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Hydrologic Responses of a Himalayan Pine Forest Micro Watersheds, Preliminary Results.

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ABSTRACT

In recent years, the hydrology of the Himalaya has received a lot of attention from researchers and environmentlists. Several workers agree that their remains a shortage of reliable, scientific data on the hydrology of forest and forest conversion in these mountains. To understand forest hydrologic responses and to create representative scientific data hydrology, a project, viz., the Animal Park pine forested experimental watershed has been set up as a co-operation between the Department of Geography Kumaun University, India and Oxford polytechnic U.K.. The hydrological station includes a 90^{0} 'V' notch weir set behind a stilling pond and defended by a sediment trap. A standard chart-recording water level stage recorder is stationed above the pond and meteorological station which includes automatic raingauge, pan evaporation tank and temperature, humidity gauge on the upper waterdivide of the watershed.

The present paper includes operational history and some preliminary results of the pattern of channel runoff and channel erosion recorded between 1987 and 1991. The study reveals that the water generating capacity of land to channel approcahes upto 7.60 m^3 ha^{-1} d^{-1} in july and drops upto 0.0086 $m^3 ha^{-1}$ d^{-1} in the driest month, i.e., April. The average annual water generating capacity of land to channel stands at 17 $m^3 ha^{-1}$. A large part (63%) of the total annual water, discharges in the rainy season the winter flows account only for 8.7% and the remaing part, i.e, 28.3% flows during the summer.

The erosion data reveal that during these twenty four months about 12.5 tonnes of sediment (suspended, dissolved and bedload) was discharged from the entire watershed having an area of 100 ha. Out of this total sediment a large part (61.3%) was constituted of bedload sediment and a small part (7.3%) was discharged in the form of dissolved load. Remaining 31.4% was transported in the form of suspended load. It can be extrapolated that the undisturbed pine forested land is lowering at the rate of 0.004 mm/year.

INTRODUCTION

Hydrological appraisal of the Himalaya with regard to its streams, glaciers and lakes is the basic prerequite for the planning, designing, construction and operation of small and multipurpose water resource projects that are being contemplated. In recent years, the hydrology of the Himalaya has received a lot of attention from researchers and environmentalists. This work has been reviewed by Rawat and Bisht(1988), Haigh et.al (1990). Nevertheless, several workers agree that there remains a shortage of reliable, scientific data on hydrology of pasture/ barren land, agricultural land, urban land, soil conservation, land reclamation and forest's and forest conservation in these mountains. In truth, the number of scientific field studies remains small and the research litrature is bulked out by studies based on inference, speculation, reconnaissance, or folklore. Much of the international litrature is provided by outsiders, workers who are fielded for a few weeks field study, or worse for a one-off "expedition".

This situation is by no means unique to the Himalaya. There are few universities or government research stations which are located in the high mountain regions of the developing world. The resources and expertise to tackle the very demanding disciplines of hydrological monitoring. Symptomatic is the observation, that to the best knowledge of this research team, there may still be only three instrumented hydrological catchment projects in the fragile Himalayan steeplands. The biggest and, potentially, the best of these is a complex of 5 instrumented catchments established by Pakistan Forest institute of Peshawar, near Mingoro City, in the Swat Valley. This 5 chtchment (4-20 ha) study, which is still in its calibration period, is designed to measure the impact of different forestation strategies on runoff and sediment yield from steep(30^0) slopes on schists. Local hillsides are seriously grazed and rock is exposed over 63-78 % of the surface. Closer to grazing increased forage yields from 0.28 to 0.4 t/ha, and the ground cover by vegetation from 40 to nearly 60 % Forested with a variety of forest trees, notably Chir (Pinus roxburghii) but also Eucalyptus some and Robinia Pseudoaccacia, in conjunction with the checkdams on small tests, will it is hoped, reduce sediment yield and improve the hydrologic regime.

This paper concerns the first instrumented catchment established in the Central Lesser Himalaya and contains some preliminary results. The aim of this project is to creat a representative hydrological record of an increasingly rare land system. Its site is a steep mountain headwater catchment mantled with Chir (Pinus roxburghii) forest, near Almora town, viz., Animal Park.

METHODOLOGY FOR THE SELECTION OF WATERSHED.

Selection of watershed for hydrological instrumentation and study depends upon the objectives of the project. As the aim of the present project is to define the responses of hydrologic cycle under pine forest, hence piolet survey was carried out in the Nainital and Almora region in 1985 to select a micro watershed (1 km^2) having following geographical characteristics:

(a) Lithologically homogeneous.

(b) Covered by pine forest.

(c) Undisturbed or least effectec by human activities.

(d) Drained by a first order perinnial stream.

We find micro watersheds having above characteristics in both Nainital and Almora regions. The watersheds of the Nainital region are underlain by highly fractured and jointed rocks of Paleozoic age and are covered by thick mantle of debris while the watersheds of Almora region are underlain by Crystalline rocks of pre-cambrian age covered by a thin mantle of soil. Selection of gauging site near the mouth of watershed for hydrological instrumentation, constitute an important part of the field surveying. Requirments of the gauging sites for hydrological instruments varies according to the types of equipments. We have used traditional Indian equipments which includes a 90^0 V-notch weir set behind a stilling pond and defended by a sediment trap. A standard chart recording water level stage recorder is stationed above the pond. Selection of site for the instrumentation of these equipment requires the following knowledge and charateristics of the site.

(a) At the site of instrumentation the land should be level to built-up designed structure of the hydrological station as shown in figure 1.

(b) To avoid the seepage problem from the 'V' notch pond which creates aproblem to study minimum flows, there must be rock flow at the selected site for the installation of 'V' notch.

(c) To avoid frequent damming of 'V' notch pond and damage of the station, knowledge of the debris flow pattern is required.

(d) The maximum bankful discharge should be known. It should not exceed than the capacity of weir.

(e) A watchman, atleast high school pass should be available near by the selected instrumentation site which could keep an eye on the station.

In view of the above factors, the pine forest watersheds of the Nainital and Almora were examined. It was found that none of the first order watershed covered by pine forest in the Nainital region are suitable for the installation of 'V' notch weir because the watersheds are made-up of highly fractured, sheared and shattered rocks, and are covered by thick mantle of debris. Hence, during mansoon rain, the streams are filled with huge debris. Thus, due to very high bedload flow on stream, the weir may dammed or damaged by first high intensity rainstrom. It is suggested that such area should be avoided for the hydrological instrumentation.

The watershed of the Almora region are developed on crystlline rocks and provide appropriate site for the hydrological instrumentation. By careful observations of some of the watersheds finally the Animal Park watershed (Fig.2) was selected for the hydrological instrumentation in 1985 because—

(i) it has a perinnial stream;

(ii) at the mouth of the watershed there is rockflow;

(iii) the bedload is not very coarse as the watershed is covered by a thin film of soil and there is no such over burden which could increase the bedload during high intensity rain;

(iv) a pond is already available to trap the bedload material;

(v) the watershed is least affected by human activities and is fenced for human interferance; and

(vi) forest department offices are near by to keep an eye on the instrumented site.

CHARACTER OF PROJECT

The Animal Park project has been set up as a co-operation between Department of Geography, Kumaun University at Almora and Oxford Polytechnic U.K.. The Project, its design, and equipments are typical of European academic hydrology. The project's prototypes are to be found at Institute of hydrology's Plynlimon field station in MidWales. One of many similar stations has been established by the Agricultural University of Prague in the forest headwaters of the Jizera Mountains in northern Bohemia.

The Animal Park instrumentation includes a 90^{o} notch set behind a stilling pond and defended by a sediment trap. A standard chart recording Water Level Stage Recorder is stationed above the pond. A meteorological station, which includes a W.M.O. standard rainfall intensity gauge, and since july 1989, a pan evaporation tank, and temperature gauges, is established on the upper water divide of the catchment.

In practice both the meteorological station, and the hydrological station are overseen by enthusiastic young researchers from the Geography Department of Kumaaun University Almora, one of whom resides adjacent to the meteorological sites. The hydrological station is protected by 2 metres high fence and it is watched over by the local Forest Department whose offices are close by.

Instruments are inspected and checked on a daily basis for the meteorological station and once a week for the hydrological station. The field check of the hydrological station is combined with the collection of samples for the measurement of suspended and dissolved sediments. Bedload measurements have been collected since August 1989 during a monthly cleaning of the stilling pond above the weir.

THE ANIMAL PARK CATCHMENT

The Animal Park catchment (Lat 29° 41′ 30″ N, Long 79° 41 E) is drained by a perennial first order stream(Fig.2). This drains a western facing ridge on the eastern margin of Almora town. Its elevation ranges from around 1708 to almost 1830 metres so it has a local relief of approximately 120 metres. The area of the catchment is approximately 1 km (or 100 hectares). The mean slope of the channel is 27° and that of the side slopes is approximately 35°. The catchment is underlain by rocks of the Almora Crystalline schist underlies around 92% and interbedded quartzites 8% of the catchment area. The schistocity dips 15° to 30° towards NE. A quartz intrusion cuts across the catchment from NE to SW. The area is almost entirely mantled with soil. soil depth range from 0.1 to 1.0 metre. Preliminary measurements suggest that the stable infiltration rate for these soils is about 13.1 cm/hour (range 0.5 to 32.4 km/hr.) The valley floor immediately above the stream gauge is relatively gentle in slope (3^{o}) and here there has been some valley alluviation.

The major part of the catchment is forested with mature chir pine at a density of 120 trees/hectare. Crown canopy cover sampled at 22 locations averages 82% There is ban on green felling. Several other tree spacies are represented in the valley floor. These include Myrica esculenta, Cedres deodera, Alnus nepalensis and Quereus levcotrichophora. Although the catchment is fenced against most human intrusion, it is managed as a preserve for three spacies of deer with density of 0.65 deer/hectare and supports a wide range of other wildlife spacies. Close to the shelters provided for the deer, the grazing pressure is rather high and this has had a negative impact on ground surface vegetation. The heavily grazed areas have a thin cover of leaf litter and undergrowth (90% ground cover), In less heavily grazed areas the ground cover rise to 98% and there is very little exposed bare earth. Further human interference included the existence of two small waterstorage tanks and gravity fed out take - pipe used for domestic supply. The tanks and pipe have a capacity of 1000 litres, 500 litres, and 0.07 litre/second and 0.14 liter/ second. In addition, there is distrubance due to the construction of small shelters for the animals and due to occasional illegal intrusions of local people and tourists. However, the park is protected by a high fence and defended by permanent staff, so the level of intrusion may be regarded as minimal given the location on the suburban fringe of Almora city. Before the construction of this park (1977) there were several problems of forest fire, tree felling and overgrazing by cattles of local villagers. Now these problems have been controlled by the construction of this park by State Government.

OPERATIONAL HISTORY OF ANIMAL PARK PROJECT

The real history of most hydrology projects is seldom discussed. It tends to be a catalogue of equipment failure vandalism, and unforseen hydrological events which managed to overwhelm or by pass the gauging station. In academic environments, these problems are normally compounded by crises of staffing and funding which tend to ensure that these stations are inactive for long periods and deficient in some respect for further period. The history of the Animal Park Project is typical. Preliminary research and negotiations for the project began in March 1985 when the site was selected and permissions obtained. In the month which followed, the team overcome major problems in obtaining reliable equipments. Eventually a company called Hindustan clockworks come up with the goods.

A first phase of data collection, was undertaken between March 1987 and Jabuary 1988 (Rawat, Haigh and Bisht 1988). Some useful preliminary results were obtained but several major problems emerged (Haigh, Rawat and Bisht 1988). First the senior author was posted overseas and briefly to another institute. This meant 18 months until the junior author joined the team and tookover in May 1989. Second, as time went on, it was decided that an unacceptable volume of water was bypassing the weir as underflow, consequently the weir had to be removed and relocated at a lower level with its base on bedrock. This operation was completed in July 1989., Third, it became obvious that the peak flows of the monsoon, season were overflowing the stream guage access flume and bypassing the weir. Correcting this problem required redesigning the channel above the weir and, converting the current V notch into a compound weir/flume capable of deeling with the monsoon flood peeks. Finally, the stream gauge, which was located above the stilling pond, began to receive the attention of local children who decided to use the wire connecting chart and float for stone-throwing target practice. Their regular "hits" caused some damage and as a result the stream gauge had to be relocated inside a brick structure closer to the stilling pond. This was achieved on August 1989.

PRELIMINARY RESULTS

The data for the first period (1987-88) of observation has fairly limited value (Rawat, Haigh and Bisht, 1988). The rainfall results are correct but the water level records underestimate low flow discharge because of seepage below the weir and underestimate monsoon flood peaks where these flows exceed the capcity or by pass the weir. Howerver, the data does provide on accurate record of rainfall/runoff lag times since peak flows are indicated by the charts, even if their scale is not accurately measured. The problems of underestimate low flow discharge because of seepage and the problem of underestimate of flood peaks were solved by redesigning the weir in July 1989. Since August 1989, the data of water discharge are accurate. Sediment date collected weekly may be of limited value during the monsoon when the hydrological condition varies dramatically, but they are a valuable guide to sediment transport during the more stable low flow conditions which hold for the balance of the year.

During the first 8 months of record, from April 17th, 1987 to January 1st 1988, the catchment received 488.3 mm of precipitation of which 80% fell in the monsoon season of July to September. Discharges during this period ranged from a low of 0.09 l/s on June 6th to a high of 38 l/s on August 12, 1987. Suspended sediment concentrations ranged from 0 mg/l during May and November-December to a peak of 870 mg/l near the close of the Monsoon in early September. Dissolved loads proved much less variable and were, on average, of greater dimension (Durgin, 1984). The peak concentration was 428 mg/l recorded in early September while the lowest concentrations, 80 to 40 mg/l, were measured in samples collected in October through December.

Preliminary analysis of the data suggests that there is an annual cycle of sediment release controlled by successive phases of discharge. High suspended sediment loads are associated with each new sustained peak discharge. Subsequent repetition of the same discharge tends to be associated with lower suspended sediment loads. Indeed, suspended sediment loads decline to zero in the stable flow conditions at the close of the monsoon.

Table:1 Discharge recession at the close of the monsoon season of 1987: Animal Park Pine Forest Watershed, Almora U.P.

Discharge 1/s	Date day/month	Time hours of the day
3.02	19/10	17/18
2.15	19/10	18/19
1.12	19/10	19/20
0.99	19/10	20/21
0.95	30/10	12/13
0.90	30/10	16/17
0.85	1/11	13/14
0.80	2/11	16/17
0.75	3/11	15/16
0.70	4/11	15/17
0.60	4/11	16/17
0.55	12/11	24/01
0.50	21/11	11/12
0.45	25/11	16/17
0.45	10/12	24/01

The pattern suggests that, during the autumn, and specially during the dry hot summer months, mobilisable sediments accumulate in the catchment and in the stream channel. With the onset of the monsoon, these sediments are progressively flushed out by the sequentially rising discharges. The character of this process, however, requires further and more detailed investigation.

Hydrographs of individual rainfall events based on hourly data indicate that catchment response to rainfll is rapid. The flow peak is achieved in the hour-following the onset of the storm. For example, on 23/4/1987 a three hour storm deposited 2.0+1.0+3.5 = 6.5 mm. Before the storm, the flow was 0.61 l/s, this rose to 0.69 l/s in the second hour of the storm and fell back to 0.62 l/s in the hour following the storm, after which there was a long slow decline in flow rates which stabilised as 0.613 l/s 9 hours later.

The last rainfall of the monsoon season fell on the 19/10/1987. This storm deposited 8+2 = 10 mm in two hours. Discharge rose from 0.9 to 3.0 l/s in the first hour of the storm. Two hours later, discharge was down to 1.1 l/s, and stabilised at 1.0 l/s some 23 hours after the peak was achieved. Further recession proceeded slowly (Table 1), though not especially evenly. Abrupt drops in discharge were recorded on October 30th and again on the 4th November. However, whether these are real, or due to faults in data collection, is not yet determined. If real, these features may relate to thresholds of exhaustion in certain categories of catchment storage. It is, of course, no coincidence that most flow mimima are achieved in late afternoon when both evaporation and transpiration rates are highest.

Climate which have clearly defined rainy seasons generate a hydrograph which is qualitatively different of those from areas where precipitation occurs throughout the year. The rainfall occurs in June to September (90% of the total annual).

The character of hydrograph are controlled by:

(1) the intensity of rain shown rather than the amount of water;

(ii) the condition of ground cover; and

(iii) the amount of evaporation moisture condition and infiltration etc.

For example, on 13th February 1990. relatively low amount of rainfall (20 mm) generated very high peaked hydrograph but on 18th February 1990 relatively high amount (27.5 mm) of rainfall generated small peaks hydrograph (Fig.3). Thus, under identical rain amount the pattern of hydrograph may vary due to different intensity. Therefore, for correct rainfall-runoff relationship, correlation should be conducted between runoff and rainfall intensity rather than runoff and rainfall amount.

Ground cover soil moisture condition, and evaporation which vary from season to season and even month to month in the Animal Park area, are other important parameters by which the hydrographs are controlled. For example, on 15th June 1990. (Fig.4) relatively high intensity rain shower generated considerably low peaked hydrograph than that of 13th February 1990 low intensity rain shower (Fig.3). It is due to high temperature in June (mean $20^{o}c$) than that of February (mean 11^{o}) by which soil moisture was decreased and rate of evaporation increased in the month of June. Thus, under identical rainfall intensity the character of hydrograph may vary due to the changing nature of ground cover, soil moisture, evaporation and infiltration etc in different seasons or months. Therefore, to develop accurate and reliable rainfall-runoff model for flood prediction and for water resource planning, rainfall - runoff models for different months are required. It is being done in case of this Himalayan Pine forest experimental watershed, viz., the Animal Park watershed.

The preliminary results reveals that the water generating capacity of the pine forest steep land (made up of mica-schist) to channel approaches upto 7.60 m^3 ha^{-1} d^{-1} in July and drops to 0.0086 m^3 $ha,^{-1}$ d^{-1} in the driest month, i.e., April. The average annual water generating capacity of land to channel stands at $17m^3$ $ha.^{-1}$ A large part (63%) of the total annual water discharges in the rainy season. The winter flow accounts only for 8.7% and the remaining part, i.e., 28.3% of the total annual, flows during the summer season (Fig.5).

The erosion data reveal that during 1989-91 (24 months) about 12.2 tonnes sediment (suspended, dissolved and bedload) was discharged from the entire watershed having an area of 100 hectare. Out of this total sediment a large part (61.3%) was constituted of bedload sediment and a small part (7.3%) was discharged in the form of dissolved load. Remaining 31.4% was transportd in the form of suspended load (Fig.6). With the help of these erosion data it can be extrapolated that the undisturbed Himalayan pine forest land is lowering at the rate of 0.004mm y^{-1}.

To define hydrological responses from Oak forest and from disturbed systems (barren/agricultural), recently 6 micro watersheds in Almora region have been instrumented like the Animal Park watershed under a D.E. En (New Delhi) project (Valdiya, et.al., 1991). The fundamental aim of the project is to understand the responses of the hydrological cycle under different ecological stresses and to formulate environmental management strategies and holistic models. The project is in caliberating stage. It is hoped that within next two three years models of hydrologic responses under varied ecological condition of the Himalaya will be developed.

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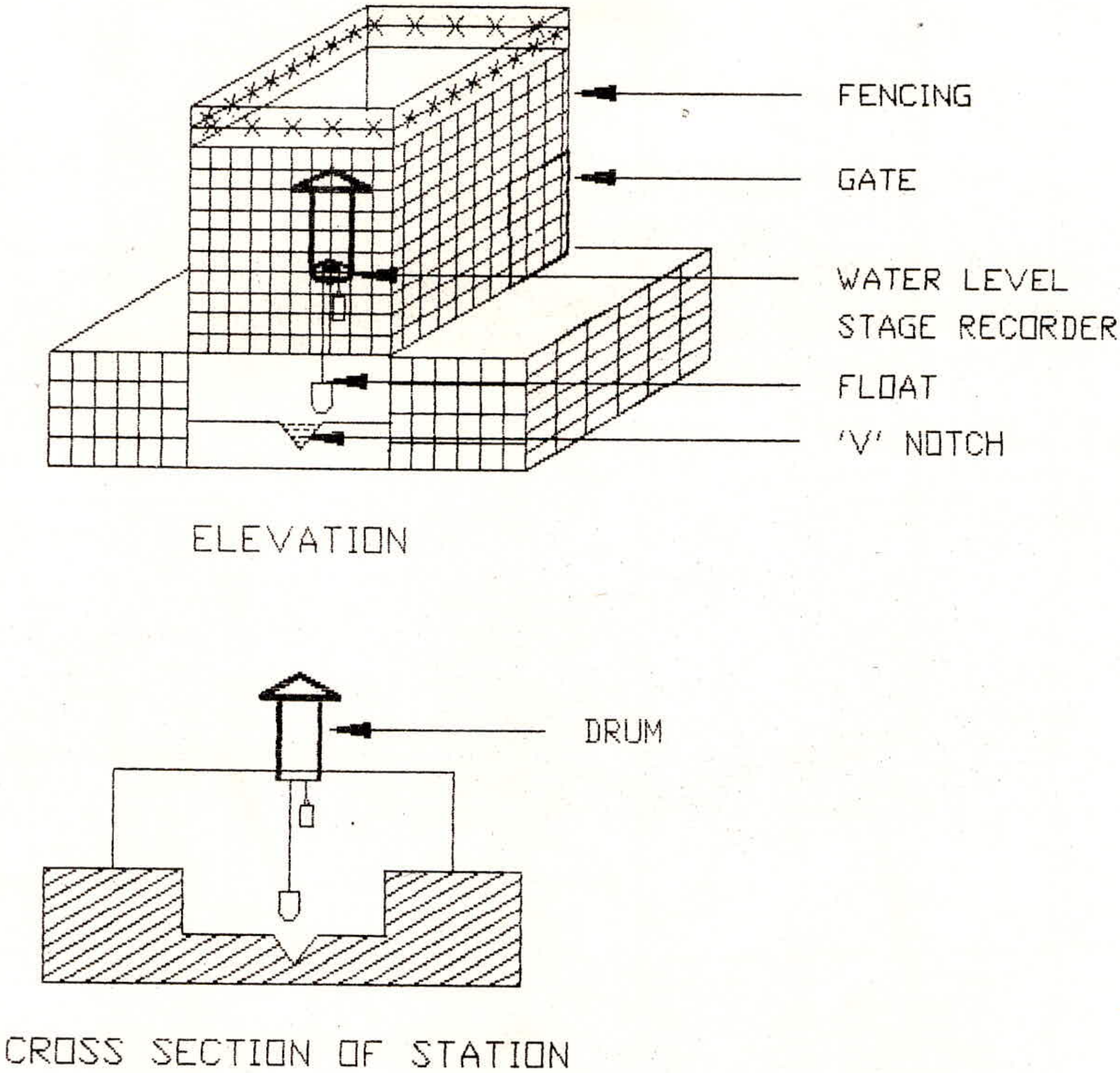

FIG: 1 *PLAN (Above) AND SECTION (Below) OF THE PARK HYDROLOGICAL STATION.*

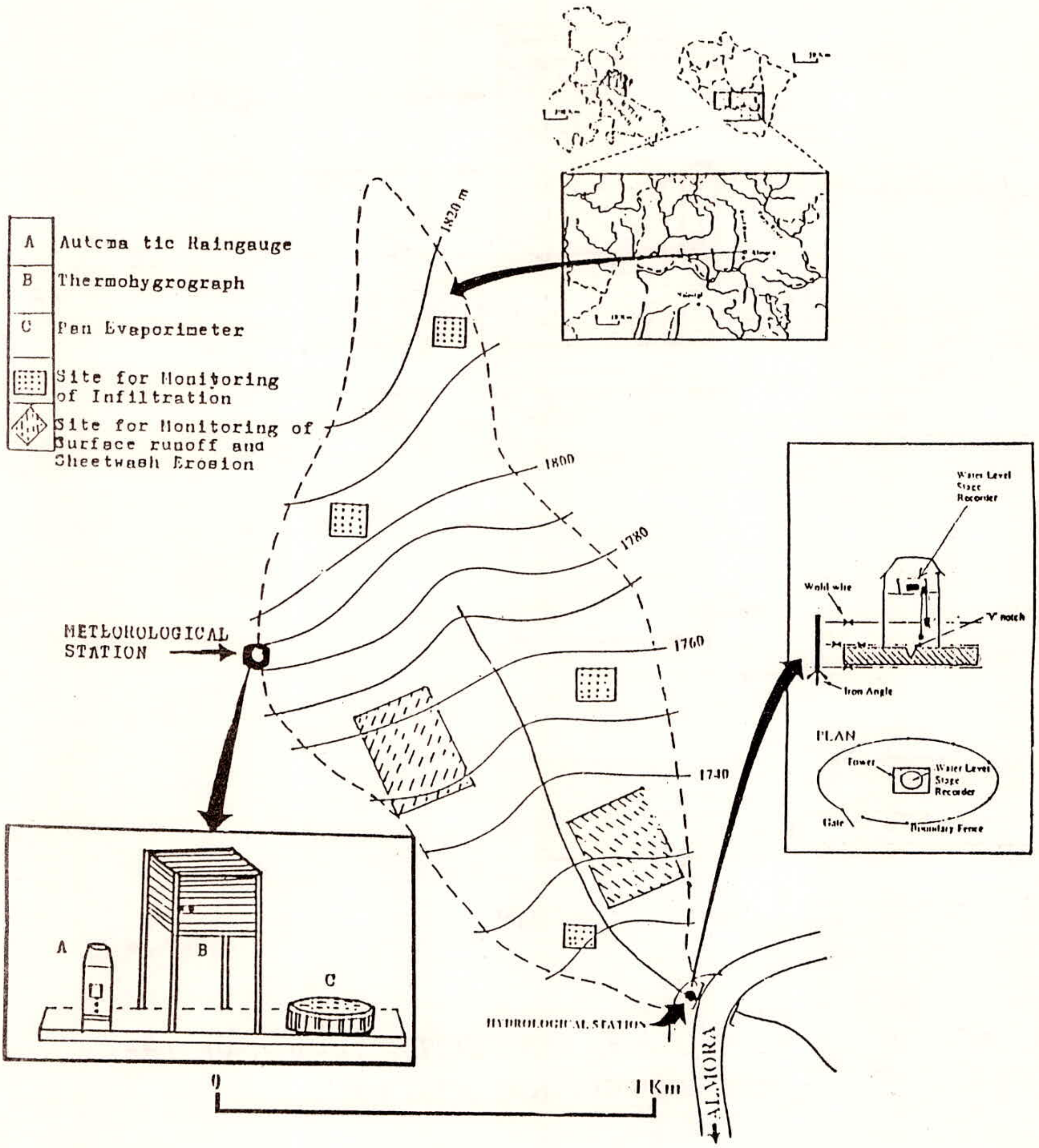

FIG: 2 THE INSTRUMENTED FIELD LABORATORY FOR PINE FORESTED MICRO WATERSHED VIZ., THE ANIMAL PARK WATERSHED NEAR ALMORA, KUMAUN LESSER HIMALAYA.

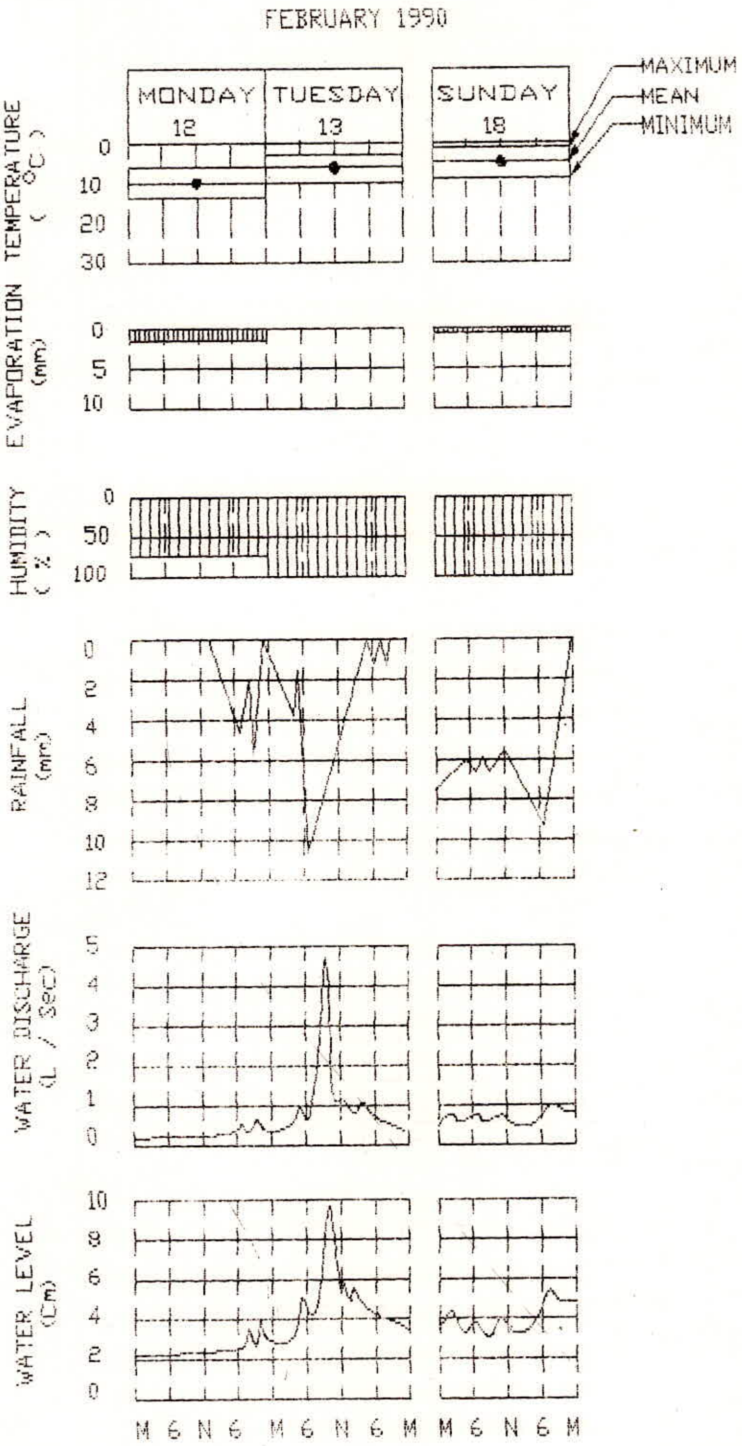

FIG: 3 HYDROMETEORLOGICAL CHART OF THE ANIMAL PARK WATERSHED FOR 12th, 13th AND 18th OF FEBRUARY 1990.

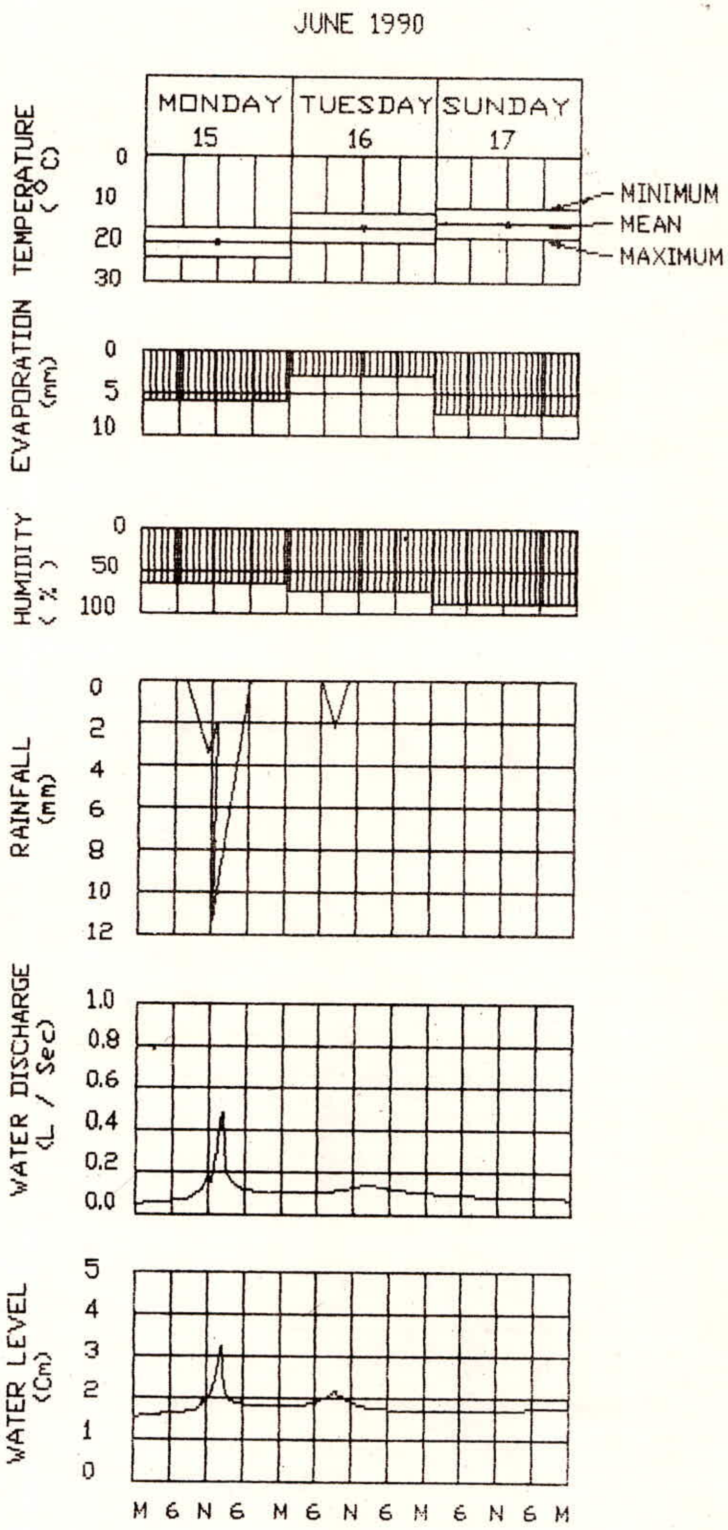

FIG: 4 HYDROMETEOROLOGICAL CHART OF THE ANIMAL PARK WATERSHED FOR 15th, 16th AND 17th OF JUNE 1990.

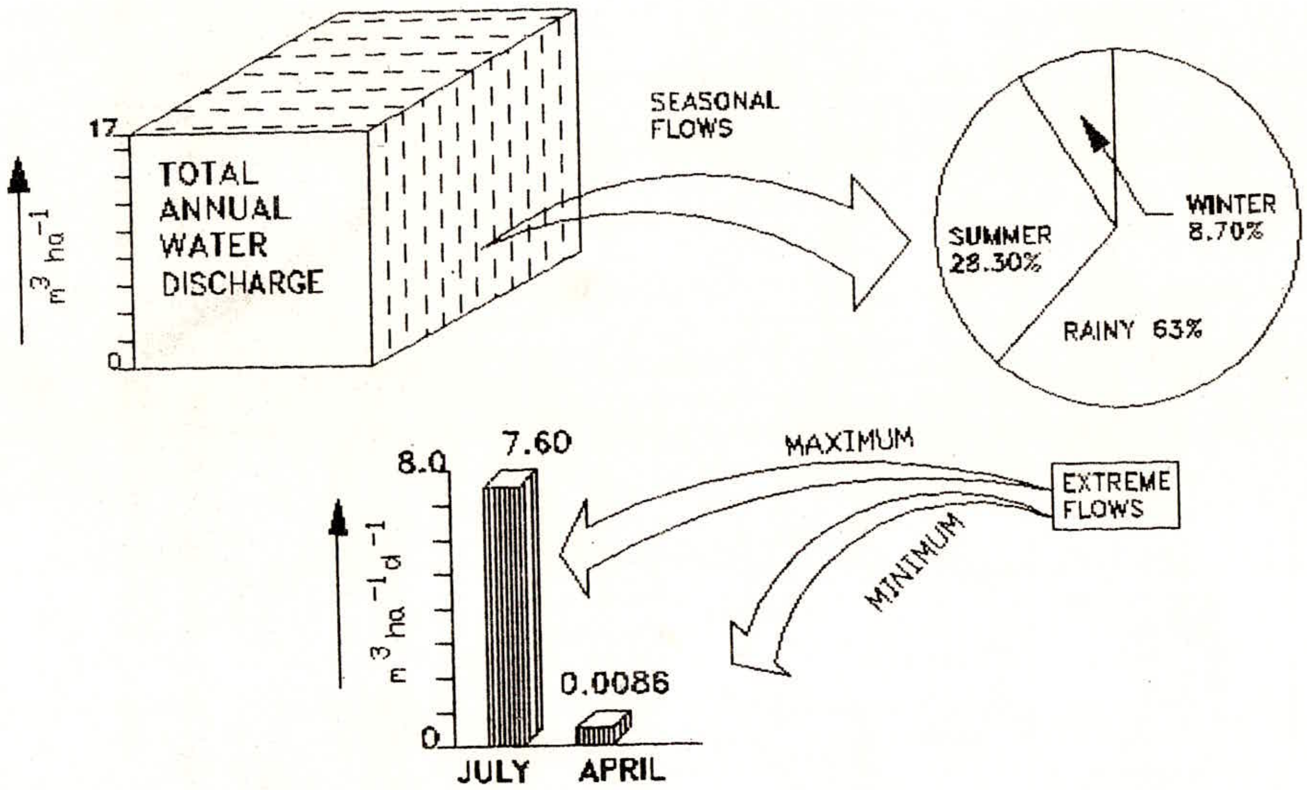

FIG. 5 ANNUAL, SEASONAL AND EXTREME FLOW CHARACTERISTICS (1989–91) OF THE ANIMAL PARK WATERSHED, KUMAUN LESSER HIMALAYA.

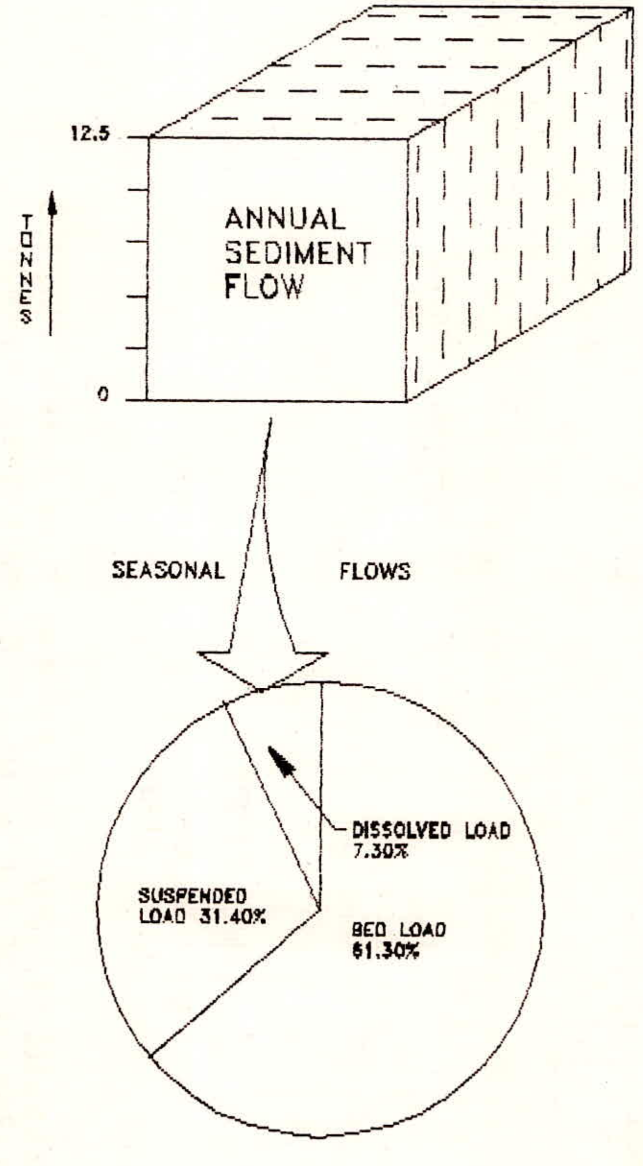

FIG. 6. SEASONAL AND ANNUAL SEDIMENT FLOWS (1989–91)
OF THE ANIMAL PARK WATERSHED, KUMAUN LESSER HIMALAYA.