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HYDROLOGICAL INVESTIGATIONS ON CHHOTA SHIGRI GLACIER (H.P.)

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PREFACE

Water stored in the form of snow and glacier in the Himalayas is a major of water during spring and summers in the rivers originating from Himalayas. The contribution from the glaciers starts generally in the month of June/July when seasonal snow is ablated and continues till September/October depending on the prevailing weather during summer. Hydrological investigations carried out on the glaciers in the Himalayas are very limited. The glacier melt processes and sediment transport with glacier melt runoff are the important aspects to be understood to conduct the hydrological studies.

Scientists from the Mountain Hydrology Division have participated in the expedition to Chhota Shigri glacier (H.P.) for carrying out hydrological investigations including estimation of suspended sedimentation transportation in the channel of the glaciers. The expedition was organized by Wadia Institute of Himalayan Geology, Dehradun and was funded by Deptt. of Science and Technology, New Delhi. Efforts were made to establish gauging site and recording of water level in the channel using automatic water level recorder. Various techniques have been used to measure the glacier melt runoff. Sri Anand Verdhan, Scientist C and Dr. Pratap Singh, Scientist B carried out the studies. Dr. Pratap Singh participated in the expedition for the years 1986, 1987 and 1988 while Sri Verdhan could participated only for the year of 1988. This report has been prepared by Dr. Pratap Singh, Scientist B, Mountain Hydrology Division, NIH, Roorkee.

(Satish Chandra)

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

ABSTRACT

There area a number of glaciers which cover significant zones of the mountains. The glacial melt contributes to the flow in rivers rising in the Himalayas especially during April to September. For a better understanding of the physics of glaciers and for estimation of glacier melt, hydrological investigations have been carried out in Chhota Shigri Glacier in Himachal Pradesh over a period of 3 years (1986-88). The discharge measurements in the melt stream have been conducted by velocity-area method and salt dilution technique. The coefficient between average velocity and surface velocity of flow is determined by observations taken by current meter. The average value of discharge has been observed about 10 cumecs in the month of July and August. However,it reduced to 1 cumec in the beginning of September.

A complete hydrograph is obtained making hourly observations of discharge for 48 hours.A comparison of diurnal variation in discharge with recording of temperature at the glacier surface helped to determine the time lag in melting of glacier and observation at the gauging site. A time lag between 1-3 hours was observed for this glacier. It has been found that time lag depends upon the accumulation area, ablation area and drainage pattern of the glacier. A water level recorder was installed to record the fluctuation in water level of the melt stream.

Snow density and temperature profile of the snowpack and firn over the glacier have been measured in the accumulation and ablation zones during expedition in 1987 and 1988. The magnitude of suspended sediment transport in the glacier melt has also been made by scooping a certain volume of water and sediment mixture at the discharge measurement site.

1.0 INTRODUCTION

Glaciers act as natural reservoirs, storing precipitation in the winter and releasing melt water in the Summer, thus augmenting flows into the rivers. Himalayas constitute the largest reservoir of snow and ice outside the polar regions and support a multitude of glaciers. There are a number of Indian Himalayan Glaciers which store an abundant water in solid phase in the glaciers elevation zones of the mountains.

The glacial melt constitutes a significant part of the flow in river rising in Himalayas. Reliable estimates of glacial melt are, therefore needed for management of water resources. The scope of water resources management engulfs the problems associated with sediment transport also as sedimentation largely determines the storage of many reservoirs.

Very limited work has been carried out in India towards the hydrology of the glaciers and scientific management of the available water resources. One of the cause for it is that hydrological investigations in glaciated regions are difficult because of problems associated with organizing long-term observations. The difficult terrain and cold climate are main causes to limit the investigations.

To study the physics of glaciers, the glacier hydrology and glacier contributions to the stream flow, hydrological investigations were under taken by a scientific team of National Institute of Hydrology in 1986, 1987 and 1988 on Chhota Shigri Glacier situated in the Western Himalayas. The opportunities had been provided by a multi-disciplinary expedition to Chhota Shigri Glacier, sponsored by Department of Science and Technology, New Delhi and organised by Wadia Institute of Himalayan Geology, Dehradun.

2.0 STATUS OF GLACIER STUDIES IN INDIA

Interest in snow and glaciers of Himalayas began with observations regarding snowline or the line of perpetual snow early in 1810s (Vohra, 1981). The Pindari glacier was first to be investigated upon (Madden, 1947) and Himalayan glaciology was accepted as a scientific pursuit by nineteenth century. Few visits to Gangotri glacier were made by Hogson and Herbert (1842) in 1817, Greisbach (1891) of Geological Survey of India in 1891 and Auden (1935) in the year of 1935. During these visits a sketch of snout of Gangotri glacier was prepared. Auden prepared the map with reference to the cairns erected by him. He stated that the glacier must have receded by 2400 ft during the last century alone. Write and Ross (Auden, 1935) of Survey of India also visited Gangotri glacier in the same Year and resurveyed the glacier.

The survey of Gangotri glacier was continued even after independence. Jangpangi (1958) of GSI visited this glacier in 1956 and surveyed the snout with reference to the cairns erected by Auden. The retreat of glacier was determined to be of the order of about 90 m in 21 years since 1935. Further Tiwari (1967) of GSI prepared a sketch map showing the position of snout of the glacier in 1956 and 1967. He estimated the recession of the snout to be about 600m from its 1935 position.

Historical records of fluctuations of glaciers in Himalayas and trans-Himalayas date back to early nineteenth century but records are widely distributed. However, a good account covering regional synthesis of 112 glaciers since 1812 has been reported by Mayewski and Jeschke (1979). In a gross sense Himalayan and trans-Himalayan glaciers have been in a general state of retreat since 1850.

The Indian National Committee for International Hydrological Decade (HYDCOM) in its early deliberations identified a major gap in the information regarding our water resources viz. snow and glaciers in the Himalayas and their water resources potential. The HYDCOM set up a High Level Committee on Ice, Snow and Glaciers areas and assigned to the committee the task of making scientific glacier surveys of glacier areas to assess their water resources potential. The first inter-disciplinary team of scientists for training cum study expedition to Gangotri glacier was sent under the leadership of Dr. C.P.Vohra, then senior Geologist of the GSI. The other members of expedition were from Departments like the Survey of India (SOI) India Meteorological Department (IMD), Central Water and Power Commission (CWPC) and

Defence Science Organisation. The expedition was organised in September-October , 1971 and the water discharge from the glacier determined by the salt dilution technique in early October was reported to be about 29.5 cumecs. The relevant geological and geomorphological studies were also carried out by the team of scientists. It included glacier movement along two lines in the ablation zone of the glacier.

Systematic and planned studies could be carried out in India only after 1974.These studies have been grouped in the following broad areas from hydrological studies point of view.

2.1 Glacier Inventory

The glacier inventory in the Himalayan region was initiated in 1974 by the GSI after the inception of Glaciology Divisions. The Glaciology Divisions in the Northern Region at Lucknow and in the Eastern Region at Calcutta came into existence in 1974 and 1979 respectively. The first generation of inventory of glaciers in J&K, H.P.,U.P. and Sikkim has been completed by GSI. This inventory covers the number of glaciers, glaciation level and area of glaciers etc with few generalised ideas about the glaciers. The second generation of inventory being carried out. The data on second inventory is under compilation for publication (Sahai,1992). Kulkarni (1991) used satellite images for the purpose of glacier inventory. The literature reveals that various authors have shown different number of glaciers in the Indian Himalayas. A brief summary has been given by Rao (1992). A list of principal glaciers in Himalaya is given in Table 1 (SOI, 1985, Bahadur,1992). The principal glacier fed river system of the Himalaya is shown ir Table 2 (Bahadur, 1992).

2.2 Mass Balance Studies

Glacier mass balance is the most meaningful description of its hydrological cycle and a way to evaluate the water storage aspects and associated processes of snow movement, variation in glacier thickness, erosive and deposition capacity resulting in creating the glacial landscape. Mass balance in considered as the life history of a glacier at any particular time stage. It is either positive or negative displaying a surplus or deficit of ice on the glacier body. Surplus mass balance results in glacier advance while deficit results in glacier retreat. The main part of the change in mass is usually assumed to take place in a relatively thin surface layer of the glacier (Bahadur,1992). It is mainly related to temperature and precipitation but other

Table 1 - PRINCIPAL GLACIERS IN HIMALAYA

1.	Rakhiot	Punjab Himalaya
2.	Kolhai	
3.	Neh-Nar	
4.	Sarbal	
5.	Kangriz	
6.	Brahma	
7.	Drung Drung	
8.	Mulkila Group	
9.	Barashigri	
10.	Glacier in Dibi Bokri Area	
11.	Gara	
12.	Gorgarang	
13.	Gangotri	Garhwal Himalaya
14.	Santopath	
15.	Kedarnath	
16.	Milam	
17.	Pindari	
18.	Shankulpa	
19.	Poting	
20.	Yaling	Nepal Himalaya
21.	Chong Kumdan	
22.	Rundun	
23.	Glaciers adjoining to Dhaulagiri & Annapurna Peaks	
24.	Kang Shung	
25.	Rupal	
26.	Khumbu	
27.	Glacier adjoining Makalu	
28.	Zemu	
29.	Glacier adjoining Kanchenjunga peak	Assam Himalaya
30.	Sanlung	
31.	Glaciers adjoining Gyara Pari Peak	

Source: Survey of India - Internal Report, 1985.

Table 2 - PRINCIPAL GLACIER FED RIVER SYSTEMS OF HIMALAYA

No.	Name of River	Major River System	Mountain area (Km^2)	Glacier area (Km^2)	Percentage glaciation
1.	Indus		268,482	8790	3.3
2.	Jhelum		33,670	170	5.0
3.	Chenab	Indus	27,195	2944	10.0
4.	Ravi		8,029	206	2.5
5.	Sutlej		47,915	1295	2.7
6.	Beas		14,504	638	4.4
7.	Yamuna		11,655	125	1.1
8.	Ganga		23,051	2312	10.0
9.	Ramganga	Ganga	6,734	3	0.04
10.	Kali		16,317	997	6.01
11.	Karnali		53,354	1543	2.9
12.	Gandak		37,814	1845	4.9
13.	Kosi		61,901	1318	2.1
14.	Tista		12,432	495	4.0
15.	Raidak	Brahmaputra	26,418	195	0.7
16.	Manas		31,080	528	1.7
17.	Subansiri		18,130	725	4.0
18.	Brahmaputra		256,928	1080	0.4
19.	Dibang		12,950	90	0.7
20.	Lohit		20,720	425	2.01
	TOTAL		1,001,294	25724	2.6

micrometeorological elements e.g. radiation, humidity, evaporation and wind velocity and direction also play their role in altering the balance. Such studies require a long term (5 to 10 years) monitoring of the glaciers considered for the mass balance assessment. Mass balance studies on Himalayan glaciers are limited (Raina et al.,1977; Kaul,1990)

Mass balance studies were first initiated in India at Gara glacier is Satluj basin in 1974 by GSI and studies were continued till 1983 i.e. over a period of ten years. The reconnaissance work to this glacier was done in 1973. The mass balance was measured to be positive during 1974-75 and 1975-76 balance years and since then it has shown a negative mass balance. The similar studies also have been conducted by GSI at Neh-nar glacier (J&K) (1975-1984). This glacier was selected as a representative in the Sind Valley, a tributary of Jhelum. The glacier has shown a negative specific budget between 1977 and 1982.

The Gor-garong glacier (H.P.) was selected by GSI for detailed glaciological studies in 1976 for studies on south facing glacier for comparing its results vis-a-vis a north facing glacier. Studies since 1976 have indicated that this glacier has shown negative mass balance till 1980-81 . It was found positive for next two years and was again negative for 1983-84. Mass balance studies at Shaune Garang glacier since 1981, have indicated negative mass balance of the glacier except in 1982-83 and 1989-90 balance years when positive mass balance was recorded.

Tipra Bank glacier (U.P.) was selected in 1981 for glaciological studies by GSI. The specific net balance during the budget years from 1981-82 to 1985-86 was found negative for this glacier. GSI initiated glaciological studies on Dunagiri glacier (U.P.) in the year of 1984. For six consective years the net balance has been found to be negative. Similar studies have also been carried out by GSI at Zemu and Changme Khangpu glacier (Sikkim), Harmukh glacier (J&K) and Rulung glacier (J&K).

Sahai (1992) reported that Gangotri glacier vacated an area of 0.243 sq.km during the last 55 years (1935-90). Moreover in the last 13 years (1977-90), the glacier melt water channel (the Bhagirthi) has shifted 30 m with respect to the position of 1977 cairns and has now carved nearly 4m of valley fill. The mass balance study conducted at Chhota Shigri Glacier (H.P.) has shown negative signature (Kumar, 92).

2.3 Glacier Melt Measurements

In order to deciper the quantam of melt water discharge from a glacier during summer months and its fluctuation vis-a-vis its mass balance and weather parameters, melt water runoff is observed by GSI for all the glaciers monitored by GSI for mass balance studies. The water discharge measurements are made at the gauging sites located down stream of the snout of the glaciers, generally, from last week of June to end of September.

More extensive study for glacial melt measurements its diurnal variation have been carried out for Chhota Shigri glacier under multidisciplinary expedition for the years from 1986-1989. Participants from NIH, CWC and JNU made consolidated efforts to understand the behaviour of flow variation in the melt stream. It was found that generally maximum discharge occurs during day between 1530 hrs and 1900 hrs, while minimum occurs between 0300 to 800 hrs. The ratio of maximum and minimum discharge was found in the range of 1.35 to 1.59 which indicates that during the nights also a signficant contribution from the glacier was received in the channel due to characteristics of melt water storage in the accumulation zone of the glacier. The time lag between melting at the glacier surface and reaching at gauging site was determined to be between 2-3 hrs. The details of studies carried out by NIH are being reported in the next sections of this report.

The maximum flow was observed in the middle of August and minimum in July. The average velocity flow was determined to be 2.238 m/s .During the 1988 expedition, an automatic water level recorder was installed by NIH at the gauging site and stage discharge relationship was established. The density of firn in the accumulation area has been measured to be 0.55 gm/cc. The crystals of the round shape and apoproximately 1 mm in size were found in the snowpack.

During preliminary visit to Kolhai glacier by NIH and Irrigation & Flood Control Deptt. of J&K state and SOI was made inthe year of 1989 , flow measurements for short duration were made (Singh 1990).

2.4 Suspended Sediment Transport

Regular and repeated sampling for the assessment of the suspended sediment in the melt stream, is carried out by GSI for the glacier undertaken for study. NIH also estimated suspended sediment transport for the Chhota Shigri glacier by collecting the samples from the channel. The silt load passed on a day varied between 83 Tonn/day to 2011 Tonn/day (Kumar, 1992). It indicates that sediment transport characteristics of the melt stream fluctuates widely. No direct relationship could be established between discharge and sediment though broadly it could be concluded that an increase in discharge corresponds to increase in suspended sediment concentration. A drastically high concentration observed on the day of first high peak of discharge is supposed to be due to side wash load stored in moraines, debris and other alluvial fill.

GSI has reported that Lime stone country produces half the quantity of suspended sediment per sq.km. of ice cover, as compared to gneissic or granitic terrain (DST, 1984).

2.5 Radio Isotope Study

Since 1977, the Glaciology Groups of physical Research Laboratory has been engaged in applications of isotopic techniques to study diverse glaciological problems on few selected Himalayan glaciers. During last decade, problems related to ice dynamics (movement of glacier ice, accumulation ratio of ice) based on natural and artificial radio isotopes like ^{32}Si, ^{210}Pb, ^{137}Cs etc. and climatic variations in the Himalayan environment based on stable isotopes have been studied. Basically, these isotopes provide ages (residence time of snow/ice in the glacier) of the glacier ice all along the glacier and provide time index to study various processes and glaciological parameters of different time scales. In the recent years, studies on chemical pollution using chemical tracers on Chhota Shigri glacier have also been undertaken, (Nizampurkar, 1992). These studies were conducted earlier in collaboration with GSI. The physical characteristics of the glaciers with snow ages and average flow rates have been given in Table 3.

A review of isotopic techniques for snow an glacier hydrology has benn made by Bahadur (1983), and Jain and Navada (1983)

Table 3 : PHYSICAL CHARACTERISTICS OF THE GLACIERS WITH SNOUT AGES AND AVERAGE FLOW RATES

Glacier	Location	Altitude (m.a.s.l.)	Length of glacier(km)	^{32}Si Modelage (yr.)	Post flowrate (m/yr)	Modern flowrate (m/yr)
Nehnar (Kashmir)	34°09'N 75°31'E	3920-4925	3.4	500	6	>12
*Chhota Shigri (H.P.)	32°15'N 77°31'N	4050-5000	9.0	250	28	23
Gara (H.P.)	31°30'N 78°26'E	4710-5600	6.0	200	20	60
*Gorgarang (H.P.)	31°26'N 78°24'E	4765-5360	3.5	160	18	NA
*Zemu (Sikkim)	27°43'N 88°17'E	4260-6000	26.0	120	200	NA
Chang me Khangpu (Sikkim)	27°58'N 88°42'E	4850-5800	5.8	100	40	13

*Unpublished data as on 1.3.1988

3.0 EXPEDITION TO CHHOTA SHIGRI GLACIER

Multi-disciplinary expedition to Chhota Shigri glacier (H.P.) was organised by the Department of Science & Technology, India. The expeditions were led by Dr. S Kumar from Wadia Institute of Himalayan Geology, Dehradun. Since 1986, NIH is participating in these expeditions to study the physics of glaciers, the glacier hydrology, sediment transport, and glacier contributions to the stream flow etc. A scientific team of NIH conducted field experiments for hydrological investigations in 1986, 1987 and 1988.

4.0 SALIENT FEATURES OF CHHOTA SHIGRI GLACIER

Chhota Shigri Glacier lies on the northern slope of the main ridge of the Pir Panjal range in the east of the Rohtang Pass (H.P.). The high, steep ridges and mountain terrain provide an ideal condition for the development of this glacier. The Chhota Shigri Glacier is located at 32° 15′N 77° 31 E covering about 10 km^2 area. There is very high gradient from accumulation to ablation area and snout as well.

A natural drainage system exists all over the ablation zone of the glacier. The glacier melt was draining out from the glacier in a single confined stream and meets the Chandra river (Figure 1). The total drainage area of Chhota Shigri Glacier stream is not well marked, but it is approximately 45 km^2. From its western slopes four small glacier flow to this glacier and add approximately 5% to the glacial melt of Chhota Shigri Glacier.

Lateral moraines have been observed to exist all along the body of the glacier up to accumulation zone. In the ablation zone lot of debris were found which accelerate the glacier melt process on the surface. The view of accumulation and ablation zones of the glacier is shown in Figure 2(a) and 2(b).

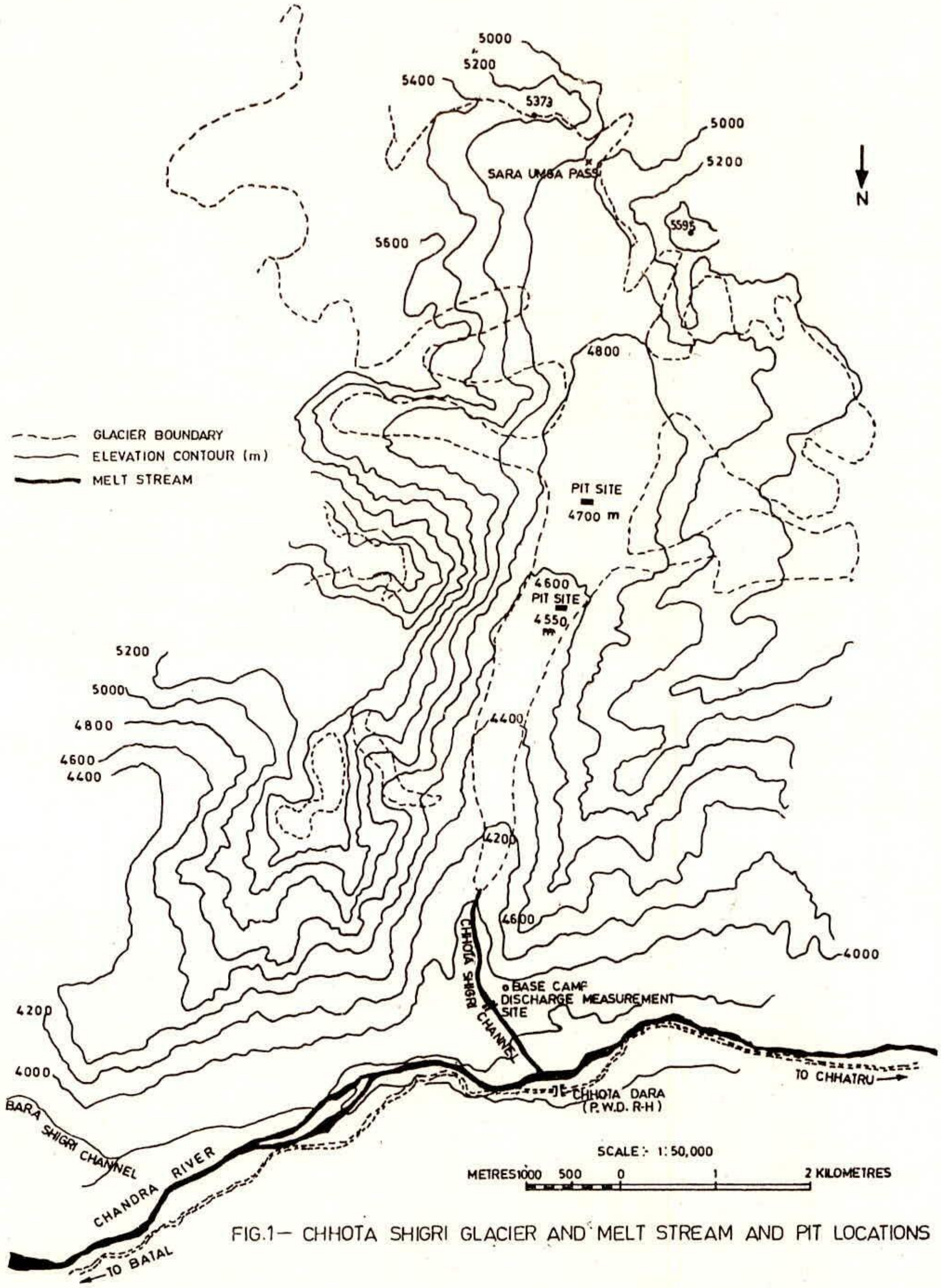


FIG.1— CHHOTA SHIGRI GLACIER AND MELT STREAM AND PIT LOCATIONS

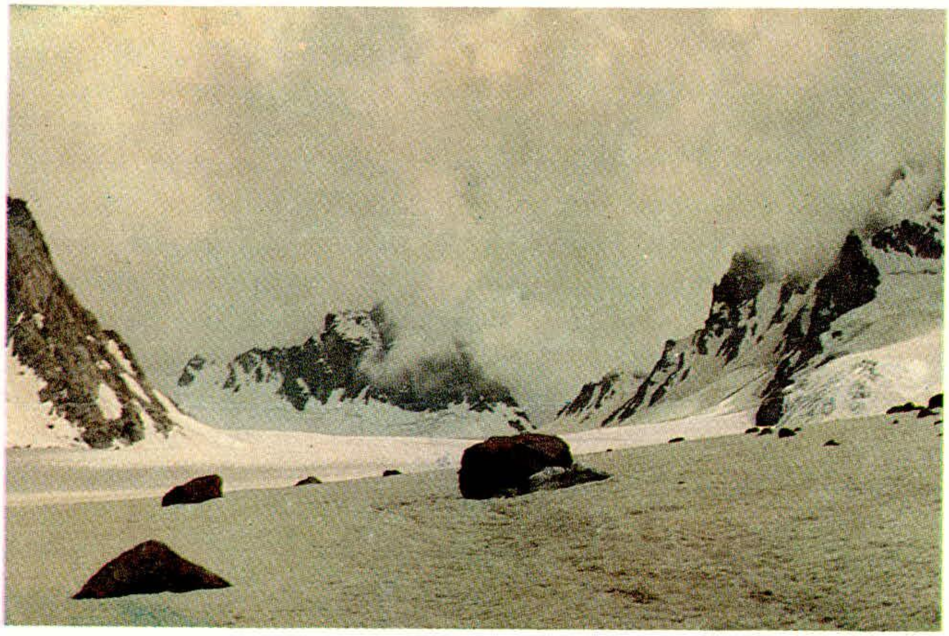


Fig.2(a) - A view of accumulation zone of Chhota Shigri glacier

Fig.2(b) - A view of ablation zone of Chhota Shigri glacier

5.0 SNOWPACK STRATIGRAPHY

Stratigraphy studies of snowpack above ice bed of glacier were conducted at altitude of 4550 metres (near glacier camp) and at an altitude of 4700 meters during the 1987 investigations. The studies were conducted by digging the pits of approximately 1m x 1m and depth ranging from 0.5 to 1.5 meter. Several layers were identified on the pit walls. During 1988 investigations snow was not found at the same elevation where it was observed in 1987. Consequently, a limited pit experiments were conducted in 1988. The Cold Regions Research Engineering Laboratory (CRREL), USA instruments were used for stratigraphic study of the pack. The following parameters were collected through stratigraphic study:

i) Density and water equivalent of the firn above the old glacier ice;
ii) Temperature at intervals of 20 cm depth;
iii) Total depth of seasonal snowpack;
iv) Size and shape of the snow crystals and their wetness.

The average density was observed to be 0.54 gm/cc and 0.55 gm/cc in the year of 1987 and 1988 respectively. Not much variation in temperature was found. The details of the results have been shown in Tables 4 to 10 and Fig. 3(a) - 3(f).

The snow crystal in all the experiments were observed of round shape having uniform grain size in range of fine to medium (0.5 mm to 2 mm). Layers wetness varied between moist to wet and hardness varied medium hard to hard. A view of experiment at site is shown in Fig.4.

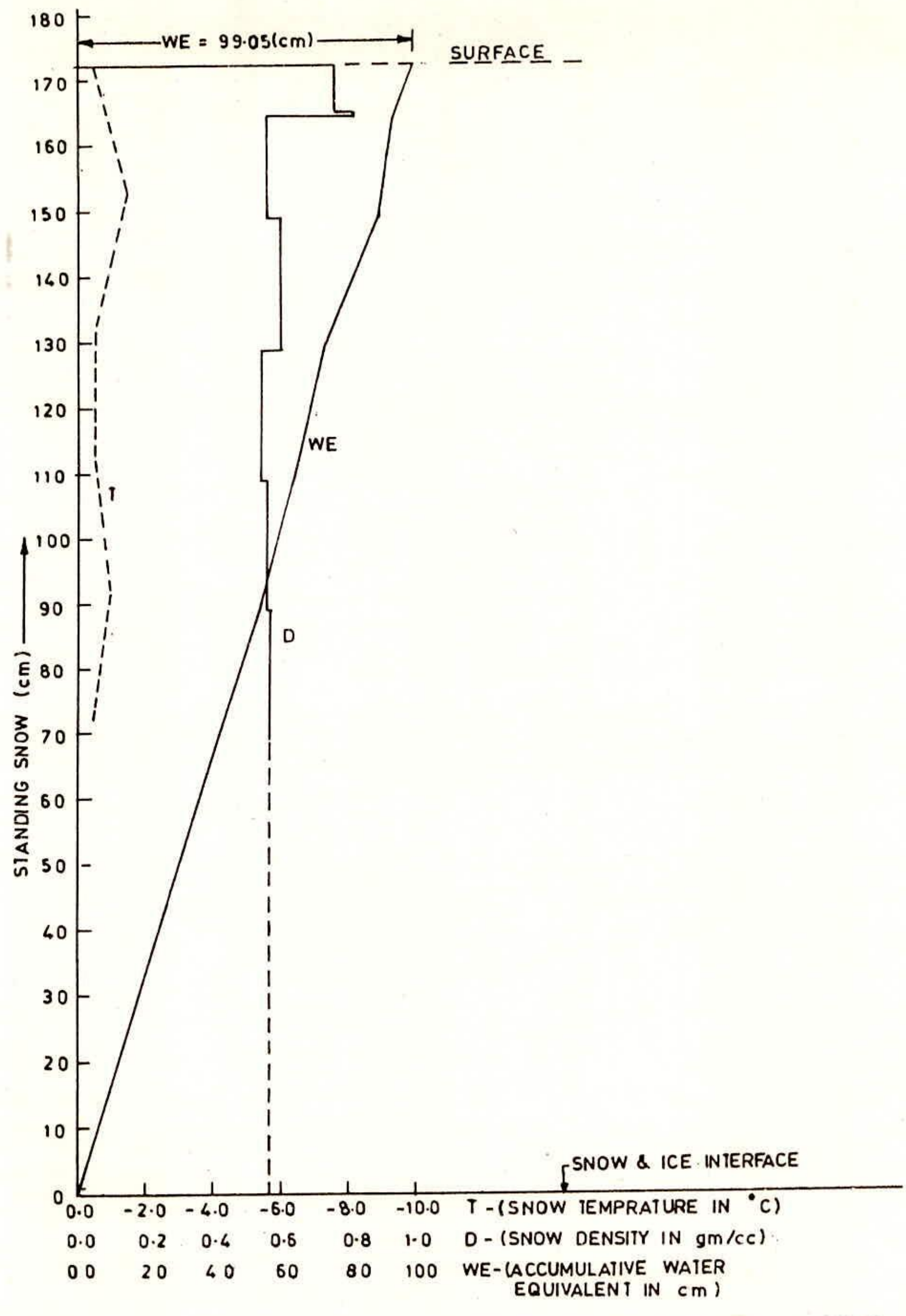


FIG.3(a) SNOW PIT PROFILE DATA OBSERVED ON 25.7.87 AT 4700 METERS ALTITUDE OF CHHOTA SHIGRI GLACIER.

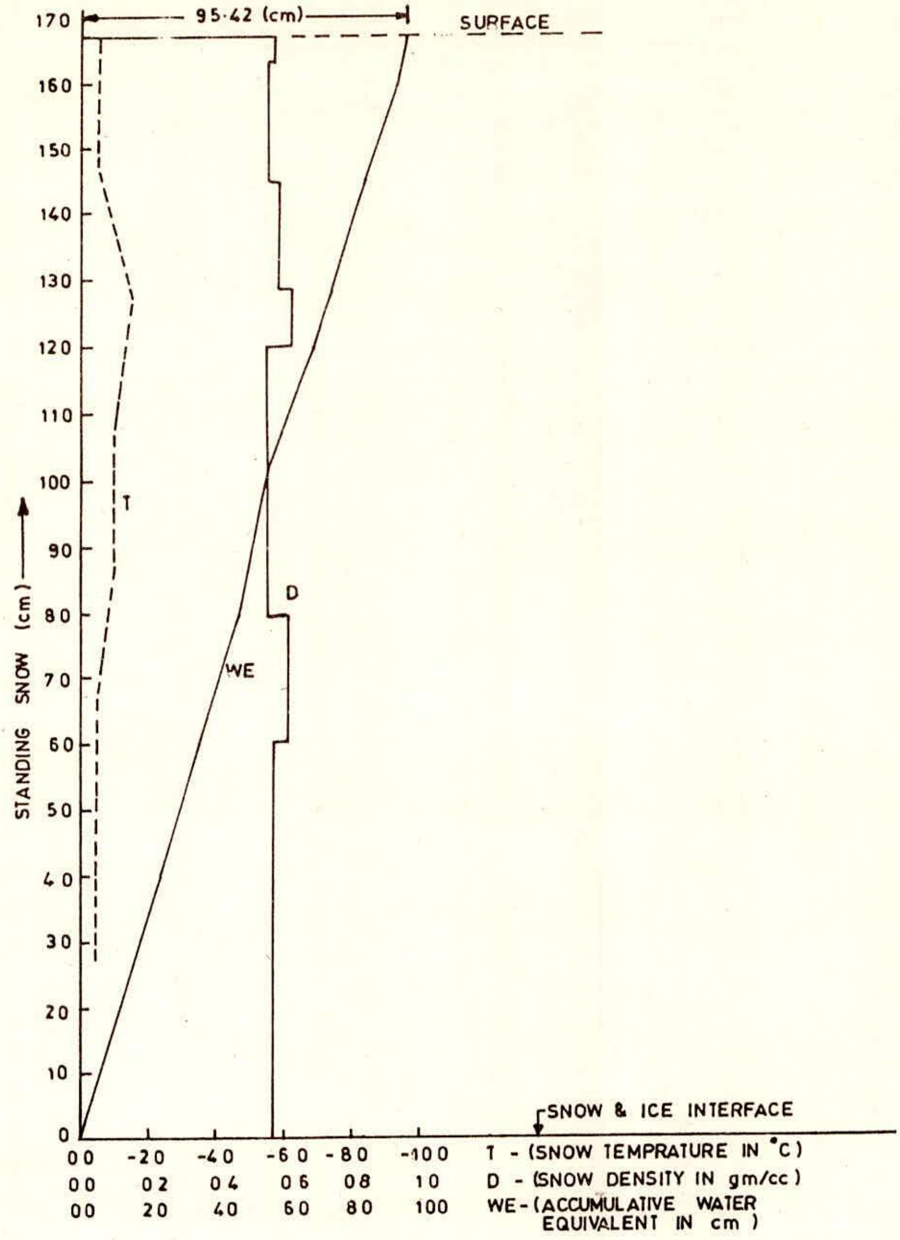


FIG.3(b) SNOW PIT PROFILE DATA OBSERVED ON 26·7·87 AT 4700 ALTITUDE OF CHHOTA SHIGRI GLACIER

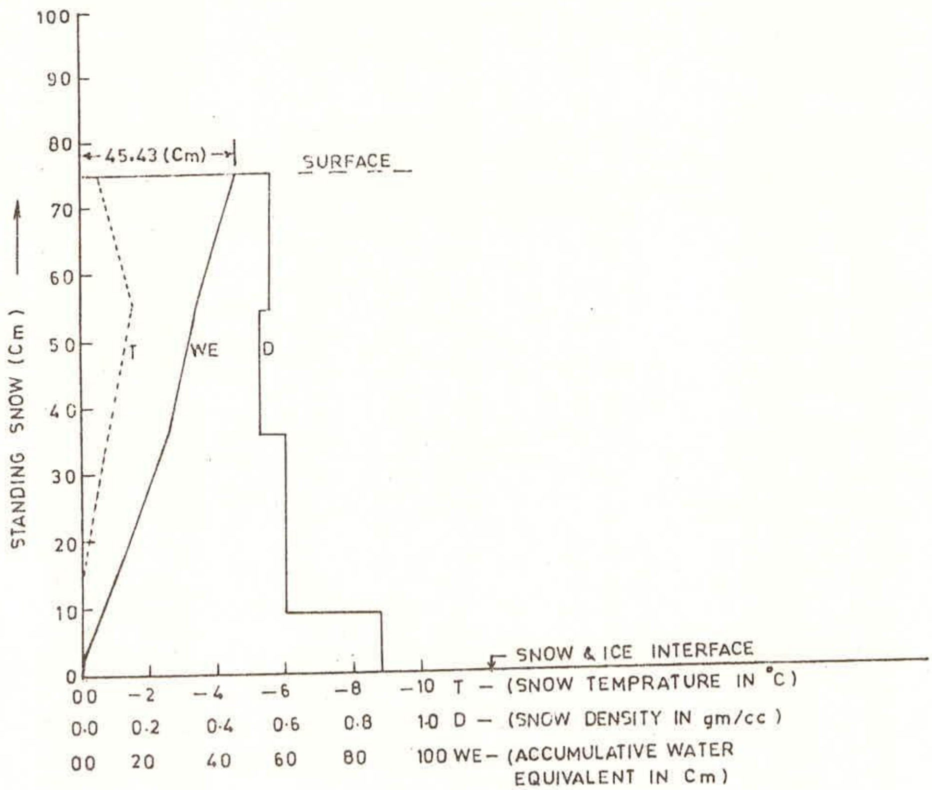


FIG.3(c) SNOW PIT PROFILE DATA OBSERVED ON 27.7.87 AT 4550 M ALTITUDE OF CHHOTA SHIGRI GLACIER.

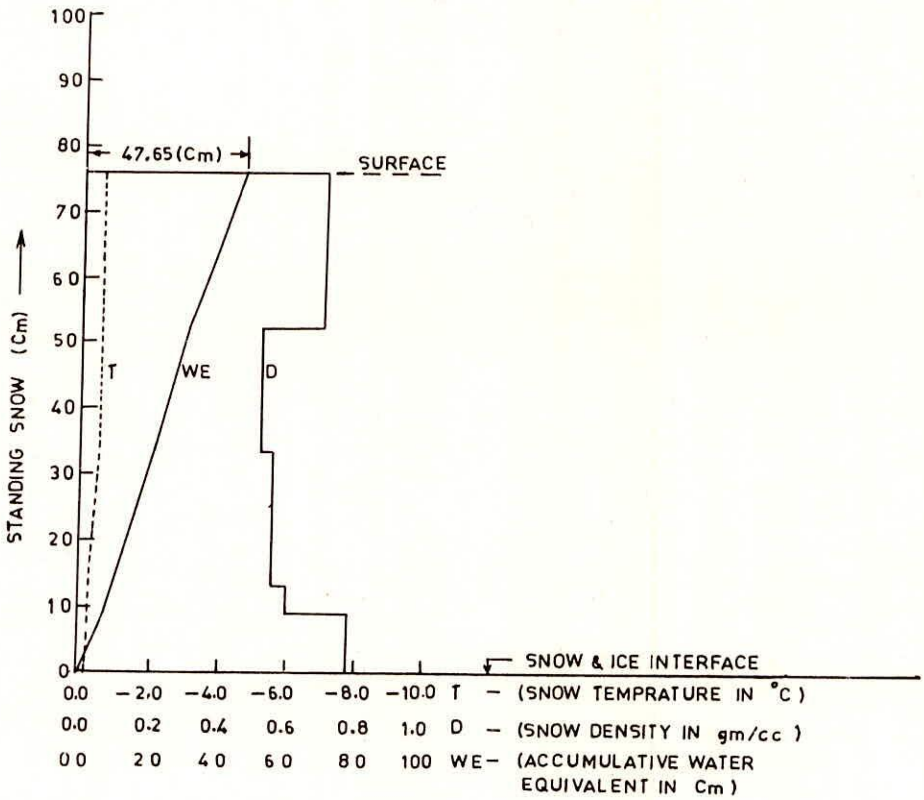


FIG.3(d)-SNOW PIT PROFILE DATA OBSERVED ON 26.7.87 AT 4550 M ALTITUDE OF CHHOTA SHIGRI GLACIER.

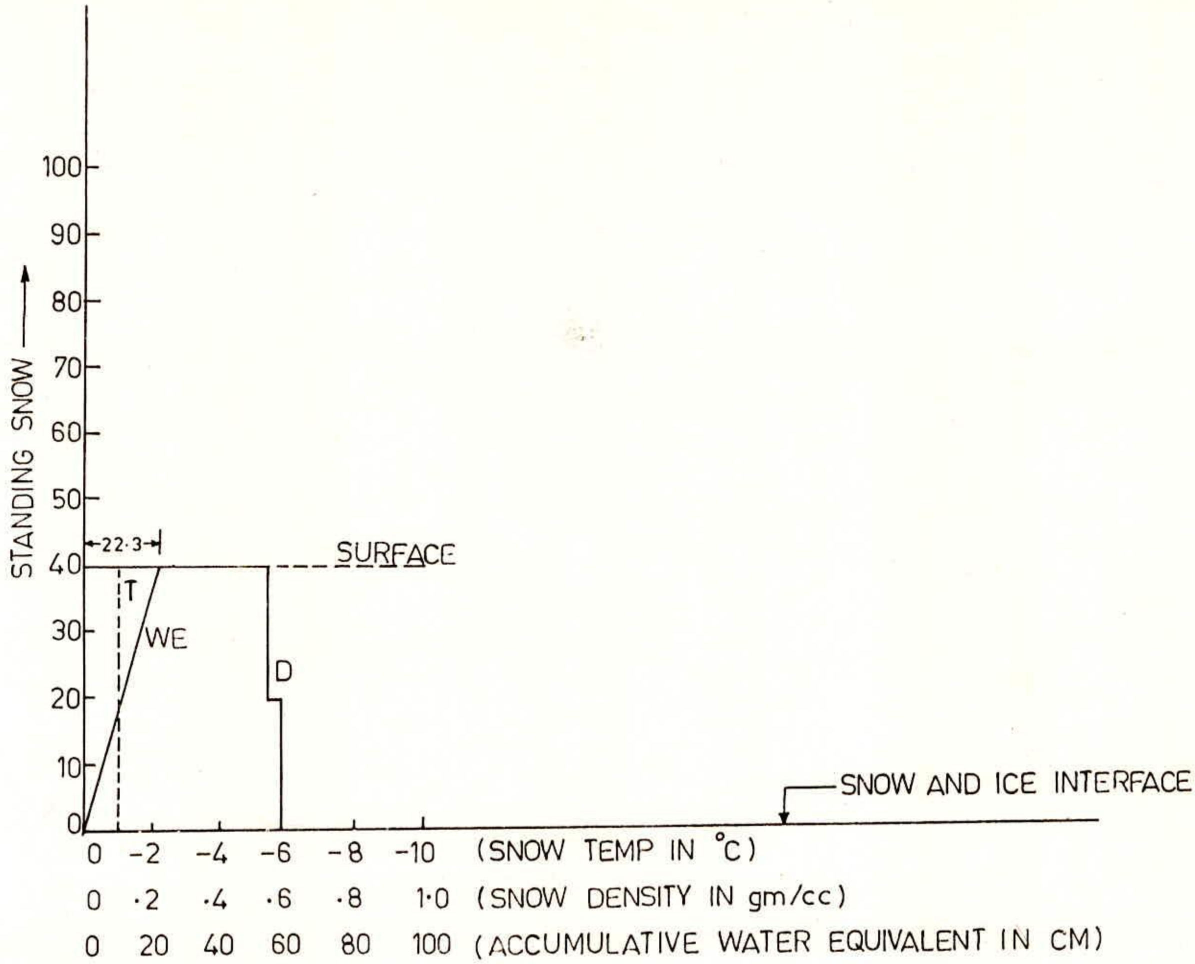


FIG. 3(e)— SNOW PACK PIT PROFILE DATA OBSERVED ON 5.8.87 AT 4550 METERS ALTITUDE OF CHHOTA SHIGRI GLACIER AT 1300 HRS.

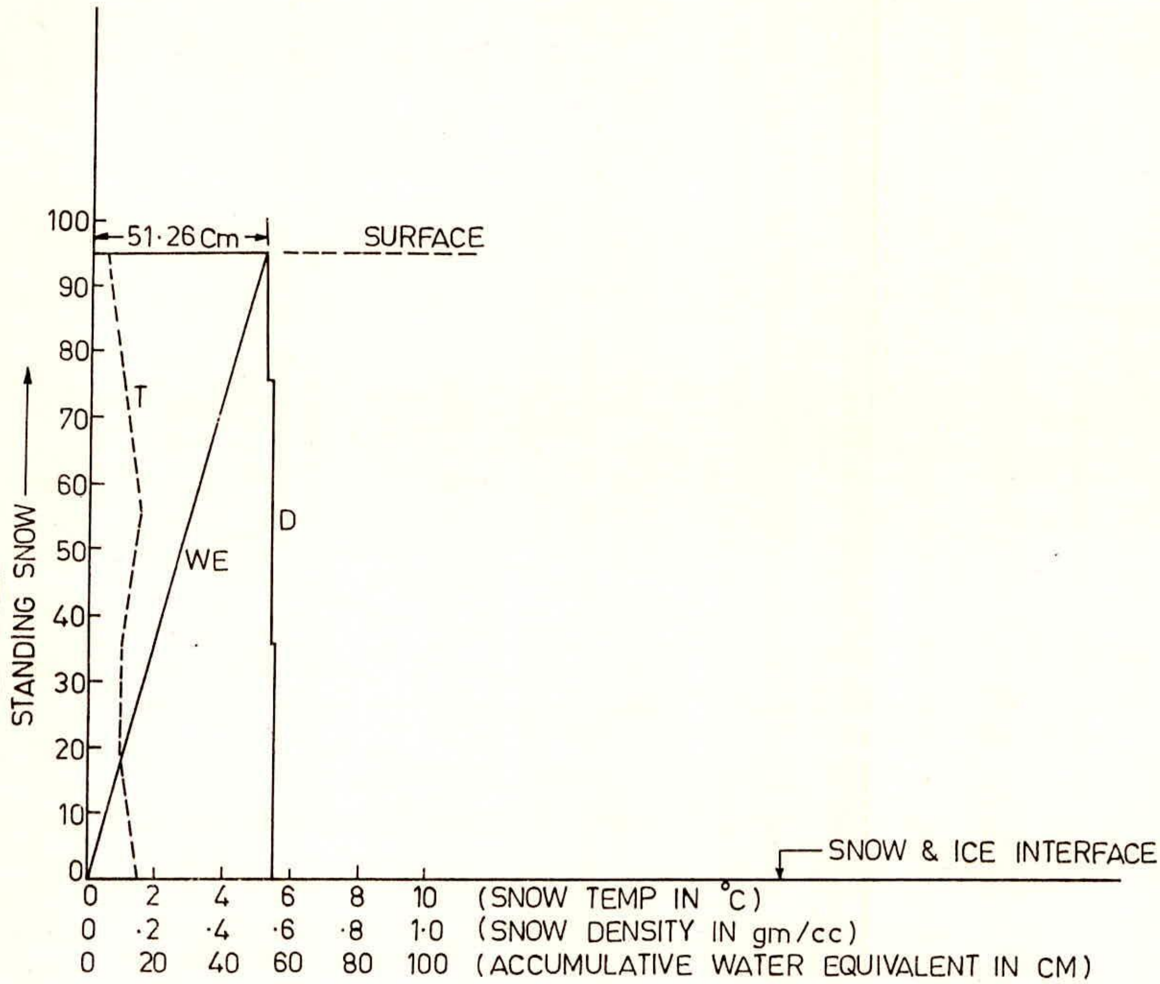


FIG. 3(f) — SNOW PACK PIT PROFILE DATA OBSERVED ON 5.8.87 AT 4700 METERS ALTITUDE OF CHHOTA SHIGRI GLACIER AT 1230 HRS.

Table 4 - SNOWPACK PIT PROFILE DATA FROM TOP
(Observed on 25th July 1987 at 1030 hrs)

Altitude :	4700 mts.,	Air Temperature	3.0 °C
Weather :	Cloudy (8 Octa)	Snow surface temperature	-0.5 °C

Total depth of snow cover over ice : 172.5 cm.

Depth (cm)	Temperature (°C)	eight of snow column (cm)	Density (gm/cc)	Water Equivalent (cc)
0 Surface	-0.50	8.00	0.75	5.98
20	-0.15	15.00	0.56	8.43
40	-0.50	20.66	0.60	12.35
60	-0.50	19.85	0.54	10.78
80	-1.00	20.10	0.56	11.17
100	-0.50	20.10	0.57	11.37
		68.85	0.57	38.97
	Total	172.50		99.05

Average density : 0.574 gm/cc

Table 5 - SNOWPACK PIT PROFILE DATA FROM TOP
(Observed on 26th July 1987 at 1000 hrs)

Altitude	:	4700 mts.,	Air Temperature	3.0 °C
Weather	:	Drizzling, transition to snowfall	Snow surface temperature	-0.5 °C

Total depth of snow cover over ice : 167.1 cm.

Depth (cm)	Temperature (°C)	Height of snow column (cm)	Density (gm/cc)	Water Equivalent (cc)
0 Surface	-0.5	3.8	0.57	2,16
20	-0.5	18.6	0.55	10,19
40	-1.5	16.0	0.58	09.21
60	-1.0	08.8	0.62	05.49
80	-1.0	20.6	0.55	11.37
100	-0.5	19.6	0.55	10.78
120	-0.5	19.6	0.61	11.96
140	-0.5	19.6	0.57	11.17
		40.5	0.57	23.09
	Total	167.10		95.42

Average density : 0.571 gm/cc

Table 6 - SNOWPACK PIT PROFILE DATA FROM TOP
(Observed on 26th July 1987 at 0730 hrs)

Altitude :	4500 mts.,	Air Temperature	3.0 °C
Weather :	Cloudy (8 Octa)	Snow surface temperature	-0.5 °C

Total depth of snow cover over ice : 76 cm.

Depth (cm)	Temperature (°C)	Height of snow column (cm)	Density (gm/cc)	Water Equivalent (cc)
0 (Surface)	-0.5	23.6	0.71	16.78
20	-0.5	19.0	0.53	10.11
40	-0.5	19.6	0.56	10.90
60	-0.2	04.8	0.60	02.88
76	-0.25	09.0	0.78	06.98
	Total	76.0		47.65

Average density : 0.627 gm/cc

Table 7 - SNOWPACK PIT PROFILE DATA FROM TOP
(Observed on 27th July 1987 at 0900 hrs)

Altitude	:	4500 mts.,	Air Temperature	3.0 °C
Weather	:	Clear	Snow surface temperature	-0.5 °C

Total depth of snow cover over ice : 75.0 cm.

Depth (cm)	Temperature (°C)	Height of snow column (cm)	Density (gm/cc)	Water Equivalent (cc)
0 (Surface)	-0.5	20.6	0.56	11.56
20	-1.5	18.1	0.53	09.61
40	-0.7	19.0	0.60	11.36
60	0.0	08.0	0.60	04.80
		09.0	0.87	07.83
		00.3	0.90	00.27
	Total	75.00		45.53

Average density : 0.606 gm/cc

Table 8 - **SNOWPACK PIT PROFILE DATA**
(Observed on 5th Aug. 1987 at 1230 hrs)

Altitude :	4700 mts.,	Air Temperature	6.0 °C
Weather :	Clear	Snow surface temperature	-0.5 °C

Total depth of snow cover over ice : 1.05 m.

Depth (cm)	Temperature (°C)	Height of snow column (cm)	Density (gm/cc)	Water Equivalent (cc)
0 (Surface)	-0.5	19.6	0.52	10.19
20	-1.0	19.6	0.54	10.58
40	-1.5	19.6	0.54	10.58
60	-1.0	17.6	0.55	9.68
80	-1.0	18.6	0.55	10.23
100	-1.5			
	Total	95.0		51.26

Average density : 0.54 gm/cc

Table 9 - **SNOWPACK PIT PROFILE DATA**
(Observed on 5th Aug. 1987 at 1300 hrs)

Altitude :	4550 mts.,	Air Temperature	6.0 °C
Weather :	Clear	Snow surface temperature	-0.5 °C

Total depth of snow cover over ice : 40 cm.

Depth (cm)	Temperature (°C)	Height of snow column (cm)	Density (gm/cc)	Water Equivalent (cc)
0 Surface	-1.0	20.6	0.55	11.33
20	-1.0	18.6	0.59	10.97
	Total	39.2		22.30

Average density : 0.57 gm/cc

Table 10 - SNOWPACK PIT PROFILE DATA
(Observed on 12th Aug. 1988 at 1230 hrs)

Altitude : 4900 mts., Air Temperature 6.0 °C
Weather : Cloudy, Drizzling

Total depth of snow cover over ice : 37.30 cm.

Depth (cm)	Temperature (°C)	Height of snow column (cm)	Density (gm/cc)	Water Equivalent (cc)
0 Surface	-0.5	13.3	0.57	7.58
10	-0.5	12.0	0.53	6.36
20	0.25	12.0	0.55	6.60
	Total	37.30		20.54

Average Density : 0.55 gm/cc

6.0 DISCHARGE MEASUREMENTS

6.1 Selection of Gauging Site

The proper selection of discharge measurement is of major importance, as the quality of site and particularly the hydraulic characteristics of the channel affect not only the method of observation but also type of equipment adopted at the station and ultimately the accuracy of the records. Site selection in the mountainous streams is more difficult because of high gradient and presence of boulders in the streamflow and channel.

A reconnaissance survey was conducted from the snoût of Chhota Shigri Glacier (Figure 5) to the confluence of stream with Chandra river. One site could be selected for the glacial melt measurement. This gauging site was about 1200 m from the snout and about 500 m above the confluence with Chandra river. The site elevation was about 3830 m. Melt from the glacier was transversing through the confined channel having sustantially stable boundaries with two big boulders present on both banks of the stream. A small bund on the left bank of the channel was made to channelize the whole water into a single stream. For a small reach the flow was found nearly non-turbulent at the gauging site.

This gauging site was easily accessible from the glacier base camp which was approximately 1 km west of the site. The site was free from any natural or artificial obstructions on the banks or in the channel, which are likely to cause disturbances, distortions or reverse of flow. No weed growth was near the gauging site.The selected site was far enough in upstream from the confluence with Chandra river to avoid the effect of any backwater from other stream.(Fig.6). The same site was used for all years of investigations.

6.2 Velocity-Area Method

6.2.1 Measurement of velocity

The channel was divided into two segments of 6.30 and 3.30m width each and velocity of water in each segment was determined separately. The wooden surface floats having dimension 10 x 10 x 2 cm were used for this purpose. The floats were released in the mid of each segment and using a stop watch the time taken by the float to travel over a stretch of 7 meters between the cross-sections of the reach in the stream was

Fig. 4 - Snowpack stratigraphic study by digging a pit

Fig. 5 - Snout of Chhota Shigri glacier

Fig.6 - A view of Chhota Shigri glacier melt stream and gauging site

determined. No straight reach more than 7 meters having non-turbulent flow was available. The float reach was also marked at the bank of the channel. The estimated position of each float with respect to the bank had also been noted at the down stream cross-section.

The float velocity represented the surface velocity of the flow. The procedure was repeated with float in each of the segments across the channel. The velocity coefficient was also determined to compute the average velocity in each segment.

6.2.2 Elevation of average velocity

The mean velocity in the vertical is equal to the surface float velocity multiplied by a coefficient whose value is dependent on the shape of the vertical velocity profile of the stream. To compare this coefficient the velocity observations were made by current meter at surface and 0.6 d (where d is the total depth) point in the channel assuming that 0.6 d velocity represents the average velocity of the channel at the site. Observations at several vertical points could not be carried out because of excessive velocities and flow of boulders with water.

The mean of average velocity at 0.6 d point was observed to be 2.238 m/s while that of surface velocity was 2.459 m/s at the same time. These figures provided the average velocity coefficient as 0.910.

The cross sectional profile of the stream and bed shape at the gauging site is shown in Fig.7. The pattern of the cross-sectional area versus depth of the channel for each segment and whole channel at the discharge measurement site is depicted in Figure 8.

6.3 Salt Dilution Technique

In turbulent streams, application of the chemical method is generally more advantageous than any other discharge measuring methods. The relative salt dilution measurement is one of the chemical methods which was used on 28.7.1987 at 1030 hrs and 1630 hrs for measuring the discharge of melt water from Chhota Shigri Glacier. The best suitable stream reach and site for salt brine injection and observational points were selected with the help of homogeneous mixture of Rohdamine colour. A concentrated salt brine (primary solution) dumped into the stream water and the passage of salt wave was observed by conductivity meter while time was observed by stop watch. The water temperature variation was 3.0°C

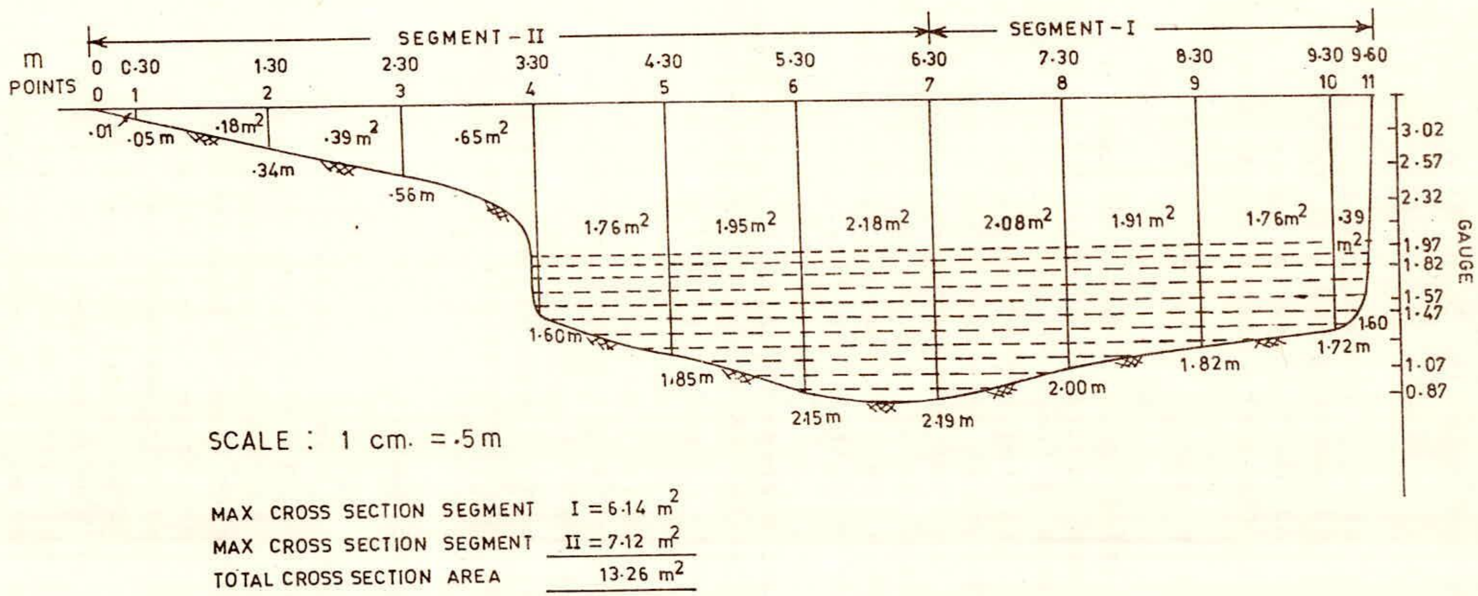


FIG. 7 — CROSS-SECTION OF THE DISCHARGE OBSERVATION SITE IN CHHOTA SHIGRI STREAM.

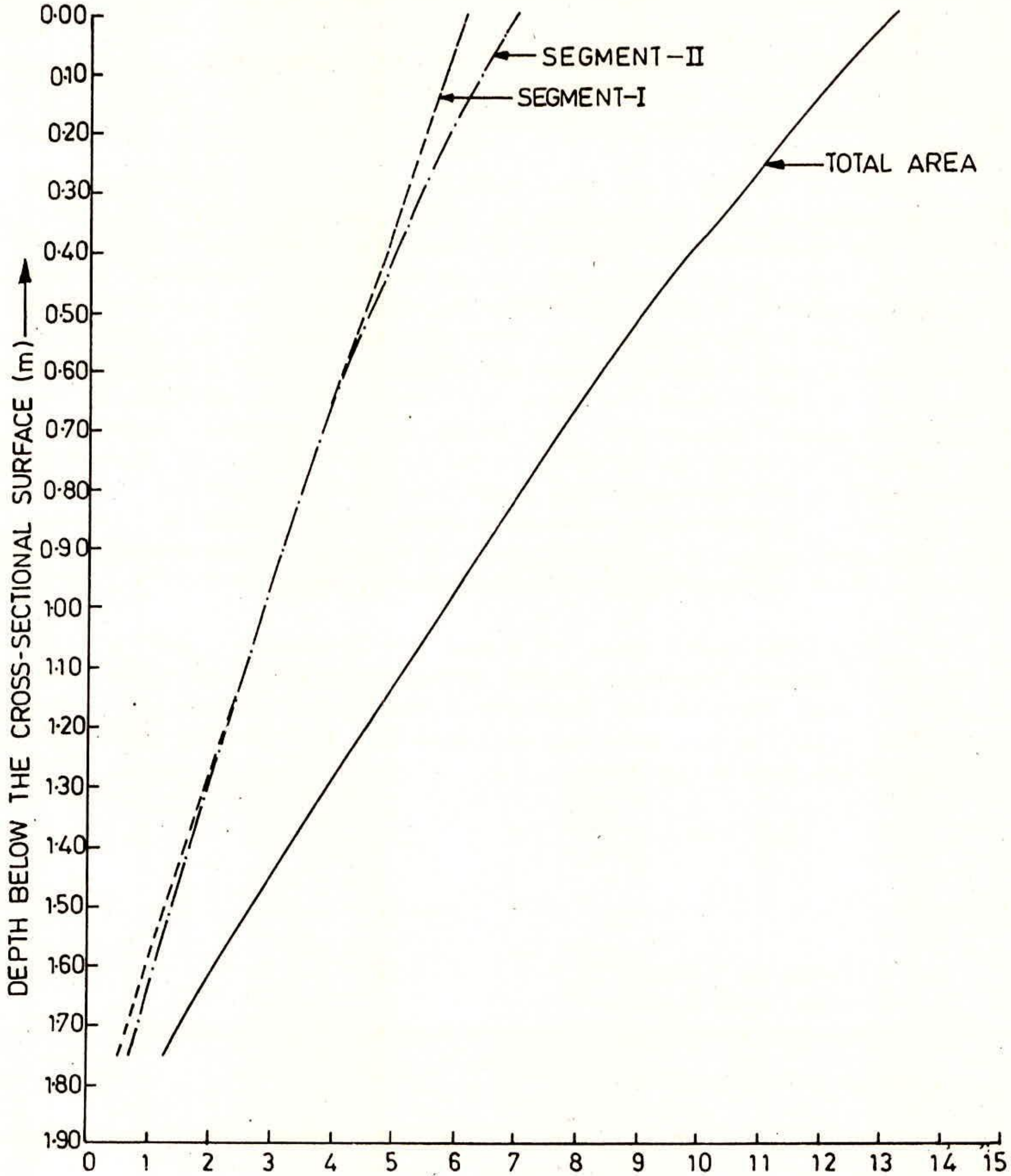


FIG. 8 -DEPTH AREA CURVE OF THE GAUGING SITE

to 4.0°C during observations. The discharge at 1030 hrs and 1630 hrs was computed to be 6.94 and 7.54 cumecs respectively.

The observed values of discharge for years 1986, 1987 and 1988 have been shown in Fig.9. Hourly discharge during day time of 1986 is given in different plots of Appendix A.

6.4 Stage-Discharge Relationship

Based on the data collected on stage and discharge in the stream during the expedition to the Chhota Shigri Glacier, efforts have been made to develop a relation between stage and discharge. For this purpose, the gauge scale was painted on an existing structure (big boulder) having vertical and plane surface exactly at the right bank of the stream. The scale was graduated in meters and centimeters. The stage could be easily read from the other bank of the stream because of the narrow width of the stream. The night observations of stage and discharges were made with the help of powerful lights. A sufficient number of discharge measurements with corresponding stage have been collected to get more accurate relationship between them. The relation between stage and discharge is established by correlating measurements of discharge with corresponding observations of stage.

The observed values of stage and discharge are plotted in Fig.10. A smooth curve is drawn through the array of the data points suitably distributed throughout the whole range of water level. The relation has been established on the basis of these records in the following form:

$$Q = a(h - h_o)^b$$

where,

Q = discharge (m/s)
h = gauge height (m)
h_o = the gauge reading corresponding to zero discharge
a and b are constants

The values of a and b in equation for a given range are obtained by the least square method.

Based on the data observed at the Chhota Shigri Glacier discharge size, the following relation is obtained:

$$Q = 9.28\ (h - 1.07)^{2.08}$$

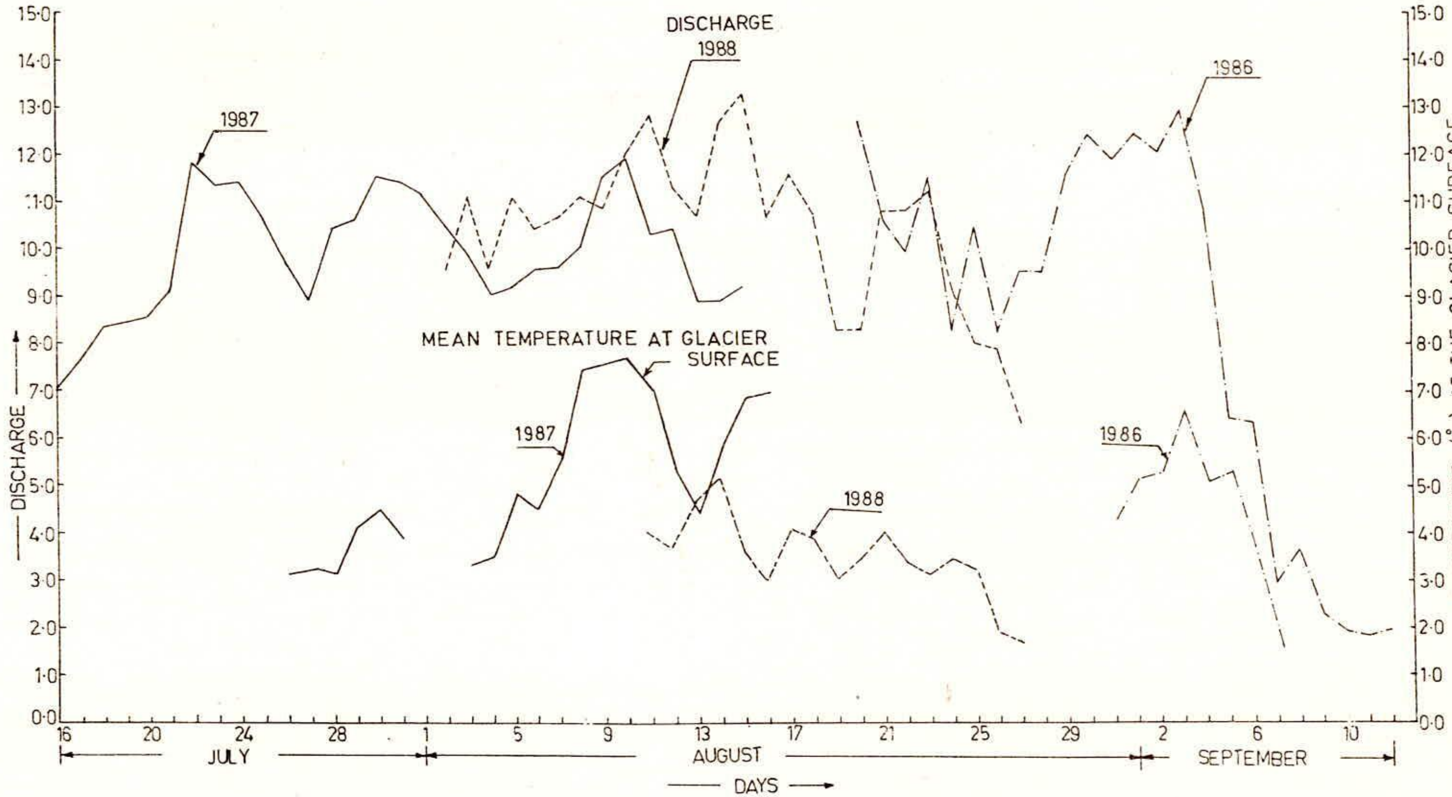


FIG. 9. OBSERVED DISCHARGE AT THE GAUGING SITE OF THE GLACIER MELT STREAM.

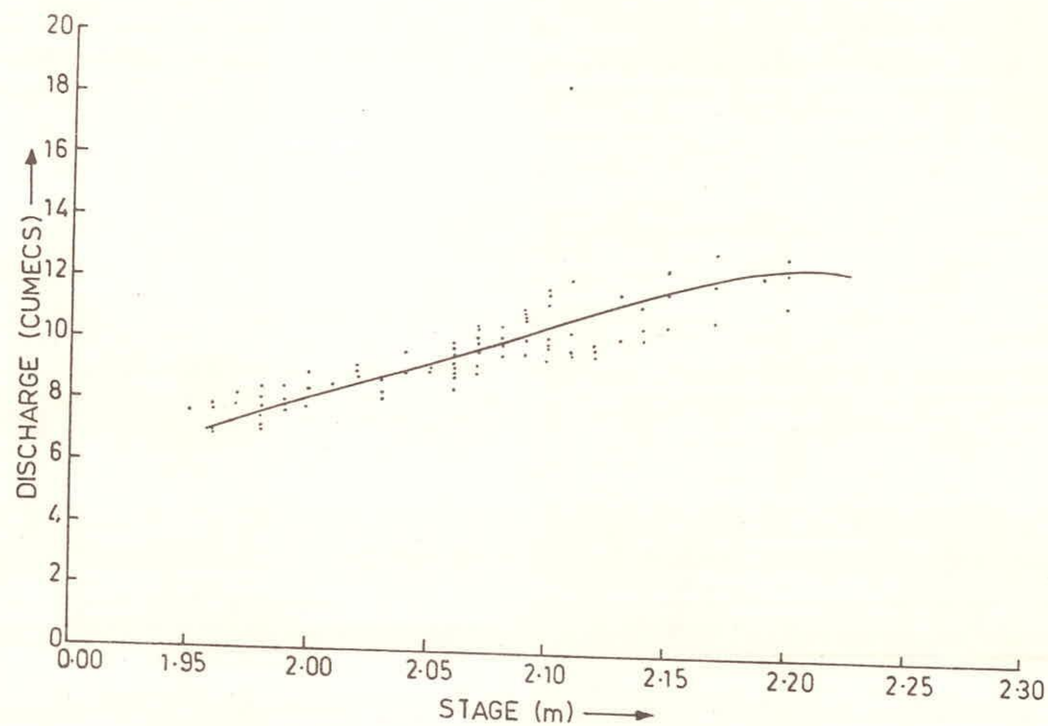


FIG. 10 STAGE-DISCHARGE RELATIONSHIP AT THE GAUGING SITE

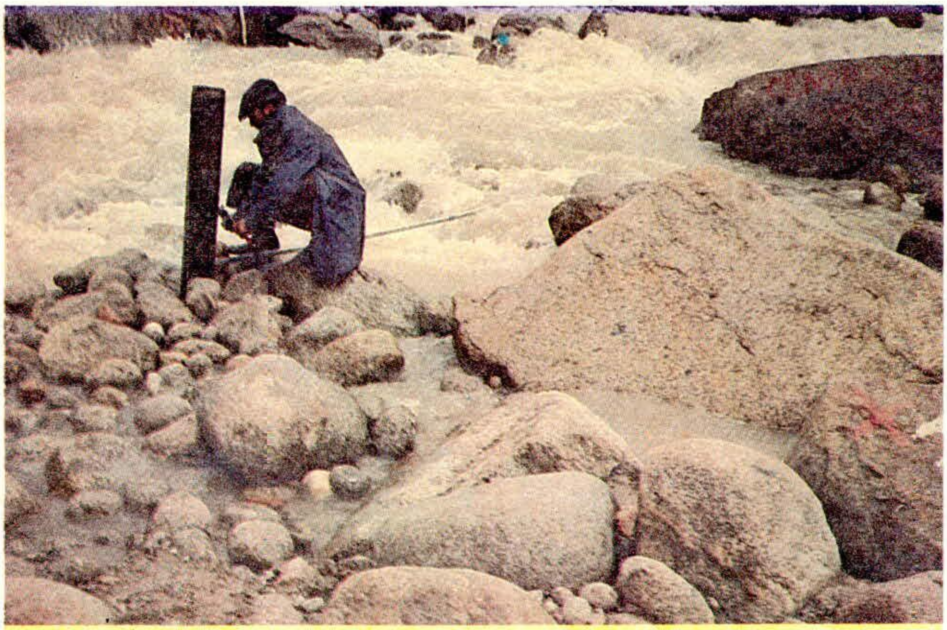


Fig.11 - Installation of stilling well at the gauging site

Fig.12 - Water level recorder installed at the gauging site

6.5 Installation of Water Level Recorder

Because continuous measurement of discharge is not feasible, records of discharge are computed from the relation between stage and discharge.To record the water level in the glacier melt stream, a water level recorder was installed near the gauging station of the stream. The float actuated recorder was used for recording. The stilling well in which float activated was designed and fabricated at NIH workshop. The well was connected with channel through galvanized iron pipes. A fine mesh was fitted at one end of the pipe which was leading to the channel to prevent the debris entering the stilling well.(Fig.11 and 12)

A specimen of the recorded water level is shown in Fig.13. Such records are able to provide the information regarding maximum and minimum flows in the channel on diurnal or monthly basis. Once the relationship between stage and discharge is developed, the discharge can be computed directly from the known water level in the stream.

6.6 Diurnal Variation in Discharge and Time Lag

The diurnal variation in discharge was determined by hourly observation of discharge. The pattern of streamflow fluctuation is shown in Fig.14 and 15. The discharge exhibits a diurnal rhythm superimposed upon a base flow whose volume varies more slowly. The peaks in the discharge are because of the contribution of the ice melt from the ablation area which reaches the site rather immediately after few hours. The contribution from the accumulation zone take relatively longer time. Consequently, the discharge observed during night hours is also found very significant.

It has been noticed that generally the maximum discharge occurs during day between 1530 hrs and 1900 hrs, while minimum occurs between 0300 to 0700 hrs. The difference Q between daily maximum discharge, Q_{max} and the daily minimum discharge Q_{min} has been found to be 4.93, 3.51 and 5.58 cumecs for 22.7.87, 9.8.87 and 10.9.87 respectively. The ratio of Q_{max} and Q_{min} for the same dates has been computed as 1.56, 1.35 and 1.59 respectively. The ratio of Δ Q to Q is called the relative daily variation extent of discharge, Q being the daily mean discharge. These ratio are useful to compare the daily discharge fluctuations of the day to day melt from a glacier and also from different glaciers. The

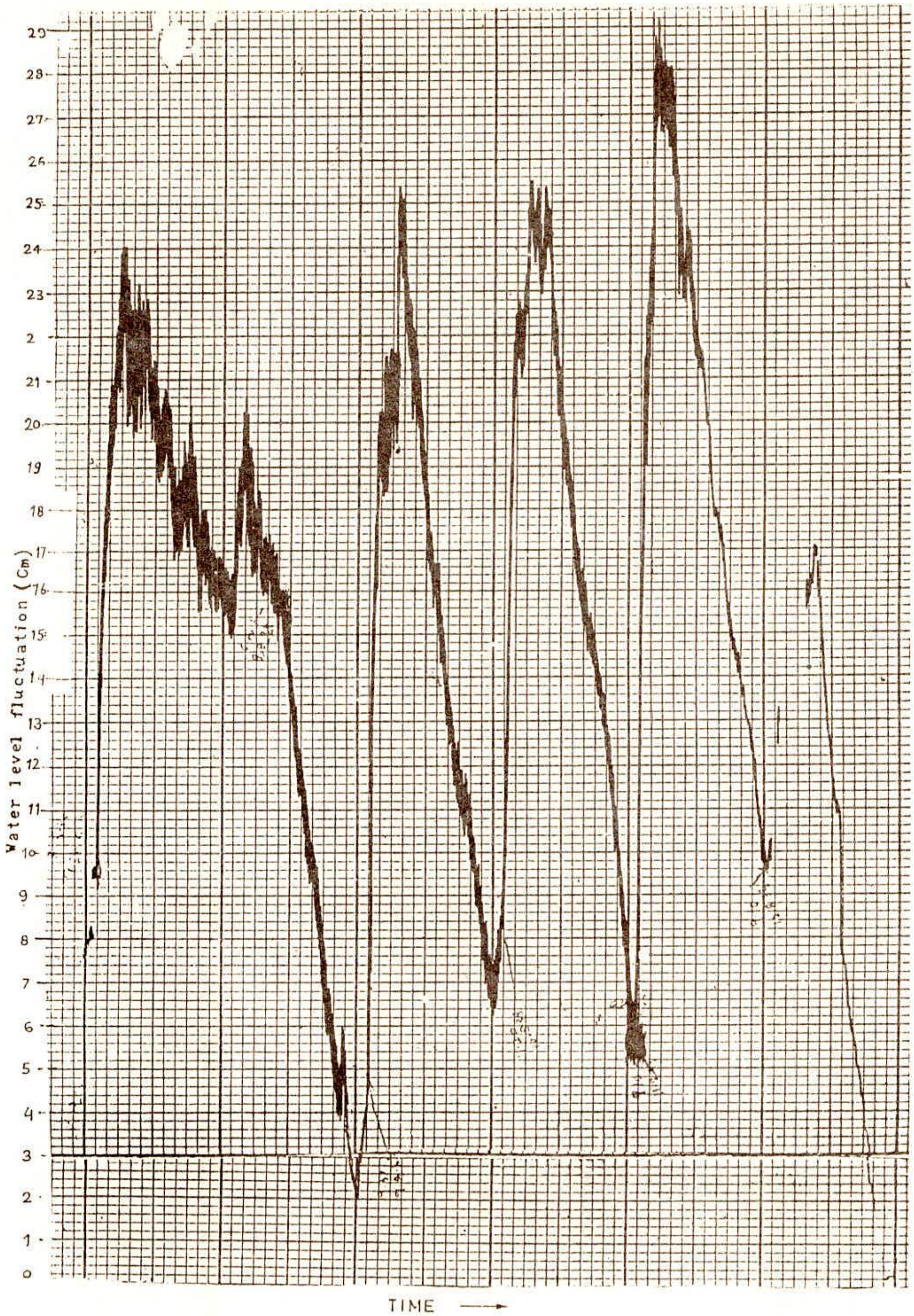


FIG.13. A SAMPLE OF WATER LEVEL RECORDED IN THE MELT STREAM

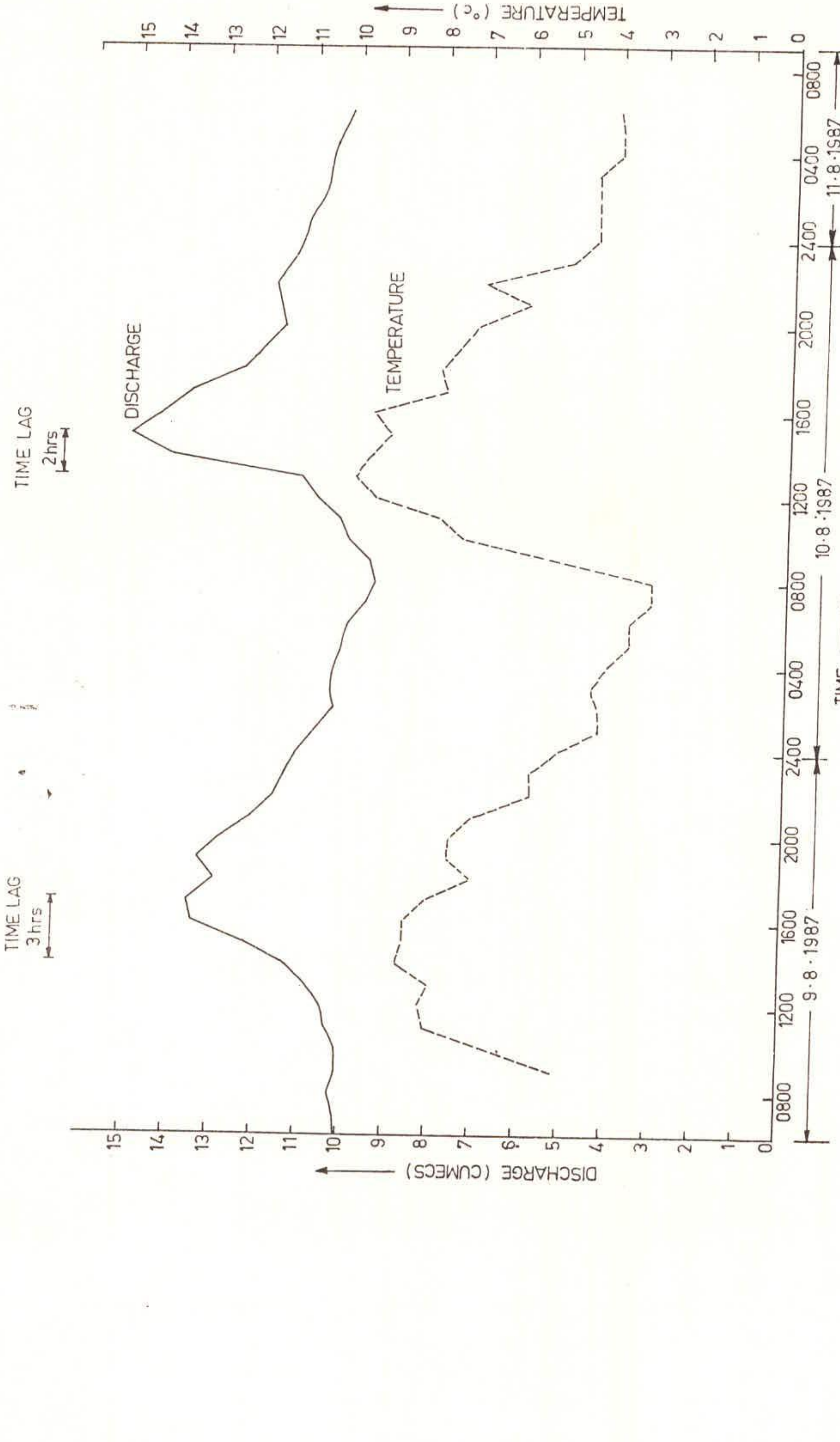


FIG.14 - DIURNAL VARIATION IN FLOW WITH TEMPERATURE AT GLACIER SURFACE

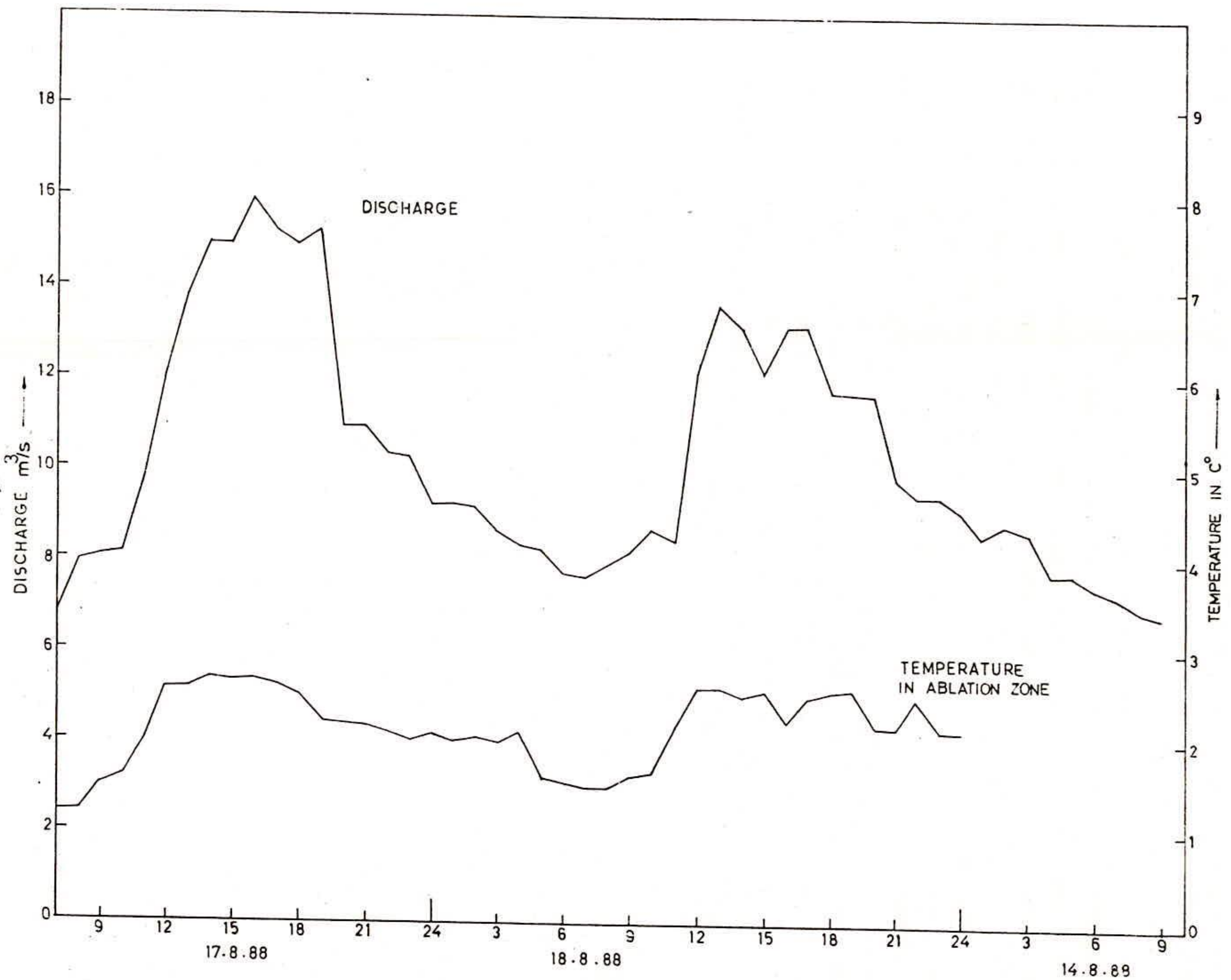


FIG.15. HOURLY OBSERVATION OF DISCHARGE WITH TEMPERATURE RECORDED IN ABLATION ZONE

value of this ratio for Chhota Shigri Glacier has found to be 0.45 , 0.31, 0.51 on 22.7.87, 9.8.87 and 10.8.87 respectively.

The plot of hourly temperature along with hourly observed discharge recorded in 1987 shows that maximum discharge generallyoccurred 2-3 hours after the maximum temperature was observed at the glacier surface (Fig.14). This gives a rough indication of the travel time of melt water from its point of generation on the glacier (ablation area) to the discharge measuring site. The time lag from total glacialised basin would be in days because as mentioned above the melt water from the firn area takes very long time to reach the stream.

The ablation zone temperature and complete hydrograph recorded in 1988 indicate time lag between 1-2 hours (Fig.15). The 1988 time lag is about one hour less than the time lag of 1987. The reduction in the time lag may be explained on the basis of ablation area and drainage pattern of the glacier. It has been noticed that this year,the ablation zone was sufficiently large in the areal extent in comparison to the 1987 observations. An increase in the ablation area means the reduction in the accumulation area of the glacier, provided the total area of the glacier has not been much changed. Consequently, there is drastic change in the drainage pattern of the glacier. Therefore it can be concluded that by decreasing in the accumulation area or increase in the ablation area results in short duration time lag, which has been found from the observations.

7.0 SUSPENDED SEDIMENT TRANSPORT

The sediment transport in steep mountain streams is more complex than in rivers with gentle slope. Sediment concentration can become extremely high, moving particles can range from boulders to clay sizes and because of structuring and restructuring of the bed, the transport rate is expected to vary widely in time. By systematic observation of sediment and discharges in mountain streams it should be possible to evolve relationships between suspended sediment and discharge in the stream.

7.1 Sediment Sampling in Glacial Melt and Analysis

To obtain the information on the magnitude of the suspended load transport, water samples were collected with the help of samplers at the discharge site. Using the sampler of 1000 cc capacity, the mixture of water and sediment was scooped from the surface flow of channel. Daily samples were collected at 1200 hrs assuming that an average discharge passes at this time. The sample were kept for at least 24 hrs duration adding few drops of the alam solution containing 5% concentration. This solution was used to acceleate the process of settling down the suspended sediments. Afterwards, sediment samples were filtered in an ashless filter paper (whatman-40). To remove the residue of the alum solution, the samples were washed several times in the funnel itself. The samples were dried and packed very carefully in a polythene bag noting down the detaiis of the sample and brought to the laboratory for further analysis.

In the laboratory the samples were heated to such temperatures that the filter paper was burnt leaving no ash in the sediment sample. The weight of the residue was determined which provided the suspended sediment concentration in mg/1000 cc. The sediment transport was found by the product of sediment concentration and discharge in a section of the stream. Suspended sediment transport in ppm (by weight) has been shown in Fig.16 and Fig.17 for the year 1987 and 1988 respectively.These figures elucidate that an increase in the discharge corresponds to an increase in sediment concentration. However, the first high peak of discharge shows a highest concentration of suspended sediment. This could be attributed to the wash load which is stored in the alluvial tones and moraines etc.

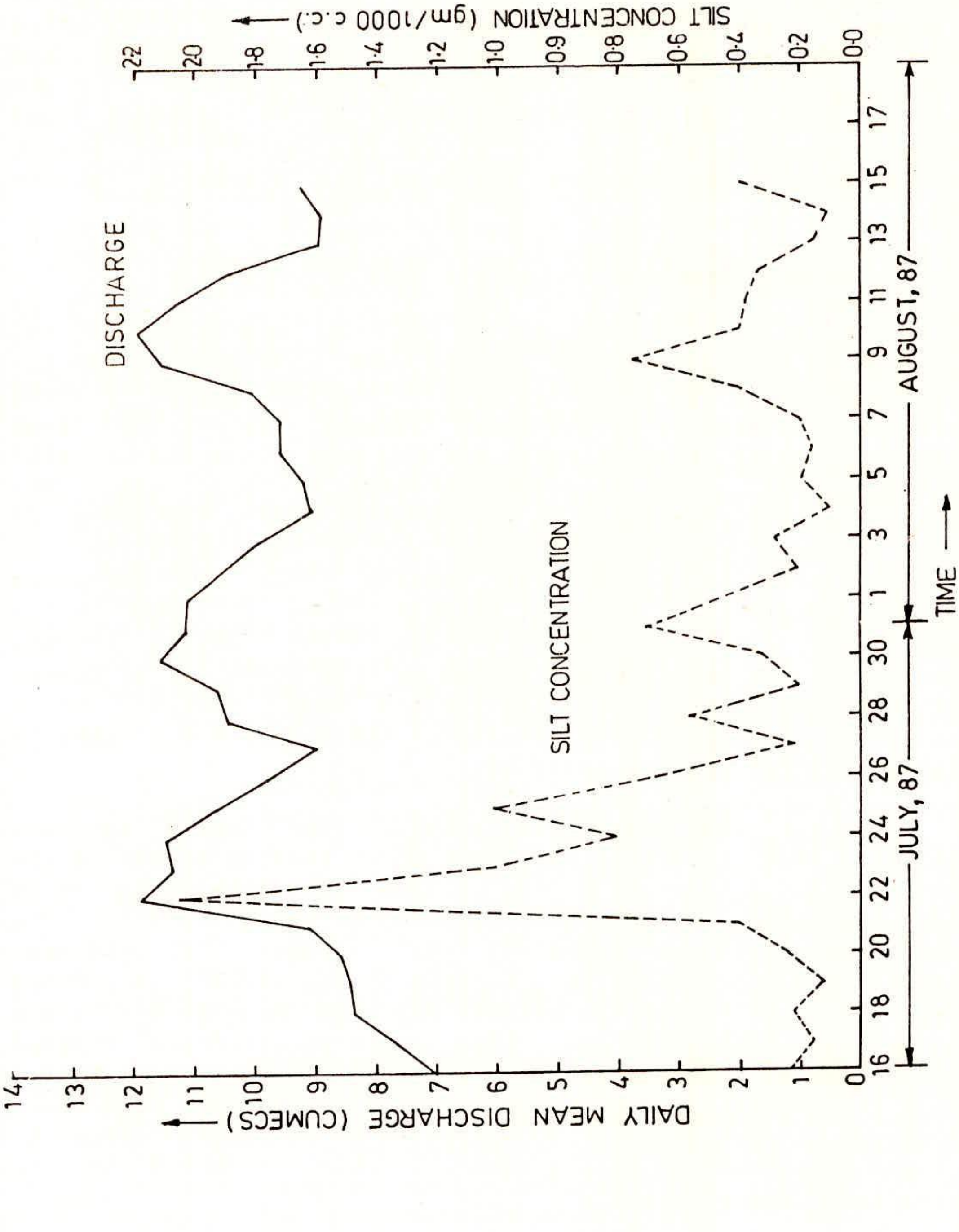


FIG.16–SUSPENDED SEDIMENT TRANSPORT CONCENTRATION WITH DISCHARGE

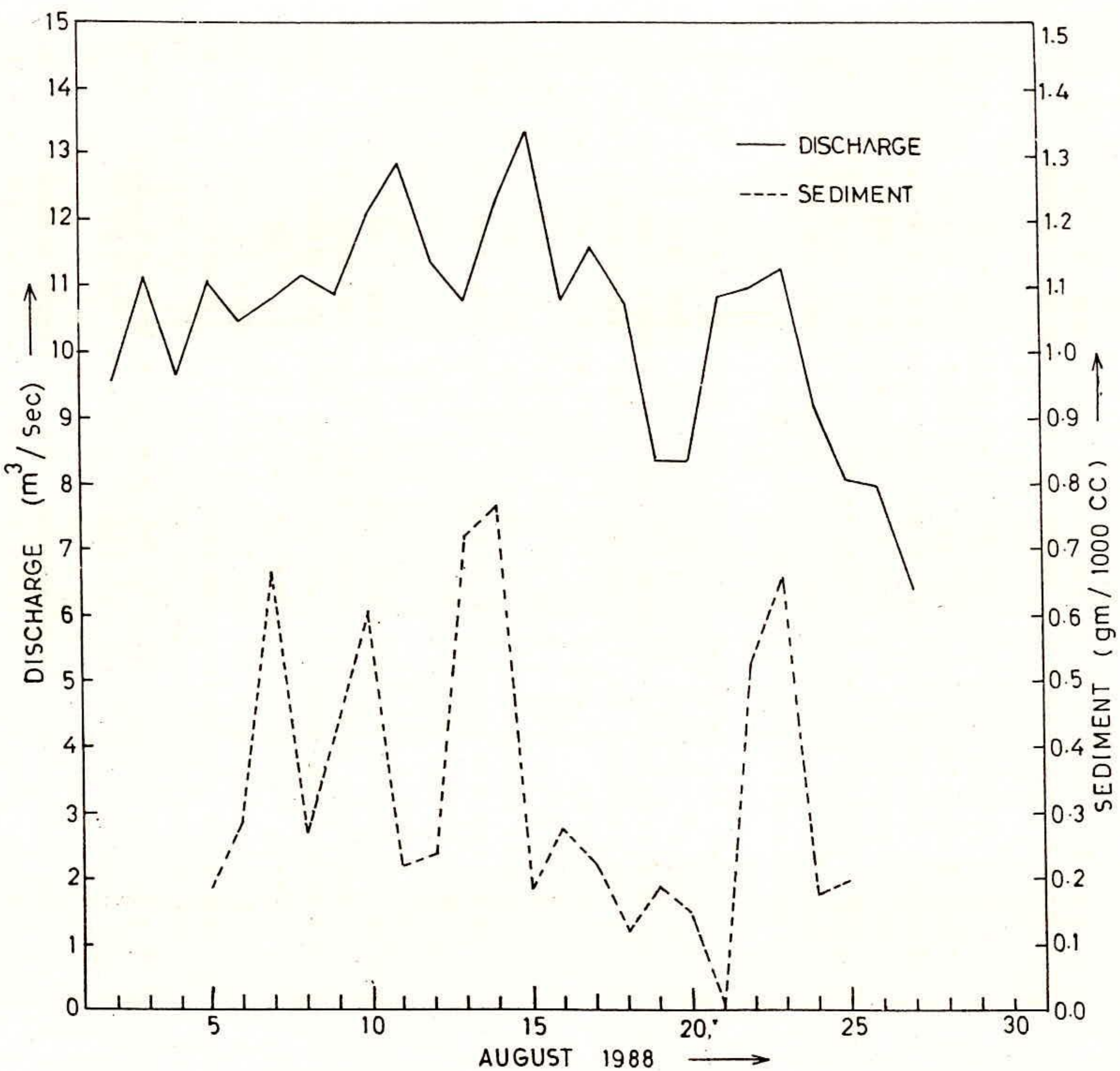


FIG. 17. SUSPENDED SEDIMENT TRANSPORT WITH DISCHARGE

8.0 CONCLUSIONS

Based on the above investigations, the following conclusions are drawn:

1. The density of firn in the accumulation has been measured to be 0.55 gm/cc. The crystals of round shape and approximately 1 mm in size were found in snow-pack of both zones.

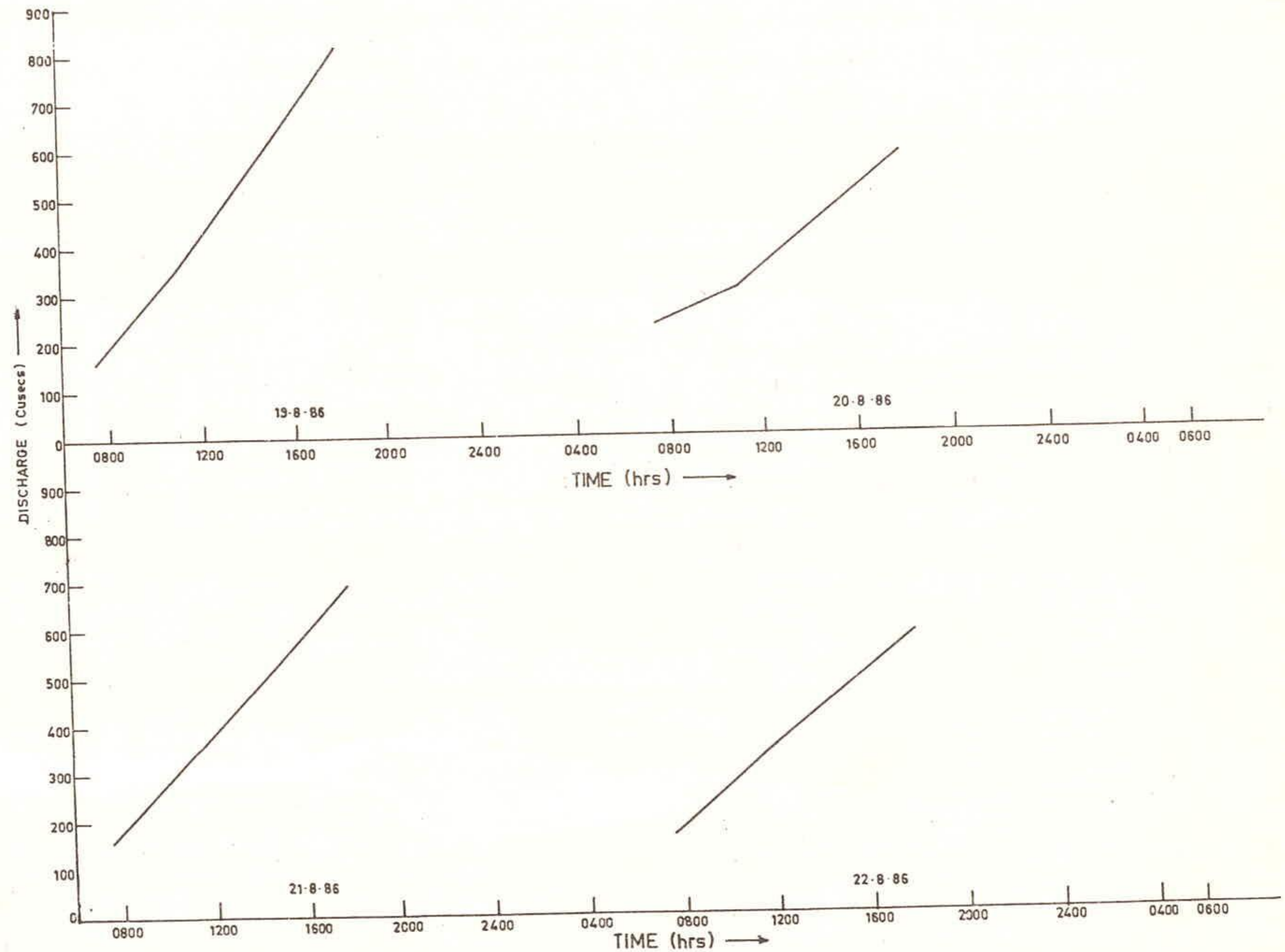
2. A coefficient of 0.91 has been obtained to arrive at average velocity from surface velocity of stream.

3. It was found that generally maximum discharge occurs during day between 1530 hrs and 1990 hrs, while the time for the minimum discharge was noticed to be between 0300 hrs to 0800 hrs. The ratio of maximum and minimum flow was computed to be in the range of 1.35 to 1.59. This lower value of ratiosreveals that glaciers contribute significantly even during the nights.

4. The time lag between ice melting at the glacier surface (ablation zone) and reaching at gauging site is determined to be between 2 and 3 hours in the year 1987. It was reduced to 1-2 hours in 1988. This reduction in time lag in comparison to 1988 might have resulted because of an increase in the ablation area and decrease in the accumulation area of the glacier. In such condition the drainage pattern of the glacier is likely to be largely modified.

5. The sediment transport characteristics of the melt stream have been observed to fluctuate widely. No direct relationship could be established between discharge and sediment transport though broadly it could be concluded that an increase in discharge corresponds to increase in suspended sediment concentration. A drastically high concentration observed on the day of first high peak of discharge is supposed to be due to side wash load stored in moraines, debris and other alluvial fills.

6. It is understood that debris and boulders present in the ablation zone accelerate the melting process at the glacier surface. Therefore a separate study should be carried out for such contribution determining the albedo of such surface and the coverage.


DISCHARGE (Cusecs)
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700
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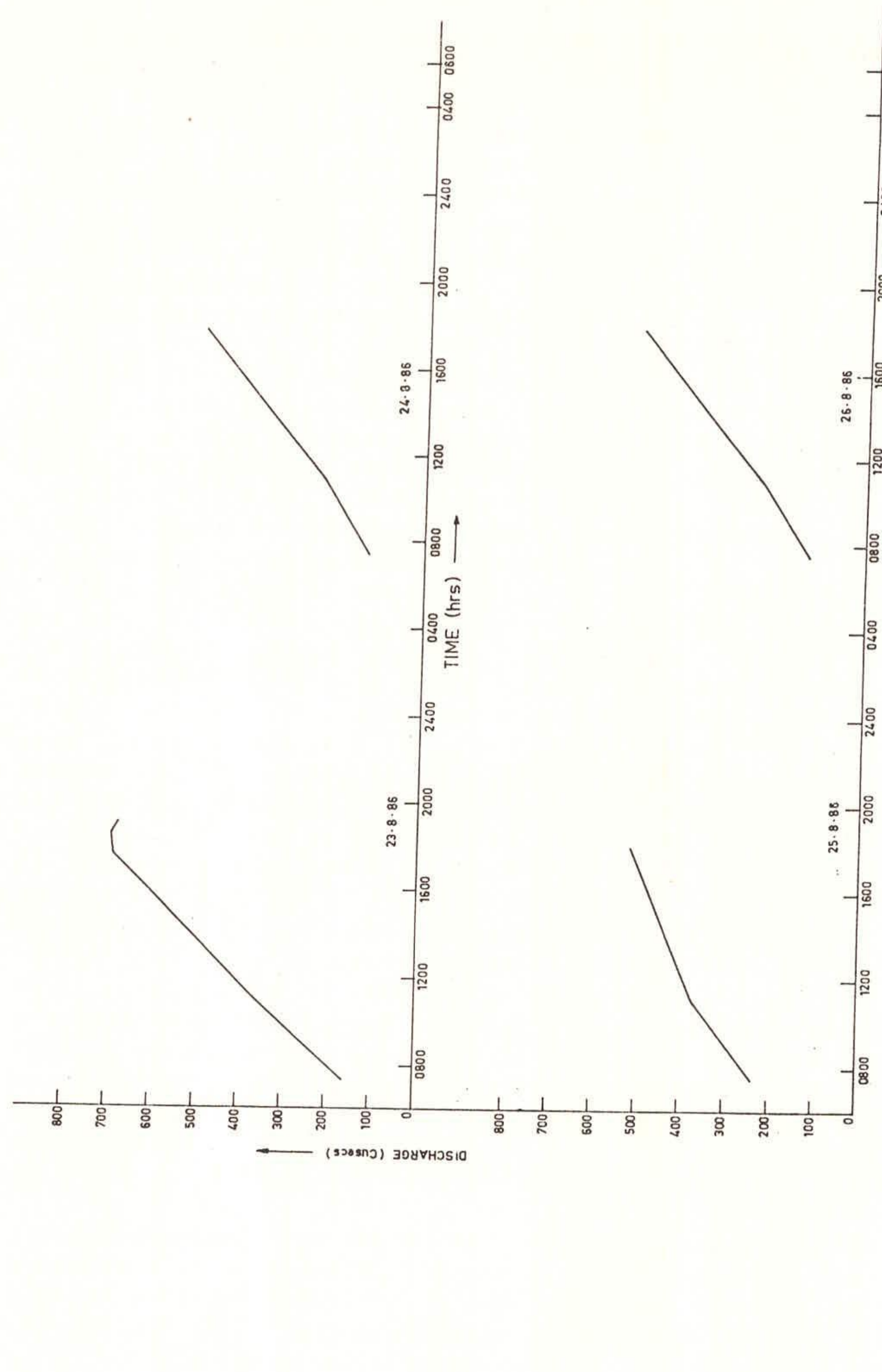
400
300
200
100
0
19-8-86
20-8-86
0800
1200
1600
2000
2400
0400
0800
1200
1600
2000
2400
0400
0600
TIME (hrs)
21-8-86
22-8-86
TIME (hrs)


DISCHARGE (Cusecs)
TIME (hrs)
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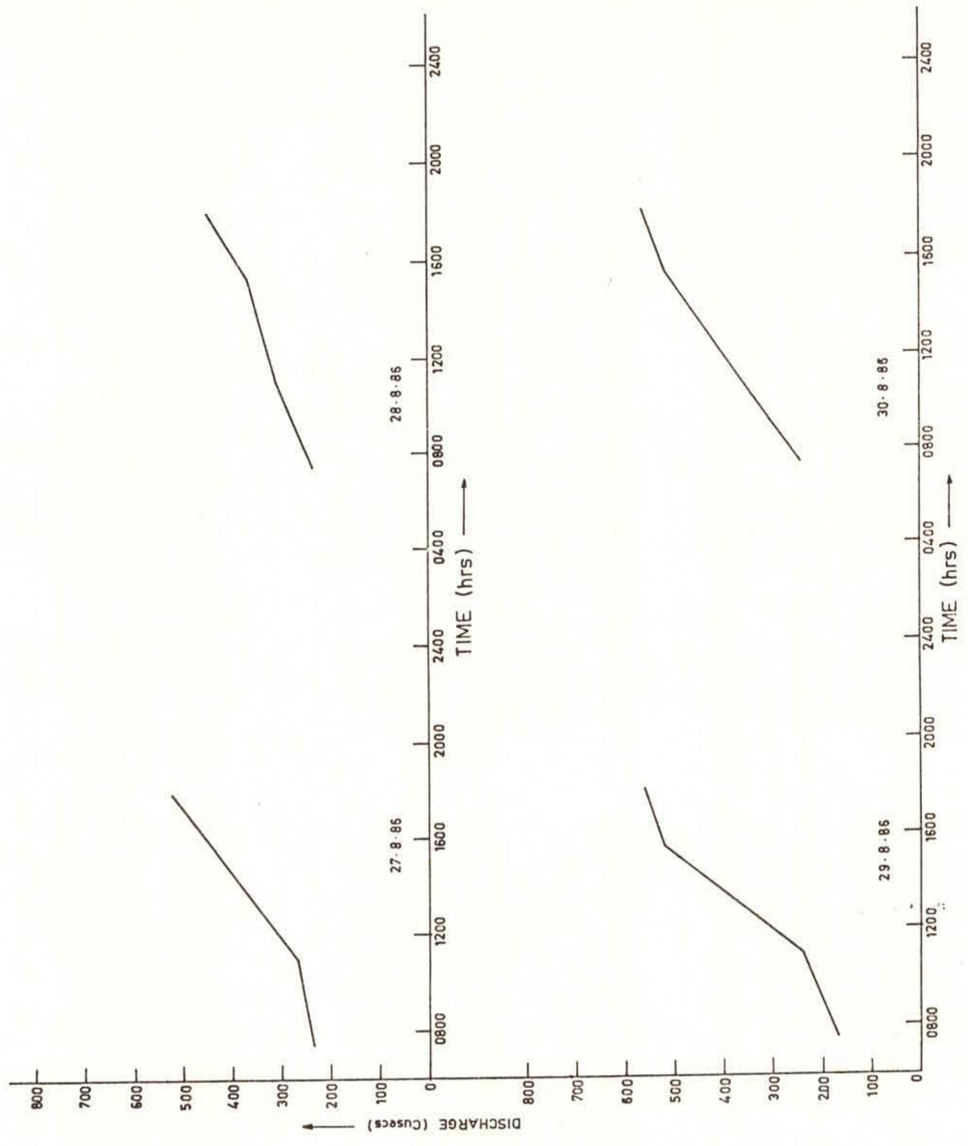
DISCHARGE (Cusecs)
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29·8·86
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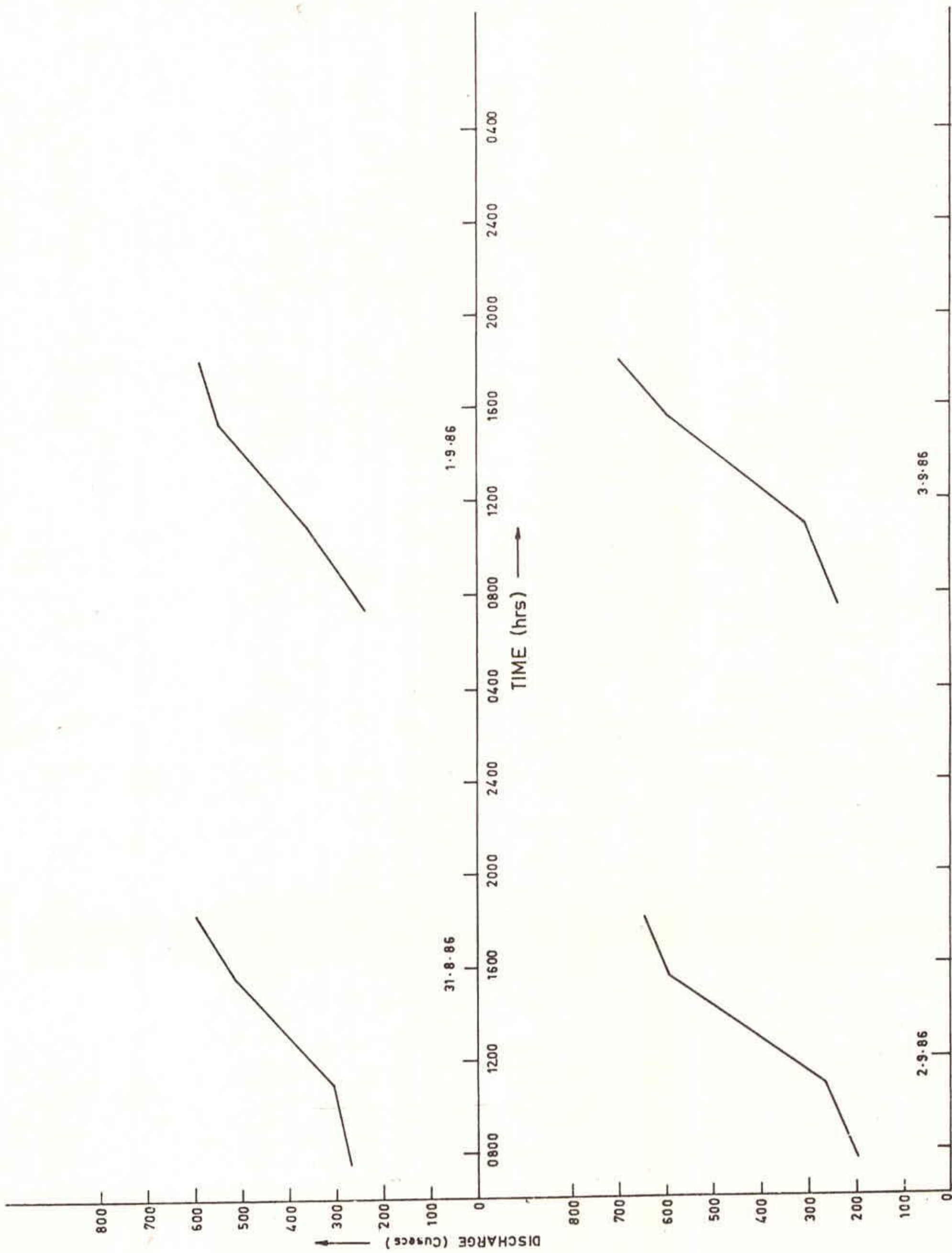

DISCHARGE (Cusecs)
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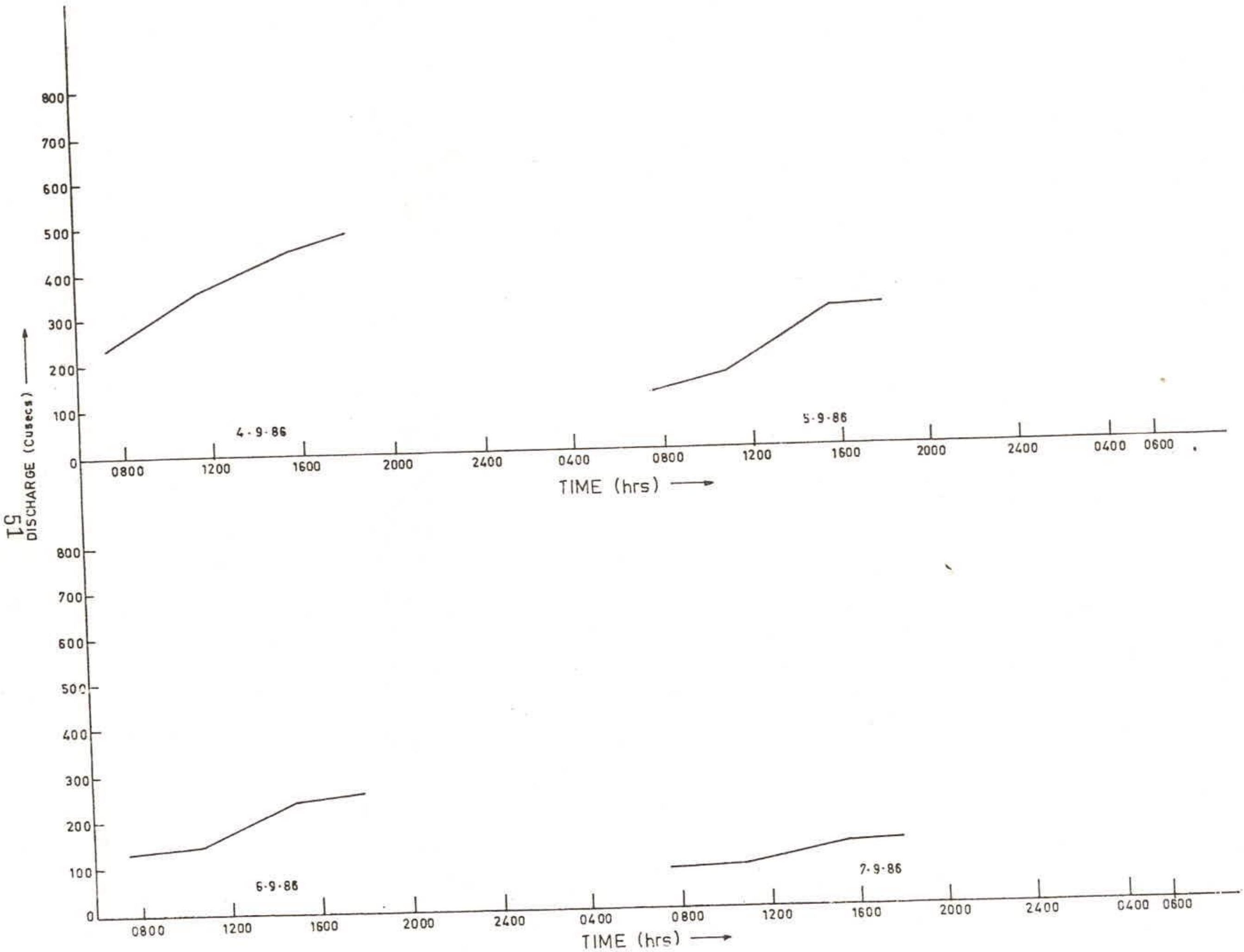
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DISCHARGE (Cusecs)
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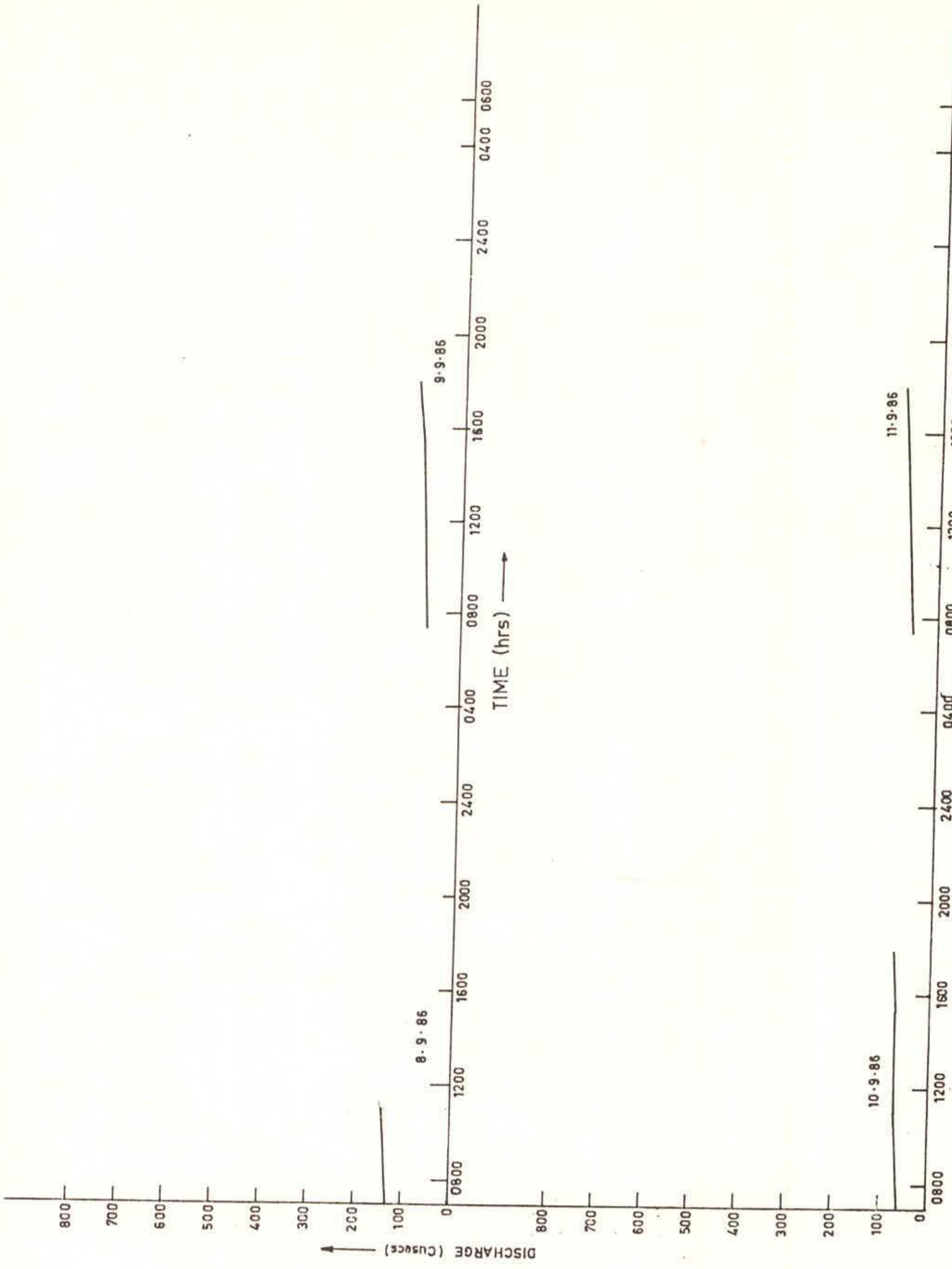
7 · 9 · 86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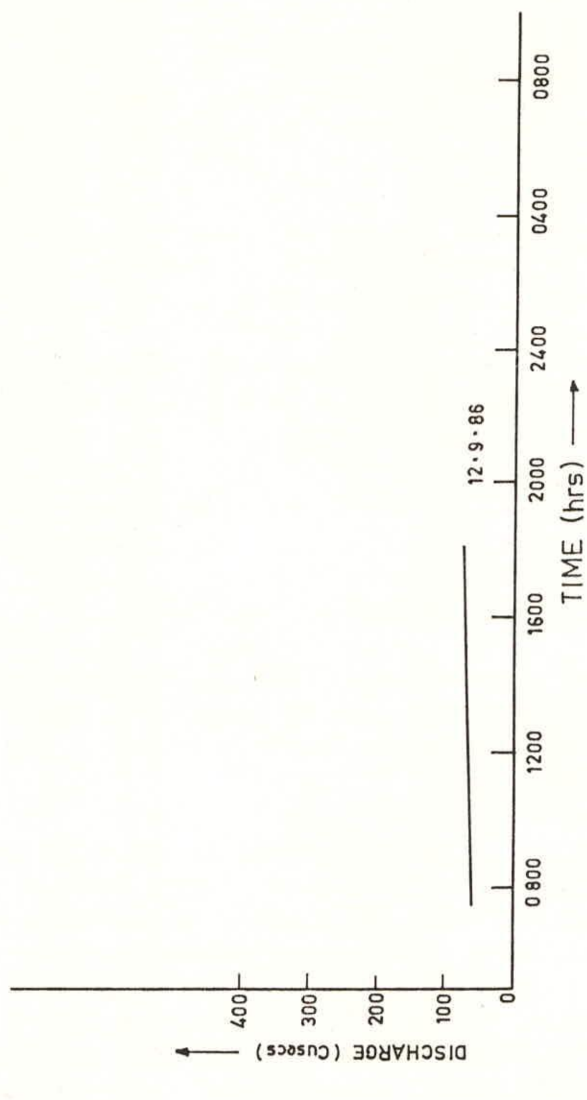
DISCHARGE (Cusecs)
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0800
1200
1600
2000
2400
0400
0800
12·9·86
TIME (hrs)

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