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A CONTRIBUTION TO INDIAN NATIONAL COMMITTEE ON HYDROLOGY

# STATUS REPORT ON SATLUJ CATCHMENT UPTO RAMPUR

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August, 1991

## PREFACE

The major river systems of the Northern India, namely the Indus, the Ganga, the Brahamputra and their tributaries originate in the Himalaya and constitute a large part of water resources of our country. The spring and summer streamflow in these river systems comprise mostly snowmelt runoff which is very much of use for irrigation, hydro-electric power and water supply. The accurate estimation of snowmelt contribution is required for planning and management of water resources.

A study of snowmelt runoff forecasting in the Satluj catchment is being carried out. The temperature index method is proposed for snowmelt computation due to availability of only precipitation and temperature data in the basin. To carry out this study, the catchment would be divided into various elevation zones and temperature would be interpolated/extrapolated to these zones using computed temperature lapse rate. The snowcover depletion curve will be prepared for the basin using the satellite imageries. If required, the catchment would be divided into subcatchments and for each subcatchment study would be carried out separately and flow would be routed to the outlet of the basin.

The snowmelt simulation models such as SRM, UBC, SSARR and HEC-1 are proposed for testing for streamflow simulation for the snowmelt season in this basin. The simulation will be done over the period of three years. The model's capability for forecasting snowmelt will be tested. As a first step of the proposed study, this status report on Satluj catchment upto

Rampur has been prepared. Description of study area, data status and existing network is given in the report. This report has been prepared by Dr. Pratap Singh, Scientist 'B', Mountain Hydrology Division, National Institute of Hydrology, Roorkee.

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## ABSTRACT

Snowmelt runoff constitute a significant part of annual flow in the Satluj river and needs flow forecasting during snowmelt season for operation of Bhakra reservoir. This status report on Satluj catchment upto Rampur is prepared as a first step towards snowmelt modelling studies in this basin. This report includes description of study area, and status of data with network of precipitation (snow and rain) temperature, discharge, sedimentation, snowmelt and glacier melt studies in this catchment. A brief description of the approach to be adopted for snowmelt modelling studies has also been given.

## 1.0 BRIEF INTRODUCTION ABOUT OBJECTIVES OF SNOWMELT MODELLING STUDIES PROJECT

The Snow and Ice Panel of INCOH has proposed to carry out snowmelt studies using temperature index method because of availability of only precipitation and temperature data in the basin. The snowmelt models such as UBC, SRM,SSARR and HEC-1 are proposed to be tested for the basin for snowmelt simulation over a period of 3 years data. The snowcover area would be estimated from Landsat / IRS satellite imageries for the required period. The model's capability for forecasting snowmelt contribution for operational use would be tested. The methodology would include the division of basin into various elevation zones and temperature will be interpolated / extrapolated using the derived value of temperature lapse rate for the basin. The snowcover depletion curves would be established with time and degree -days as well. The other hydrological parameters of the basin to be used in the snowmelt modelling would be established from available data of streamflow and characteristics of the basin. If required, the catchment will be divided in to sub catchments and study would be carried out for each subcatchment separately and the flows would be routed to the outlet.

## 2.0 DESCRIPTION OF STUDY AREA

The river Satluj is one of the main tributaries of Indus and has its origin also very near to Indus. It rises in the lakes of Mansarover and Rakastal in the Tibetan Plateau at an elevation of about 4,572 meters ( Figure-1 ). It travels about 322 km in the Tibetan province of Nari- Khorsam forming a plateau by successive deposits of boulders, gravel, clay and mud. The flow of Satluj, obtained mainly from glaciers has cut a valley about 914 meters deep through these deposits. After flowing in north-westerly direction ,it changes direction towards south-west and covers another 322 km up to Bhakra gorge, where the 225.55 meters (740 ft) high straight gravity dam has been constructed. The entire area in Tibetan plateau and some areas down stream are without rainfall and has cold desert climate. This large river flows through different areas which have varying climatic and topographic features. At Namgia, near Shipki, it is joined by it's principal Himalayan tributary, the Spiti. Below this dry region, it flows through the Kinnaur district of Himachal Pradesh, where it gets both snow and rain. Numerous glaciers, large and small, drain directly into Satluj at various points along its course and many Himalayan glaciers drain into it's tributaries in Kinnaur district. Below Suni up to Bhakra dam, it flows through a region which gets only rainfall.

The total catchment area of Satluj is about 56,874 sq km of which 37,048 sq km lies in Tibet and remaining 19,826 sq km in India. However, main planning and work has been concentrated only in 19,826 sq km area lying in India. The catchment of river Satluj has been divided in three parts (A to C) as shown in the Figure 2. The area of the portion (A) upstream of Bhakra dam

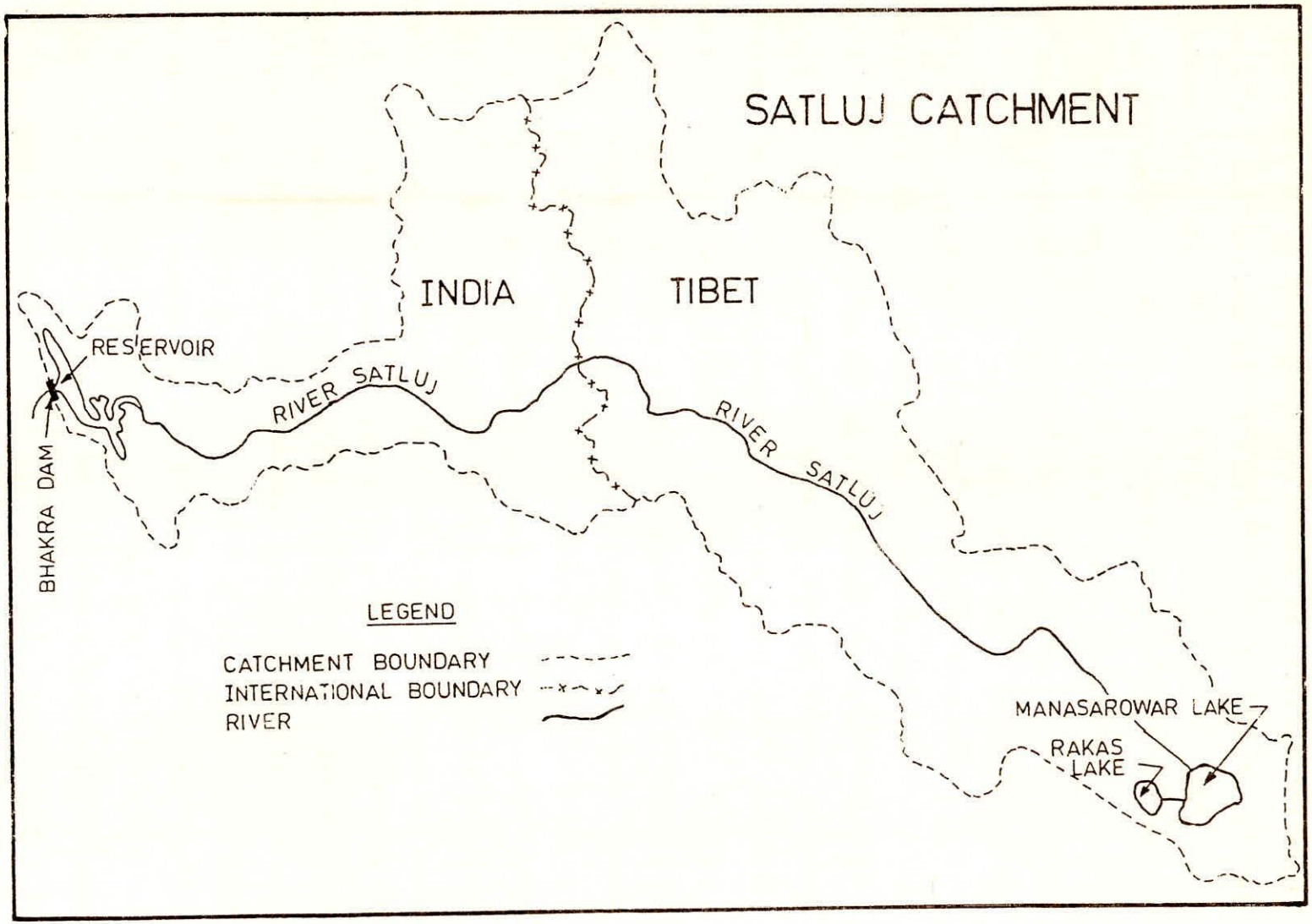


FIG. 1- CATCHMENT OF SATLUJ RIVER INCLUDING TIBET AND INDIAN PART

measuring about 5032 sq km shows the catchment getting rainfall only. The portion (B) measuring about 5548 sq km shows the area getting both snowfall and rainfall, whereas portion (C) measuring about 9246 sq km (above elevation 2000 m) gets only snowfall in winter and almost no rainfall. The permanent snowline in this portion of Himalayan range is at elevation of 5400 m (BBMB, 1988). Upadhyay et al (1983) reported that about 11% area of the total Satluj catchment lies under glaciers.

The contribution of snowmelt is quite significant in the Satluj river. The snowmelt contribution is less than rainfall runoff during winter months because the melting conditions are not adequate. After middle of March, snowmelt exceeds the rainfall component which leads to a significant rise in the gradient of runoff of the hydrograph. The snowmelt contribution increases continuously as the snowmelt season advances. The south-west monsoon activity is experienced in the lower catchment area during the period normally from the end of June to middle of September. Peak values of the total discharge in July and August is essentially due to major contribution of monsoon rains in the lower catchment. The catchment area is fed by western disturbances in the form of winter precipitation comprising snowfall at high altitude and winter rainfall in the lower catchment area. The main snowfall period for Satluj catchment is from December to March and some times extending from October to April. Due to large differences in seasonal temperature and great range of elevation variation in the catchment, the snowline changes its position considerably. Approximate height of snowline at the start and end of snowmelt season has been reported to be approximately 11000 ft and 17500 ft respectively (Chatterji and Chopra, 1976).

## 3.0 DATA STATUS

Presently the status of data in Satluj catchment up to Rampur is as follows.

### 3.1 Meteorological Data

#### 3.1.1 Rainfall observations

In the Satluj catchment up to Rampur rainfall is observed at 11 stations. India Meteorological Department (IMD); Bhakra Beas Management Board (BBMB); Director, Land Records of Himachal Pradesh (DLRHP) and Forest Department of Himachal Pradesh (FDHP) are the organizations involved in measuring the rainfall. In the Satluj catchment up to Rampur, ordinary raingauges (ORG) have been installed at all stations except Rampur where a self recording rain gauge (SRRG) is installed and maintained by BBMB. The details of the rain gauge stations and availability of rainfall data with concern organizations is given in Appendix-I. The location of rainfall measuring stations in map is shown in Figure 2.

#### 3.1.2 Snow water equivalent observations :

BBMB is maintaining 21 snowgauge stations at present in the Satluj basin. The snow precipitation is recorded by a standard snow gauge of IMD as per IMD publication/specification No I.S.C. No 13, and in terms of it's water equivalent in mm Snow is put into a cylinder and a measured quantity of hot water is added to melt it. The volume of known quantity of hot water substracted from the total melted water measured in measuring cylinder gives the net water equivalent of snow precipitation in

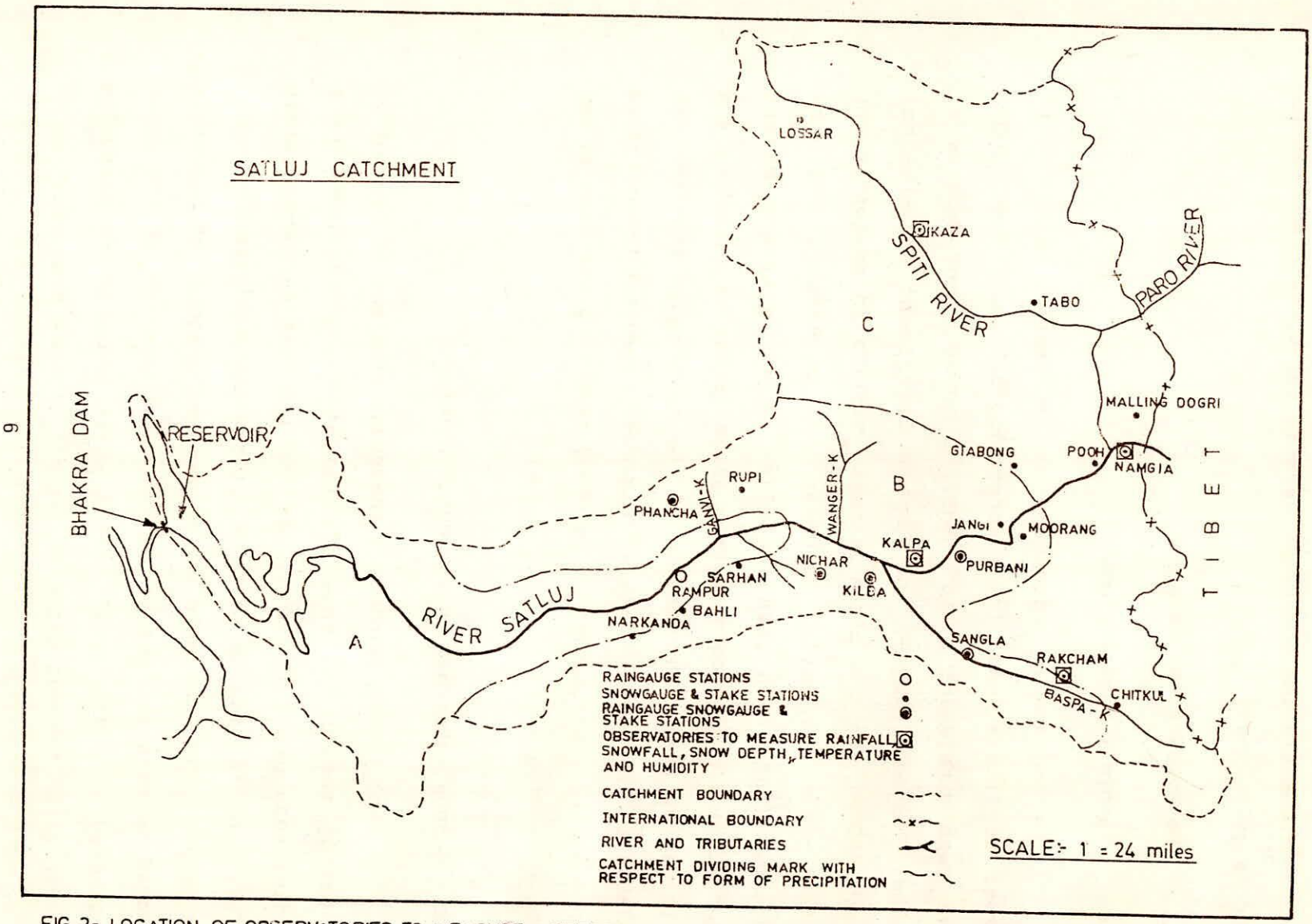


FIG. 2- LOCATION OF OBSERVATORIES TO MEASURE METEOROLOGICAL PARAMETERS IN SATLUJ CATCHMENT UP TO RAMPUR

mm . The most of the observatories have been inspected by IMD experts. The locations of stations is shown in Figure 2.

Part time observers record the daily data and dispatch the same to BBMB Hydrology Cell at Nangal Township. It takes a very long time for data to reach, particularly, when the area is inaccessible and remains snowbound for a very long period.

In view of the fact that observations were being made by part time observers , the data could not be considered very reliable. To overcome these difficulties , BBMB decided to establish snow observatories at few representative places in the snow bound catchment area. These were established at Kaza (3639m) in November, 1983 ; Namgia ( 2910 m) in January, 1983 ; Kalpa (2439 m) in August 1983; and Rakchham (3130 m ) in August 1984. Full time observers are posted at these obervatories. The list of observatories and details of data availability are given in Appendix-II.

### 3.1.3 Stake observations :

Snow stakes have been installed by BBMB at 21 observatories. Snow depth is measured from snow stakes installed at each site. Snow stake is a graduated/painted marked pole fixed in ground to determine the depth of snow during successive snowfall. The location and other details of snow depth observatories is given in Figure 2 and Appendix-III.

### 3.1.4 Temperature and humidity observations :

Maximum and minimum temperature, dry and wet bulb temperature and relative humidity are observed at 5 observatories

maintained by BBMB in Satluj catchment up to Rampur. The temperature observations are also made by IMD at Kalpa and Sarhan. The location, elevation and details of data availability are shown in Appendix-IV and Figure 2.

At four observatories BBMB has installed instruments to record continuous temperature using thermographs. Such observatories are listed in Appendix-V. Recently BBMB has installed instruments for temperature measurement at Mallingdogri , Chitkul and Jangi as suggested by the Snow and Ice Panel of Indian National Committee on Hydrology ( INCOH). The same instruments are being installed at Lossar also by BBMB.

The mean monthly maximum and minimum temperatures for Kalpa, Namgia, Rakchham and Kaza are given in Table 1.

### 3.2 Hydrological Data :

#### 3.2.1 Discharge observations:

HPSEB and BBMB are measuring discharge on main Satluj river and on it's tributaries. There are 15 discharge observation sites in total on Satluj and it's tributaries up to Rampur in the Indian territory. Out of these 15 sites, 9 sites are on the main river and 6 are on the tributaries. HPSEB is taking the discharge observations using velocity - area technique where flow velocity is determined by the float method. The details of all gauging sites are given in Appendix- VI and Figure 3.

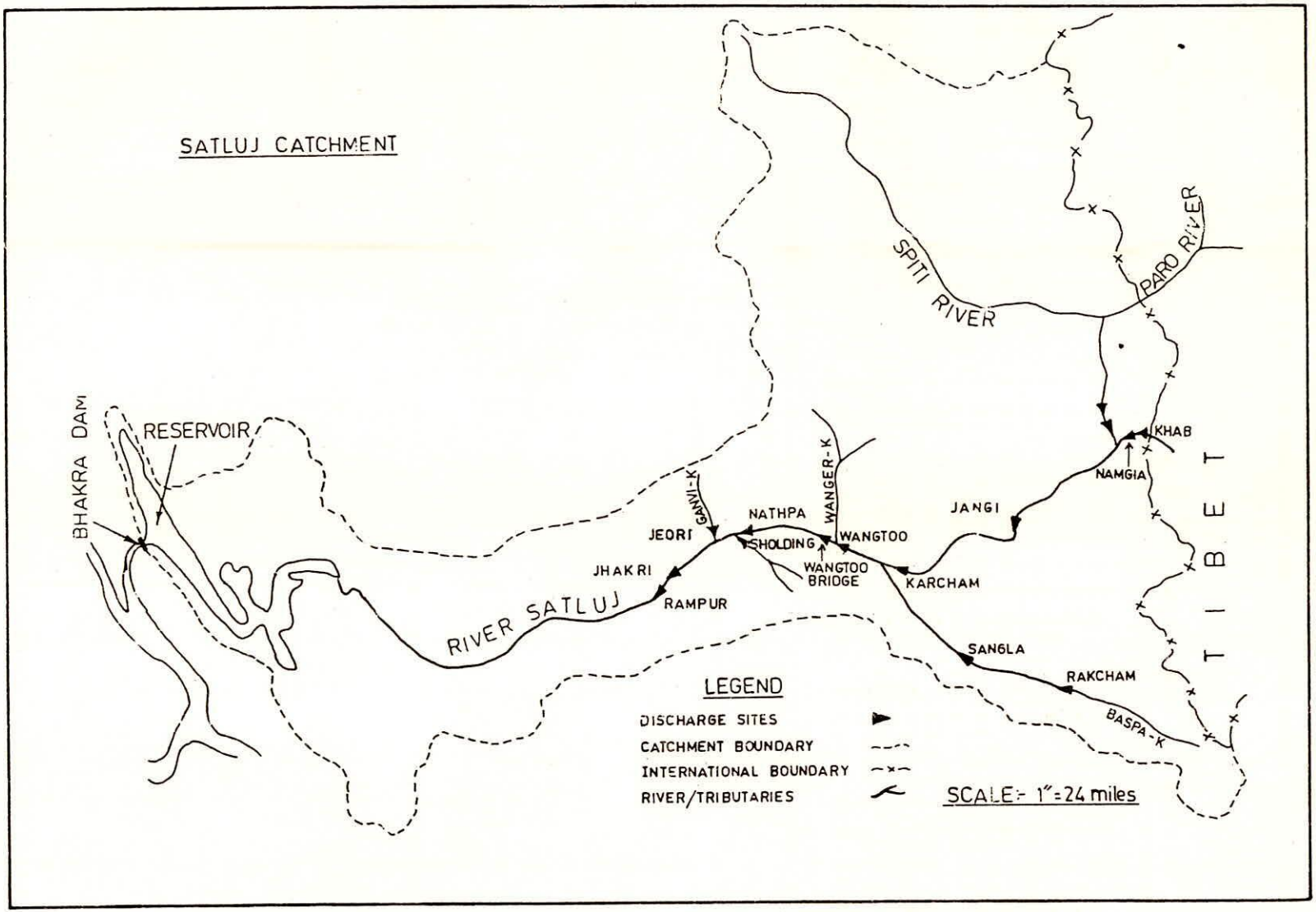


FIG. 3 - DISCHARGE GAUGING SITES AT SATLUJ AND ITS MAJOR TRIBUTARIES UP TO RAMPUR

**Table 1 : Mean monthly maximum and minimum temperatures (°C)**

| Month | Kalpa | | Namgia | | Rakchham | | Kaza | |
|---|---|---|---|---|---|---|---|---|
| | Max | Min | Max | Min | Max | Min | Max | Min |
| Jan | 3.5 | -6.0 | 3.2 | -8.2 | 4.0 | -12.4 | -4.7 | -18.9 |
| Feb | 5.6 | -4.3 | 5.2 | -4.6 | 6.6 | -9.2 | -8.3 | -21.6 |
| Mar | 13.0 | -8.0 | 11.1 | -0.9 | 9.4 | -5.0 | -5.0 | -17.9 |
| Apr | 15.3 | 3.6 | 15.7 | 2.9 | 12.2 | 2.0 | 2.8 | -10.5 |
| May | 19.4 | 6.6 | 20.4 | 6.8 | 15.5 | 3.2 | 12.0 | -0.7 |
| Jun | 23.5 | 11.5 | 25.5 | 9.6 | 20.3 | 7.1 | 17.6 | 5.8 |
| Jul | 25.2 | 13.0 | 29.6 | 12.0 | 20.3 | 10.2 | 23.4 | 10.0 |
| Aug | 22.8 | 13.7 | 26.9 | 12.9 | 23.4 | 9.6 | 24.5 | 11.3 |
| Sep | 21.2 | 10.5 | 24.6 | 8.8 | 18.1 | 5.4 | 19.0 | 7.3 |
| Oct | 17.3 | 4.9 | 18.9 | 3.2 | 14.4 | -0.1 | 13.3 | -0.3 |
| Nov | 13.6 | 2.0 | 14.2 | -0.5 | 11.4 | -2.9 | 7.5 | -8.5 |
| Dec | 6.8 | -2.2 | 6.7 | -3.8 | 6.6 | -7.2 | 1.0 | -11.7 |

## 4.0 REVIEW OF INVESTIGATIONS AND STUDIES :

### 4.1 Snowmelt Studies

The snowmelt estimation in the catchment area depends upon various factors such as extent of snow cover , depth of snow cover, snowpack density, temperature regime, albedo, relative humidity, wind velocity and glacier avalanche activity in addition to topographical features. It has been noted that snowmelt contribution in river Satluj varies from 50% to 60% in different years depending upon the quantum of snowfall in the winter and rainfall in the monsoon period (BBMB, 1988) Ramanathan and Ranganathan (1976) proposed that a regression relationship between total runoff at Bhakra during period April-June and precipitation index for preceeding accumulation season from the past data may be helpful in forecasting summer inflow into Bhakra reservoir prior to commencement of monsoon. The computation of temperature index for each year for the period April to June was suggested by finding out departure from the normal temperature for each of the three months April, May and June. Since departures of temperature in June have greater influence than those in May and similarly departures in May have greater influence than in April , therefore, weighing of temperature index is to be done before the temperature index is computed . The values predicted by regression line between runoff and precipitation index and that of between runoff and temperature index would help in establishing correction curves. For such studies the Satluj catchment may be considered in three different runoff regimes. One for Satluj up to Namgia, another

Spiti up to confluence with Satluj and third for catchment below Namgia. It was also pointed out that forecasting of inflows in the Bhakra reservoir may be possible provided reliable observations of snowfall are arranged in the catchment even at few selected places.

A methodology to estimate the snowmelt contribution to the annual inflow at Bhakra resevoir was proposed by Ramanathan and Ghanekar (1976). It included (i) preparation of ten daily flow distribution at Namgia after Spiti and Satluj confluence by adding ten daily discharges of Spiti to the corresponding ten daily discharges of Satluj, (ii) preparation of ten daily flow distribution at Rampur, (iii) superimposition of (Spiti and Satluj) at Namgia hydrograph on Rampur hydrograph and prepare the difference hydrograph. The difference hydrograph represents the ten daily distribution of the contribution of the catchment between Namgia and Rampur assuming that there are no channel losses.

National Remote Sensing Agency (NRSA) is making streamflow forecast in Satluj river during the period April to June. This forecast is based on the regression relationship between snow cover area and streamflow data for the above mentioned months. The extent of snow cover is delineated from the satellite imageries. The other important factors such as temperature, depth of snowcover etc have not been taken into account in these forecast.. The forecast by NRSA and actual inflows during period April to June for the different years has been reported by BBMB (1988) and reproduced in the following Table 2.

**Table 2 : A comparison between observed and predicted inflows by NRSA**

| Year | Actual inflows (cusec days) | Predicted inflows (cusec days) | % Variation predicted-actual inflows |
|---|---|---|---|
| 1980 | 15,60,378 | 13,50,000 ± 5% | + 15.6% |
| 1981 | 13,88,890 | 17,00,000 ± 10% | - 18.3% |
| 1982 | 18,36,301 | 16,75,000 | + 9.6% |
| 1983 | 17,12,527 | 20,50,000 ± 10% | - 16.5% |
| 1984 | 17,16,137 | 11,50,000 ± 10% | + 49.2% |
| 1988 | 17,82,009 | 19,50,000 ± 10% | + 8.6% |
| 1989 | 14,52,478 | 14,25,000 | + 1.9% |

Upadhyay et al ,(1983) analyzed past 50 years of rainfall and discharge data of the Satluj basin. Snowfall and rainfall have been considered as distinct series. Attempts have been made to develop an empirical relationship to estimate monthly snowmelt runoff as a function of degree - day factor and area under seasonal snowcover. The factors governing rainfall and glacier melt components have also been empirically estimated as a function of real mean of rainfall events , freezing level and maximum altitude level of rainfall in the catchment.

Mohile et al ,(1988) made a study to develop an empirical regression model for extending snowmelt data by the temperature recorded at Kaza by BBMB for a proposed diversion dam across river Spiti, 4 km upstream of Kaza at an elevation of about 3639 m. Discharge measurement of river Spiti near proposed dam site were started in July ,1986 by Center Water Commission. This data was used for analysis along with Kaza temperature data recorded by BBMB. The extension of discharge data at the dam site based on temperature discharge relation was investigated. Effort were also made to develop a relationship between Kaza and Namgia discharge.

A model of snow cover area versus runoff against a concurrent flow correlation model in the Western Himalayas has been evaluated using data of Satluj river (Dey and Goswami, 1984). It was found that the concurrent flow correlation model explains more than 90% of the variability of flows , while the snow cover model explains some what less of the variability in flows. It is mentioned in the study that Satluj river carries a significant amount of snowmelt runoff. The following relationship

between snowcover area and seasonal runoff has been established for the Satluj river.

$$Y = 0.06493\ X - 0.363325 \qquad (1)$$

where ,

Y = seasonal runoff (April-July) in $10^9$ $m^3$

X = average percentage of snowcover of the satluj basin.

Mr Wendell Tangborn, Hymet Company, Seattle, Washington, USA, was supplied snow precipitation data of 21 snow stations , maximum and minimum temperature of four snow observatories and inflows of Spiti river and Satluj river at Khab, and Satluj river at Rampur along with rainfall at Rampur, Kalpa and Rakchham under USAID Program with CWC ,New Delhi. After analyzing all the above data from 1984 to June 1988 for 4 snow obervatories and river inflows and precipitation data from October ,1976 to June, 1988, a forecasting model was designed to produce both short term (1-30 days) and long term ( 1-9 months) forecast of discharge of basin with sufficient snowpack. In his final model for Satluj streamflow forecasting , Tangborn used a high level station (Kaza) and a low level station (Kalpa) and Satluj river inflows at Rampur. Forecast of snowmelt streamflow of Satluj river at Rampur by Tangborn model from April to September, 1989, is given in the Table3.

### 4.2 Snow Surveys :

For the purpose of information on intensification of snow and proper assessment of water equivalent of the snowpack,

Table 3 : Comparison of actual and predicted inflows of Satluj river at Rampur (Tangborn model) during the year, 1989

| Month | Actual inflows cusec days | Predicted inflows cusec days | % Variation |
|---|---|---|---|
| Apr | 1,39,330 | 1,80,630 | -22.8% |
| May | 3,57,805 | 4,10,504 | -12.8% |
| Jun | 7,72,067 | 8,12,394 | -4.9% |
| Total | 12,69,202 | 14,03,528 | -9.57% |
| | | 14,85,530 (long range) | -14.56% |
| Jul | 10,78,591 | 12,05,460 | -10.5% |
| Aug | 7,97,497 | 10,52,187 | -24.2% |
| Sep | 4,24,075 | 4,92,859 | -14.0% |
| 1st Apr to 30 Sep,89 | 35,69,365 | 41,54,034 | -14.07% |

snow survey was undertaken / IMD during April, 1977 in this catchment. Another snow survey was undertaken during March-April, 1981 to study the physical parameters of snowfall in the area.

## 4.3 Glacier Studies :

The first generation glacier inventory of Satluj made by Geological Survey of India ( GSI) reveals that there are 495 glaciers in the catchment with mean level of glaciation at 5300 m (asl). Second generation glacier inventory was done to get more detailed knowledge about the subbasins. The following subbasins of Satluj basin have been studied.

| S No | Subbasin | No of glaciers | Total ice vol $km^3$ | Glacierized area $km^2$ | Glacierized % area |
|---|---|---|---|---|---|
| 1 | Baspa | 89 | 13.42 | 244.0 | 22.18 |
| 2 | Tirung khad | 60 | 5.39 | 135.0 | 14.7 |
| 3 | Tangla-Gymath -ing khad | 27 | 0.57 | 19.24 | 10.26 |
| 4 | Ropa Gad | 46 | 6.89 | 27.21 | 4.33 |

Kulkarani (1991) reported 36 glaciers covering 271 sq km area in the Indian part of Satluj basin. This information was extracted using satellite images and mapping on 1:250,000 scale. It was also suggested by him that mapping on larger scale, say 1:50,000 , will lead to a further revision as many small glaciers and other features will get mapped.

Three glaciers namely Gara glacier ( Tirung khad), Gor Garang glacier ( Baspa basin) and Shaune Garang glacier ( Baspa basin) have been studied by GSI since 1974. The selection of glaciers was done so that the glaciers selected are ' type

glaciers' in that region, depending upon aspect, size, and shape etc. The study over the period has revealed that during the assessment years 1974-1975, 1975-1976, the mass balance was positive followed by five succeeding years negative balance. During the years, 1982-1983, 1988-1989, the glacier had again showed positive balance. However, the cumulative mass balance over the last 15 years was negative. The glacier regime in Himalayas indicates a reverse relation with the annual monsoon precipitation in the plains.

Glacier melt contribution have been recorded at each glacier by erecting gates, gauges, installing automatic water level recorder during the ablation period (July-September) each year. Discharge analysis shows that discharge per sq km per day during the ablation season varies from $0.05 \times 10^6$ $m^3$ to $0.07 \times 10^6$ $m^3$ being lowest during the period when mass balance of the glacier is positive.

Suspended sediment transport was monitored/being monitored at each glacier under observation. The data on country rock in glacierized area was also collected. The contribution from granitic country rock area was found to be much higher than limestone area. The contribution from granitic/metamorphic area was found to be 5-6 tonns/sq km /day during the ablation period.

Dating of Gara and Gor Garang glaciers by radio isotope, $^{32}Si$ , method was undertaken by GSI in collaboration with Physical Research laboratory (PRL). The snout of Gara glacier was dated to be 200 years.

**Acknowledgements**

Author is very grateful to Bhakra Beas Management Board, Himachal Pradesh Electricity Board, India Meteorological Department and Geological Survey of India, Snow and Avalanche Study Establishment for suppling the information on the status of studies carried out by the respective organisation in the Satluj basin.

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Appendix-I

RAINFALL OBSERVATORIES

| S.No. | Observatory | Elevation (m) | Maintained by | Installation year | Data availability | Remarks |
|---|---|---|---|---|---|---|
| 1. | Rampur | 975 | DLRHP<br>BBMB | 1951<br>1961 | 1951-<br>Jul, 1961 onward | |
| 2. | Pancha | 2348 | DLRHP | 1951 | 1951-1975<br>1977-1978 | |
| 3. | Sarhan | 2374 | IMD | 1987 | Oct, 1987 onward | |
| 4. | Nichar | 2287 | DLRHP<br>FDHP | 1951<br>1985 | 1951-1983<br>May, 1985 onward | |
| 5. | Kilba | 2030 | DLRHP<br>FDHP | 1951<br>1985 | 1951-1983<br>May, 1985 onward | |
| 6. | Sangla | 2439 | DLRHP<br>FDHP | 1951<br>1985 | 1951-1983<br>May, 1985 onward | |
| 7. | Purbani | 2439 | DLRHP<br>FDHP | 1951<br>1985 | 1951-1983<br>May, 1985 onward | |
| 8. | Kalpa | 2439 | DLRHP<br>FDHP<br>IMD | 1951<br>1984<br>1984 | 1951-1983<br>Apr, 1984 onward<br>May, 1984 onward | |
| 9. | Rackchham | 3130 | BBMB | 1984 | Sep, 1984 onward | |
| 10. | Namgia | 2910 | BBMB | 1984 | - | |
| 11. | Kaza | 3639 | BBMB | 1983 | - | |

DLRHP - Director, Land Records of Himachal Pradesh.
FDHP - Forest Department of Himachal Pradesh.

Appendix-II

## SNOW WATER EQUIVALENT MEASURING OBSERVATORIES

| S.No. | Observatory | Elevation (m) | Maintained by | Installation year | Data availability | Remarks |
|---|---|---|---|---|---|---|
| 1. | Narkanda | 2774 | BBMB | 1972 | Oct 1976 onward | |
| 2. | Bahli | 2598 | BBMB | 1972 | Oct 1976 onward | |
| 3. | Sarhan | 2374 | BBMB | 1972 | Oct 1976 onward | |
| 4. | Pancha | 2348 | BBMB | 1972 | Oct 1976 onward | |
| 5. | Rupi | 2439 | BBMB | 1972 | Oct 1976 onward | |
| 6. | Nichar | 2287 | BBMB | 1972 | Oct 1976 onward | |
| 7. | Kilba | 2030 | BBMB | 1972 | Oct 1976 onward | |
| 8. | Sangla | 2439 | BBMB | 1972 | Oct 1976 onward | |
| 9. | Chitkul | 3841 | BBMB | 1972 | Oct 1976 onward | |
| 10. | Purbani | 2439 | BBMB | 1972 | Oct 1976 onward | |
| 11. | Moorang | 2744 | BBMB | 1972 | Oct 1976 onward | |
| 12. | Jangi | 3201 | BBMB | 1972 | Oct 1976 onward | |
| 13. | Giabong | 2896 | BBMB | 1972 | Oct 1976 onward | |
| 14. | Pooh | 2835 | BBMB | 1972 | Oct 1976 onward | |
| 15. | Mallingdogri | 3811 | BBMB | 1972 | Oct 1976 onward | |
| 16. | Tabo | 3260 | BBMB | 1972 | Oct 1976 onward | |
| 17. | Lossar | 4079 | BBMB | 1972 | Oct 1976 onward | |
| 18. | Kalpa | 2439 | BBMB | 1972 | Oct 1976 onward | upgraded to snow obs. in Aug. 1983 |
| 19. | Namgia | 2910 | BBMB | 1982 | Oct 1976 onward | upgraded to snow obs. in Aug. 1983 |
| 20. | Rakchham | 3130 | BBMB | 1984 | Aug 1984 onward | Newly es-blished snow obs. |
| 21. | Kaza | 3639 | BBMB | 1972 | Oct 1976 onward | upgraded to snow obs. in Aug. 1983 |

Appendix-III

SNOW DEPTH MEASURING OBSERVATORIES

| S.No. | Observatory | Elevation (m) | Maintained by | Data availability | Remarks |
|---|---|---|---|---|---|
| 1. | Narkanda | 2774 | BBMB | Oct 1983 onward | |
| 2. | Bahli | 2598 | BBMB | Oct 1983 onward | |
| 3. | Sarhan | 2374 | BBMB | Oct 1983 onward | |
| 4. | Pancha | 2348 | BBMB | Oct 1983 onward | |
| 5. | Rupi | 2439 | BBMB | Oct 1983 onward | |
| 6. | Nichar | 2287 | BBMB | Oct 1983 onward | |
| 7. | Kilba | 2030 | BBMB | Oct 1983 onward | |
| 8. | Sangla | 2439 | BBMB | Oct 1983 onward | |
| 9. | Chitkul | 3841 | BBMB | Oct 1983 onward | |
| 10. | Purbani | 2439 | BBMB | Oct 1983 onward | |
| 11. | Moorang | 2744 | BBMB | Oct 1983 onward | |
| 12. | Jangi | 3201 | BBMB | Oct 1983 onward | |
| 13. | Giabong | 2896 | BBMB | Oct 1983 onward | |
| 14. | Pooh | 2835 | BBMB | Oct 1983 onward | |
| 15. | Mallingdogri | 3811 | BBMB | Oct 1983 onward | |
| 16. | Tabo | 3260 | BBMB | Oct 1983 onward | |
| 17. | Lossar | 4079 | BBMB | Oct 1983 onward | |
| 18. | Kalpa | 2439 | BBMB | Sep 1983 onward | |
| 19. | Namgia | 2910 | BBMB | Jan 1983 onward | |
| 20. | Rakchham | 3130 | BBMB | Sep 1983 onward | |
| 21. | Kaza | 3639 | BBMB | Nov 1983 onward | |

Appendix-IV

MAXIMUM AND MINIMUM TEMPERATURE, DRY AND WET BULB TEMPERATURE, HUMIDITY MEASURING OBSERVATORIES

| S.No. | Observatory | Elevation (m) | Maintained by | Installation year | Data availability | Remarks |
|---|---|---|---|---|---|---|
| 1. | Rampur | 1066 | BBMB | 1962 | Dec 1962 onward | |
| 2. | Kalpa | 2439 | BBMB | 1983 | Sep 1983 onward | |
| 3. | Namgia | 2910 | BBMB | 1983 | Jan 1983 onward | |
| 4. | Rackchham | 3130 | BBMB | 1984 | Sep 1984 onward | |
| 5. | Kaza | 3639 | BBMB | 1983 | Jan 1984 onward | |

Appendix-V

CONTINUOUS TEMPERATURE RECORDING OBSERVATORIES

| S.No. | Observatory | Elevation (m) | Maintained by | Installation year | Data availability | Remarks |
|---|---|---|---|---|---|---|
| 1. | Kalpa | 2439 | BBMB | 1983 | Aug 1984 onward | |
| 2. | Namgia | 2910 | BBMB | 1983 | Jan 1984 onward | |
| 3. | Rackchham | 3130 | BBMB | 1984 | Sep 1986 onward | |
| 4. | Kaza | 3639 | BBMB | 1983 | Jan 1986 onward | |

DISCHARGE GAUGING SITES ON MAIN SATLUJ AND
MAJOR TRIBUTARIES UPSTREAM OF RAMPUR

| S.No. | Observatory | Maintained by | Installation year | Data availability | Remarks |
|---|---|---|---|---|---|
| **Main River** | | | | | |
| 1. | Khab-upsream of confluence of Spiti and Satluj | HPSEB | 1965 | | |
| 2. | Khab-down sream of confluence of Spiti and Satluj | HPSEB | 1966 | Apr 1966 onward (with BBMB Oct 1976 onward) | |
| 3. | Jangi | HPSEB | 1971 | Jan 1971 | |
| 4. | Karcham | HPSEB | 1975 | Jan 1975 | |
| 5. | Wangtoo | HPSEB | 1970 | Apr 1970 | |
| 6. | Wangtoo(near bridge) | HPSEB | 1967 | Nov 1867 | |
| 7. | Nathpa | HPSEB | 1975 | Jan 1975 | |
| 8. | Jakhri | HPSEB | 1977 | Jan 1977 | |
| 9. | Rampur | BBMB | 1962 | Jul 1962 | |
| **Tributaries** | | | | | |
| 10. | Khab-at Spiti river upstream of Satluj confluence | HPSEB | 1966 | Apr 1966 (with BBMB Oct 1976 onward) | |
| 11. | Sangla- at Baspa khad | HPSEB | 1964 | Jan 1964 | |
| 12. | Rackchham- at Baspa khad | HPSEB | 1970 | Sep 1970 | |
| 13. | Humta- at Babha khad | HPSEB | 1970 | Mar 1970 | |
| 14. | Sholding-at Sholding khad | HPSEB | 1968 | May 1968 | |
| 15. | Jeori- at Ganvi khad | HPSEB | 1977 | Jan 1977 | |

| | | |
|---|---|---|
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