SNOWMELT RUNOFF STUDIES IN UPPER YAMUNA BASIN

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ABSTRACT

Snow accumulation in the Himalayas forms a good reservoir of water for use in the snowmelt period. In India the rivers having their origin in the Himalayas draw a considerable percentage of snowmelt water during winter and spring period. Better understanding of snowmelt dynamics and quantification of snowmelt-runoff is of vital importance for optimum water resources management. An indepth study of this source of water is of immense use for forecasting low flow as well as floods and is of much interest to the personnel engaged in agriculture and water resources management.

With a view to have an idea of snowmelt contribution in the total flow of the river, Central Water Commission has taken up snow studies in a small test watershed in Upper Yamuna basin on experimental basis. Although first attempt in India in this field, the experiment has given encouraging results and has proved to be of much interest and use. This paper gives details about the test basis, data acquisition and development of snowmelt-runoff correlation using Streamflow Synthesis and Reservoir Regulation (SSARR) model.

1. INTRODUCTION

River Yamuna has its origin in the Himalayas at the place called Yamunotri at a height of about 3300 metres above mean sea level. The river drains an area of about 11000 sq km in the mountains before entering plains at Tajewala. Total area in the upper reaches of the river where snowfall occurs is about 6000 sq.km and snow stays permanently throught the year in about 500 sq.km, whereas in rest of the area it melts completely upto April/May. Snowfall generally occurs during the month of December and January with few exception when there is snowfall in the month of November or even October in the higher reaches of the catchment. The following paragraphs describe about equipments, data acquisition, some problems in data collection and model output. A map showing the Yamuna river from source to Delhi and identifying test watershed in it is at Plate-I.

2. TEST AREA

Snowmelt-runoff studies are being carried out in a small watershed called Sundli Nala a small stream draining 4.86 sq.km area. Sundli Nala outfalls in Biskalti Nala which joins river Pabar which itself is a tributary of the Yamuna. The watershed is located near Jubbal town of Shimla district in Himachal Pradesh. The slope of the watershed is South-North. Highest elevation of the watershed is about 3350 m. while the lowest is about 1800 m above mean sea level. The vegetation cover is coniferous forest consisting of tall pine trees. The tree canopy closure varies directly with the elevation. Since there were no observation in the past no records are available about intensity of snowfall in the watershed. However, as gathered from local people's knowledge, 30 to 45 cms snowdepth is considered to be a normal seasonal snowfall at about 2000 metres above m.s.l. Top of the watershed receive about 300 cms snowfall during the normal season. Equipments for data collection have been installed in the watershed at an elevation of approximately 2450 metres above m.s.l. An index map of test watershed is at Plate-II.

3. EQUIPMENT

Central Water Commission has executed a Pilot Scheme for the Yamuna upto Delhi "Improvement of River & Flood Forecasting System in India" with the assistance of UNDP. The scheme was implemented during 1980-88. Snow Hydrology activities were taken up as a component of this project to study the snowmelt runoff contribution in the river discharge. A snow hydrology observatory was established at Jubbal in 1984-85. The following equipments have been installed at the observatory site for recording snow data and other related meteorological parameters.

3.1 Tipping Bucket Precipitation Gauge

The instrument consists of a small vessel made up of light metal and devided into two equal compartments. The vessel rests on the horizental axis and in its normal position remains tilted on one side so that one of the two compartment faces the lower orifice of the funnel provided to collect precipitation.When a pre-determined amount of rainfall is collected in the compartment the vessel gets tilted to the otherside. In the process the precipitation full compartment get emptied and the other compartment comes in position under the orifice of the funnel. The process is repeated continuously Each tipping of the vessel is used to operate a relay contact and produce a record on the recorder. As the equipment can measure liquid only, initially there was some problem in measuring snowfall as the snow gets struck up in the orifice of the funnel. The problem was overcome by fixing a heating element provided with a thermostat with the precipitation gauge.

3.2 Net Radiometer

Net radiometer consists of a blackened thermopile covered with polyethylene wind shield dome and is used for measuring the difference between incoming (shortwave) and outgoing (longwave) radiation, both short and long waves. A desiccant tube containing silica get is included to absorb internal moisture.

3.3 Snow Pillow & Pressure Tranceducer

A set of four stainless steel snow pillows is installed at the observatory site to measure snow water equivalent. The pillows are connected to each other with 1.27 cm copper pipe fitted for transmitting the pressure of snow which fails on the pillows. This pressure is further routed through a pressure tranceducer to the recorder to record snow water equivalent. The pressure tranceducer system is made up of pressure transducer and signal conditioning circuit and is attached to the final copper pipe coming out off the snow pillows.

3.4 Anemometer

The system consist of two major assemblies, the recorder console and the wind speed and direction sensor. Anemometer is installed at a height of 10 metre above the ground level in a clear unobstructed location. A single chart is provided to record both speed and direction simultaneously and for easy correlation between the two parameters.

3.5 Thermograph

The equipment records continuous temperature variations. The records are made on a graph chart provided on a clock driven cylinder. The clock of the quipment is spring wound for 176 hrs. with an eleven jewelled level escapement. The instrument is housed in a wind shield at the observatory site. The temperature range of instrument is -20 to + 40C.

3.6 Microbarograph

This instrument measures ambient barometric pressure indoors or outdoors and records the parameter on a stip chart. The barometric pressure element is a multiple aneroid cell that has been completely executed. One end is attached to the pen linkage while the other is attached to the instrument base. Ambient pressure variations cause the aneroid to expand or contract, which is mechanically linked to the pen arm which move on the chart fixed on the clock drum to record the barometric pressure. The clock operaties on 1.5 volt DC battery. This parameter is not being used in the snowmelt runoff model, but is helpful in assessing the weather situation in immediate future.

3.7 Hygrograph

The sensor employed for recording relative humidity at the observatory site is hair hygrometer. Human hair when absorbs moisture expands slightly and contracts when loses moisture. The expansion of bunch of human hair with dampness in air is used to measure relative humidity. When the relative humidity change, the length of hair changes and a pointer attached to the hair moves on a caliberated circular scale of clock drum working on 1.5 volt battery. The position of the tip of the pointer at a time gives the relative humidity of the air at that time.

3.8 Float Actuated River Gauge

A V-notch weir is constructed at the downstream end of the watershed to measure the snowmelt-runoff during the snow accumulation and ablation period. A stiiling well is erected at the weir site which accomodate a float type sensor which moves with rise or fall in water level. The movements are recorded by the recorder on a graph chart which in turn are decoded to get actual levels and flow.

In addition to above sensors, the following axiliary equipments are also installed and used at the snow observatory.

(i) Maximum and minimum thermometer

(ii) Wet and Dry bulb thermometer

(iii) Fortin Barometer

Manual readings are taken on these instruments everyday during snow season.

4. DATA ACQUISITION

In the year of start i.e. 1984 data collected during the 1984-85 winter season was scanty due to initial problems in installation and caliberation of equipments. However, with experience and overcome of the problems the quality and quantity of data collected was very much improved in the successive years. Presently the following parameters are being observed at the observatory site in the watershed.

(i) Precipitation (Rain/and snow)

(ii) Snow cover characteristic (snow water equivalent, density and depth)

(iii) Water level and discharge of the stream.

(iv) Net Radiation (Difference of/incoming solar radiation and outgoing terrestrial rad iation, both short and longwave.)

(v) Air temperature (Daily maximum & minimum)

(vi) Humidity

(vii) Wind (speed and direction)

5. MODEL OUTPUT

Streamflow Synthesis and Reservoir Regulation (SSARR) Model is being used for development of snowmelt runoff correlation. The latest version of SSARR consists of two separate models namely, Snowband model and Depletion curve model. Climatological data is used in snowband model to compute snowpack volume and extent. While using the model the watershed can be devided into a number of elevation bands. Model can accomodate maximum 20 such bands. In the present case SSARR model is being used with snow band option approach. The whole watershed is devided into four band of varying elevation. Each elevation band is treated as separate watershed with respect to snow accumulation and melt. Data for the 1984-85 and 1985-86 snow seasons was not considered to be sufficient to run the model. Hence data for 1986-87 winter season was used as the same was more consistent. Apart from the basin characteristic the temperature, precipitation wind data, dew point and discharge data are the only variable parameters being used to run the model, Snowmelt-runoff correlation developed for 1986-87 snow season showing the observed and simulated discharge hydrograph is at plate III. Further caliberation of the model with more data is being carried out to arrive at a reliable method to compute Snowmelt-runoff contribution in the watershed. This will further be utilised for a reliable forecast for the snowmelt-runoff in the river during summer.

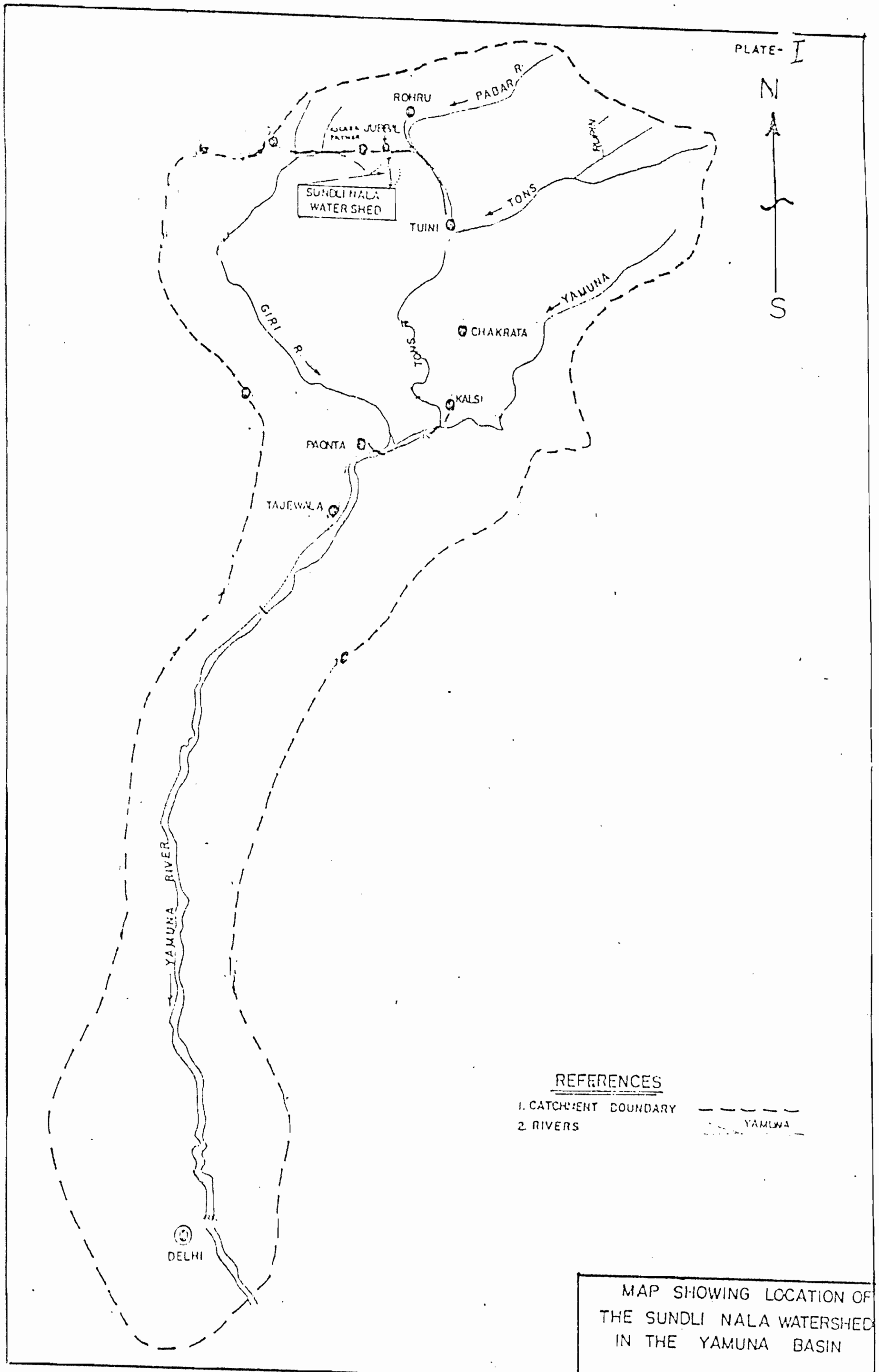
6. CONCLUSION

The results of the studies done in Sundli Nala has been encouraging. With the data of couple of years more, it is hope to make a reliable snowmelt-runoff studies and snowmelt contribution in the river. Based on the experience of this Pilot Project, Snow Hydrology Observatory is proposed to other Indian river basins.

Reference

i) SSARR Manual

ii) Snow Hydrology Project in the Yamuna Basin.



MAP SHOWING LOCATION OF THE SUNDLI NALA WATERSHED IN THE YAMUNA BASIN

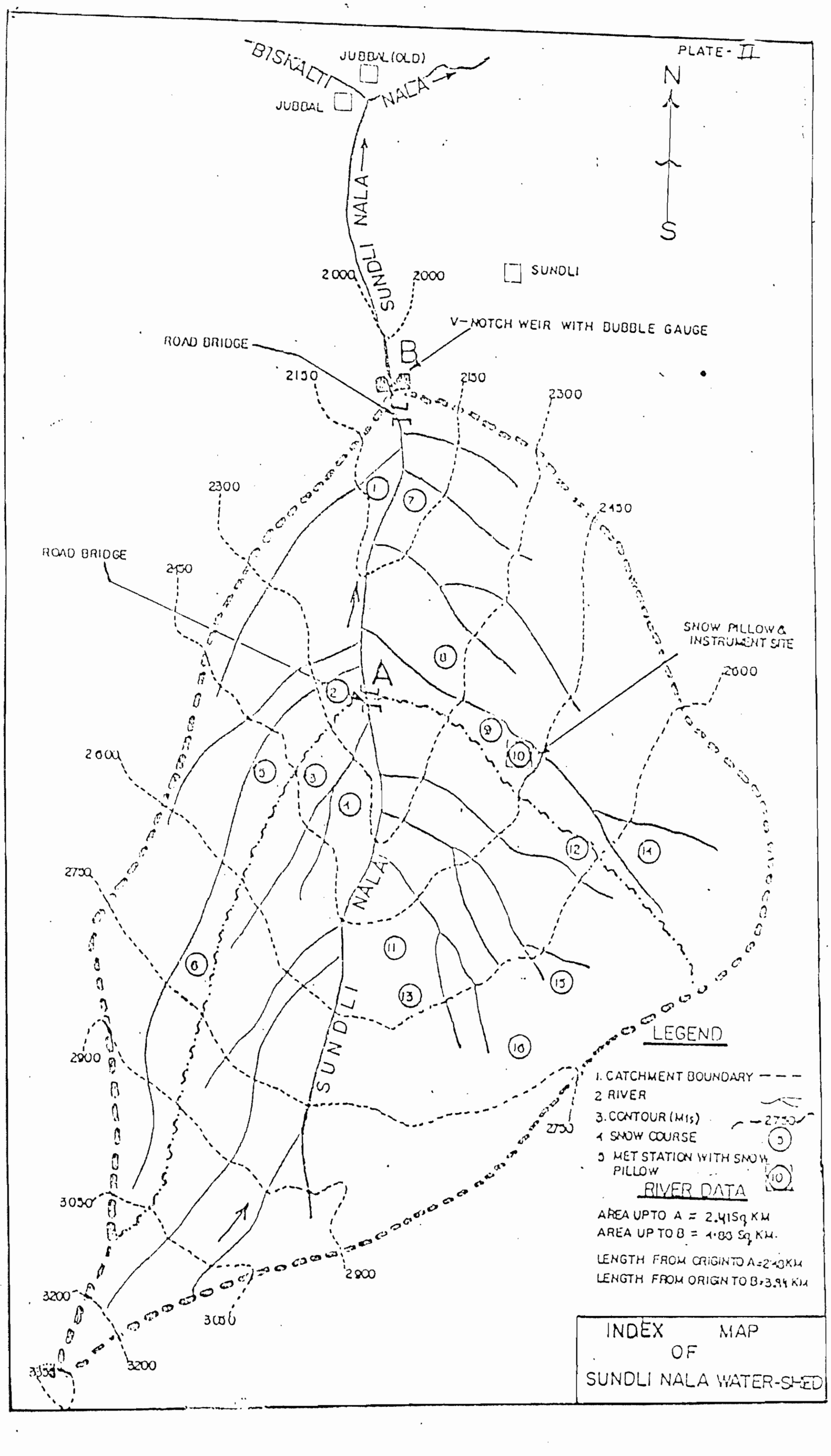
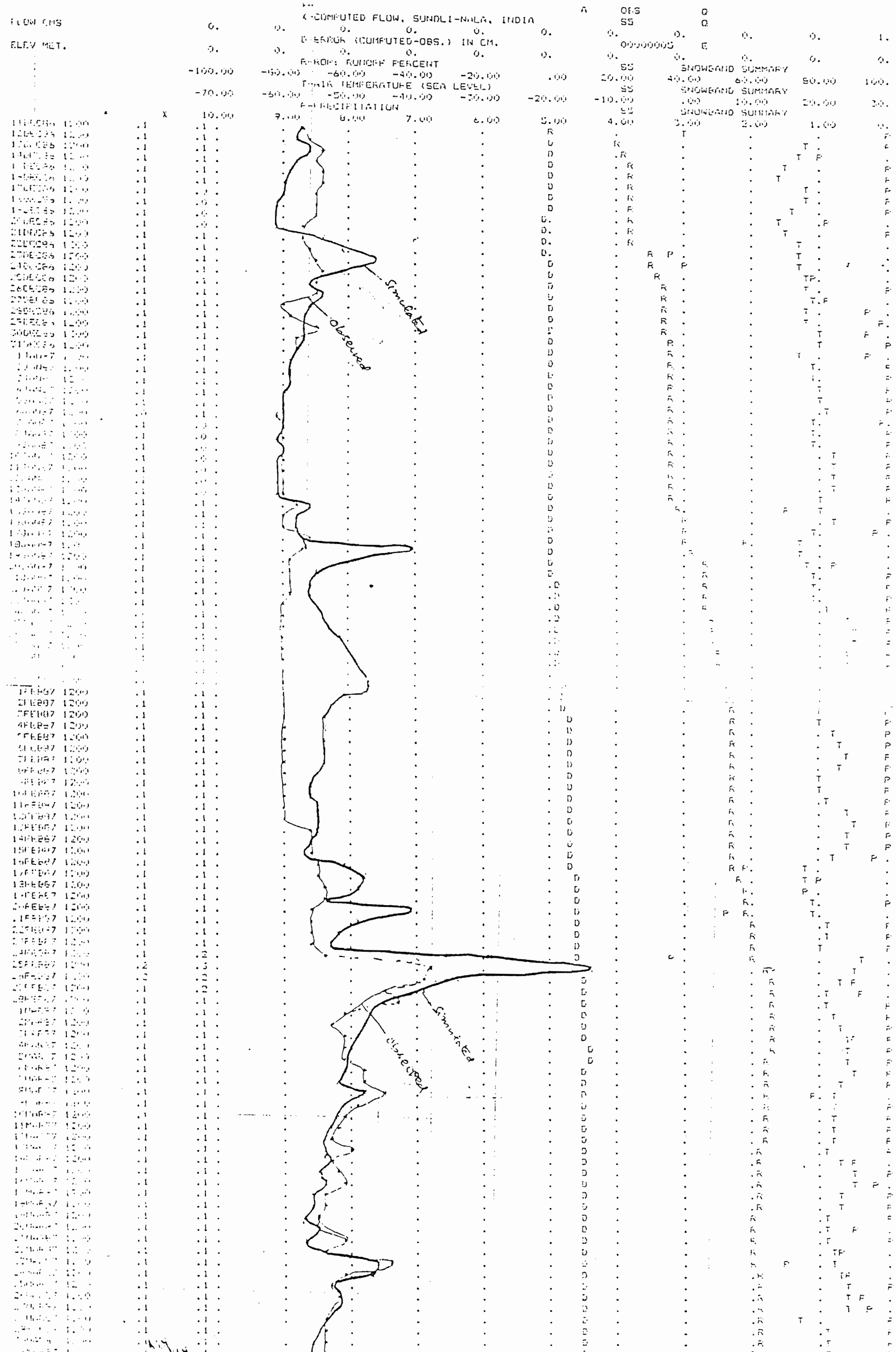


PLATE - II
N
S
BISKALTI NALA
JUBBAL (OLD)
JUBBAL
SUNDLI NALA
SUNDLI
2000
2000
V-NOTCH WEIR WITH BUBBLE GAUGE
ROAD BRIDGE
B
2150
2150
2300
2300
2450
ROAD BRIDGE
2450
SNOW PILLOW & INSTRUMENT SITE
A
2600
2600
2750
2750
2900
2900
3050
3050
3200
3200
3350
SUNDLI NALA
LEGEND
1. CATCHMENT BOUNDARY
2 RIVER
3. CONTOUR (Mts)
4 SNOW COURSE
5 MET STATION WITH SNOW PILLOW
RIVER DATA
AREA UPTO A = 2.41 Sq KM
AREA UP TO B = 4.80 Sq KM.
LENGTH FROM ORIGIN TO A = 2.40 KM
LENGTH FROM ORIGIN TO B = 3.94 KM
INDEX MAP OF SUNDLI NALA WATER-SHED

PLOT CHARACTER	DESCRIPTION	STATION NAME	CONTROL
X	COMPUTED FLOW, SUNDLI-NALA, INDIA	A OBS	Q
		SS	Q
D	ERROR (COMPUTED-OBS.) IN CM.	00000000S	E
R	ROFF RUNOFF PERCENT	SS	SNOWBAND SUMMARY
T	AIR TEMPERATURE (SEA LEVEL)	SS	SNOWBAND SUMMARY
P	PRECIPITATION	SS	SNOWBAND SUMMARY



Chemistry of Snow Pack Accumulation and Melt in a Deciduous Forest

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For this paper we have examined

(a) the variability of water equivalent, pH and concentrations of major anions in the snow falling in a mixed deciduous forest and in a clearing

(b) the total inputs of these entities at the forest site and in the clearing relative to those measured at the nearby AES CAPMON monitoring site

(c) the stability of these entities during the accumulation phase of winter, and finally,

(d) the relative quantities of these entities recovered from the run-off from a 5 m square plastic lined lysimeter after the melt is finished.

VARIABILITY

Variability was measured by deploying bulk collectors fashioned from garbage cans having an area of opening of 1400 cm^2 and lined with poly-ethylene bags. Collections were made after each major input. Up to 29 and 9 collectors were used in the forest and clearing respectively. Variability is relatively large (C.V. = 0.16 - 0.39) within the forest for the ionic components in wet snow and freezing rain on December 22 and 26 respectively. Water equivalent however, was much less variable (C.V. = 0.03 - 0.14). Interaction with the forest canopy, rather than variable input of precipitation, appears to be the cause of increased spatial variability and enhanced deposition of the ionic components. If the incidences of c.v. > 0.05 are compared the variability increases in the order

$$H_2O < NO_3^- < H^+ < SO_4^=$$

at the open site and in the order

$$NO_3^- < H^+ < H_2O < SO_4^=$$

in the forest.

The total depositions of water, nitrate, sulphate and hydrogen ions to the bulk collectors and to the nearby AES CAPMON collectors were summed and compared. The results are shown in the table below.

	Dec 22 - Mar 3		Jan 28 - Mar 3	
	AES/OPEN	AES/FOREST	AES/OPEN	AES/FOREST
WATER	0.93	1.08	0.94	1.05
NO_3	0.90	0.82	0.95	1.01
SO_4	0.78	0.73	0.92	0.95
H^+	0.98	0.99	0.98	1.05

The difference in the two sets is that the period Dec 22-Mar 3 includes the wet snow and freezing rains of Dec 22 and 26. The ratios AES/OPEN and AES/FOREST agree reasonably well for the predominantly dry snow deposition period after January 28. When the wet snow deposition is included, there is a large variability between collectors and they are relatively enriched with respect to the AES site. This is particularly so for sulphate ion.

STABILITY

Stability was investigated by periodically collecting cores from the snow pack and cutting them into 5 cm deep slices. The product of the water equivalent and the concentration of the solutes in each slice gives the loading of each ion. The loadings were then summed from the bottom up and the cumulative loading plotted against the corresponding cumulative water equivalent. Results for H^+, NO_3^- and $SO_4^=$ for the spring of 1987 are shown in Figure 1. also plotted there, are the cumulative inputs measured at the CAPMON site and at the forest site using the bulk collectors.

Results for the winter of 1986-87 can be summarized as follows. No melting occurred during the period between Feb 12 to 24. Skies were clear throughout with daytime temperatures approaching within a few degrees of the melting point and low night time temperatures. The loadings of the three ions are almost identical on each date showing that the 3 ions are stable in the pack under the conditions described. It also shows that, if dry deposition occurred in the period, the amounts deposited were too small to detect by the method used. Between February 24 and March 4 warmer temperatures prevailed and snow and rain fell. By March 7 substantial melting had also occurred. These events have caused hydrogen ion to be lost at both the bottom and the top of the pack by March 4. By March 7, however, additions to the top of the pack and melting have resulted in appreciable replenishment of the pack particularly at the top and bottom.

Nitrate appears to be more stable with small losses occurring at the top of the pack by March 4 followed by further losses throughout the pack by the 7th.

MELT

A 5 m square plot was lined with polyethylene sheeting, the edges being delineated by wooden planks 30 cm high and covered with extensions of the polyethylene flooring. Melt water from the lower most corner was channelled to an underground bunker where the volumetric flow of water was continuously monitored and samples taken for analysis. The product of the volumetric flow and the mean concentrations is a measure of the fluxes of the various chemical constituents. The final integral of the fluxes less the amounts added as precipitation over the whole melt period is a measure of the total amount of an entity stored in the pack at the start of the melt. This can be compared with the amounts measured in snow cores taken immediately before the start of the melt.

Results for 1987 and 1988 are shown in the table along with values for 1985. For the latter, precipitation was measured at the AES site only.

The most important results are:

1) The amounts of water equivalent by the two methods agree quite well in all cases.

2) In 1985, the melt started February 22 and there was a large amount of precipitation during the melt period. The total run-off of both nitrate and sulphate was less than the input during the melt.

3) In 1987 there was relatively less precipitation. Losses of both nitrate and sulphate were smaller. The apparent gain of hydrogen ion relative to forest input is not explained. The fact that about half of the precipitation during that melt period was wet snow which was followed by a period of freezing temperatures may account for some of the anomalies.

4) In 1988 there was even less precipitation during the melt period. With the exception of hydrogen ion relative to forest inputs, losses from the lined plot were negligible.

CONCLUSIONS

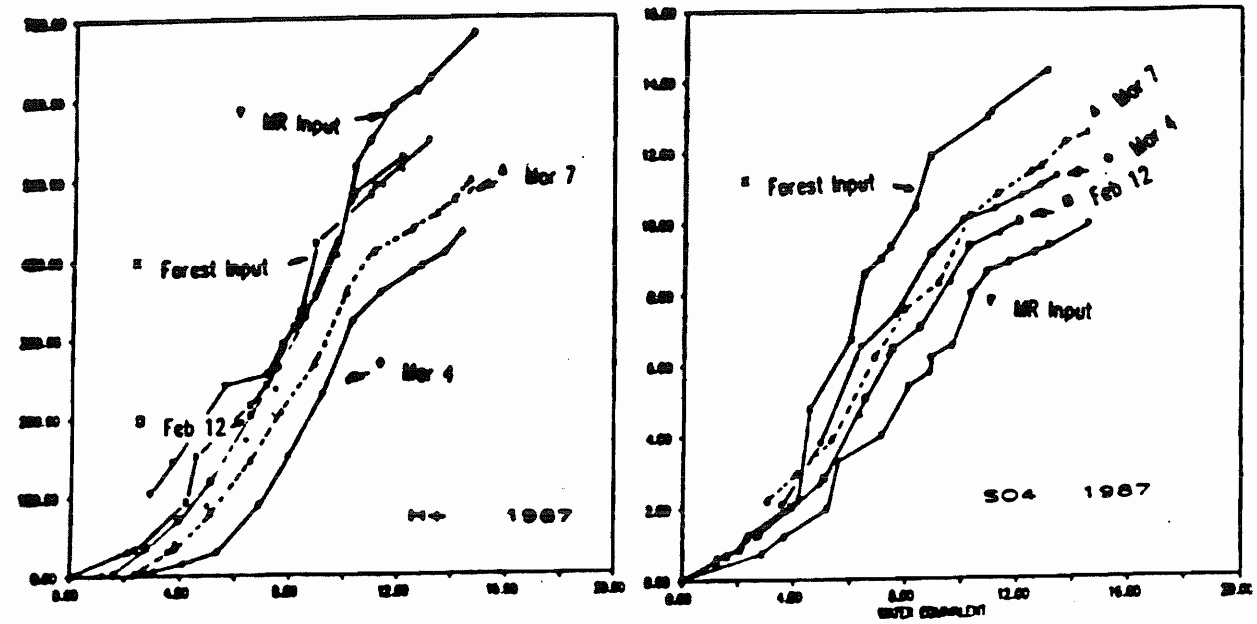
1) Substantial differences have been found between the inputs of solutes to the snow pack by the "wet only" protocols at a nearby CAPMON monitoring site and with "bulk" collectors in the forest. The differences appear to be due to interaction between the snow and the forest canopy and are greater when wet snow or rain falls.

2) The variability of inputs within the forest is small. For the most part, the standard deviation is less than 5% of the mean when the snow is dry and tends to rise when the snow is wet or mixed with rain.

3) The composition of the snow pack is stable in the absence of melting or rain-on-snow events. Melting and rain tend to cause vertical redistribution of solutes within the pack and relatively much greater loss of solutes than loss of water equivalent.

4) The large loss of nitrate ion in the run-off from the lined plot noted in previous years may have been due to large amounts of precipitation during the melt period.

	RUN-OFF	INPUT DURING MELT		AMOUNT STORED AT START OF MELT				
		A-AES	b-FOREST	LINED PLOT a AES	LINED PLOT b FOREST	SNOW CORE c	RATIO a/c	RATIO b/c
WATER 1985	27.75	17.24		10.51		10.51	1.00	
WATER 1987	21.34	7.15	5.10	14.19	16.24	14.52	0.98	1.12
WATER 1988	19.37	3.23	2.22	16.14	17.15	17.33	0.93	0.99
NO3 1985	53.59	61.81		-8.22		25.8		
NO3 1987	30.19	7.98	10.26	22.21	19.93	24.96	0.89	0.80
NO3 1988	46.6	8.66	9.55	37.94	37.05	41.28	0.92	0.90
SO4 1985	42.91	44.77		-1.86		9.30		
SO4 1987	21.11	9.61	12.88	11.5	8.23	12.51	0.92	0.66
SO4 1988	29.67	9.16	11.58	20.51	18.09	19.59	1.05	0.92
H+ 1987	843	400	110	443	733	432	1.03	1.70
H+ 1988	764	257	79	507	685	750	0.68	0.91



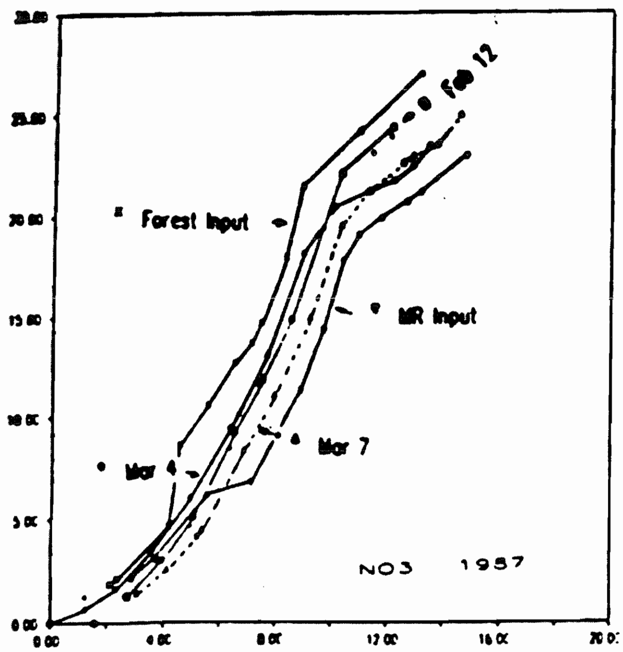


Fig. 1 Cumulative loadings of hydrogen, nitrate and sulphate ions in snow at various times during the winter of 1986-1987.

(Abcissa = water equivalent, cm; ordinate = ion loading, $\mu g.\ cm^{-2}$)