.[15] It is also interesting to note that the snow coverage in the imageries taken on the same day in Band 5 and Band 7 are not the same. These can be observed from the figures 4.1(i), 4.1(ii), 4.2(iii), 4.2(iv), 4.2(vi) and 4.3(vii).

These imageries in the infra-red Band 7 indicates less snow than in those of the visible Band 5. These values of areal extent of snowcover as measured on Band 5 and Band 7 LANDSAT imageries at 1:100,000 scale have been tabulated in table No.(4.3) and also plotted as a graph in figure (4.4). A linear trend inclined at an angle of 37° from the X-axis of the HSS 5 has been observed from the graph.

4.4.3. THE SNOW COVER AND RUNOFF RELATION.

The imageries of the months of March indicate the extent of snow coverage in the basin before the melting season. Therefore, it is possible to get a relationship between the snow coverage of the basin before the melting season and the subsequent seasonal melt runoff. From the figures (4.3(vii), (viii), (ix) and (x)) the snow-covered areas of the sub-basins have been measured and the values tabulated in table No. (4.3). The cumulative sum of daily discharges in the months March-April-May as shown in table (4.4) and the snow coverage have been

TABLE No. 4.4

Cumulative volume of daily discharges for the months March-April-May

Sainj

Year	Month	Monthly sum of daily discharges (m^3/s)	Total monthly Base flow (m^3/s)	Monthly sum of daily discharges excluding baseflow. (m^3/s)	Monthly sum of the volume daily discharge (m^3)	Cumulative monthly discharge/vol. (m^3)
1	2	3	4	5	6	7
1973	March	655.24	308.45	346.79	928842330	928842330
	April	1152.63	298.5	854.13	2213904900	3142747230
	May	1732.09	308.95	1423.16	3811738100	6954485330
1975	March	597.88	370.14	227.74	609978810	609978810
	April	747.18	359.20	388.98	1008236100	1618214910
	May	1215.26	370.14	845.12	2263569400	3881784310
1976	March	503.61	362.08	141.53	379073950	379073950
	April	858.39	350.40	507.99	1316710000	1695783950
	May	1223.09	362.08	861.01	2306129100	4001913050
1977	March	374.4	354.95	19.45	52094880	52094880
	April	447.7	343.50	92.75	240408000	292502880
	May	711.88	354.95	356.93	956001310	1248504190

C...d....

Tirthan

1	2	3	4	5	6	7
1973	March	827.82	8290.78	536.54	1437335500	1437336500
	April	1137.82	281.40	856.43	2219864500	3657203000
	May	972.33	290.78	681.55	1825463500	5482666500
1975	March	656.75	221.03	435.72	1167032470	1157032400
	April	909.13	213.9	695.23	1802036100	2969068500
	May	872.60	221.03	551.57	1749165000	4714233500
1976	March	579.92	300.39	279.53	768893150	768893150
	April	1012.20	290.70	721.50	1870128000	2619821150
	May	849.15	300.39	548.76	1469798700	4088619850
1977	March	304.57	200.88	103.69	277723290	277723290
	April	336.67	194.40	172.27	446523840	724247130
	May	509.07	200.88	308.19	825456090	1549703220
			Prazaki			
1973	March	899.42	719.51	179.91	481870940	481870940
	April	1468.31	696.3	772.01	2001049900	2482920840
	May	3256.15	719.51	2536.64	6794136500	9277057340

Contd.....

1	2	3	4	5	6	7
1975	March	1189.96	644.8	545.16	1460156500	1460156500
	April	1635.94	624	1011.94	2622948400	4083104900
	May	2533.94	644.8	1889.14	5059872500	1942977400
1976	March	1121.66	699.36	422.3	1131088300	1131088300
	April	1701.61	676.8	1024.81	2656307500	3787395800
	May	2626.57	699.36	1927.21	5161839200	8949235000
1977	March	789.41	699.36	90.05	241189920	241189920
	April	946.81	676.8	270.01	699865920	941055840
	May	3811.48	699.36	3112.12	8335502200	9276558040
			Lardi			
1975	March	3712.72	1497.61	2215.11	5932950600	5932950600
	April	6241.7	1449.3	4792.4	12421900000	18354850600
	May	10139.18	1497.61	8641.57	23145591088	41500441688

1	2	3	4	5	6	7
1976	March	4591.08	1470.33	3120.75	8358616800	8358616800
	April	7324.57	1422.90	5901.67	15297128000	23655744800
	May	8931.34	1470.33	7461.01	19983569184	43639313984
1977	March	2202.7	1645.79	556.91	1491627700	1491627700
	April	2772.97	1592.70	1180.27	3059259800	4550887500
	May	5977.41	1645.79	4331.7	11602025280	16152912780
			Maneli			
1978	March	623.88	284.58	339.3	908781120	908781120
	April	1549.03	275.40	1273.63	3301248900	4210030020
	May	2549.03	284.58	2264.45	6065102800	10275132820
1977	March	506.31	217.31	289.00	774057600	774057600
	April	734.6	210.3	524.30	1358985600	2133043200
	May	999.88	217.31	782.57	2096035400	4229078600

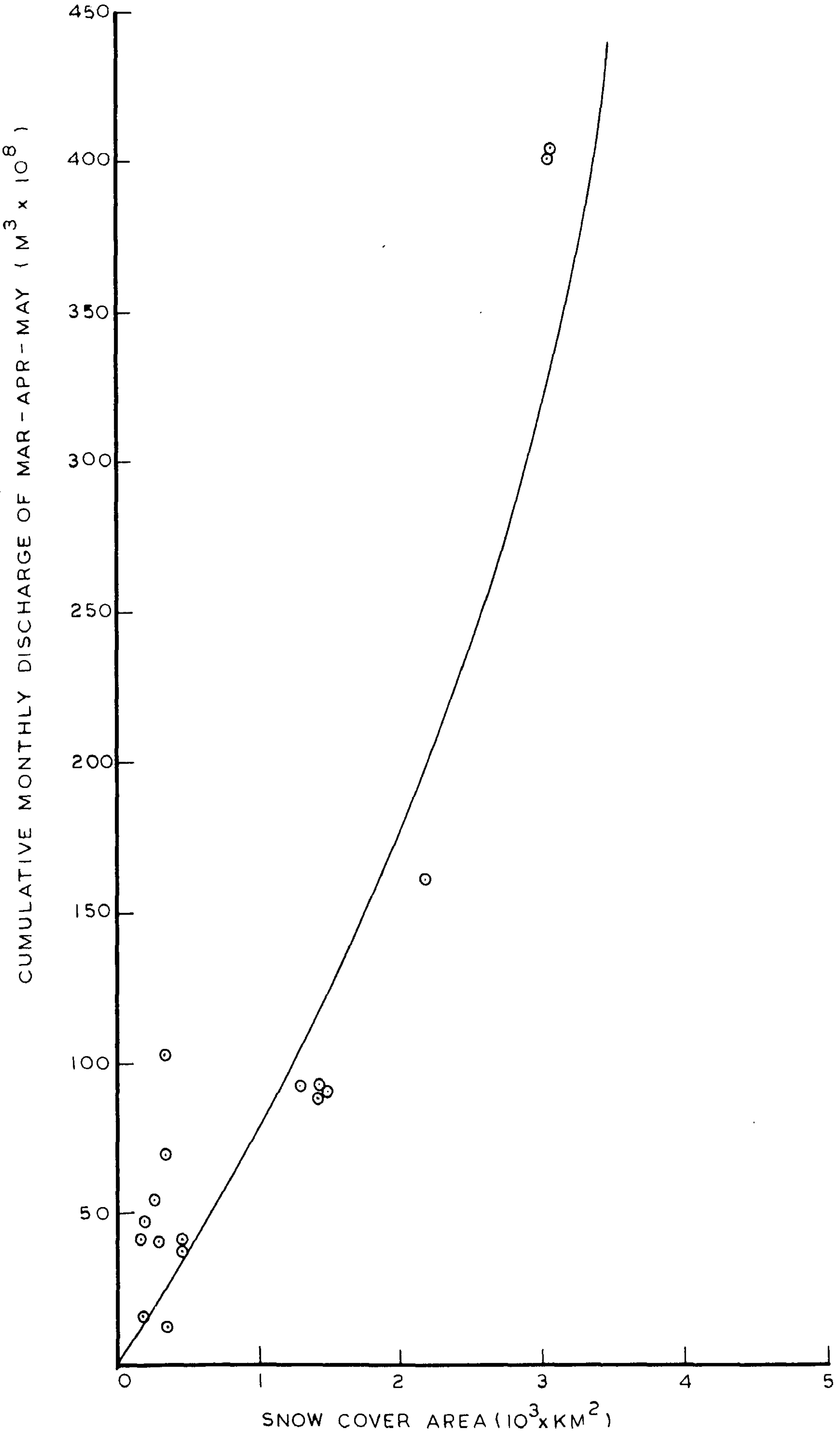


FIG. 4·5 RELATION BETWEEN THE SNOW COVERAGE AND CUMULATIVE MONTHLY DISCHARGE OF MONTHS MARCH-APRIL-MAY IN LARGI CATCHMENT plotted as shown in figure (4.5). An exponential curve can be fitted to these limited plotted points. Here discharge data of 1973, 1975, 1976 and 1977 have been used. A better relationship can be got by using more number of years of data.

The snow covered areas in the basins and the cumulative sum of average discharges obtained from the maximum and minimum discharges of the months March-April and May as shown in table no. (4.5) have been also used in getting a similar relationship. Here an exponential curve also can be fitted.

As shown in figure (4.6). It is giving a better fit than in the former case. From these curves it is evidently concluded that with more snow coverage more seasonal runoff can be expected.

No consideration of the change in the geological and geohydrological feature have been taken into account, where as this could change locally and affect the discharge.

4.5. METHODOLOGY FOR SNOWMELT RUNOFF COMPUTATION DURING MELT SEASON (MARCH TO MAY).

The basic phenomena involved in the snowmelt process has been of major interest to hydrologists and others involved in stream flow forecasting. It is

TABLE-4.5

Cumulative volume of monthly average discharge for the months March-April-May.

Sub Catchment Sainj

Year	Month	Minimum daily discharge (m^3/s)	Maximum daily discharge in cumecs	Average daily discharge in cumecs	Baseflow cumec	Average daily discharge excluding baseflow in (m^3/s)	Discharge volume for the month (m^3)	Cumulative average discharge volume (m^3)
1	2	3	4	5	6	7	8	9
1973	March	10.10	29.87	23.99	9.95	14.04	37604735	37604736
	April	21.32	73.69	47.76	9.95	37.81	98003520	135608256
	May	32.71	79.04	55.88	9.45	45.93	123018910	258627166
1975	March	15.72	22.08	18.90	11.94	6.96	18641664	18641664
	April	21.66	29.24	25.45	"	13.51	35017920	53659584
	May	29.13	71.73	50.43	"	38.49	103091610	156751194
1976	March	11.06	29.24	20.15	11.68	8.47	22686048	22686048
	April	19.33	40.24	29.79	"	18.11	46941120	69627168
	May	31.20	60.05	45.63	"	33.95	90931680	160558848
1977	March	10.63	14.97	12.8	11.45	1.35	3615840	3615840
	April	13.64	20.32	16.98	"	5.53	14333760	17949600
	May	16.03	43.48	29.75	"	18.30	49014720	66964320

Sub catchment - TIRTHAN

1	2	3	4	5	6	7	8	9
1973	March	14.80	55.56	35.18	9.33	25.00	69102720	69102720
	April	32.14	45.58	38.86		29.48	76412160	145514880
	May	23.47	45.81	34.64		25.26	67656384	213171264
1975	March	13.90	29.33	21.62	7.13	14.49	38810016	38810016
	April	25.18	42.03	33.62		26.49	68662080	107472076
	May	20.86	34.39	27.63		20.50	54907200	162379296
1976	March	12.90	34.39	23.65	9.69	13.96	37390464	37390464
	April	18.16	42.74	30.48		20.77	52539840	89930304
	May	21.20	31.97	26.59		16.90	45264960	135195264
1977	March	7.7	13.64	10.67	6.48	4.19	11222496	11222496
	April	11.25	21.46	16.36		9.88	25308960	35831456
	May	13.5	23.13	18.32		11.24	31712256	68543712

Sub catchment- PARVATI

1	2	3	4	5	6	7	8	9
1973	March	32.45	59.02	45.74	23.21	22.53	60344352	60344352
	April	44.98	149.20	97.09		73.88	191496960	251841312
	May	105.154	181.88	143.52		120.31	322238300	574079612

1	2	3	4	5	6	7	8	9
1975	March	48.28	62.66	55.47	20.80	34.67	92860128	92860128
	April	174.18	136.42	155.30		134.50	348624000	441484128
	May	65.26	233.06	159.15		138.35	370556680	812040768
1976	March	26.14	82.41	54.29	22.56	31.70	85119552	85119552
	April	36.37	76.73	56.55		34.05	88257600	173377152
	May	65.11	142.10	103.61		81.21	217245020	390622172
1977	March	22.65	31.74	27.20	22.56	4.64	12427776	12427776
	April	22.96	51.32	37.14		14.58	37791360	50219136
	May	31.23	82.41	56.82		34.26	91761984	141981120
			Sub Catchment- LARJI					
1975	March	76.22	173.08	124.65	48.31	76.34	204469050	204469050
	April	147.10	266.55	206.63		150.52	410883840	615352890
	May	174.19	588.29	381.24		332.93	891719710	1507072600
1976	March	86.43	241.57	164	47.43	116.57	312221080	312221080
	April	176.20	314.01	245.11		197.69	512386560	824607640
	May	229.97	363.78	296.875		249.45	668126860	1492734520
1977	March	60.39	85.15	72.77	53.09	19.68	52710912	52710912
	April	74.03	224.43	149.23		96.14	249194880	301905792
	May	94.81	480.58	287.70		234.61	628379420	930285212

Sub Catchment – [illegible]

1	2	3	4	5	6	7	8	9
1977	March	23.33	16.09	11.30	7.01	0.30	22177152	22177152
	April	41.50	10.34	30.31		21.01	55720720	73037072
	May	45.95	26.10	55.30		23.03	72155063	151183800
1978	March	45.07	15.20	30.44	0.20	21.23	55942704	53962704
	April	71.59	27.51	60.72		60.53	105053730	131983900
	May	107.09	62.72	83.70		73.00	203195040	357101904

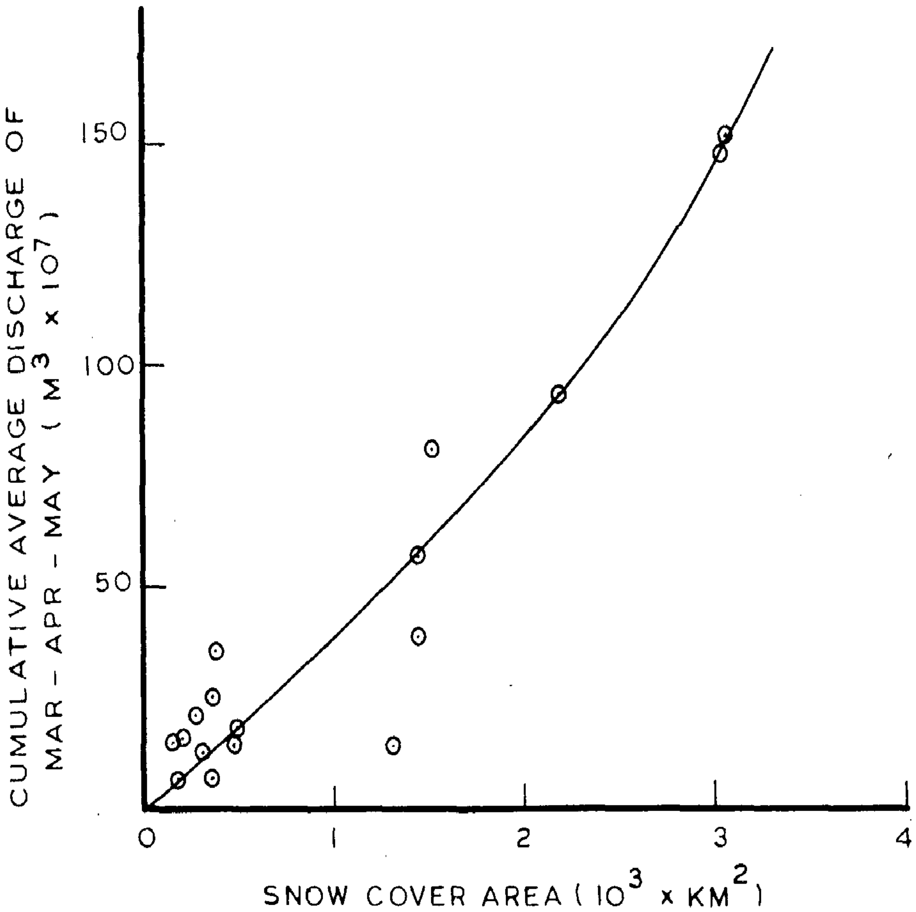


FIG. 4·6 RELATION BETWEEN THE SNOW COVERAGE AND CUMULATIVE AVERAGE DISCHARGE OF MONTHS MARCH - APRIL - MAY. IN LARGI CATCHMENT.

important that the hydrologist understand the nature and distribution of snowfall and mechanism involved in the snowmelt process if he is to make adequate estimates of the stream flow derived from this source.

Usually limited data is available in mountainous basins and generally temperature and precipitation are the only available ones.

In such basins the snow accumulation season (December to February) and the snowmelt season (March to May) are considered for the forecasting of the snowmelt runoff. During these seasons the basins can have permanent snow-covered area, temporary snow-covered area, and the nonsnow-covered area.

The aerial photography can provide the extent of snow coverage in such remote and inaccessible basins.

Due to the great elevation range, differences in temperature and precipitation have to be taken into consideration.

6.5.1. ASSUMPTIONS IN THE METHODOLOGY.

1. The catchment is divided into altitudinal bands to take into account the orographic effect on the precipitation and the temperature.

2. The contribution to snowmelt comes from both the temporary and permanent snow-covered areas.

3. The accumulation season is considered to extend from November to around Mid-March and the snow-melt season from around mid-March to May. This is to be judged by considering the meteorological conditions prevailing in the catchment.

4. The precipitation, rain as well as snow, received by the different altitudinal bands are substantially affected by the orographic effect. Therefore, each band gets different amount of precipitation increasing with the altitude.

5. During the accumulation season the snowmelt is negligible. The storage of snow in the various altitudinal band starts depleting during the melt season only.

6. The losses accounted from the snowmelt as well as the rainfalling on the snow-covered area will including those due to evaporation and infiltration

7. The predominant factors affecting snow-melt rate are the air temperature and rainfall. The other processes influencing heat transfer to the snow pack are relatively less important and are not taken into consideration.

8. During the accumulation season the base station can occasionally record rainfall and snow fall on the same day. During such time since the temperature is near freezing point, the rain falling on the accumulated snow pack is considered to be frozen through contact with the colder underlying snow. However, the higher altitudes can get snowfall instead due to the orographic effect.

4.5.2. THE DIVISION OF THE BASIN

The basin is divided into the temporary snow-covered zone, the permanent snow-covered zone, and the nonsnow-covered zone, provided that the basin is not completely covered by snow. These divisions can be made with the help of regular satellite or aerial photographs.

4.5.3. THE TEMPERATURE IN THE ELEVATION ZONES

The base station is used to provide input temperature data to the various elevation zones. The basin with a certain contour internal is divided into a number of elevation zones, the median heights of which are considered to be representative of the zone. The number of zones will depend on the size of the catchment and the availability of the contour maps.

By use of the lapse-rate approach, the

daily temperatures for each zone are computed by extending data from the base station.

$$\theta_i = \theta_b - \gamma (h_i - h_b) \qquad (4.1)$$

Where θ is the daily mean temperature (in °C)

h is the elevation (in m)

i and b are subscripts, referring to elevation zone i and the base station respectively

γ is an emperically derived coefficient which represents the lapse rate.

4.5.4. THE PRECIPITATION IN THE ZONES

The precipitation both rain as well as snow in the mountaineous basin increases with height due to orographic effect. Instead of using a single value of the precipitation recorded at the base station, some reasonable incremental values of precipitation for the different elevation zones are assigned for taking into account the orographic effect. The precipitation received by a given zone will be given by the equation.

$$H_i = H_b + H_c \qquad (4.2)$$

where H_i is the daily precipitation received by the zone i in mm.

H_b is the daily precipitation recorded at the base station in mm.

M_c is the incremental values of the precipitation with elevation in mm per ~~mm~~ km

4.5.5. THE ACCUMULATION OF SNOW IN THE ELEVATION ZONES

Snowfall occuring from November to around mid-March can be taken into account as the stored water in the form of snow, keeping in view that negligible amount of snowmelt occur during this period as temperature generally remains near freezing point. Different amounts of snow is stored in various elevation zones due to the orographic effect on the snowfall.

4.5.6. COMPUTATION OF SNOWMELT

Since there is scanty rain during the snowmelt season, the flow in the streams are mainly contributed from the snowmelt.

(A) <u>The degree-day method</u>

The daily snowmelt depth in centimeter using the dgree day method is given by

$$M = a.T_d$$

where 'M' is the daily snowmelt in cm

'a' is the degree day factor in cm $°C^{-1}$ d^{-1}

'T_d' is the number of degree days in °Cd.

(B) Snowmelt due to rain

R The depth of water melted by rain in centimeter is given by

$$D = H \frac{T_r}{80} \qquad (4.4)$$

Where D is the depth of water melted by rain in cm.

H is the rainfall depth in cm.

T_r is the temperature of rain in °C, which can be represented by the wet bulb temperature

80 is the ratio of heat of fusion of ice to the specific heat of water (dimension : °C)

Now taking into consideration an elevation zone A, the daily snowmelt in (m^3/s) is with the degree day method given by,

$$Q_A = a_A \cdot T_{dA} \frac{A_A}{86400(S)} \qquad (4.5)$$

Where Q_A is the daily snowmelt in m^3/s

a_A is the degree day factor in $m°C^{-1}d^{-1}$

T_d is the number of degree days in deg-cd

A_A is the snowcovered area of zone A in m^2

86,400(S) is the number of seconds per day, which converts the daily snow melt volume into daily discharge.

The snowmelt due to the rain in the elevation zone A is given by

$$Q_{rA} = H_A \cdot \frac{T_{rA}}{80} \frac{A_A}{86400(s)} \qquad (4.6)$$

Where Q_{rA} is the snowmelt due to rain in zone A in m^3/s

H_A is the rainfall depth in m.

T_{rA} is the temperature of the rain in zone A in °C

A_A is the snow covered area of the zone A in m^2

86400 (s) is the number of seconds per day

80 is the ratio of the heat of fusion of ice to the specific heat of water (dimension : °C)

Therefore, the total daily snowmelt discharge in m^3/s for the combined effect is given by

$$A_{A,rA} = Q_A + Q_{rA} \qquad (4.7)$$

The term Q_{rA} exists only if rain is there on the particular day.

The snowmelt continues till all the snow has completely depleted out of the zone. Therefore, it is important to keep in account the daily balance of the equivalent water stored in the temporary zone.

4.5.7. TRANSFORMATION OF SNOWMELT TO RUNOFF

In most cases, snowmelt calculations must be simplified owing to lack of detailed data on the energy balance. However, in accuracies which might result can be overshadowed by complications invalued in extrapolating snowmelt relations from one point to the whole basin in order to determine the runoff. Apart from necessity of extrapolating meteorological data to the various parts of the basin, the retention of the meltwater on its way, to the outlet must be considered in a broad variety of conditions.

In snow-lysimeter studies, the melt water is only delayed by percolation through the snow. Consequently the daily runoff ~~mmmk mmmk~~ coincides with the daily snowmelt . Owing to the larger area of a basin and owing to the subsurface runoff, only a part of melt water appears in the outflow within the next 24 hours. If no further snowmelt were to take place, the remaining melt water would follow on subsequent days as recession flow according to the equation,

$$Q = Q_o k^t \qquad (4.8)$$

where Q_o is the initial discharge of the snowmelt recession curve

k is the recession coefficient

t is the time as dimensionless number of time increments.

If k refers for example, to discharge on two consecutive days, is the number of days.

Runoff R is obtained by integrating the hydrograph.

$$R = \int_0^t Q\,dt = \int_0^t Q_0 \; k^t \, dt$$

$$= Q_0 \left[\frac{k^t}{l_n k} \right]_0^t = Q_0 \; \frac{k^t - 1}{l_n k} \qquad (4.9)$$

With Q in units of m^3/s, R in m^3 and k referring to 1-day internal, the runoff R_1 in the first 24 hours starting with Q_0 and ending with Q_t is

$$R_1 = Q_0 \; \frac{k-1}{l_n k} \times 86400 \text{ (S)} \qquad (4.10)$$

The totalrun of R_t for $k < 1$, $t = \propto$ is

$$R_t = Q_0 \frac{-1}{l_n k} \times 86400\text{(S)} \qquad (4.11)$$

Substituting $Q_0 = - l_n k \cdot R_t$ into equation (4.10)

$$R_1 = R_t \; (1-k) \qquad (4.12)$$

Recalling the initial assumption that no further snowmelt takes place, R_t equals the first days snowmelt

(disregarding runoff losses). Thus the recession coefficient k determines (according to equation (4.12)) which part of the meltwater flows off in the first 24 hours.

If the successive daily runoff volumes are regarded as geometric series, equation (4.12) is simply derived as follows:

$$R_t = R_1 \frac{k^{\alpha} - 1}{k - 1} = R_1 \frac{-1}{k-1} \qquad (4.13)$$

$$R_1 = R_t \frac{k-1}{-1} = R_t (1-k) = M_1(1-k)$$

Where M_1 is the daily snowmelt. Considering now that further snowmelt will take place on the second day, the total daily runoff is calculated as

$$R_2 = M_2(1-k) + R_1 k \quad (4.14)$$

The practical computation values of k must be derived from the discharge data of the watershed. Thus taking into account the retention of melt water, the daily snowmelt runoff comprises of two components:

$$R_n = M_n (1-k) + k \; R_{n-1} \qquad (4.15)$$

Where R_n is the runoff on the n^{th} day in m^3

M_n is the snow melt on the n^{th} day in m^3

n is an index indicating the sequence of days

k is the recession coefficient in the melting period and is given by the relation,

$$k = \frac{R_n}{R_n - 1}$$

4.5.8. THE DAILY DISCHARGE FROM ALL THE VARIOUS ZONES

A particular zone A is first considered. Dividing the equation (4.15) throughout by 85400 seconds to get the discharge and snowmelt in m^3/s and including the snowmelt due to rainfall, the following equation is arrived at as given below.

$$(Q_s)_n = (Q_{A,rA})_n (1-k) + k (Q_s)_{n-1} \quad (4.16)$$

Where Q_s is the daily snowmelt discharge in m^3/s

k is the recession coefficient with 1 day interval.

$Q_{A,rA}$ is the total daily snowmelt discharge (m^3/s) obtained by the degree-day method and due to the rain as given in equation (4.7)

Taking into account the losses and the retention of the snowmelt, the daily snowmelt discharge contributed by all the snow-covered zones, is given by the equation below

$$(Q_s)_n = C (Q_{A,rA} + Q_{B,rB} + Q_{C,rC} + Q_{D,rD}) (1-k)$$

$$(Q_s)_{n-1} k \quad (4.17)$$

Where Q_s is the daily snowmelt discharge in (m^3/s)

$Q_{A,rA}$, $Q_{B,rB}$, $Q_{C,rC}$, and $Q_{D,rD}$ are the total daily snow-melt discharge in m^3/s obtained due to rain and by the degree day ~~a~~ method in four respective temporary & permanent snow covered zones A, B, C, and D that have been assumed.

$Q_{P,rP}$ is the melt due to rain & temp. effect in the permanent snow covered area.

k is the recession coefficient for 1 day interval.

n is an index expressing the sequence of day

C is ~~an~~ a coefficient accounting for the losses.

The rainfall during the snowmelt season is usually scanty and thus most of the flow in the river is contributed by the snowmelt. Therefore, with the degree day method snowmelt can be calculated with various different values of the degree-day factor so that the snowmelt hydrograph obtained from the daily computed discharges by the equation (4.17) match the observed direct runoff hydrograph (i.e. excluding the base flow). A typical year with scanty rain in the melt season is to be analysed first. With many trails the most suitable values of the degree-day factor for the month of March and April and that for the month of May are to be arrived at. The month of ~~Ma~~ May having higher temperatures for longer day hours gets the higher value of the degree-day factor. These values of degree-day factors can be applied for computing the daily snowmelt discharge for other~~s~~ YEARS provided that no large deviation in the meteorological conditions prevail from one year to other.

4.5.9. COMPUTATION OF THE RUNOFF COEFFICIENTS FOR THE TEMPORARY SNOW-COVERED AREA AND THE NONSNOW-COVERED AREA.

The cumulative sum of daily discharges due to snowmelt $\leq Q$ (in m^3/s) and the cumulative sums of gauged discharges excluding the base flow $\leq Q_0$(in m^3/s) during the melt season can be calculated.

The difference between these values will give the amount of discharge $\leq Q_R$(in m^3/s) contributed from the excess rainfalll during the melt season.

$$\leq Q_R = \leq Q_0 - \leq Q_m \qquad (4.18)$$

Generally during the melt season $\leq Q_R$ will be a small quantity in comparison to $\leq Q_m$.

This amount contributed by the rainfall must equal to two components as given below:

$$Q_R = C_1 \frac{(\leq H_1)}{86400} A_1 + C_2 \frac{(\leq H_2)}{86400} A_2 \qquad (4.19)$$

Where $\leq Q_R$ is the total discharge contributed from the rainfall in m^3/s during the melt season.

C_1 is the runoff coefficient which takes into account loss due to evaporation from the temporary snow-covered area A_1 in m^2.

C_2 is the runoff coefficient to consider the loss due to evaporation and infiltration from the nonsnow-covered area A_2 in m^2.

ΣH_1 and ΣH_2 are the total of the daily rainfall depth (m) in the temporary snow covered area and the nonsnow covered area respectively during the melt season. 86400 is the number of seconds in a day which converts the volume of rainfall (m^3) into discharge(m^3/s)

Working with different years similar equations like that of equation (4.19) are obtained. The solution to such linear equations can be done by an algebraic method as outlined in the subsequent paragraph.

4.5.10. THE ALGEBRAIC METHOD TO SOLVE A SET OF LINEAR EQUATIONS.

In the mathematical discussion of the results of observations, it is required to derive from the data the best or plausible results which they are capable of affording.

When the quantities which are observed directly are junction of several unknown quantities which are to be determined, the problem can be generally reduced to a formulation such as the following.

The immediate problem is to find values for a set of unknown quantities X, Y in such as way that a set of given equation.

$$\left.\begin{aligned} a_1 X + Y &= n_1 \\ a_2 X + Y &= n_2 \end{aligned}\right\} \qquad (4.20)$$

$$a_n X + Y = n_n$$

Called the equation of conditions may be satisfied as nearly as possible, when the number of equations is greater than the number of unknowns X, Y and the equations are not strictly compatible with each other.

The solution to such linear equation s may be done in the following steps.

1. Multiply each linear equation by its own constants a_1, a_2, ... a_s and then add them to get a single equation i.e.

$$a_1^2 X + a_1 Y = a_1 n_1$$

$$a_2^2 X + a_2 Y = a_2 n_2$$

$$a_s^2 X + a_s Y = a_s n_s$$

$$(a_1^2 + a_2^2 + \ldots . a_n^2) X + (a_1 + a_2 + \ldots a_s) Y \quad (4.21)$$
$$= (a_1 + a_2 + x\ldots a_s) n_s$$

2. All the linear equations may be added as such to obtain a single equation as

$$(a_1 + a_2 + \ldots . a_s) X + Y = (n_1 + n_2 + \ldots n_s) \quad (4.22)$$

Now equation (4.21) and (4.32) can be solved simultaneously to get the values of X and Y

4.5.11. SNOWMELT DISCHARGE INCLUDING THE RAINFALL RUNOFF

Part of the rainfall on the temporary snowcovered area also flows along with the melt water. With this consideration the daily discharge can be expressed as

$$(Q_{sx})_n = (Q_s + Q_x)(1-k) + (Q_{sx})_{n-1}\, k \qquad (4.23)$$

Where Q_{sx} is the daily discharge in m^3/s due to the melting of snow and the daily discharge in m^3/s contributed by the rain, if any, on the temporary snow-covered area.

$$Q_x = \frac{C_1 H_1 A_1}{86400} \qquad (4.24)$$

Where Q_x is the discharge contributed by the rainfall on the temporary snowcovered area

C_1 is the runoff coefficient accounting the loss in the temporary snow covered area A_1 in m^2

H_1 is the rainfall in m in the temporary snow covered aarea.

86400 is the number of seconds in a day.

Using the equation (4.23) hydrograph can be plotted. The daily discharge (m^3/s) due to the rainfall, if any, falling on the nonsnow-covered area is given by

$$Q_y = \frac{C_2 H_2 A_2}{86400} \qquad (4.25)$$

Where Q_y is the discharge contributed by the rainfall on the non snowcovered area.

C_2 is the run off coefficient in the nonsnow-covered area A_2 in m^2

H_2 is the rainfall in m in the nonsnow-covered zone.

86400 is the no. of seconds in the day.

This discharge Q_y can be superimposed on the same day on the hydrograph obtained by equation (4.23), if the time of the concentration of catchment, provided small and having appreciable gradient, is less than a day. Hence the ~~the~~ total daily discharge thus obtained is

$$Q_{(total)_n} = (Q_{sx})_n + (Q_y)_n \qquad (4.26)$$

The hydrograph thus obtained by using the equation (4.26) should lead to a better agreement with the observed hydrograph excluding the base flow.

This methodology can be used in small remote catchments where data are limited. Usually a valley station considered as the base station provides the input data to the computation of the daily snowmelt discharge. This methodology has been extended to be used in the Manali catchment.

4.4 ANALYSIS OF BEAS CATCHMENT FOR SNOWMELT RUNOFF:

The hydrological condition of the Himalayan catchments is a complex one, since most of them are partly covered with snow at the higher elevation, and rain fed, at lower elevation.

The weather system that generally causes precipitation in the Himalayan regions are the Monsoon and the western disturbances. The year in the Beas catchment may be divided into the following four seasons.

a) The snow accumulation period.

This period refers to the months from December to mid March, precipitation in the form of snow and sleet, which generally occurs in the catchment is associated with the movement of the Western Disturbances across the region. The flow in the Beas catchment is mainly due to the groundwater supplemented by some rain and snowmelt in the lower hilly region.

b) The snowmelt period.

This period refers to the months from around mid March to Mid june. The freezing level is mostly maintained in the catchment upto mid March, and the subsequent lifting of the freezing level in this period due to above normal heating causes heavy snowmelt. Therefore, high inflows into the river are observed.

c) The monsoon period.

This period spans from mid June to mid september. Beas catchment receives bulk of its annual rain during this period.

d) The groundwater period.

This period spans from October to mid February. During this period, virtually, all the precipitation is in the form of snow, and consequently river flow is entirely dependent on ground water discharge.

4.6.1 THE HYDROLOGIC AND METEROLOGIC DATA AVAILABLE FOR THE STUDY.

4.6.1.1 THE TEMPERATURE DATA.

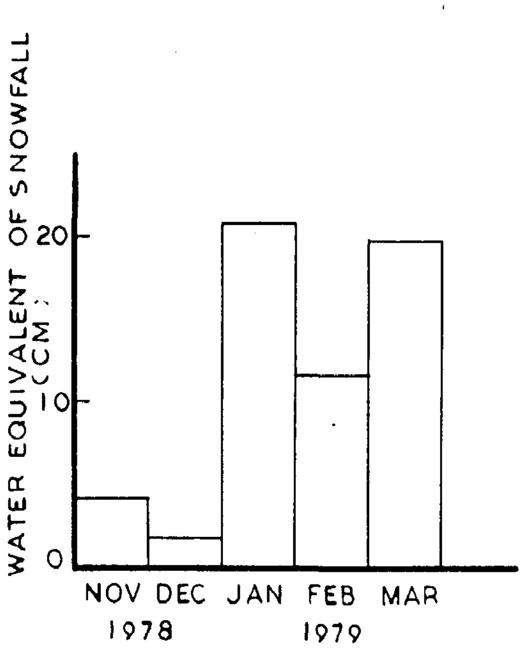
The daily maximum, and minimum data for Manali Station has been collected for the years 1976, 1977, 1978 and 1979 from the Beas sutlej link project, Reservoir sub Division, Pandoh (H.P.).

The daily mean temperature for the melting period considered in this study is tabulated in Appendix (IV a, IV b, IV c) and plotted in figures 4.7(a), 4.7(b), 4.7(c) .

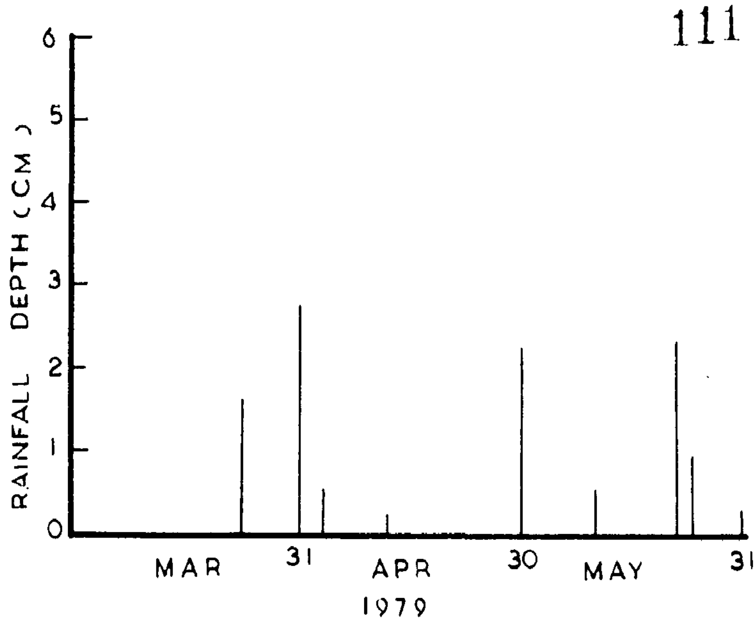
4.6.1.2 THE DISCHARGE DATA.

The daily discharge data collected for Parvati river, Sainj river, and Tirthan river from 1973 to 1979 has been obtained from the Director of Plant Design, Sundar nagar (H.P.).

The daily discharge data for the Manali and Larji gauging stations for the period 1976 to 1979 and 1973 to 1979 respectively has been collected from the Beas sutlej link project, Reservoir sub Division, Pandoh (H.P). The discharge data at Larji for the months



WATER EQUIVALENT OF THE SNOWFALL IN MANALI



DAILY RAINFALL DEPTH RECORDED MANALI

FIG. 4 8 (a)

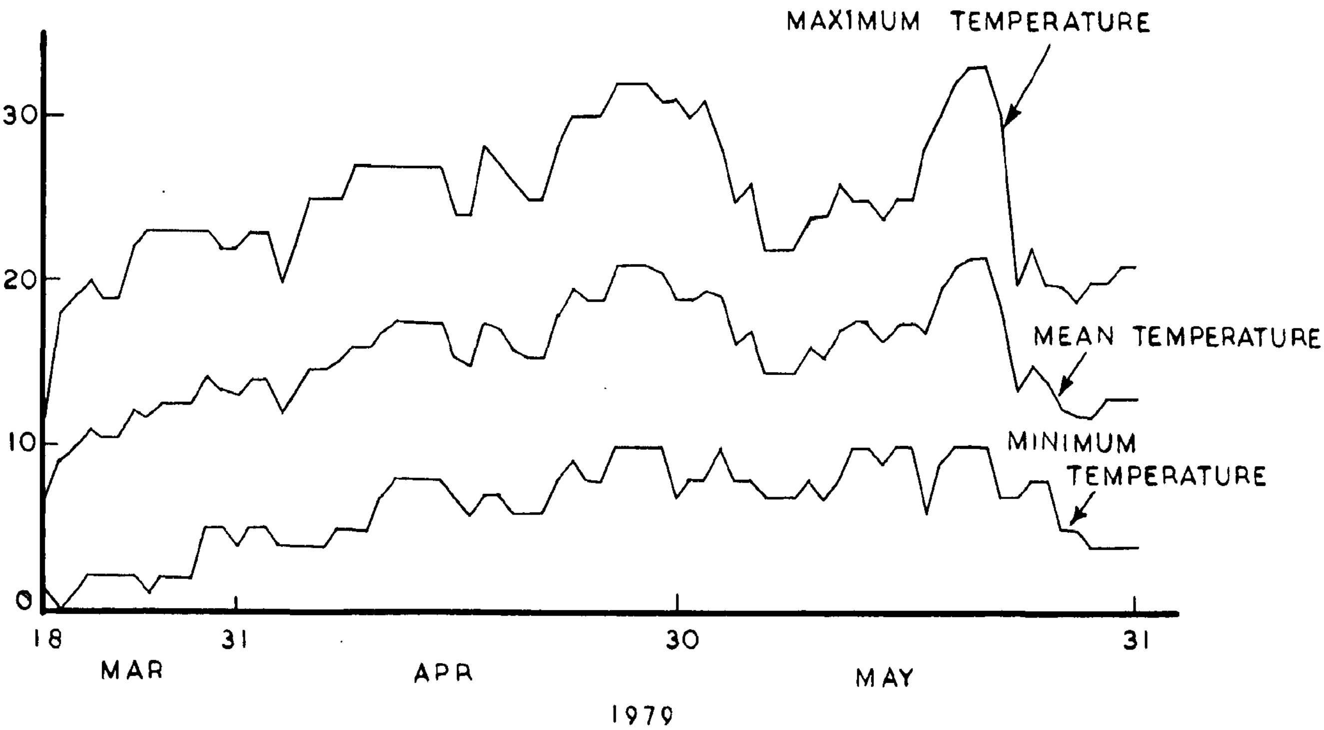
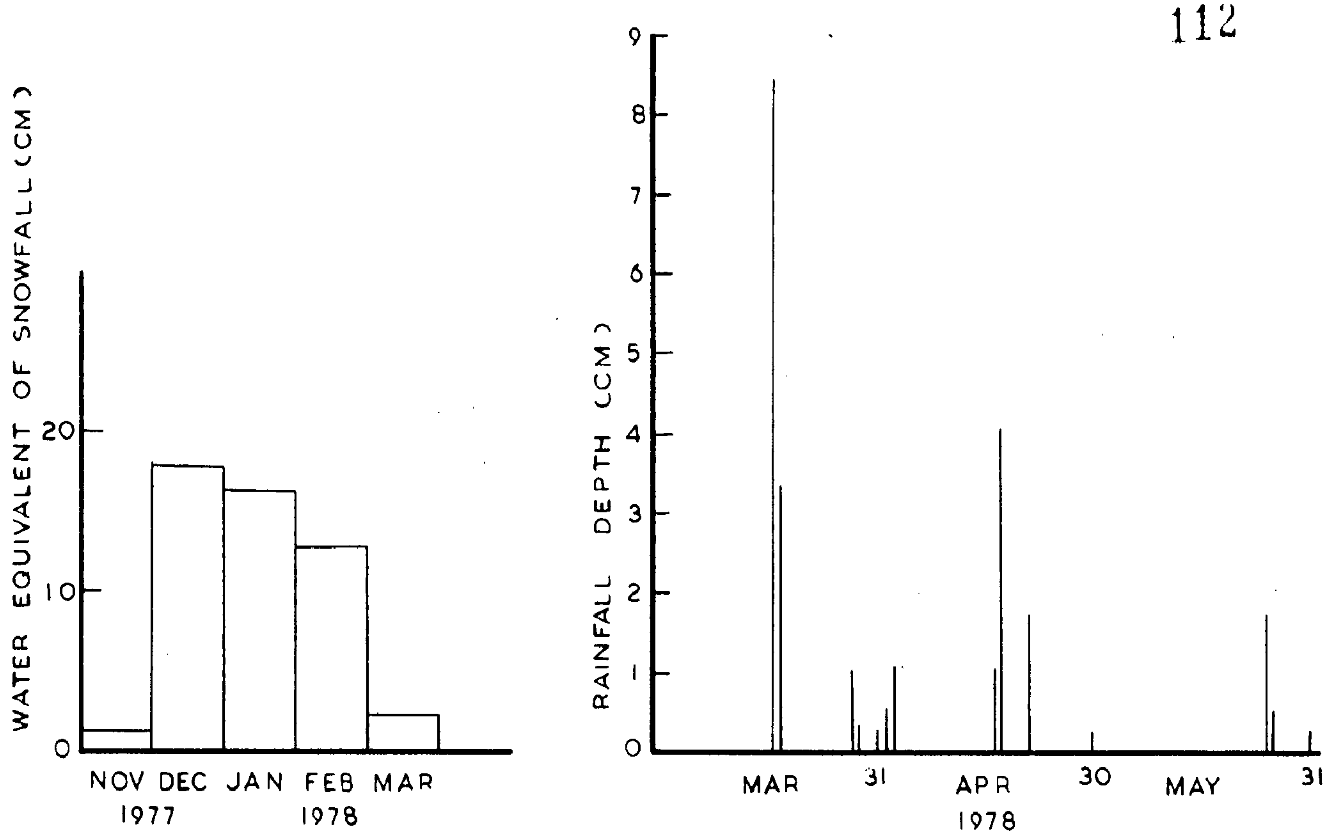


FIG.4·7(a)DAILY MAXIMUM, AVERAGE, AND MINIMUM TEMPERATURE RECORDED IN MANALI



WATER EQIVALENT OF THE SNOWFALL IN MANALI

DAILY RAINFALL DEPTH RECORDED IN MANALI

FIG. 4.8 (b)

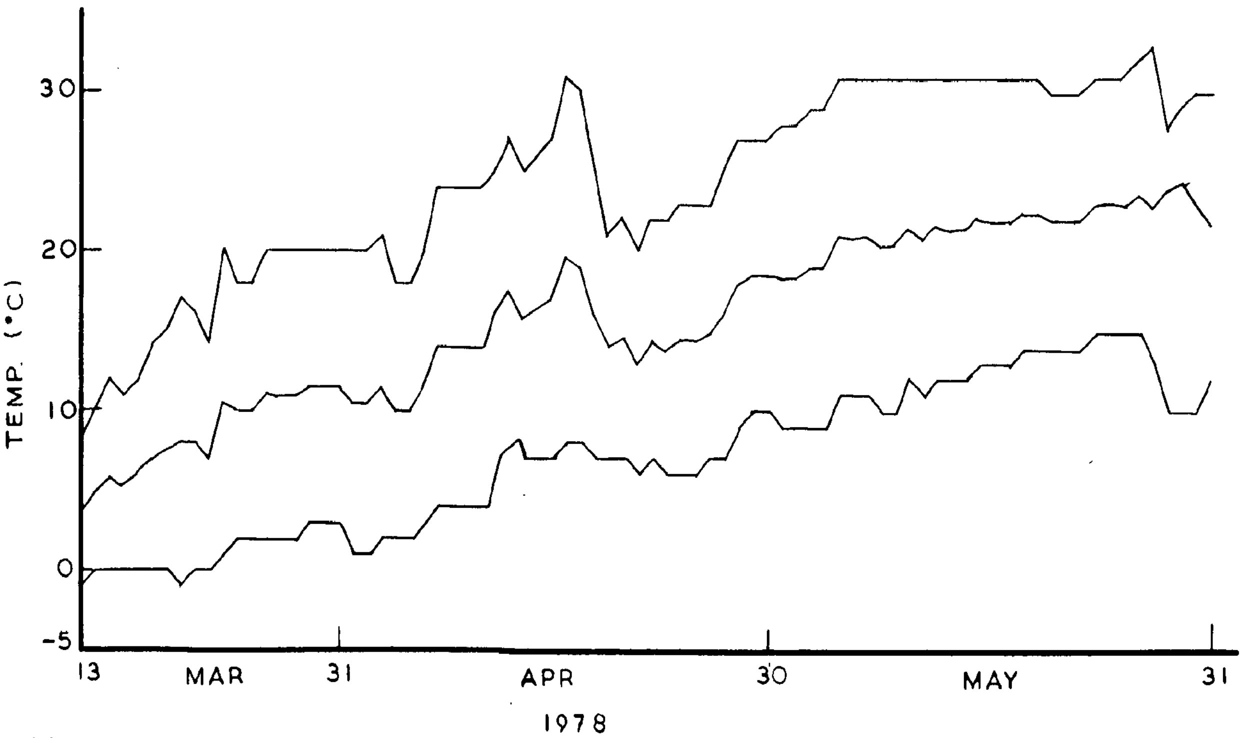


FIG 4·7(b) DAILY MAXIMUM, AVERAGE, AND MINIMUM TEMPERATURE RECORDED IN MANALI of April and May is missing for the year 1973. The daily discharge of Beas river at Manali gauging station excluding the base flow for the years 1977, 1978 and 1979 during the melting period considered in the study is tabulated in Appendix (XI a, XI b, XI c).

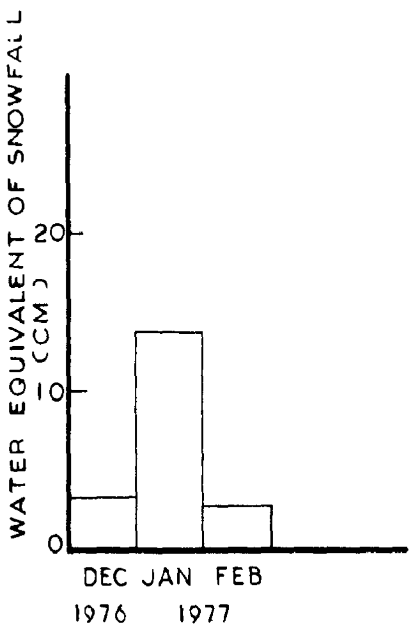
4.6.1.3 THE RAINFALL AND SNOWFALL DATA.

The rainfall and snowfall data for the Manali station for the years 1976 to 1979 was obtained through the office of S.E., Planning and Design (O)- II, H.P.S.E.B., Sundar Nagar (H.P.).

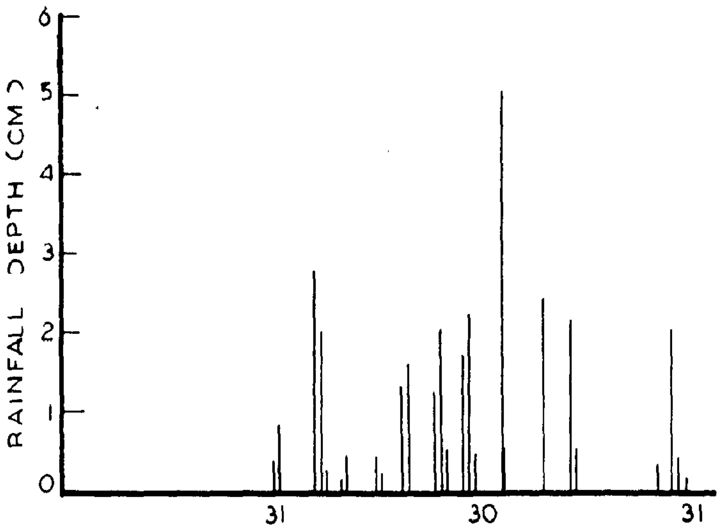
The data are tabulated in Appendix (V a, V b, V c, and VI a, VI b, VI c). The rainfall data and the water equivalent of the snowfall are plotted in the figures (4.8(a), 4.8(b), 4.8(c).

4.6.1.4 TEMPERATURE IN DIFFERENT ELEVATION ZONE.

The Manali catchment has been divided into five elevation zones at the contour interval of 2000 ft (610 m) as indicated in the table no. (4.6) below.



WATER EQUIVALENT OF THE SNOWFALL IN MANALI



DAILY RAINFALL DEPTH RECORDED MANALI

FIG. 4.8(c)

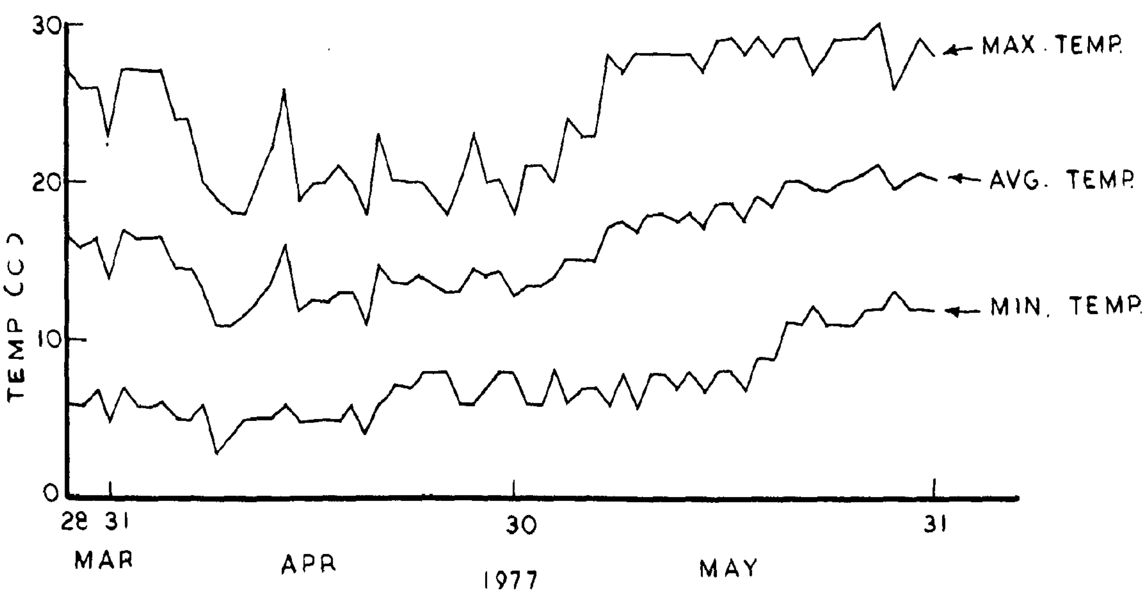


FIG.4.7(c) DAILY MAXIMUM, AVERAGE, AND MINIMUM TEMPERATURE RECORDED IN MANALI

of April and May is missing for the year 1973. The daily discharge of Beas river at Manali gauging station excluding the base flow for the years 1977, 1978 and 1979 during the melting period considered in the study is tabulated in Appendix (XI a, XI b, XI c).

4.6.1.3 THE RAINFALL AND SNOWFALL DATA.

The rainfall and snowfall data for the Manali station for the years 1976 to 1979 was obtained through the office of S.E., Planning and Design (e)- XI, H.P.S.E.B., Sundar Nagar (H.P.).

The data are tabulated in Appendix (V a, V b, V c, and VI a, VI b, VI c). The rainfall data and the water equivalent of the snowfall are plotted in the figures (4.8(a), 4.8(b), 4.8(c).

4.6.1.4 TEMPERATURE IN DIFFERENT ELEVATION ZONE.

The Manali catchment has been divided into five elevation zones at the contour interval of 2000 ft (610 m) as indicated in the table no. (4.6) below.

Table no. (4.4) Area between elevation zones.

S.No.	elevation zone ft	Area of the zones (km^2)
1	6000 - 8000	23.53
2	8000 - 10000	49.69
3	10000 - 12000	104.61
4	12000 - 14000	109.85
5	14000 and above	81.73
	Total	369.41

The median height is considered to be representative of each elevation zone. Using the lapse rate for every 1000 ft as 1.53°C, (ref 22) the daily temperature for each zone is calculated by the equation (4.1) with respect to the temperature recorded at Manali station. Which is considered to be the base station at a height of 5984.02 ft. Similar values of lapse rate as 1.53°C per 1000 ft (305 m) have been observed in the catchment by using temperature data of Manali and Bhuntar. Bhuntar has an elevation of 3555.25 ft (1084.4m) and is located further down stream of Manali (1830 m) the positive temperatures obtained in the different zones by this lapse rate are tabulated in the degree - day column in the Appendix (Xa, Xb, Xc).

4.6.1.5 THE SNOW COVERED AREA FROM THE SATELLITE IMAGERY.

The only satellite imagery available for the year 1977 (fig.4.9) has been incorporated in this study (19). The satellite imagery of scale 1:250,000 is shown in the figure (4.9).

Since the other satellite imageries of 1973,1975 and 1976 indicate that Manali catchment is generally can be completely snow covered and since the snowfall of 1978 and 1979 is 2.5 to 3 times that of 1977, it is concluded that the Manali catchment is completely covered by snow before the melting period of 1978 and 1979.
(In '77 about 59% of the catchment is covered by snow.)

4.6.1.6 THE PRECIPITATION IN THE DIFFERENT ZONES.

a) It is found that the precipitation, snow as well as rain, in the mountainous regions increase with altitude due to orographic effect. The incremental values for the rainfall and snowfall for each 2000 ft rise in altitude have been adopted from the similar studies conducted in British Columbia (9), since no Indian data was available for estimating the same. The incremental values for the rainfall and snowfall are given in Appendix (VII a, VII b). The snowfall and rainfall depthus for different elevation zones using these incremental values are given in Appendix (Va, Vb, Vc and VI a, VI b, VI c).

b) It is observed that Manali catchment generally receives the snowfall from November to around mid March. The snowfall occuring from November to around mid March has been considered to be accumulated as the stored water in the form of snow, keeping in view that negligible melt occurs during this season as

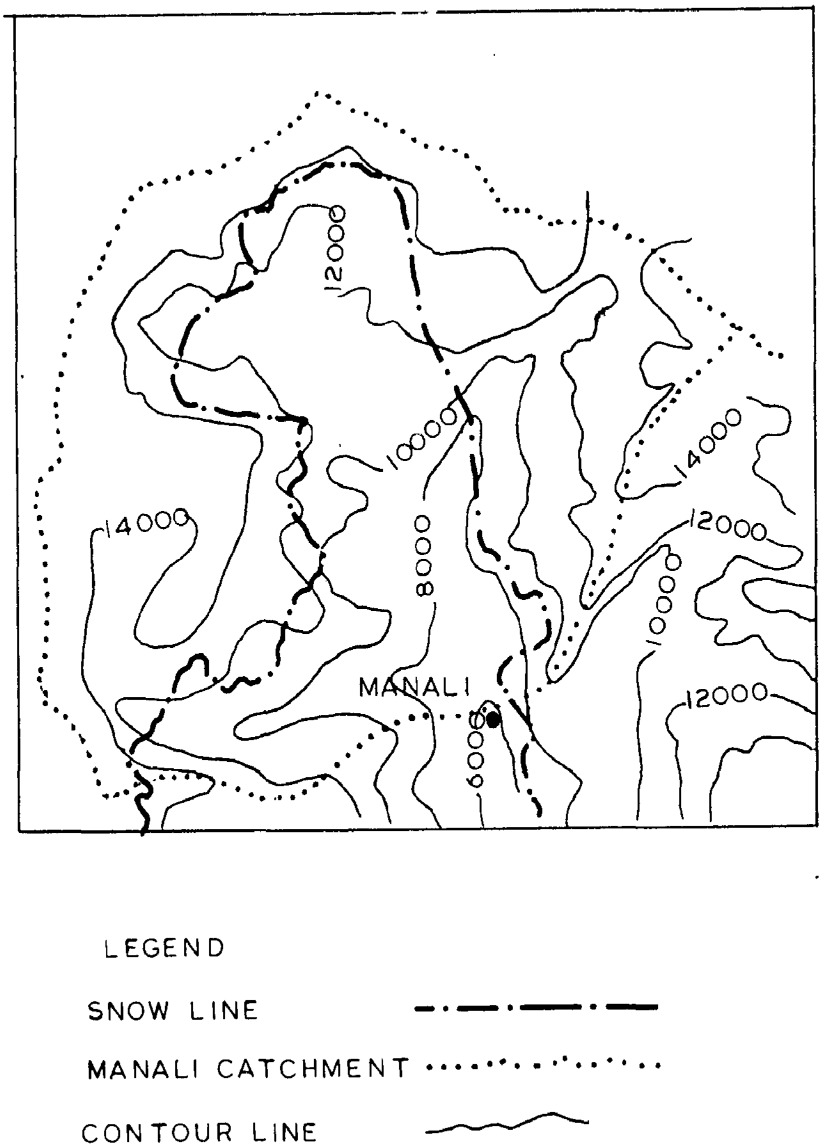


FIG. 4·9 SNOW COVER MAP OF MANALI CATCHMENT
LANDSAT IMAGE DATE 27 MAR. 1977 MSS 7

SCALE – 1 : 250,000

CONTOUR VALUES IN FEET

the temperature remains near freezing for elevations above 6000 ft. The water equivalent of the snowfall data during the accumulation period in Manali station has been worked out assuming a water equivalent value of 10%. This has been plotted in the figure (4.8(a),4.8(b),4.8(c))

The volume of water stored in the form of snow in each elevation zone is calculated with equation.

$$V_s = d.\ H_s.\ A. \qquad (4.6.1)$$

Where V_s is the volume of water stored in the accumulated snow (m^3) in an elevation zone, d is the water equivalent, H_s is the computed depth of snowfall (m) for the considered zone & A is the area of the zone under consideration (m^2).

It is generally observed from the satellite imageries that the snowline remain near the altitude of 14000 ft. Hence we consider the permanent snow covered area to be above 14000 ft. For each elevation zone up to 14000 ft. the volume of water stored in the form of snow during the accumulation season is calculated with the equation (4.6.1). The volume of water stored in the form of snow during the accumulation period for different zones in different years are given in Appendix (VIII a, VIII b, VIII c)

4.6.1.7 THE RECESSION FACTOR

The daily recession discharge in Manali are plotted against the daily discharge on the previous day for the years 1977 to 1979 during the melting seasons as shown in figure (4.10).

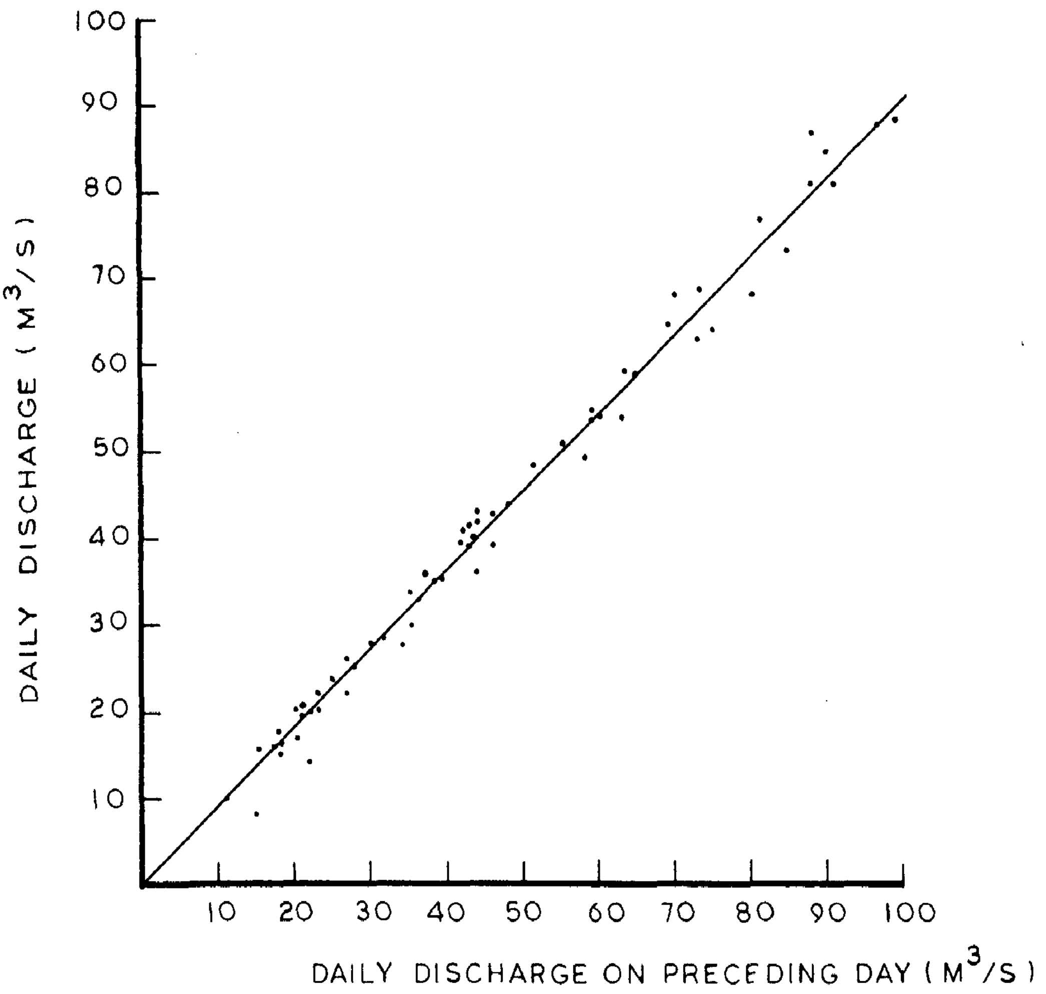


FIG. 4·10 DAILY RECESSION ANALYSIS FOR MANALI DURING SNOW MELT PERIOD 1976, 1977, 1978 AND 1979

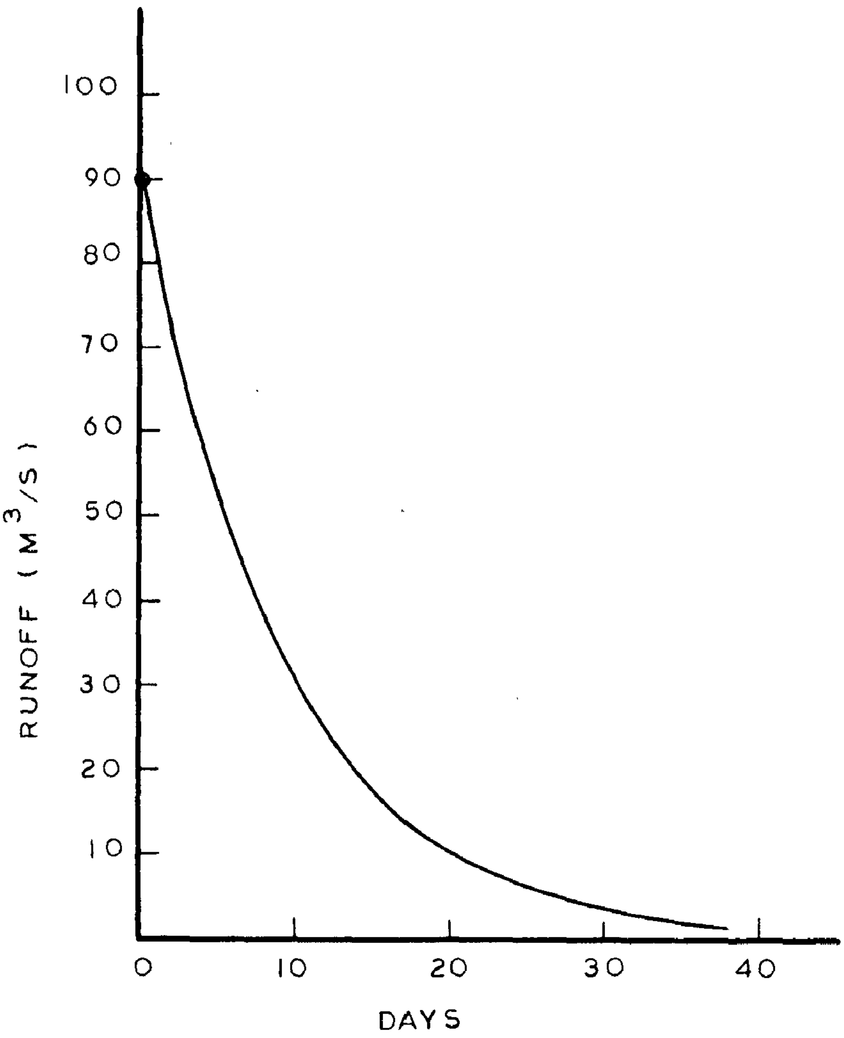


FIG. 4.11 SNOW MELT - RUNOFF RECESSION CURVE FOR MANALI

The recession factor k is derived from the slope of the straight line fitted to the plotted points as 0.90. Similar values also have been obtained in recession analysis carried out in St. Louis creek near Fraser, colorado (4). The snowmelt runoff recession curve for Manali is shown in the figure (4.11).

4.6.1.8 THE BASE FLOW

The base flow for the considered year has been taken to be the minimum discharge in the groundwater period. During this period virtually, all the precipitation is in the form of snow and consequently river flow is entirely dependent on the ground water discharge. The base flows for the years 1977, 1978 and 1979 are observed to be 8.27 m^3/s, 11.79 m^3/s and 14.27 m^3/s respectively.

4.6.1.9 COMPUTATION OF SNOWMELT DISCHARGE

With the degree day method equation (4.5) snowmelt for both temporary & permanent zones is computed with different values of the degree day factor so that the hydrograph plotted with these computed daily snowmelt discharge is reasonable matching the observed direct runoff hydrograph. The year 1979 has been tested first because it has less rainfall as compared to 1978 and 1979 during the melting season. The suitable values for degree day factor for the months of March and April is working out to be 0.0018 cm $°C^{-1}$ d^{-1} and that for the month of May as 0.00315 cm $^{\circ}C\ d^{-1}$. These values are coming around the average value of the ~~snowmelt~~ degree day factor as 0.0027 cm $^{\circ}C\ d^{-1}$ given in reference (23).

The month of May gets the higher value of the degree day factor since more snowmelt is to be observed as the temperatures in this month is relatively higher and persists for more hours of the day than the other two months. The degree day factor is also related to the snow density as has been discussed in chapter 2 from reference (8). The snow density in May due to heavy melting can have higher values them those of March and April.* The melt due to the rainfall as computed by equation (4.6) is also included snow. The melting of snow due to the rainfall in each zone is calculated and tabulated in Appendix (IX a). With the equation (4.7) the melt in all the zones are calculated and summed up. There are tabulated in the last colum, under the elevation zone above 14000 ft. table, in Appendix (Xa). Now taking into account the retention effect and the losses due to infiltration and evaporation equation (4.17) is used to get the daily snowmelt discharge considering the melt from all the elevation zones. The losses in equation (4.17) is given a value of 10%. Hence the coefficient "C" in the equation (4.17) gets a value of 0.90. Such a value has been found and used in a similar study in ~~discharge~~ DISCHMA water shed in Switzerland (9). These computed daily discharge are plotted against the observed direct runoff hydrograph

*The degree day factor depend on the density of snow. Older snow means higher density. ~~Hence~~ older snow has less albedo. Thus more radiation penetrate into the snow mantle to produce more melt. Thus the month of May gets higher value of the degree day factor as compared to Mar-April as shown in figure (4.12 a) A reasonable agreement is observed. The daily calculated snowmelt discharge for the year 1977 and 1978 are also calculated. These are tabulated in the last column, under the elevation zone above 14000 ft table, in Appendix (X b and X c). The melt due to the rainfall effect in each zone for these years are calculated and tabulated in Appendix (IX b, IX c). The computed daily discharge are plotted against the observed direct runoff hydrograph as shown in figure (4.12.b, 4.12.c). The daily snowmelt discharge is calculated by the equation (4.17) and the values are tabulated in the 2nd column of Appendix (XI a, XI b, XI c)

4.6.1.D COMPUTATION OF THE RUNOFF COEFFICIENTS FOR RAIN ON THE SNOW - COVERED AREA AND ON THE NON SNOW-COVERED AREA.

Taking into account the water budget for the concerned covered melting period the difference between the cumulative sum of the daily observed discharges $\sum Q_o$ excluding the base flow and the cumulative sum of the daily snowmelt discharge $\sum Q_M$ is equal to the total discharge contributed due to the rainfall $\sum Q_R$ as given by the equation (4.18) i.e.

$$\sum Q_R = \sum Q_o - \sum Q_m$$

The total discharge $\sum Q_R$ can be written as

$$\sum Q_R = \frac{C_1 (\sum H_1) A_1}{86400} + \frac{C_2 (\sum H_2) A_2}{86400}$$

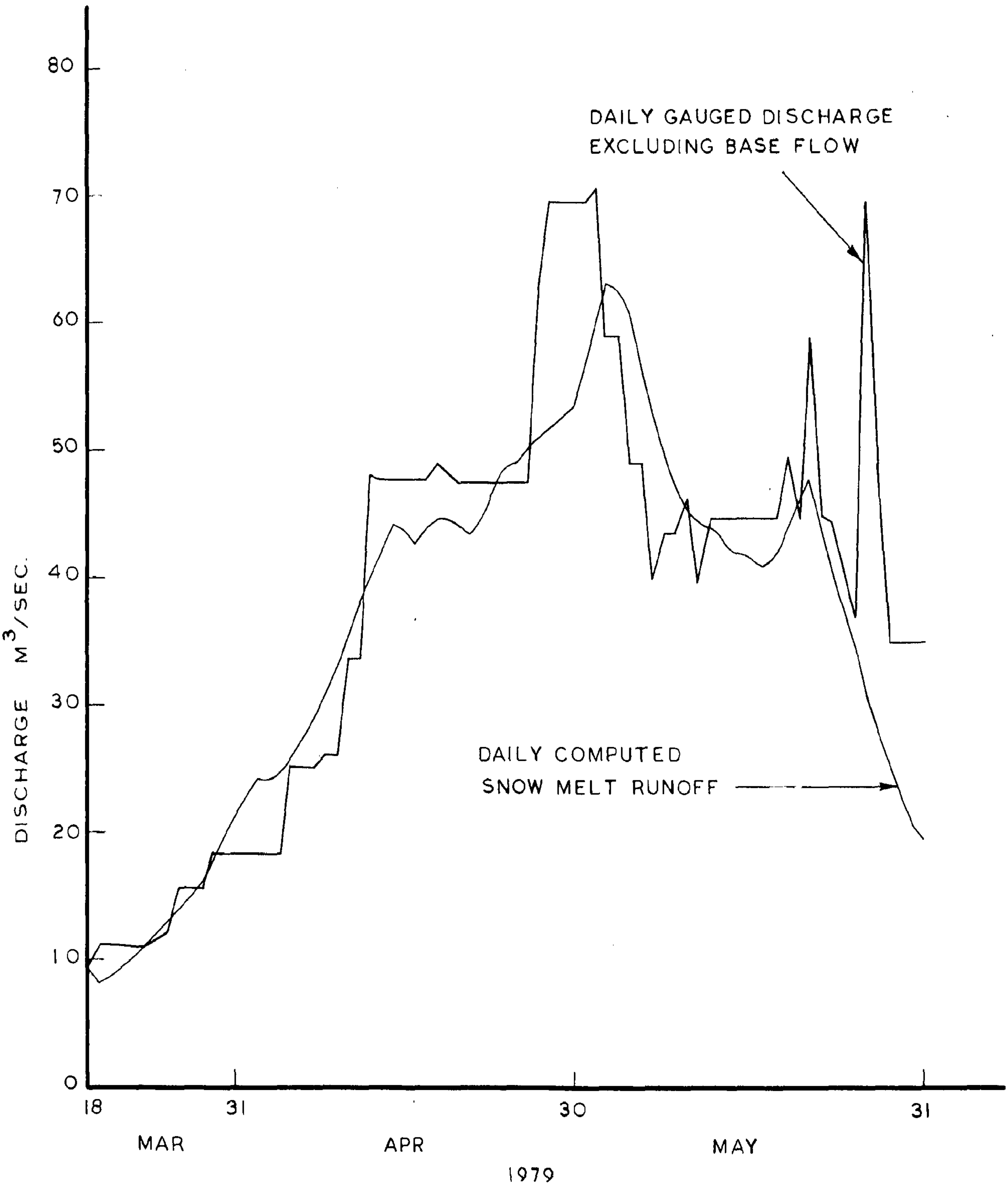


FIG.4·12(a) DAILY COMPUTED SNOWMELT RUNOFF AND DAILY GAUGED DISCHARGE (EXCLUDING BASE FLOW) IN MANALI

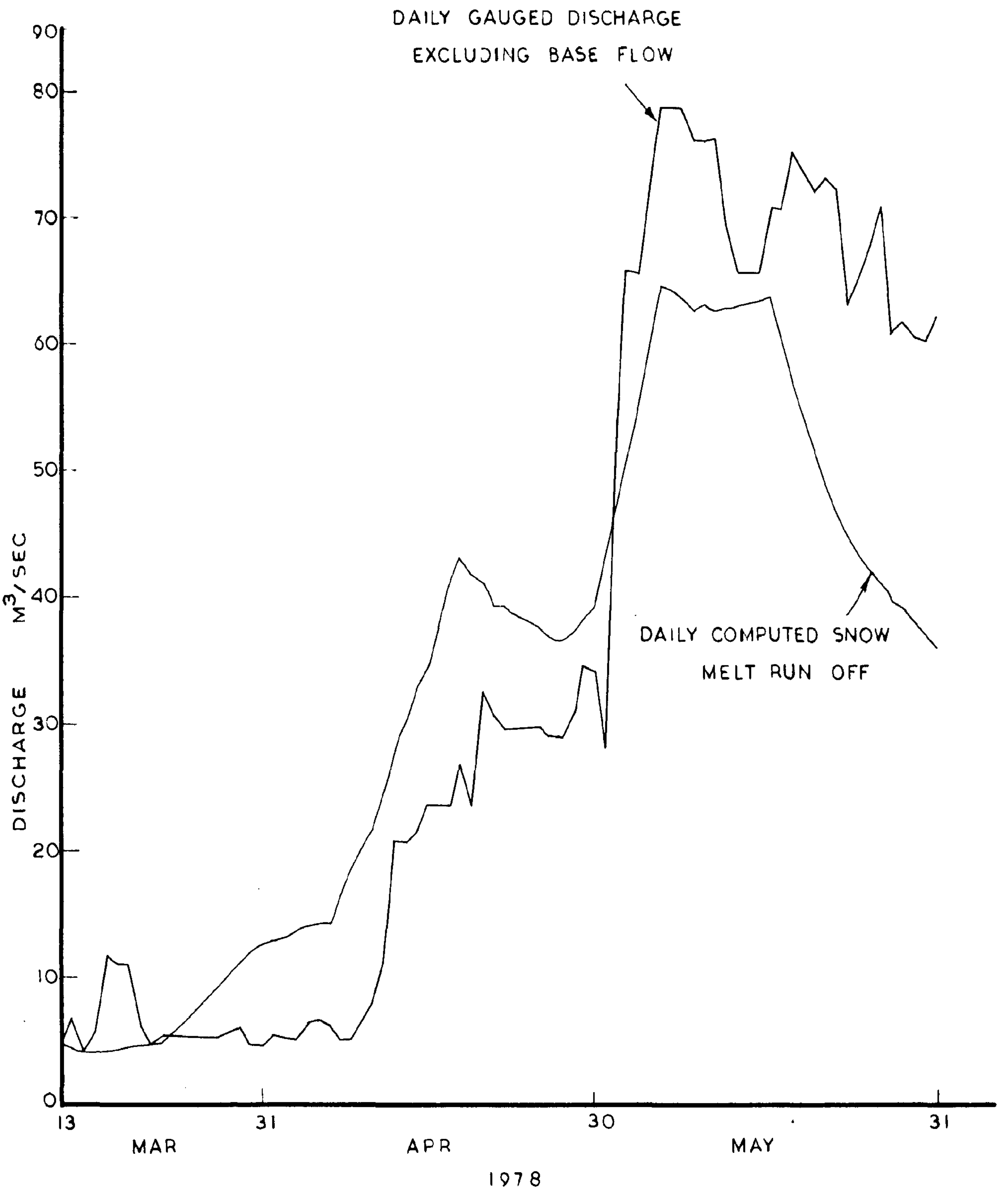


FIG.4.12(b) DAILY COMPUTED SNOWMELT RUNOFF AND DAILY GAUGED DISCHARGE (EXCLUDING BASE FLOW) IN MANALI

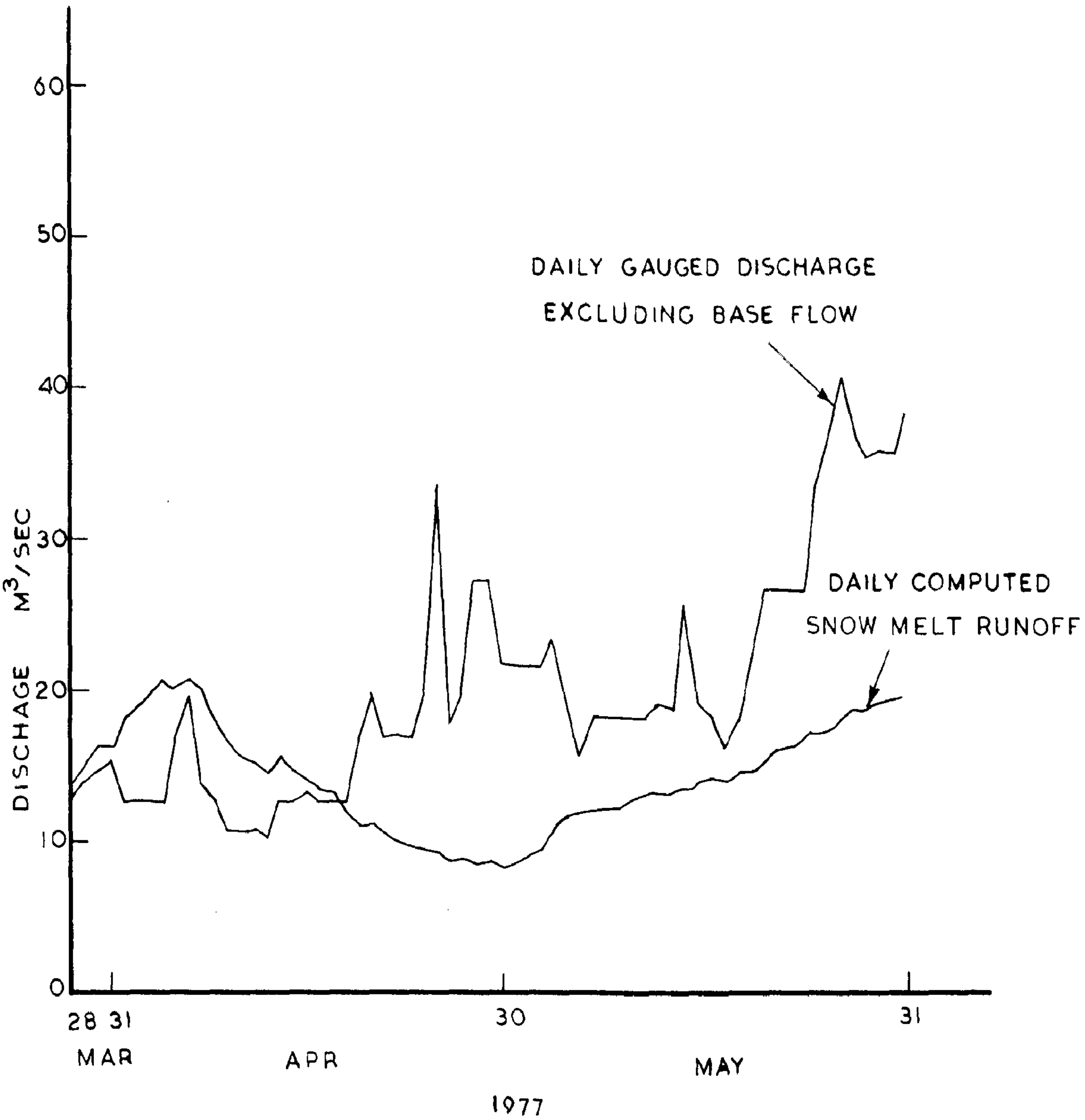


FIG. 4.12(c) DAILY COMPUTED SNOWMELT RUNOFF AND DAILY GAUGED DISCHARGE (EXCLUDING BASE FLOW) IN MANALI

Where ΣQ_R is the total discharge contributed by the excess rainfall in m^3/s during the melting period. C_1 and C_2 are the runoff coefficients for the snow covered area and non snow- covered area respectively. ΣH_1 and ΣH_2 are the total of the daily rai fall depth (m) in the temporary snow covered area A_1 (m^2) and the non-snow covered area A_2 (m^2). 86400 is the number of seconds in a day. The recession flows prior to and subsequent to the resp- ective melt periods of 1977 to 1979 have been obtained with the help of the snowmelt runoff recession curve in figure (4. 11). These have been accounted to get the values of $\Sigma \phi_o$ and $\Sigma \phi_m$

The values of the $\Sigma \phi_o$, $\Sigma \phi_m$ and ΣQ_R are given in the table no (4.9) below.

Table no. (4.9). The cumulative sum of daily observed discharge, the cumulative sum of daily snowmelt discharges, and the total discharge due to the rainfall during the melting period.

Year	Cumulative sum of the daily observed discharge (m^3/s) during the melting period ($\Sigma \phi_o$) (excluding base flow)	Cumulative sum of the daily snowmelt discharge (m^3/s) during the melting period ($\Sigma \phi_m$)	Total discharge due to rainfall (m^3/s) during the melting period ΣQ_R
1979	3071.27	2775.06	296.21
1978	3215.79	2858.75	357.04
1977	1462.45	962.78	499.67

The total runoff due to rainfall on snow covered area and non snow covered area during the melting period is given in the table no.(4.8) below.

Table no.(4.8). The total discharge due to rainfall on snow covered area and non snow covered area during the melting period.

Year	Total discharge due to rainfall during melting period on	
	snow covered area ($\Sigma H_1 A_1/86400$) (m^3/s)	non snow covered area. ($\Sigma H_2 A_2/86400$) (m^3/s)
1979	282.23	365.98
1978	532.45	142.41
1977	619.02	648.61

By using the values in table no.(4.9), and (4.8) in equation (4.19), three linear equations are obtained as given below.

$$296.21 = C_1\ 282.23 + C_2\ 365.98$$

$$357.04 = C_1\ 532.45 + C_2\ 142.41$$

$$449.67 = C_1\ 619.02 + C_2\ 648.61$$

The linear equations are solved by using the method given in section (4.5.10). The values of C_1 and C_2 thus obtained equal 0.595 and 0.278 respectively.

4.6.1.16 SNOWMELT DISCHARGE AT MANALI GAUGE SITE INCLUDING THE RAINFALL RUNOFF.

Part of the rain falling on the snow- covered area flows along with the snowmelt. The daily discharge for the melting period for 1977 to 1979 are thus calculated by the equation (4.23) and tabulated in the 4th column Appendix (XIa,XIb,XIc) The discharge contributed due to the rainfall on the non snow-covered area is super imposed on the hydrograph obtained by the equation (4.23) on the very same day since the time of concentration for the catchment is less than a day. The discharge including the runoff due to rainfall on the non-snow covered area is tabulated in the 5th. column Appendix (XIa, XIb, XIc). The hydrographs thus obtained by these computed discharges are shown in figures (4.13a, 4.13b, 4.13c). With this consideration there is an improvement in the result. A reasonable agreement is there between the computed hydrograph and the observed direct runoff hydrograph.

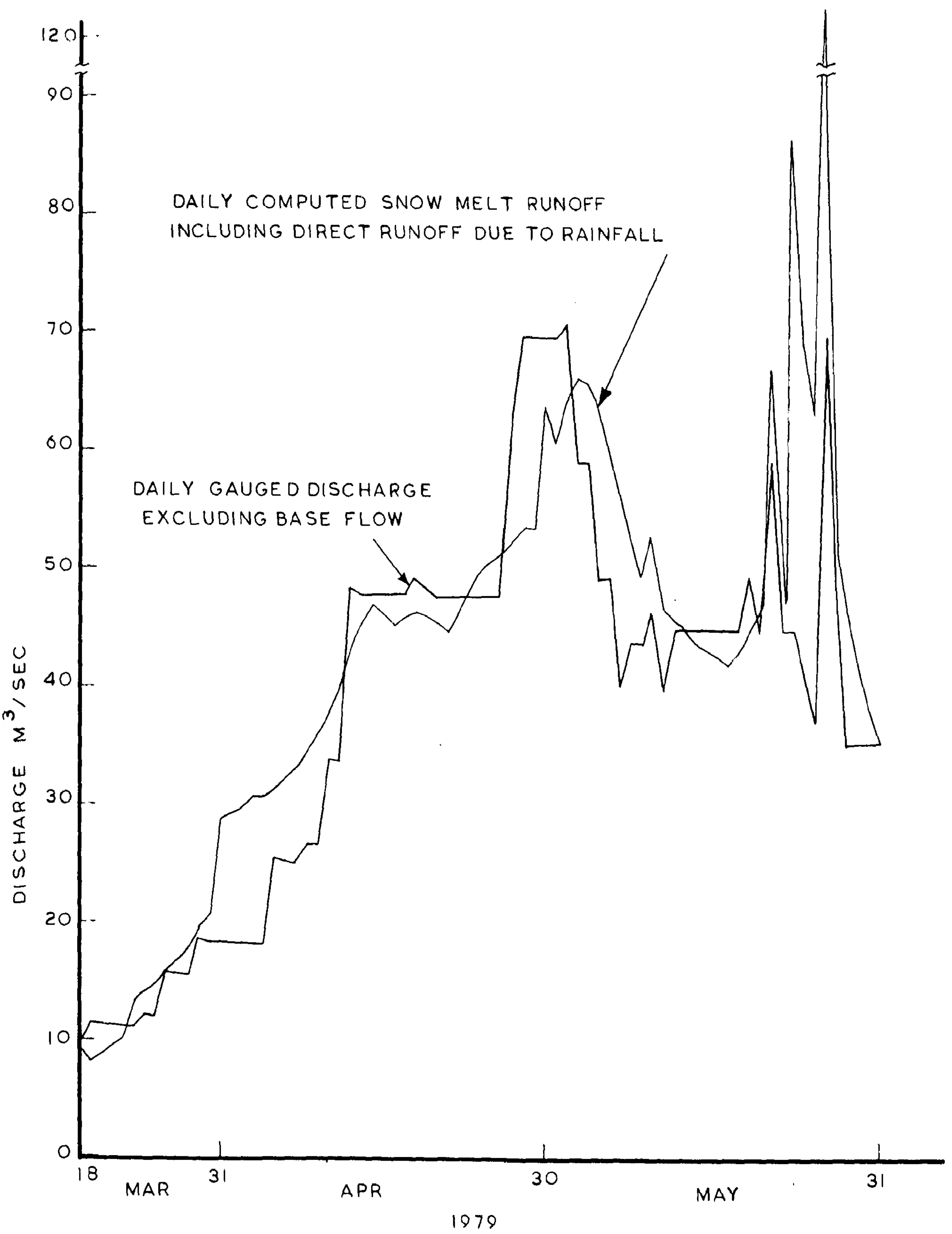


FIG.4·13(a) DAILY COMPUTED SNOWMELT RUNOFF INCLUDING DIRECT RUNOFF DUE TO RAINFALL AND DAILY GAUGED DISCHARGE (EXCLUDING BASE FLOW) IN MANALI

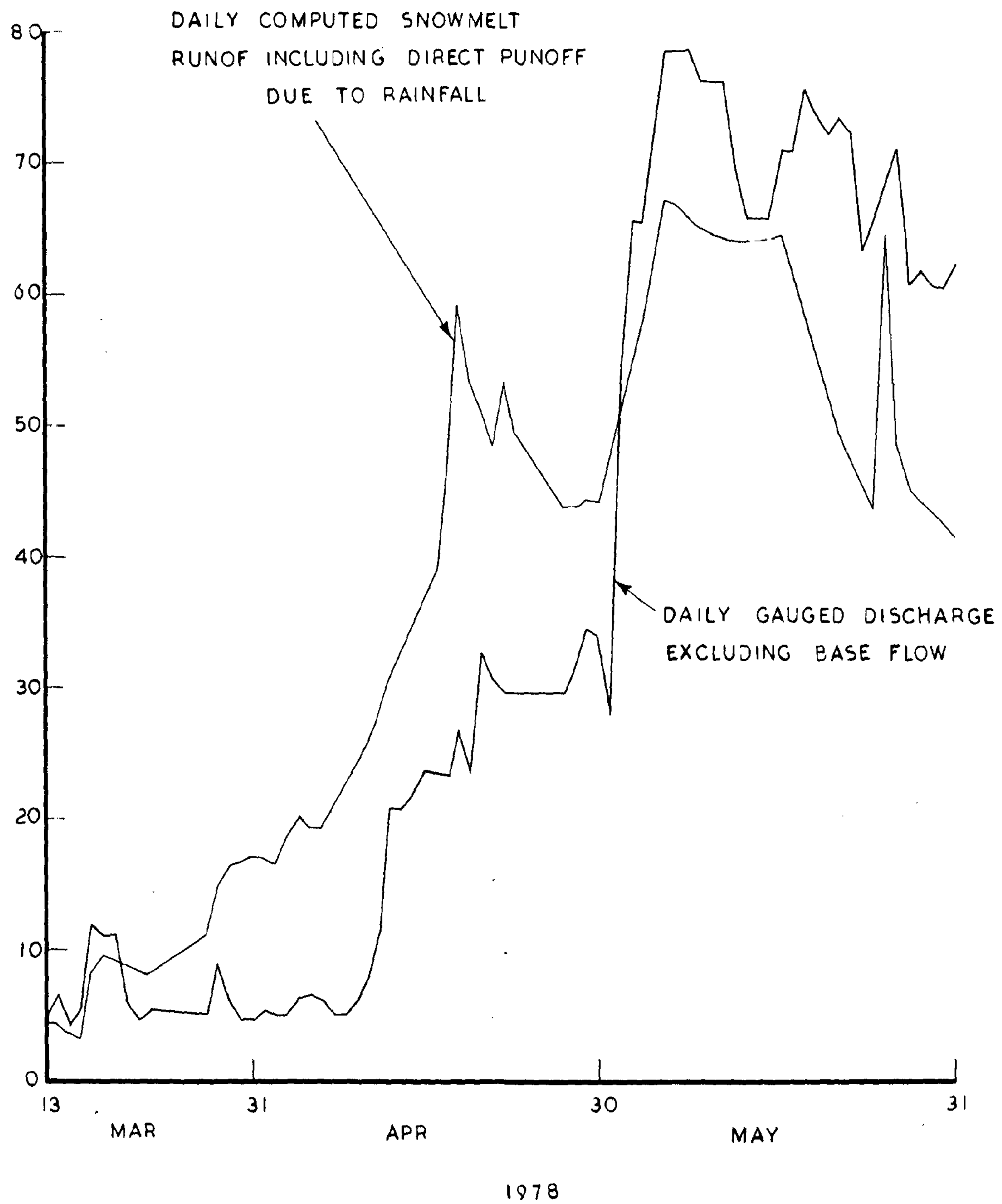


FIG.4·13(b) DAILY COMPUTED SNOWMELT RUNOFF INCLUDING DIRECT RUNOFF DUE TO RAINFALL AND DAILY GAUGED DISCHARGE (EXCLUDING BASE FLOW) IN MANALI

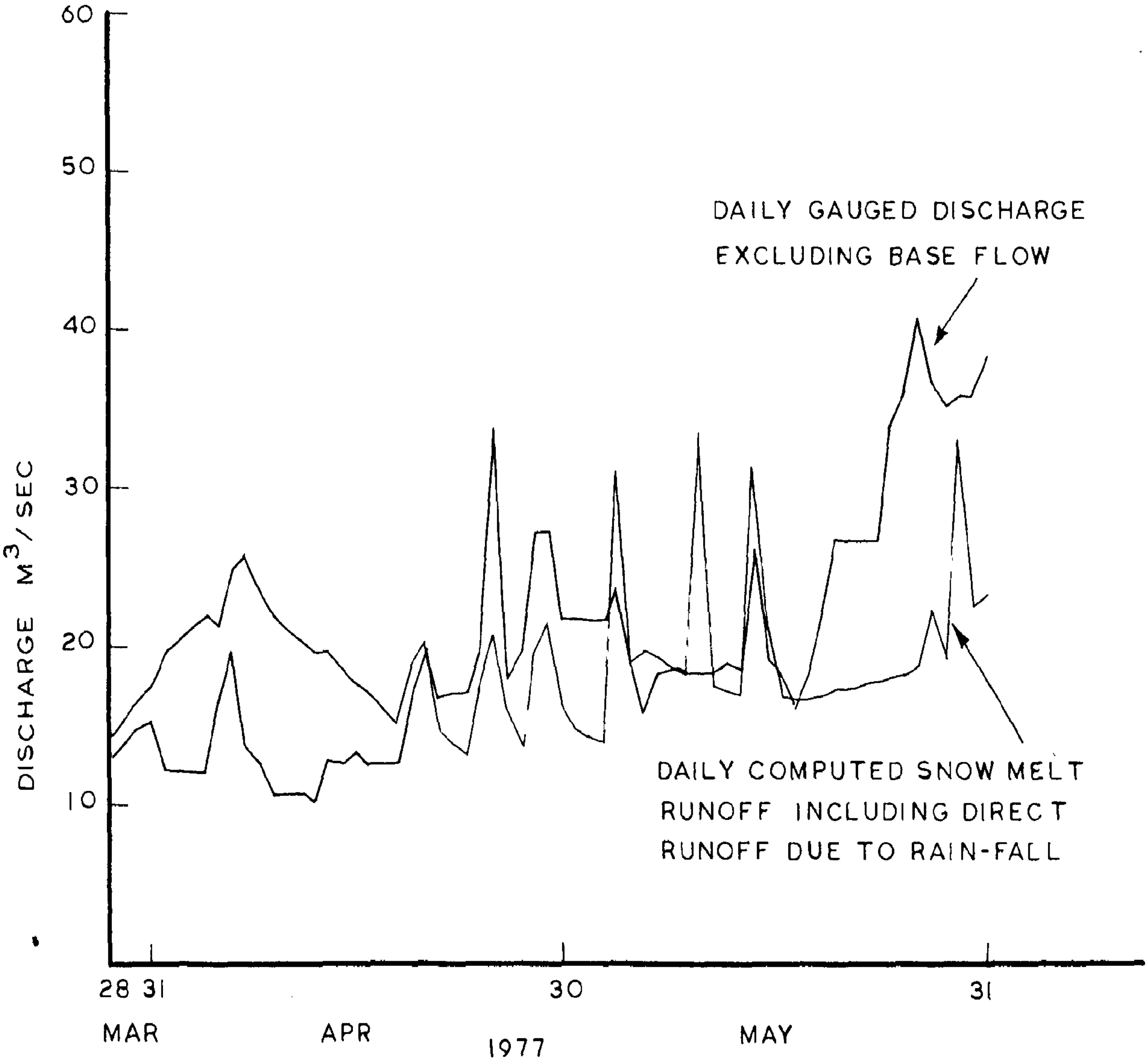


FIG.4·13(c) DAILY COMPUTED SNOWMELT RUNOFF INCLUDING DIRECT RUNOFF DUE TO RAINFALL AND DAILY GAUGED DISCHARGE (EXCLUDING BASE FLOW) IN MANALI

CHAPTER - V

DISCUSSION, CONCLUSION AND SCOPE FOR FURTHER STUDY

5.1. DISCUSSION

Remote sensing has proved to be an invaluable aid in monitoring resources in inaccessible regions. Snowbound Himalayas from which many rivers originate pose a formidable problem for ground survey or even aerial surveys for the estimation of snow-cover. Orbital remote sensing systems particularly with the advent of LANDSAT series of satellites, has opened up new viastas for monitoring snow and estimating the total quantity of water stored as snow.

Snow melting is a thermodynamic process. Thus the investigation of the processes depends basically on the accurate measurement of the various factors influencing the transmission of heat to the snow mantle. It is found that the heat within the atmosphere is the main factor. The problem is then largely compatible with an adequate snow cover, precipitation in the form of rain on snow area and the relationship of these values to the rate of snow melt.

Considerable differences in altitude, and therefore in climate, soil, and vegetative conditions, are specific features of mountainous river basin. Therefore, such basins are usually divided into elevation zones for the study. Because of the time difference between the accumulation of seasonal snowpack and its melting, the forecast of seasonal flow may be prepared well in advance. The possibilities for forecasting are most favourable for those areas where rainfalling during the melting period is scarce in comparision to the accumulated winter precipitation in the form of snow and the total heat inflow is sufficient every year for complete melting of the seasonal snow pack (i.e. from the temporary snow covered area).

Conditions for runoff in high land river basins are such that losses of melt water will not vary greatly from year to year. Under such conditions, there should exist a relationship between the accumulated winter precipitation and seasonal runoff. In principle, such a relationship can be established empirically for any basin if observational data are available over a number of years. In practice for Indian catchments, however, the problem of determining such relationship is far from easy particularly because of very limited relevant data being available. In Indian mountain basins the water equivalent data of the snowpack is not available and the measurements of precipitation and snow cover do not make it possible to determine the true amount of accumulated water and may serve only for obtaining some indicies of this value.

At least two factors have an influence on runoff and, consequently on the degree of correlation between runoff and the snow accumulation index. These factors are: the amount of precipitation for the melting season and the antecedent water storage in a basin. Both of these factors must be taken into account in the development of seasonal snowmelt runoff relations and in the preparation of forecasts.

In the Manali catchment due to the availability of limited data some assumptions are made keeping in view the physics of melting process so as to arrive at a reasonable estimate of snow melt runoff. The data available for this study comprises of some satellite imageries, daily record of temperature, snowfall, and rainfall at Manali gauging station, which is the outlet of the catchment situated at an elevation of about 6000 ft. (1830 m). The elevation in Manali catchment varies from 6000 ft (1830 m) to 14000ft.(4270 m) for the area under temporary snow cover and above 14000 ft(4270 m) for area under permanent snow cover. This information about the temporary and permanent snow cover has been obtained by comparision of a few available satellite imageries. In the present study the area under temporary snow cover from 6000 ft to 14000 ft. has been divided into four elevation zones at an interval of 2000 ft. each. The variation of the precipitation (snowfall as well as rainfall) with elevation (as given Appendix : VII a, VII b) and the lapse rate (as 1.53°C decrease for every 1000 ft (305 m) rise in elevation) have been assigned from literature survey. These assumptions have been proved to be reasonably correct as the total volume as well as the rate of snowmelt runoff at the Manali gauging site has been predicted reasonably well.

The snowmelt has been estimated by considering melt due to the influence of the temperature and due to the influence of the rainfalling on the snow covered area. The water equivalent of snow has been assumed as 0.1. The losses from snowmelt under permanent as well as temporary cover have been taken as 10%. Such a value has been found and used in a similar study in the mountanous watershed of Dischma in Switzerland. The losses of rain falling on temporary snow covered area and rain falling on the non-snow covered area have been accounted for by computing the coefficients C_1 and C_2 respectively. The values of these coefficients, C_1 as 0.595 and C_2 as 0.278, are reasonable, though some further study will require to investigate the physical significance of the values. The routing of snowmelt after accounting for losses as well as excess rainfall from the permanent & temporary snowcovered area has been made using equation (4.23) with the recession coefficient for one day K taken as 0.90 and the excess rain from non-snow covered area has been assumed as directly contributing for the runoff for that day. The direct snowmelt runoff computed using the above procedure for the period March to May of 1977 to 1979 compare quite well with the observed direct runoff for the corresponding periods.

5.2. CONCLUSIONS

The results obtained from this study ~~be~~ are quite encouraging particularly in view of limited data having been used. The following conclusions can be drawn on the basis of the results.

(1) The satellite imageries reveal that the snowline start descending to lower altitudes from September to around the first week of March. Thus this is the accumulation season. After the first or second week of March the snowline starts receding indicating the onset of the melting season. The snow accumulation is the maximum in the year 1975 and minimum in the year 1977. With these imageries one can make reasonable judgement about temporary and permanent snow cover.

(2) The imageries taken in MSS 5 indicate more snow cover than in those taken in MSS 7 on the same day. The imageries of 22 September, 1972, ~~an~~ 3 December, 1972 and 21 March, 1973 are studied in this respect. The snow covered areas of the subcatchments in Larji catchment in MSS 5 and MSS 7 are plotted and a straight line has been fitted with an inclination of 37° from the X-axis of the MSS 5. This phenomenon refers to the melting condition near the snowline causing considerable decrease in the reflected near I.R. radiation. MSS 5 is thus found to be more appropriate for snow survey since moisture interacts in MSS 7.

(3) The snow covered areas in various subcatchments have also been plotted against their cumulative discharges for March-April-May. An exponential curve has been fitted. This evidently shows that with larger areal snow coverage more snowmelt discharge can be expected in the melting season. However, the snow extents from the imageries must be considered alongwith other factors very carefully to get a meaningful estimate. Better results can be expected working with enlarged imageries and identifying snow in shadows. However, due to the ruggedness of the terrain the ~~real~~ true snow covered area cannot be estimated.

(4) Using the blown up LANDSAT image in MSS 5 of scale 1:250,000 dated Dec. 2, 1972 the vegetal cover and the land use features have been interpreted and delineated as snowcover, Alpine pasture, thin forest, thick forest and bare and cultivated land. The Larji catchment is covered by snow more than the other features, which can also be concluded from table (4.2).

(5) The division of Manali catchment in five zones of 2000 ft. interval in altitude has been adequate.

(6) A lapse rate of 1.53°C per 1000 ft. (305 m) has been assigned from literature survey. Similar values of lapse rate have been observed in the catchment using the temperature data of Manali and Bhuntar which is further down stream of Manali at an elevation of 3555.25 ft(1084.35 m). However, it is better to establish this relationship a if a station at 10,000 ft (3050 m) or also were available.

(7) Only assumed values of the variation of precipitation with elevation were based on literature survey. They have performed reasonably well. However, further study and data is needed to establish this relation.

(8) The snowline before the snowmelt season for the year 1977 was taken with the help of the satellite image. The span of accumulation season was also concluded from the satellite imageries. However, more satellite imageries are needed for better result.

(9) The water equivalent of the snow was taken as 0.1 since the actual condition of the snowpack was not known.

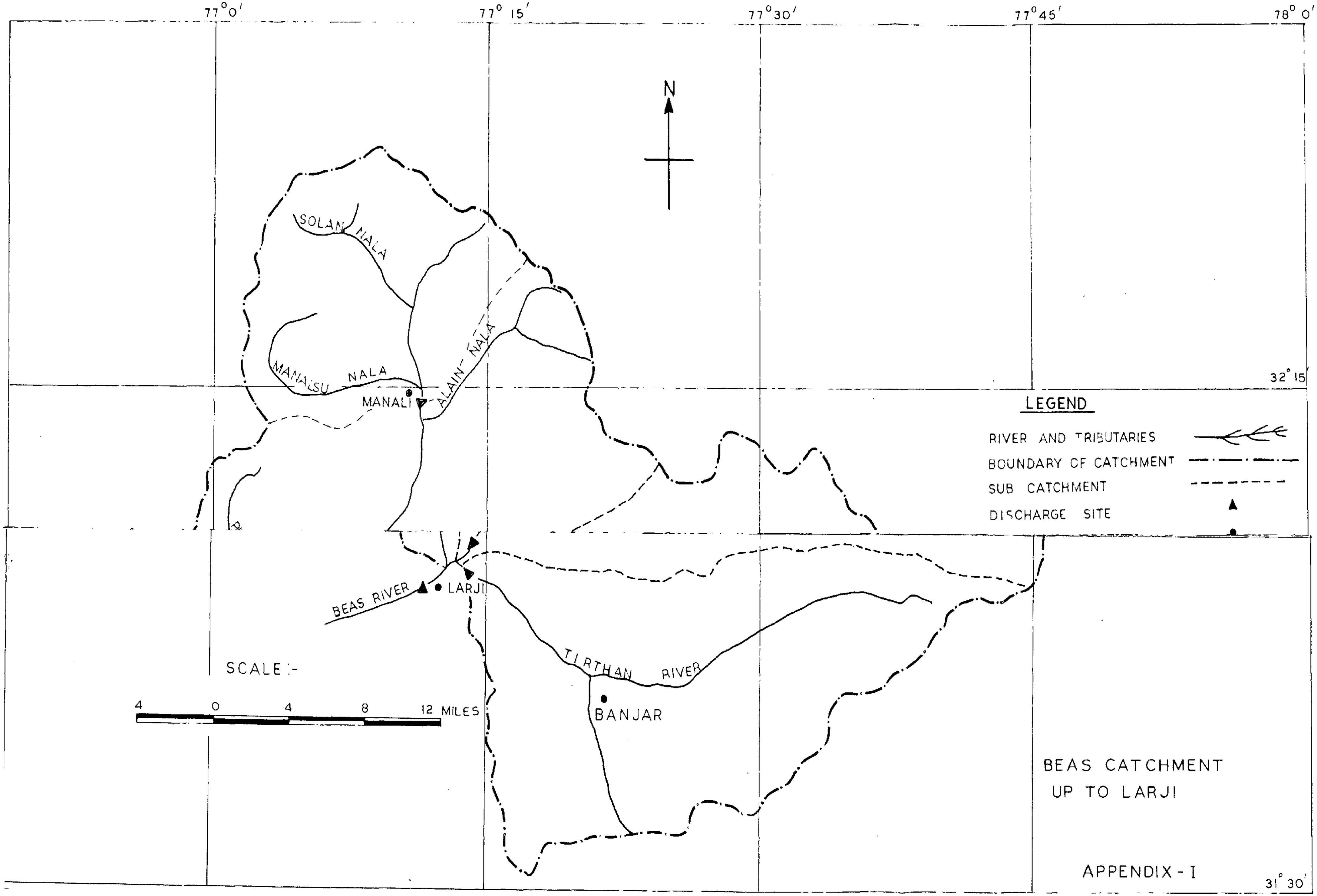
(10) The idea of using temperature as predominant factor in the process of snowmelt has given quite an encouraging result. The degree day factors of 0.0018 cm °C^{-1} d^{-1} for Mar-April and 0.00315 cm °C^{-1} d^{-1} for May have been used. These values are coming around the average value of 0.0027 cm °C d^{-1} given in the literatures reviewed. Since the rainfalling on the snow-covered area is scanty, no definite conclusion can be arrived by assuming the suitability of the snowmelt due to rain falling on the snow covered area.

(11) The calculated values of the losses C_1 and C_2 as 0.595 and 0.278 of the rain falling on snow covered area and rainfalling on the non-snow covered area respectively are reasonable though further study is required to investigate the physical significance of these values.

5.3. SCOPE FOR FURTHER STUDIES

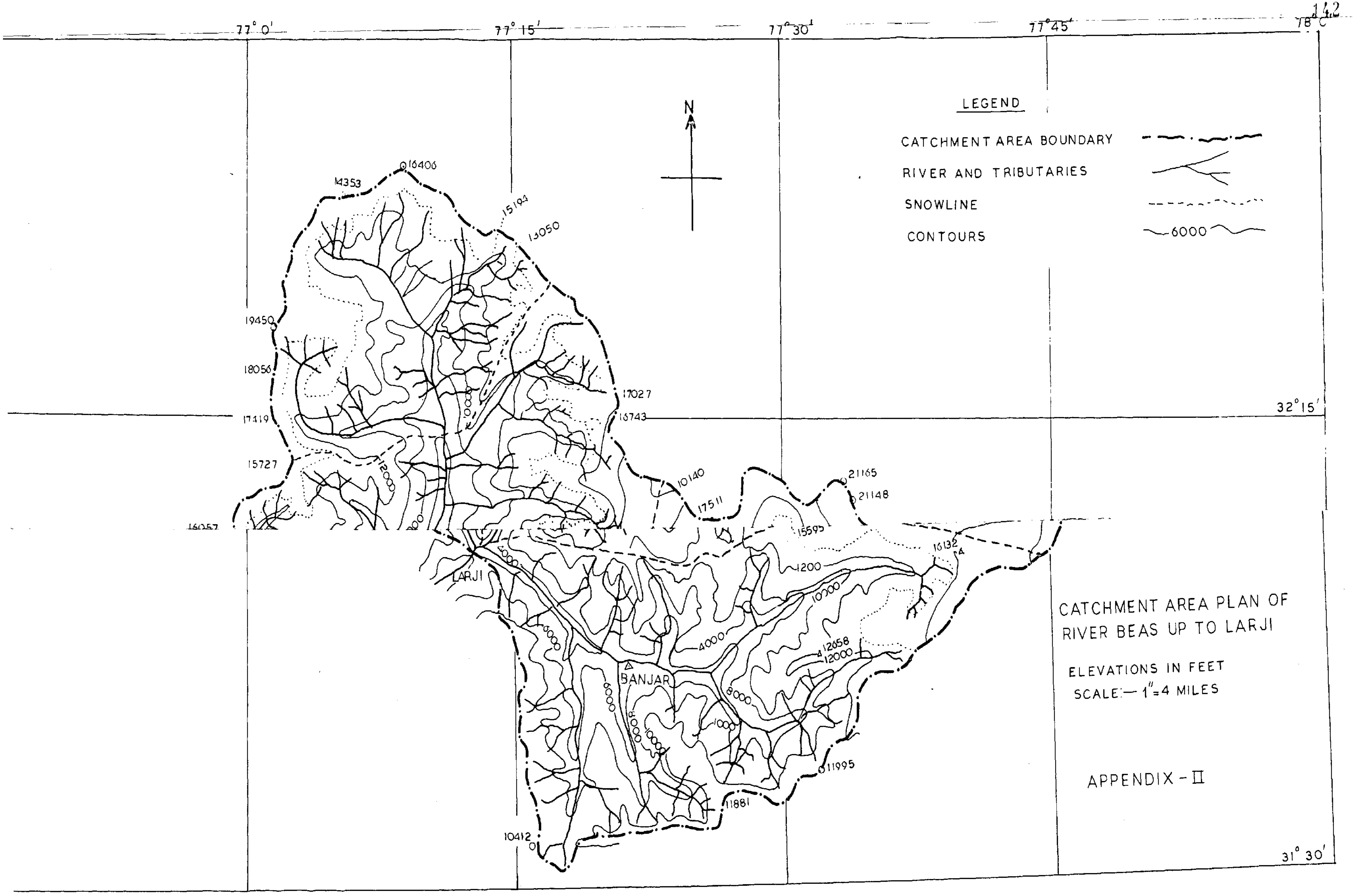
The observations of snowline, depth, and density of snow, are essential for the proper evaluation of the snowmelt runoff. Study is also needed for estimating the base flow, the losses from the snowmelt, the pana lapse rate, the degree day factor and the runoff coefficient.

The availability of the satellite remote sensed data used in conjunction with conventional methods is likely to improve the accuracy of the snowmelt forecasts. A thorough study should be made to see whether the methods used abroad are to be modified to suit the conditions prevailing in the Himalayan catchments.



BEAS CATCHMENT
UP TO LARJI

APPENDIX - I

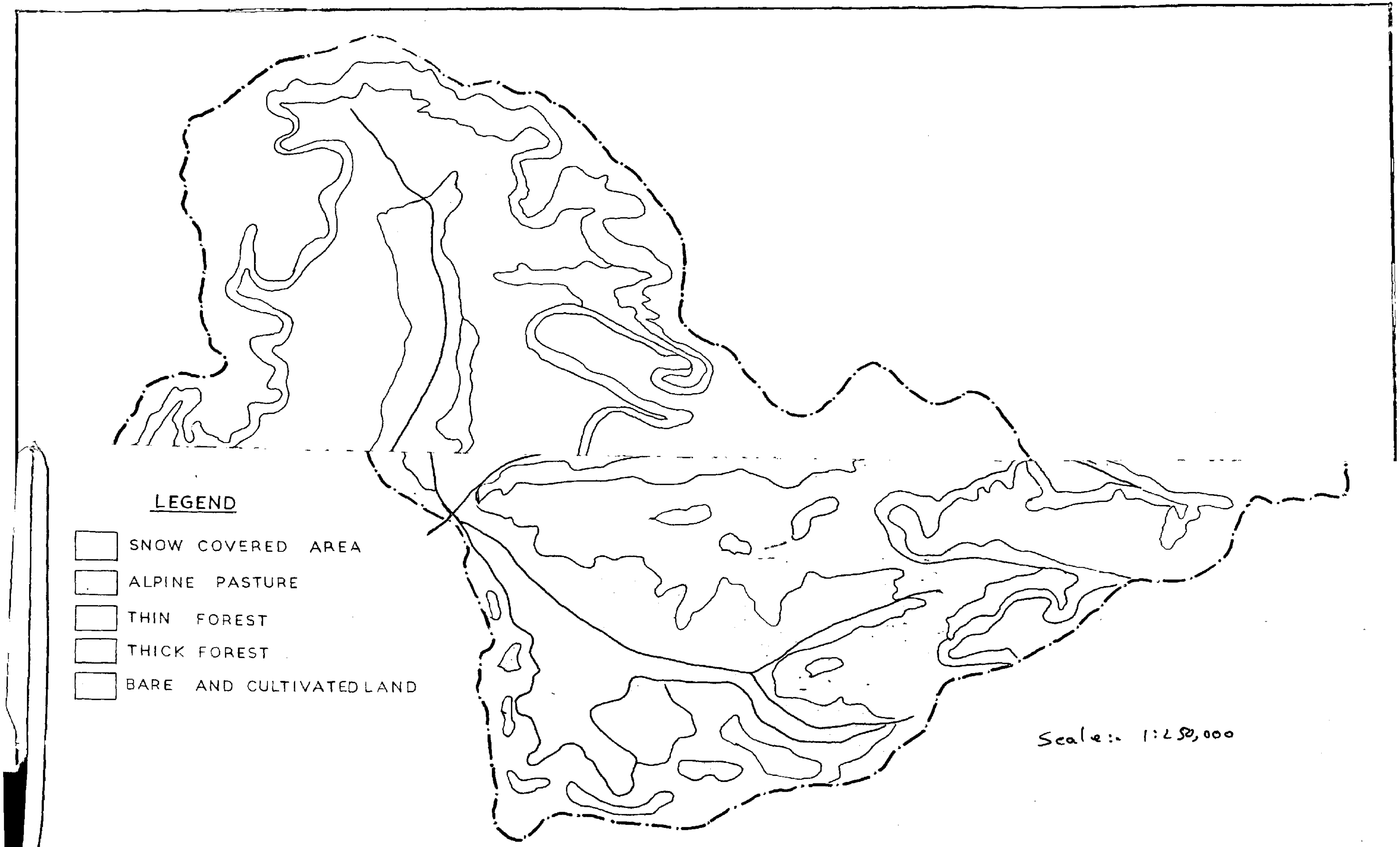


CATCHMENT AREA PLAN OF RIVER BEAS UP TO LARJI

ELEVATIONS IN FEET

SCALE:— 1"=4 MILES

APPENDIX - II



VEGETAL COVER AND LAND USE FEATURES LANDSAT IMAGE DATE 2 DEC. 1972

APPENDIX-III

APPENDIX : IV (a)

Daily Mean temperature data in Manali year 1977

Date	Daily mean Temp (°c)	Date	Daily mean Temp (oc)	Date	Dail M Mean Temp (°c)
March					
18	6.5	12	17,5	7	14.5
19	9	13	17.5	8	14.5
20	10	14	17.5	9	16
21	11	15	15.5	10	15.5
22	10.5	16	15	11	17
23	10.5	17	17.5	12	17.5
24	12	18	17	13	17.5
25	12	19	16	14	16.5
26	12.5	20	15.5	15	17.5
27	12.5	21	15.5	16	17.5
28	12.5	22	18	17	17
29	14	23	19.5	18	19.5
30	13.5	24	19	19	21
31	13	25	19	20	21.5
		26	21	21	21.5
April					
1	14	27	21	22	18.5
2	14	28	21	23	13.5
3	12	29 ~~30Apr~~	20.5	24	15
4	13	30	19	25	14
5	14.5			26	12.5
6	14.5	May 1	19	27	12
7	15	2	19.5	28	12
8	16	3	19	29	13
9	16	4	16.5	30	13
10	17	5	17	31	14
11	17.5	6	14.5		

APPENDIX : IV(b)

Dail Mean temperature data in Manali Year: 1978.

Date	Daily Mean temp. (c)	Date	Daily Mean Temp (c)	Date	Daily Mean Temp (c)
March					
13	3.5	4	10	27	16
14	5	5	10	28	18
15	6	6	11.5	29	18.5
16	5.5	7	14	30	18.5
17	6	8	14	May	
18	7	9	14	1	18.5
19	7.5	10	14	2	18.5
20	8	11	16	8	19
21	8	12	17.5	4	19
22	7	13	16	5	21
23	10.5	14	16.5	6	21
24	10	15	17	7	21
25	10	16	19.5	80	20.8
26	10	17	19	9	20.5
27	11	18	16	10	21.5
28	11	19	14	11	21
29	11.5	20	14.5	12	21.5
30	11.5	21	13	13	21.5
31	11.5	22	14.5	14	21.5
April		23	14	15	22
1	10.5	24	14.5	16	22
2	10.5	25	14.5	17	22
3	11.5	26	15	18	22.5

Appendix : IV(b) Contd..

Date	Daily Mean Temp (c)
19	23.5
20	22
21	22
23	23
24	23
25	23
26	23.5
27	23
28	24
29	24.5
30	23
31	22

APPENDIX-XV(c)

Daily Mean Temperature in [illegible], Year -1977

Date		Daily Mean Temp. (°C)	Date		Daily Mean Temp. (°C)	Date	Daily Mean Temp. (°C)
1		2	3		4	5	6
March	28	15.5		24	12.5	20	20
	29	15		25	13	21	20
	30	15.5		26	19	22	20.5
	31	16		27	18.5	23	19.5
April	1	17		28	13.5	24	20
	2	15.5		29	14	25	20
	3	15.5		30	13	26	20.5
	4	16.5				27	21
	5	16.5	May	1	18.5	28	20.5
	6	16.5		2	18.5	29	20
	7	18.0		3	16	30	20.5
	8	11		4	15	31	20
	9	11		5	19		
	10	11.5		6	19		
	11	12.5		7	17		
	12	12.5		8	17.5		
	13	10		9	17		
	14	12.0		10	20		
	15	12.5		11	10		
	16	12.5		12	17.5		
	17	13		13	20		
	18	13		14	17		
	19	11		15	18.5		
	20	14.5		16	18.5		
	21	13.5		17	17.5		
	22	13.5		18	19		
	23	14		19	20.5		

APPENDIX V (a)

Estimated daily rainfall in different zones in Manali catchment

Year 1979

Date	Daily rainfall depth recorded at Manali (cm)	Computed daily rainfall depth for different elevation zones. (cm)				
		6000 to 8000 ft	8000 to 10000 ft	10000 to 12000 ft	120000 to 14000 ft	above 14000 ft
23.3.79	1.620	1.745	1.995	2.245	2.495	2.745
31.3.79	2.720	2.845	3.095	3.345	3.595	3.845
3.4.79	0.52	0.57	0.67	0.77	0.87	0.97
12.4.79	0.22	0.27	0.37	0.47	0.57	0.67
30.4.79	2.22	2.345	2.595	2.845	3.095	3.345
10.5.79	0.52	0.57	0.67	0.77	0.87	0.97
21.5.79	2.32	2.445	2.695	2.945	3.195	3.445
23.5.79	0.94	0.99	1.09	1.19	1.29	1.39
26.5.79	5.98	6.18	6.58	6.98	7.38	7.78
Total	17.06	17.96	19.76	21.56	23.36	25.16

APPENDIX :V(b)

Estimated daily rainfall in the different zones in Manali catchment

Year 1978.

Date	Draily rainfall depths recorded at Manali(cm)	Computed daily rainfall depths for different elevation zones. (cm)				
		6000ft to 8000ft	8000ft to 10000ft	10000ft to 12000ft	12000ft to 14000ft	Above 14000ft
17.3.78	8.48	8.68	9.08	9.48	9.89	10.28
18.3.78	~~[illegible]~~ 3.37	~~[illegible]~~ 3.495	3.745	3.995	4.245	4.495
28.3.78	1.02	1.145	1.395	1.645	1.895	2.145
29.3.78	0.34	0.39	0.49	0.59	0.69	0.79
3.4.78	0.58	0.63	0.73	0.83	0.93	1.03
4.4.78	1.12	1.245	1.495	1.745	1.995	2.245
17.4.78	1.22	1.345	1.595	1.845	2.095	2.345
18.4.78	4.08	4.28	4.68	5.08	5.48	5.88
22.4.78	1.72	1.845	2.095	2.345	2.595	2.845
25.5.78	1.76	1.885	2.135	2.385	2.635	2.885
26.5.78	0.54	0.59	0.69	0.79	0.89	0.99
31.5.78	0.22	0.27	0.37	0.47	0.57	0.67
Total	24.45	25.80	28.50	31.20	33.90	36.60

APPENDIX: V (a)

Estimated daily rainfall in different zones in Manali catchment. year 1977.

Date	Daily rainfall depths recorded in Manali (cm)	Computed daily rainfall depths for different elevation zones (cm)				
		6000 ft to 8000 ft	8000 ft to 10000 ft	10000 ft to 12000 ft	12000ft to 14000ft	above 14000ft
1	2	3	4	5	6	7
31.3.77	0.40	0.45	0.55	0.65	0.75	0.85
1.4.77	0.84	0.89	0.99	1.09	1.19	1.44
6.4.77	2.82	2.945	3.195	3.445	3.695	3.945
7.4.77	2.06	2.185	2.435	2.685	2.935	3.185
8.4.77	0.22	0.27	0.37	0.47	0.57	0.67
10.4.77	0.12	0.17	0.27	0.37	0.47	0.57
11.4.77	0.44	0.49	0.59	0.69	0.79	0.89
18.4.77	0.44	0.49	0.59	0.69	0.79	0.89
16.4.77	0.22	0.27	0.37	0.47	0.57	0.67
19.4.77	1.38	1.505	1.755	2.005	2.255	2.505
20.4.77	1.62	1.745	1.995	2.245	2.495	2 .745
24.4.77	1.24	1.365	1.615	1.865	2.115	2.365
25.4.77	2.04	2.165	2.415	2.665	2.915	3.165
26.4.77	0.52	0.57	0.67	0.77	0.87	0.97
28.4.77	1.72	1.865	2.095	2.345	2.595	2.845
29.4.77	2.26	2.305	2.635	2.885	2.35	3.355
30.4.77	0.42	0.47	0.57	0.67	0.77	0.87
4.5.77	5.08	5.28	5.68	6.08	6.48	6.88

Contd....

1	2	3	4	5	6	7
10.5.77	2.42	2.545	2.795	3.045	3.295	3.545
14.5.77	2.16	2.285	2.535	2.785	3.035	3.285
15.5.77	0.52	0.57	0.67	0.77	0.87	0.97
27.5.77	0.32	0.37	0.77	0.57	0.67	0.77
29.5.77	2.08	2.205	2.455	2.705	2.955	3.205
30.5.77	0.42	0.47	0.57	0.67	0.77	0.87
Total	31.76	33.935	38.285	42.635	46.985	51.335

APPENDIX VI (a)

Estimated daily snow fall in different zones in Manali Catchment.

Year 1978-1979

Date	Daily snow depths recorded at Manali (cm)	Computed daily snowfall depths for different elevation zones (cm)			
		6000 to 8000 ft	8000 to 10000 ft	10000 to 12000 ft	12000 to 14000 ft.
1	2	3	4	5	6
25.11.78	10.80	12.05	14.55	17.05	19.55
26.11.78	17.20	15.45	17.95	20.45	22.95
27.11.78	16.20	17.75	19.95	22.45	24.95
2.12.78	16.20	17.45	19.95	22.45	24.95
14.1.79	22.20	23.45	25.95	28.45	30.95
15.1.79	49.20	51.20	55.20	59.20	63.20
16.1.79	16.40	17.65	20.15	22.65	25.15
17.1.79	8.20	8.70	9.70	10.70	11.70
20.1.79	8.20	8.70	9.70	10.20	11.70
21.1.79	25.20	26.45	28.95	31.45	33.95
26.1.79	47.20	49.20	53.20	51.20	61.20
29.1.79	6.20	6.70	7.70	8.70	9.70
30.1.79	18.00	19.25	21.75	24.25	26.75
2.2.79	16.20	17.45	19.95	22.45	24.95
16.2.79	3.20	3.70	4.70	5.70	6.70

Contd...

1	2	3	4	5	6
17.2.79	4.20	4.70	5.70	6.70	7.70
19.2.79	14.20	15.45	17.95	20.45	22.95
20.2.79	49.20	51.20	55.20	59.20	68.20
21.2.79	9.00	9.50	10.50	11.50	12.50
23.2.79	14.80	16.05	18.55	21.05	23.55
26.2.79	4.20	4.70	5.70	6.70	7.70
2.3.79	16.20	17.45	19.95	22.45	24.95
3.3.79	45.20	47.20	51.20	55.20	59.20
4.3.79	17.40	18.65	21.15	23.65	26.15
5.3.79	22.40	23.65	26.15	28.65	31.15
6.3.79	26.60	27.85	30.35	32.85	35.35
7.3.79	30.40	31.65	34.15	36.65	39.15
8.3.79	14.20	15.45	17.95	20.45	22.95
9.3.79	9.20	10.45	12.95	15.45	17.95
17.3.79	16.20	17.45	19.95	22.45	24.45
Total	571.00	606.25	676.75	747.25	817.75

APPENDIX : VI(b)

Estimated daily snow fall in different zones in Manali catchment.

Year : 1977 - 78

Date	Daily snow depths recorded at ~~Mahalir~~ Manali	Computed daily snow fall depths for different elevation zones (cm)			
		6000 ft to 8000 ft	8000 ft to 10000 ft	10000 ft to 12000 ft	12000 ft to 14000 ft
1	2	3	4	5	6
3.11.77	4.80	5.30	6.30	7.3	8.30
6.11.77	7.40	7.90	8.90	9.9	10.90
30.11.77	10.00	10.50	11.50	12.50	13.50
1.12.77	46.40	48.40	52.40	56.40	60.40
10.12.77	4.60	5.10	6.10	7.10	8.10
17.12.77	16.20	17.45	19.95	22.45	24.95
20.12.77	42.60	44.60	48.60	52.60	56.60
26.12.77	~~40.20~~ 14.20	15.45	17.95	20.45	22.95
26.12.77	39.20	40.45	52.95	45.45	47.95
23.12.77	12.00	13.25	15.75	18.25	20.75
28.12.77	2.00	2.50	3.50	4.50	5.50
29.12.77	2.00	2.50	3.50	4.50	5.50
13.1.78	14.60	15.85	18.35	20.85	23.35
14.1.78	19.20	20.45	22.95	25.45	27.95
23.1.78	9.00	9.60 50	10.50	11.50	12.50
26.1.78	45.40	47.40	51.40	55.40	59.40
28.1.78	36.80	38.05	40.55	43.05	45.55
29.1.78	38.00	39.05 25	40.75 41.75	44.25	46.75
5.2.78	3.20	3.70	4.70	5.70	6.70
6.2.78	4.00	4.50	5.50	6.50	7.50
7.2.78	21.60	22.85	25.35	27.85	30.35

1	2	3	4	5	6
8.2.78	5.00	5.50	6.50	7.50	8.50
11.2.78	13.00	14.25	16.75	19.25	21.75
13.2.78	12.20	13.45	15.95	18.45	20.95
15.2.78	4.20	4.70	5.70	6.70	7.70
16.2.78	21.20	22.45	24.95	27.45	29.95
17.2.78	26.60	27.85	30.85	32.85	35.35
18.2.78	17.80	19.05	21.55	24.05	26.55
3.3.78	2.00	2.50	3.50	4.50	5.50
11.3.78	12.00	13.25	15.75	18.25	20.75
12.3.78	10.00	10.50	11.50	12.50	13.50
Total	517.20	548.45	610.95	673.45	735.95

APPENDIX: VI (c)

Estimated daily snowfall in different zones in Manali catchment. year 1976 - 1977

Date	Daily snow depths recorded at Manali (cm)	Computed daily snowfall depths for different elevation zones (cm)			
		6000 ft to 8000ft	8000 ft to 10000 ft	10000 ft to 12000 ft	12000 ft to 14000 ft.
1	2	3	4	5	6
3.12.76	5.80	6.30	7.30	8.30	9.30
26.12.76	19.20	20.45	22.95	25.45	27.95
29.12.76	6.00	6.50	7.50	8.50	9.70
12.1.77	6.20	6.70	7.7	8.70	8.70
20.1.77	20.00	21.25	23.75	26.25	28.75
24.1.77	27.70	28.65	31.15	33.65	36.15
25.1.77	36.20	37.45	39.95	42.45	44.95
26.1.77	40.00	41.25	43.75	46.25	48.75
27.1.77	6.00	6.50	7.50	8.50	9.50
28.1.77	2.00	2.50	3.50	4.50	5 .50
5.2.77	6.00	6.50	7.50	8.50	9.50
21.2.77	3.20	3.70	4.20	5.70	6.70
27.2.77	17.20	18.45	20.95	23.45	25.95
27.2.77	17.20	18.45	20.95	23.45	25.95
Total	195.2	206.2	228.2	250.2	272.2

APPENDIX VII (a)

Values adopted for the increment of snowfall due to orographic effect.

Snowfall at base station (in cm)	Incremental values of snowfall with elevation cm per 2000 ft (610m)
0 - 10	1
10- 40	2.5
above 40	40

APPENDIX VII (b)

Values adopted for the increment of rainfall due to the orographic effect.

Rainfall at the base station (in cm)	Incremental values of rainfall with elevation cm per 2000 ft. (610 m)
0 - 1	0.1
1 - 4	0.25
above 4	0.40

APPENDIX-XXXX(a)

Estimated equivalent water stored in the snow during the accumulation season for different elevation zones in Nepal catchment.

accumulation season: 1978 Nov. to 1979 Nov.

Sl.No.	Elevation zone	Volume of equivalent water stored in deposited snow under temporary snow-covered area (m³)
1	2	3
1.	6000-8000	16035609
2.	8000-10000	33052061
3.	10000-12000	77919309
4.	12000-14000	89773409

APPENDIX-XXXX(b)

accumulation season: 1977 Nov. to 1978 Nov.

1	2	3
1.	6000-8000	12005020
2.	8000-10000	30350109
3.	10000-12000	70449304
4.	12000-14000	80040107

APPENDIX-XXXX(c)

accumulation season: 1976 Nov. to 1977 Nov.

1	2	3
1.	6000-8000	~~2000000~~ 0
2.	8000-10000	2003000
3.	10000-12000	16521000
4.	12000-14000	23409200

APPENDIX: IX (a)

Calculated snowmelt due to rain and calculated rainfall runoff in different elevation zones.

Year 1979

Elevation zone 6000 ft to 8000 ft.

Date	Rainfall (m)	Degree days (°cd)	Snowmelt volume (m^3)	Snowmelt m^{3}/s	Runoff (in m^{3}/s) from rainfall when the zone is	
					snow covered	nonsnow covered
1	2	3	4	5	6	7
March						
23	0.01745	9.95	46303.10	0.54	2.85	-
31	0.02845	11.45	96578.40	1.12	4.61	-
April						
3	0.0057	10.45	17659.70	0.20	0.92	-
12	0.0027	15.95	12767.80	0.15	0.44	-
30	0.02345	(no snow-cover in the zone)			-	1.77
May						
10	0.0057				-	0.43
21	0.02445				-	1.85
23	0.0099				-	0.75
26	0.0618				-	4.67

Elevation zone 8000 ft to 10000 ft.

1	2	3	4	5	6	7
March						
23	0.01995	5.89	73569.40	0.85	6.83	-
31	0.03095	8.39	162578.10	1.88	10.59	-
April						
3	0.0067	7.39	30999.70	0.36	3.29	-
12	0.0037	12.89	29860.3	0.35	1.26	-
30	0.02595	(no snow-cover in the zone)			-	4.14
May						
10	0.0067				-	1.07
21	0.02695				-	4.31
23	0.0109				-	1.74
26	0.0658				-	10.52

Elevation zone 10000 ft. to 12000 ft.

1	2	3	4	5	6	7
March						
23	0.02245	2.83	82977.80	0.96	16.17	-
31	0.03345	5.33	234999.5	2.72	24.09	-
April						
3	0.0077	4.33	43946.30	0.51	5.54	-
12	0.0047	9.83	60896.80	0.70	3.38	-
30	0.02845	11.33	424869.80	4.92	20.49	-
May						
10	0.0077	(nosnow-cover in the zone)			-	2.59
21	0.02945				-	9.90
23	0.0119				-	4.00
26	0.0898				-	23.49

Contd..... .

Elevation zone 12000 ft. to 14000 ft.

1	2	3	4	5	6	7
March						
23	0.02495	-	-	-	-	-
31	0.03595	2.27	112952.30	1.31	27.19	-
April						
3	0.0087	1.27	15293.00	0.18	6.58	-
12	0.0057	6.77	53411.40	0.62	4.31	-
30	0.03095	8.27	354271.90	4.10	23.41	-
May						
10	0.0087	4.77	57439.10	0.66	6.58	
21	0.03195	10.77	476274.30	5.51	24.60	
23	0.0124	(no snow cover in the zone)			-	4.38
26	0.0738					26.08

Elevation zone above 14000 ft.

March				
23	0.02745	-	-	0.339
31	0.03845	0.74	-	0.339
April				
3	0.0097	-	-	-
12	0.0067	5.24	-	0.42
30	0.03345	6.74	-	2.69
May				
10	0.0097	3.24	-	0.37
21	0.03445	9.24	-	3.80
23	0.0139	0.24	-	0.04
26	0.0778	0.24	-	0.219

APPENDIX : IX (b)

Calculated snowmelt due to rain and calculated rainfall runoff in different elevation zones.

(Year 1978)

Elevation zone 6000 ft. to 8000 ft.

Date	Rainfall (m)	Degree days (c d)	Snowmelt volume (m^3)	Snow melt (m^3/s)	Run off (in m^3/s) from rainfall when the zone is	
					snow covered	Non snow covered
1	2	3	4	5	6	7
March						
17	0.0868	4.46	114774.9	1.33	14.06	-
18	0.03495	5.45	56472.3	0.65	5.66	
28	0.01145	9.45	032079.6	0.37	1.85	
29	0.0039	9.45	10926.6	0.13	0.63	
April						
3	0.0063	(No snowcoverin the zone)			1.02	
4	0.01245				2.02	
17	0.01345					1.02
18	0.0428					3.24
22	0.01845					1.39
May						
25	0.01885					1.42
26	0.0059					0.446
31	0.0027					0.204

Elevation zone 8000 ft to 10000 ft

1	2	3	4	5	6	7
March						
17	0.0900	1.39	79020.5	0.91	31.07	-
18	0.03745	2.39	56038.5	0.65	12.81	-
28	0.01395	6.39	55910.3	0.65	4.77	-
29	0.0049	6.89	21137.9	0.24	1.67	-
April						
3	0.0073	6.89	31490.6	0.36	2.49	-
4	0.01495	5.39	50450.9	0.58	5.11	-
17	0.01595	14.39	143701.4	1.66	5.45	-
18	0.0468	14.45	423402.3	4.90	16.01	-
22	0.02095	9.89	129723.8	1.50	7.17	-
March						
25	0.02135	(no snow cover in the zone)				3.41
26	0.0069				-	1.103
31	0.0039 (7)					0.59

Elevation zone 10000 ft to 12000 ft.

March						
17	0.0948	-				
18	0.03995	-				
28	0.01645	3.33	72202.7	0.83	11.8	-
29	0.0059	3.83	29784.7	0.34	4.2	-

Contd...

1	2	3	4	5	6	7
April						
3	0.0083	3.83	41900.6	0.48	5.9	-
4	0.01745	2.33	93591.3	0.61	12.57	
17	0.01845	11.33	272894.5	3.12	13.29	-
18	0.0508	8.33	557766.5	6.45	36.59	-
22	0.02345	6.83	211109.2	2.44	16.89	
May						
25	0.02385	(no snow cover in the zone)			-	8.02
26	0.0079				-	2.65
31	0.0047				-	1.58

Elevation zone 12000 ft to 14000 ft.

1	2	3	4	5	6	7
March						
17	0.0988	-	-	-	-	-
18	0.04245	-	-	-	-	-
28	0.01895	0.27	7081.79	0.08	14.33	-
29	0.0069	0.77	7353.77	0.09	5.22	-
April						
3	0.0093	0.77	9911.61	0.11	7.03	
4	0.02995	-	-	-	15.09	
17	0.02095	8.27	239806	2.77	15.89	-
18	0.0548	5.27	399725.1	4.62	41.46	-
22	0.02595	3.77	135409.5	1.56	19.63	-

Contd

1	2	3	4	5	6	7
May						
25	0.02635	12.27	447502.8	5.17	-	9.31
26	0.0089	(no snow cover in the zone)			-	3.14
31	0.0057	-	-	-	-	2.01
		Elevation zone above 14000ft.				
March						
17	0.1028					
18	0.04495					
28	0.02145					
29	0.0079					
April						
3	0.0103					
4	0.02245					
17	0.02345	6.74		1.87		
18	0.0588	3.74		2.62		
22	0.02845	2.24		0.76		
May						
25	0.02885	10.74		3.69		
26	0.0099	11.24		1.33		
31	0.0067	9.74		0.78		

APPENDIX-IX(c)

Calculated snowmelt due to rain and calculated rainfall runoff in different elevation zones. Year - 1977

Elevation zone 8000 ft. to 10,000 ft.

...te	Rainfall (mm)	Degree days (°cd)	Snowmelt volume (m^3)	Snowmelt m^3/s	Runoff(in m^3/s) from rainfall when the zone ... Snow-covered	Non snow-covered
	2	3	4	5	6	7
..31	0.0055	9.39	5856.65	0.07	0.34	-
...ril 1	0.0099	12.39	13909.7	0.16	0.61	-
6	0.03195	9.89	35832.7	0.42	1.98	-
7	0.02435	8.39	23167.1	0.3	1.51	-
8	0.0037	6.39	2681.11	0.03		0.11
10	0.0059	7.89	5270.88	0.06		0.17
11	0.0059					0.17
15	0.0059					0.17
16	0.0037					0.11
19	0.01755					0.51
20	0.01995					0.58
24	0.01615					0.47
25	0.02415					0.70
26	0.0067					0.19
28	0.02095					0.61
29	0.02635					0.76
30	0.0057					0.16
...y 4	0.02568					0.74
10	0.02795					0.81
14	0.02535					0.73
15	0.0067					0.194
27	0.0047					0.14
29	0.02455					0.71
30	0.0057					0.16

Elevation zone 10000 ft. to 12000 ft.

1	2	3	4	5	6	7
March 31	0.065	6.33	30076.9	0.35	2.21	-
April 1	0.0109	9.33	24340.5	0.86	3.70	-
6	0.03445	6.63	171999.5	1.99	11.69	-
7	0.02685	5.33	104613.7	1.21	9.11	-
8	0.0047	3.33	11440.8	0.13	1.59	-
10	0.0037	3.83	1035.9	0.12	1.26	-
11	0.0069	4.83	2426.2	0.277	2.34	-
15	0.0069	4.83	2436.2	0.28	2.34	-
16	0.0047	4.83	16593.7	0.19	1.59	-
19	0.02005	3.33	48600	0.56		3.74
20	0.02245					4.19
24	0.01865					3.48
25	0.02665					4.97
26	0.0077					1.44
28	0.02345					4.38
29	0.02885					5.34
30	0.0062					1.25
May 4	0.0606					11.35
10	0.03045					5.68
14	0.02785					5.19
15	0.0077					1.44
27	0.0057					1.06
29	0.02705					5.05
30	0.0067					1.25

Elevation zone 12000 ft. to 14000 ft.

1		2	3	4	5	6	7
March	31	0.007	3.27	25585.1	0.31	4.44	
April	1	0.0119	6.27	80880.4	0.93	7.05	
	6	0.03595	3.77	151002.8	1.74	21.88	
	7	0.02935	2.27	71809.5	0.83	17.38	
	8	0.0057	0.27	1668.27	0.02	3.38	
	10	0.0077	0.77	3121.99	0.04	2.78	
	11	0.0079	1.77	15154.3	0.18	4.68	
	15	0.0079	1.77	15184.3	0.18	4.68	
	16	0.0057	1.77	10936.4	0.13	3.38	
	19	0.02255	0.27	6599.39	0.08	13.38	
	20	0.02495	3.77	10196.1	1.18	14.78	
	24	0.02115	2.77	635066	0.73	12.52	
	25	0.02915	2.27	71728.8	0.81	17.16	
	26	0.0087	2.27	21407.9	0.23	5.15	
	28	0.02595	2.27	77919.5	0.89	15.37	
	29	0.03135	3.27	111125.7	1.27	18.97	
	30	0.0077	2.27	18947.2	0.19	4.56	
May	4	0.0648	4.27	299938.4	3.46	38.38	
	10	0.03295	(no snow cover in the zone)			9.12	
	14	0.03035				8.39	
	15	0.0087				2.41	
	27	0.0057				1.85	
	29	0.02955				8.17	
	30	0.0077				2.13	

Elevation zone above 14000 ft.

Date	Degree day(°cd)	Daily snowmelt m^3/s	Sum of daily snowmelt for all the zones m^3/s
1	2	3	4
Mar. 31	0.0085	1.74	0.1752
April 1	0.0144	4.74	0.8130
6	0.03945	2.24	1.052
7	0.03185	0.74	0.2801
8	0.0067	-	-
10	0.0057	-	-
11	0.0087	0.24	0.0247
15	0.0089	0.24	0.0254[illegible]
16	0.0067	0.24	0.01916
19	0.02505	-	-
20	0.02745	2.24	0.7329
24	0.02365	1.24	
25	0.03165	0.74	0.27
26	0.0097	0.74	0.080
28	0.02845	1.24	0.42
29	0.03305	1.74	0.69
30	0.0077	0.74	0.08
May 4	0.0088	2.74	2.25
10	0.03545	5.74	2.24
14	0.0[illegible]	4.74	1.[illegible]
15	0.0097	6.24	0.72
27	0.0077	8.74	0.8
29	0.03205	7.74	2.96
30	0.0087	8.24	0.85

APPENDIX X (a)

Computed daily snowmelt in different elevation zones in Manali catchment

Year 1979

ELEVATION ZONE: 6000 ft to 8000 ft

Date	Degree-Day (°C d)	Dail snow melt volume (m^3)	Daily snow melt (m^3/s)	Equivalent volume of water remaining in the form of snow (m^3)
1	2	3	4	5
March				
18	4.95	209652.3	2.43	13845756
19	7.65	315537.3	3.65	13530219
20	8.45	357891.3	4.14	13172328
21	9.45	400245.3	4,63	12772082
22	8.95	379068.3	4.39	12393013
23	8.95	379068.3	4.39	11967642**
24	10.45	442599.3	5.14	11525042
25	10.45	442599.3	5.14	11082443
26	10.95	463776.3	5.37	10618667
27	10.95	463776.3	5.37	10154890
28	10.95	463776.3	5.37	9691113.7
29	12.45	527307.3	6.10	9163806.4
30	11.95	506130.3	5.86	8657676.1
31	11.45	484953.3	5.61	8076144.4**
April				
1	12.45	527307.3	6.10	7548837.1
2	12.45	527307.3	6.10	7021529.8

Contd.

1	2	3	4	5
3	10.45	442599.3	5.12	6581270.8**
4	11.45	484953.3	5.61	607631.5
5	12.95	548484.3	6.34	5527833.2
6	12.95	548484.3	6.34	4979348.9
7	13.45	569661.3	6.59	4409687.5
8	14.45	612015.3	7.08	3797672.2
9	14.45	612015.3	7.08	3185656.9
10	15.45	654369.3	7.57	2531287.6
11	15.95	675546.3	7.82	1855741.3
	Elevation zone 8000 ft. to 10000 ft.			
18	1.89	169045.3	1.96	3328961.5
19	4.39	392850.3	4.54	32893965
20	5.39	482092.3	5.58	32414873
21	6.39	571534.3	6.61	31843338
22	5.89	526813.3	6.10	31316525
23	5.89	526813.3	6.10	30716142**
24	7.39	660976.3	7.65	30055166
25	7.39	660976.3	7.65	29394190
26	7.89	705697.3	8.17	28688492
27	7.89	705697.3	8.17	27982795
28	7.89	705697.3	8.17	27982725

Contd...

1	2	3	4	5
29	9.39	839860.3	9.72	26606284
30	8.89	795739.3	9.20	25811144
31	8.39	750418.3	8.69	24898148**
April				
1	9.39	839860.3	9.72	24058288
2	9.39	839860.3	9.72	23218427
3	7.39	660976.3	7.65	22526451**
4	8.39	750418.3	8.69	21778033
5	9.89	884581.3	10.29	20891652
6	9.89	884581.3	10.24	2000657
7	10.39	929302.3	10.76	19077550
8	11.39	1018744.3	11.79	18058824
9	11.39	1018744.3	11.79	17040079
10	12.39	1108186.3	12.83	15931893
11	12.89	1152907.3	13.34	14778985

Elevation Zone 10000 ft to 12000 ft.

March				
18	-	-	-	77919385
19	1.33	250436.3	2.89	7766948
20	2.33	438734.3	5.08	77230214
21	3.32	627032.3	7.26	76603182
22	2.83	532883.3	6.17	76070298

Contd.....

1	2	3	4	5
23	2.83	532883.3	6.17	75454437**
24	4.33	815330.3	8.44	74639107
25	4.33	815330.3	9.44	73823777
26	4.83	909479.3	10.53	72914297
27	4.83	909479.3	10.53	72004841
28	4.83	909479.3	10.53	71095339
29	6.33	1191926.3	13.80	69903412
30	5.83	1097777.3	12.71	68805635
31	5.33	1003628.3	11.62	67767007**
April				
1	6.33	1191936.3	13.80	66575081
2	6.33	1191926.3	13.80	65383155
3	4.33	815330.3	9.44	64523878**
4	5.33	1003828.3	11.62	63520250
5	6.83	1286075.3	14.88	62234175
6	6.83	1286075.3	14.88	60948099
7	7.33	1380224.3	15.97	59567875
8	8.33	1568522.3	18.15	57999353
9	8 .33	1568572.3	18.15	56481267
10	9.33	1756820.3	20.33	54724446
11	9.83	1850969.3	21.42	52873477
	Elevation zone 12000 ft to 14000 ft.			
18	-	-	-	-
19	-	-	-	-

Contd.....

1	2	3	4	5
20	-	-	-	89776489
21	0.27	53387.1	0.62	89723081
22	-	-	-	
23	-	-	-	
24	1.27	25117.1	2.91	89471944
25	1.27	251117.1	2.91	89220827
26	1.77	349982.1	4.05	88870845
27	1.77	349982.1	4.05	88520863
28	1.77	349982.1	4.05	88170881
29	3.27	646577.1	7.48	87524304
30	2.77	547712.1	6.34	86976592
31	2.27	448847.1	5.19	86414792**
April				
1	3.27	646577.1	7.48	85768215
2	3.27	646577.1	7.48	85121638
3	1.27	251117.1	2.91	84855228**
4	2.27	448847.1	5.19	84406381
5	3.77	745442.1	8.63	83660939
6	3.77	745442.1	8.63	82915497
7	4.27	844307.1	9.77	82071189
8	5.27	1042037.1	12.06	81029152
9	5.27	1042037.1	12.06	79987115
10	6.27	1239767.1	14.35	78747348
11	6.27	1338632.1	15.49	77462104

Elevation zone above 18000 ft.

Date	Degree days ('md)	Snow daily snow melt (m^3/s)	Sum of daily snow melt from all the zones (m^3/s)
1	2	3	4
March			
18	-	-	4.39
19	-	-	11.08
20	-	-	14.80
21	-	-	18.50
22	-	-	16.66
23	-	-	19.01 *
24	-	-	25.14
15	-	-	25.14
26	0.24	0.41	28.53
27	0.24	0.41	28.53
28	0.24	0.41	28.53
29	1.74	2.96	40.06
30	1.24	2.11	35.22
31	0.74	1.26	39.74*
April			
1	1.74	2.96	40.06
2	1.74	2.96	40.06
3	-	-	27 20.00 *
4	0.74	1.26	32.37
5	2.24	3.81	43.90

Contd...

1	2	3	4	5
6	2.24	3.81	43.90	
7	2.74	4.66	47.75	
8	3.74	6.37	55.45	
9	3.74	6.37	55.45	
10	4.74	8.07	63.15	
11	5.24	8.92	66.99	
	Elevation zone 6000 ft to 8000 ft.			
April				
12	15.95	675546.3	7.82	1377082.2**
13	15.95	675546.3	7.82	701535.9
14	15.95	675546.3	7.82	25989.6
15	13.95	25989.6	0.30	0
	Elevation zone 8000 ft to 10000 ft.			
April				
12	12.89	1152907.3	13.34	13596217**
13	12.89	1152907.3	13.34	12443310
14	12.89	1152907.3	13.34	11290403
15	10.89	974023.3	11.27	10316379
16	9.39	839860.3	9.72	9476519.5
17	12.89	1152907.3	13.39	8323612.2
18	12.39	1108186.3	12.83	7215425.9

Contd.....

1	2	3	4	5
19	11.39	1018744.3	11.79	6196681.6
20	10.89	974023.3	11.27	424835
21	10.89	974023.3	11.27	424835
22	13.39	1197628.3	13.86	3051806.7
23	14.89	1331791.3	15.41	1719215.4
24	14.39	1287070.3	14.90	432145.1
25	14.39	432145.1	5.00	0

<u>Elevation zone 10000 ft to 12000 ft.</u>

April				
12	9.83	1850969.3	21.42	50961610**
13	9.83	1850969.3	21.42	49110640
14	9.83	1850969.3	21.42	47259672
15	7.83	1474373.3	17.06	45785299
16	7.33	1380224.3	15.97	44403056
17	9.83	1850969.3	21.42	42552086
18	9.33	1756820.3	20.33	40795266
19	8.33	1568522.3	18.15	39226744
20	7.83	1474373.3	17.06	3775237
21	7.83	1474373.3	17.06	36277996
22	10.33	1945118.3	22.51	34332878
23	11.83	2227565.3	25.78	32105313
24	11.33	2133416.3	24.69	29971896
25	11.33	2133416.3	24.69	27838480
26	13.33	2510012.3	29.05	25328468

Contd....

1	2	3	4	5
27	13.33	2510012.3	29.05	22810455
28	13.33	2510012.3	29.05	20308443
29	12.83	2415863.3	27.96	17892580
30	11.33	2133416.3	24.69	15334294**
May				
1	11.33	3733478.5	43.21	11600815
2	11.83	3898239.3	45.12	7702576.2
3	11.33	3733478.5	43.21	3969097.7
4	8.83	2909674.8	33.68	1059422.9
5	9.33	1059422.9	12.26	0

Elevation zone 12000 ft. to 14000 ft.

April				
12	6.77	13386321	15.49	7607006**
13	6.77	13386321	15.49	74731427
14	6.77	13386321	15.49	73392795
15	4.77	9431721	10.91	72449622
16	4.27	8443071	9.77	71605315
17	6.77	13386321	15.49	70266683
18	6.27	12397671	14.34	69026916
19	5.27	10420371	12.06	67984879
20	4.77	9431721	10.91	67041707
21	4.77	9431721	10.91	66098535
22	7.27	14374971	16.64	62926945

Contd.....

1	2	3	4	5
24	8.27	16352271	18.92	61291718
25	8.27	16352271	18.92	59656491
26	10.27	20306871	23.50	57625804
27	10.27	20306871	23.50	55595117
28	10.27	20306871	23.50	5356443
29	9.77	19318221	22.35	51632608
30	8.27	16352271	18.92	49643109**
May				
1	8.27	28616474	33.10	46701461
2	8.77	30346611	35.12	437468
3	8.27	28616474	33.10	40885153
4	5.77	199965786	23.11	38888574
5	6.27	21695924	25.11	36710982
6	3.77	13045236	15.10	35414458
7	3.77	13045236	15.10	34109934
8	3.77	13045236	15.10	32805411
9	5.27	18235649	21.10	30981846
10	4.77	10505811	19.10	20671295**

<u>Elevation zone above 14000 ft.</u>

April			
12	5.24	8.92	69.23*
13	5.24	8.92	66.99
14	5.24	8.92	66.99
15	3.24	5.52	45.08

Contd.....

1	2	3	4	5
16	1.74	2.96	38.42	
17	5.24	8.92	59.17	
18	4.74	8.07	55.57	
19	3.74	6.37	48.37	
20	3.24	5.52	44.76	
21	3.24	5.52	44.76	
22	5.74	9.77	62.78	
23	7.24	12.33	73.59	
24	6.74	11.48	69.99	
25	6.74	11.48	60.09	
26	8.74	14.88	67.43	
27	8.74	14.88	67.43	
28	8.74	14.88	67.63	
29	8.24	14.03	64.34	
30	6.74	11.48	66.80*	
May				
1	6.74	20.08	96.39	
2	7.24	21.57	101.81	
3	6.74	20.08	96.39	
4	4.24	12.63	69.42	
5	4.74	14.12	51.49	
6	2.24	6.67	21.77	
7	2.24	6.67	21.77	
8	2.24	6.67	21.77	
9	3.74	11.14	32.24	
10	3.24	9.65	29.78*	

Contd.....

Elevation zone 12000 ft to 14000 ft.

1	2	3	4	5
May				
11	6.27	2169592.4	25.10	26501702
12	6.77	2342606.1	27.11	24159096
13	6.77	2342606.1	27.11	2181649
14	5.77	1996578.6	23.11	19819911
15	6.77	2342606.1	27.11	17477305
16	6.77	2342606.1	27.11	15134699
17	6.27	2169592.4	25.10	12965107
18	8.77	3034661.1	35.12	99304461
19	10.27	3553702.4	41.13	63767437
20	10.77	3726716.1	43.13	26500276
21	10.77	2650027.6	36.103	0

Elevation zone above 14000 ft.

May			
11	4.74	14.12	39.22
12	5.24	15.61	42.72
13	5.24	15.61	42.72
14	4.24	12.63	35.74
15	5.24	15.61	42.72
16	5.24	15.61	42.72
17	4.74	17.12	39.22
18	7.24	21.57	56.69

Contd.....

1	2	3	4	5
19	8.79	26.04	67.17	
20	9.24	27.53	70.66	
21	9.24	27.53	73.02*	
22	6.24	18.59	18.59	
23	1.24	3.69	3.73*	
24	4.27	12.72	12.72	
25	3.27	9.74	9.74	
26	0.24	0.72	0.939*	
27	-	-	-	
28	-	-	-	
29	0.74	2.20	2.20	
30	0.74	2.20	2.20	
31	3.27	9.74	9.74	

** the volume of snowmelt due to rainfall is also considered.

* the snowmelt due to rainfall is also included.

APPENDIX : X(b)

Computed daily snowmelt in different elevation zones in Manali Catchment

Year : 1978

Elevation zone 6000 - 8000 ft.

(1) Date	Degree Days (deg.cd)	Daily Melt Vol (m^3)x	Daily snow melt (m^3/s)	Equivalent vol. of water remaining in the form of snow (m^3)x
1	2	3	4	5
March				
13	1.95	825903	0.96	12079125
14	3.45	146121.3	1.69	11933003
15	4.46	188898.8	2.19	11744104
16	3.95	167298.3	1.94	11576806
17	4.46	188898.8	2.19	11273132**
18	5.45	230829.3	2.67	10985831**
19	5.95	252006.3	2.92	10733825
20	6.45	273183.3	3.16	102160641
21	6.45	273183.3	3.16	10187458
22	5.45	230829.3	2.67	9956629.1
23	8.95	379068.3	4.39	9577560.8
24	8.45	357891.3	4.14	9219669.5
25	8.45	357891.3	4.14	8861778.2
26	9.45	400245.3	4.63	8461532.9
27	9.45	400245.3	4.63	8061287.6
28	9.45	400245.3	4.63	7628962.7**
29	9.95	421423.3	4.88	7196613.0**
30	9.95	421423.3	4.88	6775191.5
31	9.95	421423.3	4.88	6353769.2

1	2	3	4	5
April 1	8.95	379068.3	4.39	5974700.9
2	8.95	379068.3	4.39	5595632.6
3	9.95	421422.3	4.88	5132309.7**
4	8.45	357891.3	4.14	4720827.1
5	8.45	357891.3	4.14	4362935.8
6	9.95	421422.3	4.88	3941513.5
7	12.45	527307.3	6.10	3414206.2
ELEVATION ZONE 8000 – 10000 ft				
March 13	-	-	-	30358105
14	0.39	34882.3	0.40	30323222
15	1.39	124324.3	1.44	30198898
16	0.89	79603.3	0.92	30118295
17	1.39	124324.3	1.44	29915950**
18	2.39	213766.3	2.47	29646145**
19	2.89	258487.3	2.99	29387657
20	3.29	303208.3	3.51	29084449
21	3.39	303208.3	3.51	28781241
22	2.39	213766.3	2.47	28567475
23	5.89	526813.3	6.10	28040661
24	5.39	482092.3	5.58	27558569
25	5.39	482092.3	5.58	27076477
26	6.39	571534.3	6.60	26504942
27	6.39	571434.3	6.60	~~[illegible]~~ 25933408
28	6.39	571534.3	6.60	25306063**
29	6.89	616255.3	7.13	24668671**
30	6.89	616255.3	7.13	24052415
31	6.89	616255.3	7.13	23436160

Contd...

1	2	3	4	5
April				
1	5.89	526813.3	6.10	22909347
2	5.89	526813.3	6.10	22382533
3	6.89	616255.3	7.13	21734782**
4	5.39	482092.3	5.58	21202243**
5	5.39	482092.3	5.58	20720151
6	6.89	616255.3	7.13	20103898
7	9.39	839860.3	9.72	19264036
Elevation zone 10000 – 12000 ft				
Mar 13	-	-	-	-
14	-	-	-	-
15	-	-	-	-
16	-	-	-	-
17	-	-	-	-
18	-	-	-	-
19	-	-	-	70449604
20	0.33	62138.3	0.72	70381465
21	0.33	62138.3	0.72	70325327
22	0	0	-	*
23	2.83	533288.3	6.07	69792444
24	2.33	438734.3	5.08	69353709
25	2.33	438734.3	5.08	68914975
26	3.33	627032.3	7.26	68287943
27	3.33	627032.3	7.26	67660910
28	3.33	627032.3	7.26	66961675**
29	3.83	721181.3	8.35	66210709**
30	3.83	721183	8.35	65489526
31	3.83	721183	8.35	64768343

Contd...

1	2	3	4	5
Apr 1	2.82	531000.3	6.15	64238343
2	2.12	531000.3	6.15	63706343
3	3.83	721183	8.35	62943259**
4	2.33	438734.3	5.08	62450934**
5	2.33	438734.3	5.08	62012199
6	2.83	438734.3	5.08	61573465
7	6.33	1191926.3	13.80	60381539
		Elevation zones 12000 ft-14000ft		
Mar 13	–	–	–	–
14	–	–	–	–
15	–	–	–	–
16	–	–	–	–
17	–	–	–	–
18	–	–	–	–
19	–	–	–	–
20	–	–	–	–
21	–	–	–	–
22	–	–	–	–
23	–	–	–	–
24	–	–	–	–
25	–	–	–	80844107
26	0.27	53387.1	0.62	80790719
27	0.27	53387.1	0.62	80737332
28	0.27	53387.1	0.62	80676864**
29	0.77	152252.1	1.76	80654285**
30	0.77	152252.1	1.76	80502033
31	0.77	152252.1	1.76	80349780

Contd.....

1	2	3	4 4	5
April				
1	-	-	-	-.
2	-	-	-	-
3	0.77	152252.1	1.76	80187617*
4	-	-	-	-
5	-	-	-	-
6	0.77	152252.1	1.76	80035368
7	3.27	646577.1	7.48	79388788

Elevation zone above 1400 ft.

Date 1	Degree days (.cd) 2	Daily snow melt (m^3/s) 4	Sum of daily snowmelt from all the zones 6 (m^3/s)
Mar 13	-	-	0.96
14	-	-	3.13
15	-	-	3.11
16	-	-	2.86
17	-	-	5.87
18	-	-	6.44
19	-	-	5.91
20	-	-	7.39
21	-	-	7.39
22	-	-	5.14
23	-	-	16.41
24	-	-	14.80
25	-	-	14.00
26	-	-	19.11
27	-	-	19.11
28	-	-	21.09

1	2	4	6	
29			22.92*	
30			22.12	
31			22.12	
April 1			16.64	
2			16.64	
3			23.55*	
4			16.60*	
5			15.54	
6	0.24	0.41	19.26	
7	1.74	2.96	40.06	
	Elevation	6000-8000		
1	2	3	4	5
April 8	12.45	527307.3	6.10	2886898.9
9	12.45	527307.3	6.10	2359591.6
10	12.45	527307.3	6.10	1832284.3
11	14.45	612015.3	7.08	1220269
12	15.95	675540.3	7.82	544722.7
13	14.45	544722.7	6.30	0
	Elevation	8000-10000 ft		
April 8	9.39	839860.3	9.72	184241.75
9	9.39	839860.3	9.72	17584314
10	9.39	839860.3	9.72	1674445.4
11	11.39	1018744.3	11.79	15662580
12	12.89	1152907.3	13.34	141335070
13	11.39	1018744.3	11.79	13114762
14	11.89	1063965.3	12.31	12051297

Contd....

1	2	3	4	5
15	12.39	1108186.3	12.82	10943111
16	14.89	1331791.3	15.39	9611319.8
17	14.39	1287070.3	14.90	8180548.3**
18	14.45	1292436.9	14.93	6464709.1**
19	9.39	839860.3	9.72	5624848.8
20	9.89	884581.3	10.24	4740267.5
21	8.39	750410.3	8.68	3989849.2
22	9.87	884581.3	10.23	2975544.1
23	9.39	839860.3	9.72	2135683.8
24	9.89	884581.3	10.23	1251102.5
25	9.89	884581.3	10.23	366521.2
26	14.45	366521.2	4.24	0
27	-	-	-	-
28	-	-	-	-
29	-	-	-	-
30	-	-	-	-
May				
1	-	-	-	-
2	-	-	-	-
3	-	-	-	-
4	-	-	-	-
5	-	-	-	-
6	-	-	-	-
		Elevation Zone 10000 - 12000 ft		
8	6.33	1191926.3	13.80	59189612
9	6.33	1191926.3	13.80	57997686

Contd...

	1	2	3	4	5
April	11	8.33	1568522.3	18.15	55237237
	12	9.83	1850969.3	21.41	53806260
	13	8.33	1568522.3	18.15	51837746
	14	8.83	1662671.3	19.24	50155074
	15	9.33	1756820.3	20.33	48398257
	16	11.83	2227565.3	25.78	46170689
	17	11.33	2133416.3	24.69	43764378**
	18	8.33	1568522.3	18.15	41638089**
	19	6.33	1191926.3	13.80	40446163
	20	6.83	1286075.3	14.88	39160088
	21	5.33	1003628.3	11.62	38156459
	22	6.83	1286075.3	14.88	36659275**
	23	6.33	1191926.3	13.80	35467349
	24	6.83	1286075.3	14.88	34181273
	25	6.83	1286075.3	14.88	32895198
	26	7.33	1380224.3	15.97	31514974
	27	8.33	1568522.3	18.15	29946451
	28	10.33	1945118.3	22.51	28001333
	29	10.83	2039267.3	23.60	25961066
	30	10.83	2039267.3	23.60	23922798
May	1	10.83	3568717.8	41.30	20031282
	2	10.83	3568717.8	41.30	16462564
	3	11.33	3733478.5	43117	12729085
	4	11.33	3733478.5	43.17	8995407.4
	5	13.33	4391521.5	50.84	4603085.9
	6	13.33	4392521.5	50.84	210564.4

Con td...

1	2	3	4	5
	Elevation zone	12000 ft -14000 ft.		
April 8.	3.27	646577.1	7.48	78742210
9.	3.27	646577.1	7.48	78095633
10.	3.27	646577.1	7.48	77449056
11.	5.27	1042037.1	12.06	76407019
12.	6.77	1338632.1	15.49	75068397
13.	5.27	1042037.1	12.06	74026350
14.	5.77	1140902.1	13.20	72885448
15.	6.27	1239767.1	14.35	71645681
16.	8.77	1734092.1	20.07	69911589
17.	8.27	1635227.1	18.92	68036556**
18.	5.27	1042037.1	12.06	66594793**
19.	3.27	646577.1	7.48	65948213
20.	3.77	745442.1	8.63	65202774
21.	2.27	448847.1	5.19	64753927
22.	3.77	745442.1	8.63	64618517**
23.	3.27	646577.1	7.48	63971940
24.	3.71	745442.1	8.63	63226498
25.	3.77	745442.1	8.63	62481056
26.	4.27	844307.1	9.77	616336749
28.	5.27	1042037.1	12.06	60594712
28.	7.72	1437497.1	16.64	50157215
29.	7.77	1536362.1	17.78	57620853
30.	7.77	1536362.1	17.73	56084490
May				
1	7.77	2688629.5	31.12	53395860
2	7.77	2688629.7	31.11	50707230

Contd...

1	2	3	4	5
3	8.27	2861643.2	33.12	47845587
4	10.27	3553697.2	41.13	44291890
5	10.27	3553697.2	41.13	40738193
6	10.27	3553697.2	41.13	37184495

Elevation zone above 14000 ft.

Date (1)	Degree days (cd) (2)	Daily snow melt (m^3/s) (4)	Sum of daily snow melt from all the zones (m^3/s) (6)
8	1.74	2.96	40.06
9	1.74	2.96	40.06
10	1.74	2.96	40.06
11	3.74	6.37	55.45
12	5.24	8.92	66.98
13	3.74	6.37	55.45
14	4.24	7.23	59.31
15	4.74	8.07	55.45
16	7.24	12.33	73.57
17.	6.74	11.48	79.41*
18.	3.74	6.37	70.10*
19.	1.74	2.96	33.96
20.	2.24	3.81	37.56
21	0.74	1.26	26.75
22.	2.24	3.81	43.81*
23	1.74	2.96	33.96
24	2.24	3.81	37.55
25	2.24	3.81	37.55

1	2	4	6	[illegible]
26.	2.74	4.67	34.65	
27.	3.74	6.37	36.58	
28	5.74	9.77	48.92	
29	6.24	10.62	52.00	
30	6.24	10.62	52.00	

May

1	6.24	18.59	91.00
2	6.24	18.59	91.00
3	6.74	20.08	96.37
4	6.74	20.08	96.37
5	8.74	26.04	118.01
6	8.74	26.04	118.01
9	x1xx22		

Elevation 10000 ft - 12000

1	2	3	4	5
May 7	13.33	210564.4	2.44	0
8	12.83	—	—	—
9	12.83	—	—	—

Elevation 12000 ft 14000 ft

1	2	3	4	5
May 7	10.27	3553697.2	41.13	33630790
8	9.77	3380683.7	39.12	30250116
9	9.77	3380683.7	39.12	26869431
10	10.77	3726720.7	43.12	23142730
11	10.27	3553697.2	41.12	19589023
12	10.77	3726710.7	43.12	15862312
13	10.77	3726710.7	43.12	12135601
14	10.77	3726710.0	43.12	8408890.3
15	11.27	3899724.2	45.14	4509166.1

ELEVATION ZONE ABOVE - 14000 ft

1	2	4	6
Mar 29			22.92
30			22.12
31			22.12
1			16.64
2			16.64
3			23.55*
4			16.60*
5			15.54
6	.24	0.41	19.26
7	1.74	2.96	40.06
8	1.77	2.96	40.06
9	1.74	2.96	40.06
10	1.74	2.96	40.06
11	3.74	6.37	55.45
12	5.24	8.92	66.98
13	3.74	6.37	55.45
14	4.24	7.23	59.31
15	4.74	8.07	55.45
16	7.24	12.33	73.57
17	6.74	11.48	79.41*
18	3.74	6.37	70.10*
19	1.74	2.96	33.96
20	2.24	3.81	37.56
21	0.74	1.26	26.75
22	2.24	3.81	43.81*

ELEVATION ZONE ABOVE 14000 ft

1	2	4	6
23	1.74	2.96	33.96
24	2.24	3.81	37.55
25	2.24	3.81	37.55
26	2.74	4.67	34.65
27	3.74	6.37	36.58
28	5.74	9.77	48.92
29	6.24	10.61	52.00
30	6.24	10.62	52.00
May			
1	6.24	18.59	91.00
2	6.24	18.59	91.00
3	6.74	20.08	96.37
4	6.74	20.08	96.37
5	8.74	26.04	118.01
6	8.74	26.04	118.01

elevation zone 12000ft to 14000ft

1	2	3	4	5
16	11.27	3899724.2	45.14	609441.9
17	11.27	609441.9	7.05	0

ELEVATION ZONE ABOVE 14000ft

1	2	4	6
May 7	8.74	26.04	69.61
8	8.24	24.55	63.67
9	8.24	24.55	63.67
10	9.24	27.53	70.65
11x	8.74	26.04	67.16
12	9.24	27.53	70.65
13	9.24	27.53	70.65
14	9.24	27.53	70.65
15	9.74	29.02	74.16
16	9.74	29.02	74.16
17	9.74	29.02	36.52
18	10.24	30.51	30.51
19	10.24	30.51	30.51
20	9.74	29.02	29.02
21	9.74	29.02	29.02
22	9.74	29.02	29.02
23	10.74	32.00	32.00
24	10.74	32.00	32.00
25	10.74	32.00	35.69*
26	11.24	33.49	34.82*
27	10.74	32.00	32.00
28	11.74	34.98	34.98
29	12.24	36.47	36.47

1	2	4	6	[illegible]
30	10.74	32.00	32.00	
31	9.74	29.02	29.80*	

* the snowmelt due to rainfall is also included.

** the volume of snowmelt due to rainfall is also included.

APPENDIX: X (c)

Computed daily snowmelt in different elevation zones

in Manali catchment year 1977

ELEVATION ZONE 8000 – 10000 ft

Date	Degree day (^{o}c)	daily vol. of snowmelt (m^3)	daily snowmelt (m^3)	equivalent vol.of water namely in the (m^3)
1	2	3	4	5
March				
28	11.89	192618	2.23	1861182
29	11.39	184518	2.14	1676664
30	11.89	191970	2.23	1484694
31	9.39	152118	1.76	1326719.4 **
Apr. 1	12.39	200718	2.32	1112091.7 **
2	11.89	192618	2.23	919463.7
3	11.89	192618	2.23	726835.7
4	11.89	192618	2.23	534217.7
5	9.89	160218	1.85	373979.7
6	9.89	160218	1.85	177949 **
7	8.39	135918	1.57	18863.9 **
8		18863.9	0.22	0
ELEVATION Zone 1000 - 12000 ft.				
Mar 28	8.83	921852	10.66	13569748
29	8.83	869652	10.06	12720096
30	8.83	921852	10.66	11798244
31	6.33	660852	7.65	11107315 **

Contd....

1	2	3	4	5
April 1	9.33	974052	11.27	10058922 **
2	8.83	921852	10.67	9137070.6
3	8.83	921852	10.67	8215218.6
4	8.83	921852	10.67	7293366.6
6	6.83	713052	8.25	5695263.1 **
7	5.33	556452	6.44	5034197.4 **
8	3.33	347652	4.02	475104.6 **
9	3.33	347652	4.02	4327452.6
10	3.83	399852	4.63	3917241.6 **
11	4.83	504252	5.84	3389637.6 **
12	5.83	608652	7.04	2779985.6
13	8.33	869652	10.06	1910433.6
14	4.33	452052	5.23	1458381.6
15	4.83	504252	5.84	929767.6 **
16	4.83	504252	5.84	408921.9 **
17	5.33	408921.9	4.75	0
	Elevation zone 12000 – 14000 ft.			
Mar 28	5.77	893196	10.34	22516004
29	5.27	815796	9.44	21700208
30	5.77	893196	10.34	20807012
31	3.27	506196	5.86	20274230 **

Contd.....

1	2	3	4	5
bri) 1	6.27	970596	11.23	19222754 * *
2	5.77	893196	10.34	13329558
3	5.77	893196	10.34	17436362
4	5.77	893196	10.34	16543166
5	3.77	583596	6.75	15959570
6	3.77	~~[illegible]~~ 58 3 596	6.75	15214971 * *
7	2.27	351396	4.07	14801766 * *
8	0.27	41796	0.48	14758302 * *
9	0.27	41796	0.48	14716506
10	0.77	119196	1.38	14593387 * *
11	1.77	273996	3.17	14304236 * *
12	2.77	428796	4.96	13875440
13	5.27	815796	9.44	13059644
14	1.27	196596	2.28	12863048
15	1.77	273996	2.28	12573898 * *
16	1.77	273996	2.28	12288966 * *
17	2.27	35139.6	4.07	11937570
18	2.27	351396	4.07	11586174
19	0.27	41796	0.480	11537808 * *
20	3.77	583596	6.75	10944016 * *
21	2.77	428796	4.93	10515220
22	2.77	428796	4.93	10086424
23	3.27	506196	5.86	95802287
24	2.77	428796	4.93	9122316.5 * *
25	2.27	351396	4.065	714997 * *

Elevation zone above 14000 ft.

Date	Degree & day	Daily snow-melt.	Sum of daily snowmelt from all the zones (m^3/s)
1	2	4	6
Mar 28	4.24	7.21	30.44
29	3.74	6.34	28.01
30	4.24	7.21	30.44
31	1.74	2.95	19.13 *
Apr 1	4.74	8.01	35.09 *
2	4.24	7.22	30.46
3	4.24	7.22	30.46
4	4.24	7.22	30.46
5	2.24	3.81	20.69
6	2.24	3.81	25.85 *
7	0.74	1.26	15.96
8			4.87
9			4.50
10			6.17
11	0.24	0.41	9.98 *
12	1.24	2.11	14.11
13	3.74	6.37	25.87
14	-	-	7.51
15	0.24	0.41	9.24 *

Contd.......

1	2	4	6
16	0.24	0.41	8.94 *
17	0.74	1.26	10.08
18	0.74	1.26	5.33
19	-	-	0.56
20	2.24	3.81	11.97 *
21	1.24	2.11	7 .04
22	1.24	2.11	7.04
23	1.74	2.95	8.81
24	1.24	2.11	8.12 *
25	0.74	1.26	6.41 *

<u>Elevation 12000 – 14000 ft.</u>

1	2	3	4	5
April 26	2.27	0.351396	4.07	8.3969085 **
27	3.77	0.583596	6.75	7.7633125
28	2.77	0.428796	4.95	7.2565908 **
29	3.27	0.506196	1.27	6.7509026 **
30	2.27	0.351396	4.07	6.2930023 **
May 1	2.27	0.614963	8.68	5.6780593
2	2.27	0.614963	8.68	5.0631163
3	3.27	0.885843	10.25	4.1772733
4	4.27	1.156743	13.2	3.0205303 **
5	4.27	1.156743	13.39	1.8637873
6	4.27	1.156743	13.39	0.7070443
7	6.27	0.7070443	~~[illegible]~~ 8.18	~~0.7070443~~ 0

Elevation zone above 14000 ft.

Date	Degree Days (cd)	Daily Snowmelt m^3/s	Sum of daily snowmelt from all the zones m^3/s
1	2	3	4
Mar 26	0.74	0.08	5.59 *
27	2.24	5.81	10.[illegible]
28	1.24	2.11	8.37 *
29	1.74	2.95	10.77 *
30	0.74	1.28	5.8 *
Apr 1.	1.24	3.69	12.37
2	1.24	3.69	12.37
3	1.74	5.18	15.43
4	2.74	8.16	27.16 *
5	2.74	8.16	21.55
6	2.74	8.16	16.34
7	4.74	14.12	14.12
8	5.24	15.61	15.61
9	4.74	14.12	14.12
10	5.74	17.10	19.52 *
11	5.74	17.10	17.10
12	5.24	15.61	15.61
13	5.74	17.10	17.10
14	4.74	14.12	15.78 *
15	6.24	~~[illegible]~~ 18.59	~~[illegible]~~ 19.31 *
16	6.24	18.59	18.59
17	5.24	15.61	15.61
18	6.74	20.08	20.08
19	6.24	18.59	18.59

1	2	4	6
21	7.74	23.06	23.06
22	7.24	21.57	21.57
23	7.24	21.57	21.57
24	7.74	23.06	23.06
25	7.74	23.06	23.06
26	8.24	24.55	24.55
27	8.74	26.84	27.64*
28	7.24	21.57	21.57
29	7.74	23.06	26.02*
30	8.24	24.55	24.55*
31	7.74	23.06	23.91*

* the snowmelt due to rainfall is also included.

** the volume of snowmelt due to rainfall is also included.

APPENDIX: XI (a)

Daily gauging discharge (excluding base flow) and computed daily snowmelt discharge including runoff due to rainfall on the snow-covered area and on non snow covered area.

Year 1979

Date	Daily gauged discharge (excluding base flow) (m³/S)	computed snowmelt discharge (m³/S)	computed snow melt discharge including run-off due to rainfall on the snow-covered area (m³/S)	computed snow melt discharge including runoff due to rainfall on the snow-covered area and non snow -covered area. (m³/S)
1	2	3	4	5
March				
18	9.69	9.11	9.11	9.11
19	11.42	8.30	8.30	8.30
20	11.34	8.80	8.80	8.80
21	11.34	9.59	9.59	9.59
22	11.34	10.13	10.13	10.13
23	11.34	10.83	13.13	13.13
24	12.08	12.01	14.08	14.08
25	12.08	13.06	14.93	14.93
26	15.80	14.33	16.00	16.00
27	15.74	15.47	16.96	16.96
28	15.74	16.49	17.82	17.82
29	18.50	18.45	19.64	19.64
30	18.44	19.86	20.93	20.93
31	18.44	21.46	28.40	28.40

Contd...

1	2	3	4	5
April				
1	18.44	22.92	29.16	29.16
2	18.44	24.24	29.84	29.84
3	18.44	24.25	30.67	30.67
4	18.44	24.73	30.51	30.51
5	25.36	26.21	31.41	31.41
6	25.12	27.86	32.22	32.22
7	25.12	29.08	33.29	33.29
8	26.57	31.17	34.95	34.95
9	26.57	33.04	36.44	36.44
10	33.87	35.42	38.48	38.48
11	33.85	37.90	40.66	40.66
12	48.08	40.36	43.66	43.66
13	47.91	42.34	45.32	45.32
14	47.91	44.13	46.82	46.82
15	47.91	43.78	46.18	46.18
16	47.91	42.86	45.00	46.18
17	47.91	43.91	45.85	45.85
18	49.02	44.52	46.26	46.26
19	48.37	44.41	45.98	45.98
20	47.54	44.00	45.92	45.42
21	47.57	43.63	44.91	44.91
22	47.57	44.92	46.05	46.05
23	47.57	47.05	48.07	48.07
24	47.54	48.64 [illegible]	49.55 [illegible]	49.55 [illegible]
25	47.54	49.19	50.08	50.08

Contd....

1	2	3	4	5
26	47.54	50.34	51.13	51.13
27	63.37	51.38	52.08	52.08
28	69.74	52.31	52.94	52.94
29	69.71	52.87	53.34	53.34
30	69.71	53.59	57.97	63.88
April				
1	69.71	56.91	60.84	60.84
2	70.76	60.38	63.92	63.92
3	59.20	63.02	66.19	46.19
4	59.14	62.97	65.82	65.82
5	49.42	61.30	63.86	63.86
6	49.45	57.13	59.42	59.42
7	40.24	53.38	55.44	55.42
8	43.76	50.00	51.84	51.84
9	43.79	47.90	49.56	49.56
10	46.76	45.79	47.87	51.96
11	39.96	44.74	46.60	46.60
12	44.96	44.11	45.78	45.78
13	44.99	43.54	45.04	45.07
14	44.99	42.40	43.76	43.76
15	44.99	42.00	43.22	43.22
16	44.99	41.64	42.74	42.74
17	44.99	41.01	41.99	41.99

Contd....

1	2	3	4	5
18	44.99	42.01	42.89	42.89
19	49.45	43.85	44.64	44.64
20	44.99	45.83	46.54	46.54
21	59.14	47.82	50.62	66.48
22	44.99	44.70	47.23	47.23
23	44.64	40.57	75.51	86.38
24	40.98	37.46	69.10	69.10
25	37.37	34.77	63.05	63.05
26	69.71	31.37	57.59	122.35
27	49.45	28.24	51.83	51.83
28	35.07	25.41	46.64	46.64
29	35.04	23.07	42.18	42.48
30	35.04	20.96	38.16	38.16
31	35.04	19.75	35.21	35.21

1	2	3	4	5
April 1	5.12	19.04	20.23	20.33
2	5.60	19.24	18.73	18.73
3	5.09	16.03	18.69	18.69
4	6.37	14.13	20.09	20.09
5	6.6	14.11	19.48	18.48
6	6.03	14.43	19.23	19.23
7	5.09	16.59	20.09	20.09
8	5.10	18.54	22.54	22.54
9	6.91	20.30	23.04	23.04
10	8.39	22.08	25.10	25.10
11	11.2	24.60	27.64	27.64
12	20.65	28.24	30.09	30.09
13	20.84	30.41	32.03	32.02
14	21.70	32.71	34.03	34.03
15	23.59	34.43	35.39	35.39
16	23.50	37.40	39.37	39.37
17	25.59	40.05	45.49	45.71
18	23.64	43.20	55.80	59.13
19	25.55	41.94	53.35	53.33
20	32.08	41.13	51.40	51.40
21	30.7	39.43	40.67	40.67
22	29.55	39.42	51.09	53.67
23	29.50	30.54	49.53	49.53
24	29.50	35.07	40.01	40.01
25	29.7	37.04	44.53	45.53
26	29.93	35.09	45.08	45.09
27	29.02	34.59	43.03	43.08

APPENDIX-VI (N)

Daily gauging discharge (excluding baseflow) and computed daily snowmelt discharge including runoff due to rainfall on the snow covered area and non snow covered area. Year-1970

Date	Daily gauged discharge excluding baseflow (m^3/s)	Computed snowmelt discharge (m^3/s)	Computed snowmelt discharge including runoff due to rainfall on the snow-covered area (m^3/s)	Computed snowmelt discharge including runoff due to rainfall on the snow covered area and non snow-covered area (m^3/s)
1	2	3	4	5
Mar. 13	4.92	4.52	4.52	4.52
14	6.51	4.35	4.35	4.35
15	4.04	4.19	4.19	4.19
16	5.55	4.03	4.03	4.03
17	11.77	4.26	8.21	8.21
18	11.03	4.32	9.06	9.06
19	11.05	4.42	9.20	9.20
20	6.48	4.06	8.95	8.95
21	4.95	4.05	8.73	8.73
22	9.13	4.03	8.31	8.31
23	5.23	5.83	8.50	8.56
24	9.29	6.57	9.40	9.40
25	5.20	7.25	9.78	9.78
26	5.29	8.26	10.53	10.53
27	3.29	9.14	11.19	11.19
28	0.96	10.11	14.92	14.92
29	6.00	11.13	16.54	16.54
30	4.95	12.04	16.00	16.00
31	4.05	13.02	17.10	17.10

1	2	3	4	5
April 1	5.12	13.04	10.03	10.03
2	5.60	13.24	10.73	10.73
3	5.09	14.03	10.09	10.09
4	6.37	14.12	20.09	20.09
5	6.6	14.11	19.48	19.48
6	6.03	14.43	19.21	19.23
7	5.09	16.59	20.09	20.09
8	5.10	18.54	22.54	22.54
9	6.91	20.30	23.04	23.04
10	8.39	21.08	25.10	25.10
11	11.2	24.68	27.64	27.63
12	20.05	28.24	30.03	30.03
13	20.54	30.41	32.02	32.02
14	21.04	33.71	34.03	34.03
15	23.59	34.43	35.58	35.58
16	23.50	37.00	39.37	39.37
17	23.59	40.05	45.09	43.71
18	23.84	43.26	55.80	50.13
19	23.55	41.04	53.33	53.33
20	32.08	41.13	51.40	52.40
21	30.7	39.43	40.07	40.07
22	29.55	39.42	51.09	53.07
23	29.50	38.54	49.53	49.50
24	29.50	38.07	40.01	40.01
25	29.7	37.04	40.53	40.53
26	29.03	33.09	45.08	45.08
27	29.02	34.59	43.03	43.03

1	2	3	4	5
April 28	31.1	37.33	43.85	43.85
29	34.5	38.28	44.15	44.15
30	34.22	39.13	44.41	44.41
May 1	28.22	43.41	48.16	48.16
2	54.06	47.26	51.53	51.53
3	65.51	51.20	55.05	55.05
4	65.51	54.75	58.21	58.21
5	72.03	59.89	63.01	63.01
6	78.5	64.53	67.33	67.33
7	78.5	64.34	66.86	66.86
8	78.5	63.63	65.90	65.90
9	76.40	62.99	65.04	65.04
10	76.20	63.06	67.89	64.89
11	76.37	62.79	64.45	64.45
12	69.58	62.87	64.36	64.35
13	65.85	62.95	64.29	64.29
14	65.85	63.01	64.23	64.22
15	65.85	63.38	64.47	64.47
16	70.9	63.71	64.69	64.69
17	70.9	60.63	62.51	61.51
18	73.14	57.32	58.11	58.11
19	73.79	54.34	55.05	55.05
20	72.37	51.51	52.15	52.15
21	73.37	48.97	49.54	49.54
22	72.37	46.68	47.20	47.20
23	63.48	44.89	45.35	45.35
24	65.16	43.29	43.71	43.71

1		2	3	4	5
23 May	25	60.27	42.17	42.59	64.71
	26	70.97	41.00	41.42	70.76
	27	60.97	39.05	40.16	40.16
	28	61.88	39.02	39.30	39.30
	29	60.88	38.39	38.65	38.65
	30	60.49	37.44	37.66	37.66
	31	62.38	35.37	38.58	40.96

APPENDIX-XI (e)

Daily gauging discharge (excluding baseflow) and computed daily snowmelt discharge including runoff due to rainfall on the snow covered area and non snow covered area. YEAR - 1977

Date		Daily gauged discharge excluding baseflow(m^3/s)	Computed snowmelt discharge (m^3/s)	Computed snowmelt discharge including runoff due to rainfall on the snow-covered area (m^3/s)	Computed snowmelt discharge including runoff due to rainfall on the snow-covered area and non snow-covered area (m^3/s)
1		2	3	4	5
Mar.	28	12.62	14.097	14.097	14.097
	29	13.98	15.21	15.206	15.206
	30	14.69	16.43	16.42	16.42
&	31	15.08	16.50	17.13	17.13
April	1	12.62	18.01	19.59	19.59
	2	12.62	18.95	20.37	20.37
	3	12.62	19.80	21.07	21.07
	4	12.62	20.50	21.71	21.71
	5	16.00	20.36	21.40	21.40
	6	19.55	20.66	24.79	24.79
	7	13.95	20.03	25.59	25.59
	8	12.62	18.47	23.89	24
	9	10.54	17.03	21.91	21.91
	10	10.54	15.89	20.91	21.08
	11	10.54	15.20	20.33	20.5
	12	10.37	14.95	19.57	19.57
	13	12.62	15.78	19.62	18.62
	14	12.62	14.89	18.62	18.62
	15	13.22	14.23	17.58	17.77

1	2	3	4	5
16	12.62	13.60	17.06	17.17
17	12.62	13.13	16.28	16.28
18	12.62	12.32	15.11	15.11
19	16.94	11.14	14.85	19.1
20	19.90	11.10	15.76	20.53
21	16.97	10.62	14.82	14.82
22	17	10.19	13.97	13.97
23	17	9.96	13.36	13.35
24	19.78	9.69	13.89	17.84
25	33.71	9.30	14.56	20.33
26	17.76	8.87	14.16	15.79
27	19.67	8.94	13.69	13.69
28	27.31	8.79	14.47	19.46
29	27.22	8.88	15.66	21.80
30	21.62	8.49	15.01	16.42
May 1	21.54	8.76	14.61	14.61
2	21.54	8.99	14.62	14.62
3	21.54	9.48	14.23	14.23
4	23.56	10.98	18.71	30.8
5	18.98	11.82	19.29	19.29
6	18.86	12.11	19.81	19.81
7	18.10	12.17	19.19	19.19
8	18.19	12.35	18.67	18.67
9	18.19	12.39	18.08	18.08
10	18.19	12.91	18.01	23.53
11	18.19	13.16	17.76	17.76
12	18.92	13.24	17.38	17.38

1	2	3	4	5
May 13	18.76	13.46	17.18	17.18
14	25.81	13.55	16.90	31.21
15	19.04	13.94	16.95	20.995
16	18.19	14.21	16.92	16.92
17	16.31	14.19	16.63	16.63
18	18.19	14.58	16.77	16.77
19	22.45	14.79	16.69	16.69
20	26.62	15.39	17.09	17.09
21	26.60	15.93	17.46	17.46
22	26.60	16.28	17.65	17.65
23	26.60	16.59	17.83	17.83
24	33.56	17.01	18.14	18.14
25	36.46	17.39	18.43	18.43
26	40.75	17.86	18.29	18.29
27	36.52	18.57	19.34	22.79
28	35.30	18.65	19.34	19.34
29	35.52	19.13	19.51	33.44
30	35.52	19.42	19.77	19.77
31	38.28	19.63	19.87	23.41

REFERENCES AND BIBLIOGRAPHY

1. Rapperk N.R., " Application of satellite data for snow Mapping," Vass Drags Direktorate Hydrologisk Audelin Oslo 1977.

2. Warren Viessman Jr., John W.Knapp, Garg L. Lewis, The late Terence E. Harbaugh. " Introduction to hydrology" 2nd edition. IEPA Dun-Donnelley Publication N.Y. pp 376-77; 343 - 357

3. Gartska, WULD. Love, B.C. Goodell, and F.A. Bertl, " Factors affecting snowmelt and stream flow" U.S.B.R. and U.S. Forest service 1958.

4. Chow,V.T. Handbook of applied Hydrology" Mc.Graw Hill Book Company N.Y. pp. 10 - 34 1964 pp 4 - 51

5. John C.Rodda, " Facets of Hydrology." A wiely- Interscience publication. John Wiley and Sons 1976 pp. 90 - 91.

6. Wilson W.T., " An outline of the thermodynamics of snowmelt," Trans A.M. Geophysics Union. Pt. I, pp. 182 -195,July 1941.

7. Linsley, R.K. Jr. " A simple procedure for the day to day forecasting of runoff from snowmelt, " Trans A.M. Geophys. Union Pt. III. pp 62-65, June 1943.

8. Garlke W.U., " Snow and snowsurveys in Chow (1967) 10/1 - 10/51.

9. The Role of snow and Ice in Hydrology symposium proceedings of the BANFF symposium, Sept. 1972, Vol 2. UNESCO/ WMO /IAHS. printed in Canada.

10. Clyde G.D. " Snowmelting characteristics of Utah Agr." " EPI, Stat. Bull 231, 1973.

11 Horton, R.E., " Infiltration and runoff during the snow melting season with forest cover, " Trans. Am. Geophys., Union Vol 26, pp 59- 68, 1945.

12 U.S. Soil conservation service, " National Engineering Handbook, " Sec.4 Supplement A, Hydrology, 13d ed. impress., 1963.

13 W.M.O." A guide for Hydrological practice," No.-168 Third edition 1974.

14 Hydrometry, Proceedings of the Koblenz symposium Sep.1970 Vol.2 UNESCO- W.M.O - IAHS 1973.

15 " Symposium on Remote sensing of snow in the Himalaya for effective water control Management for Irrigation and power" Oct.25 1978 S.B.MB, Nangal township.

16 Erwin Schanda, " Remote sensing for Environmental scince," Ecological studies 18, springer- verlag, Berlin Heidelberg, N.Y.

17. Linsley, Kohler, Paulhus," Applied Hydrology" Tata Mc-Graw Hill publication company Ltd., New Delhi 1975 pp 245.

18 Avery. T.E. " Interpretation of Aerial photograph."

19. G. Shankar, " Studies for snowmelt discharge estimation in Pandah catchment using Landsat images," M.E. Dissertation 1979. Department of Earth science, U.O.R.

20. " Operational application of satellite snow cover observations" A workshop held in South Lake, California Aug. 18-20 ,1975.

21 Warren Viessman, Jr. John W. Knapp Garly, Lewis, the late Terence E. Harbough, " Introduction to hydrology." second edition Am. 231 -237, 1977.

22 Hill, S.A., " The Meteorology of the North West Himalaya," Indian Meteorological Memoirs. Vol. X. Chap. XII, pp 377 -426.

23 Donald M. Gray, " Handbook on the principles of Hydrology" A water information centre publication.

24 J. Nemec " Engineering Hydrology," Tata Mc. Graw- Hill publishing company Ltd., New Delhi.