SNOW HYDROLOGY IN THE UPPER YAMUNA BASIN, INDIA

R. Veena Malhotra
Department of Earth Sciences
Dartmouth College
Hanover, New Hampshire, 03755

Harlan L. McKim
U.S. Army Cold Regions Research and Engineering Laboratory
Hanover, New Hampshire, 03755

R. Rangachari
Central Water Commission
New Delhi
India

ABSTRACT

Snow accumulation and ablation in the front range of the Himalayan Mountains accounts for a considerable portion of winter and spring streamflow from the Upper Yamuna River Basin. To quantify this contribution, the Central Water Commission (CWC) of India has been collecting hydrometeorological data and conducting snow surveys in the Sundli Nala Watershed, a small tributary of the Pabar River that drains into the Upper Yamuna River system.

Hydrometerological data from the Sundli Nala watershed, from December to March for the years 1984–1988, were input into the two snowmelt options of the Streamflow Synthesis and Reservoir Regulation (SSARR) model to determine the relationship of snowmelt runoff to observed discharge. For this period, the observed streamflow data indicated that snowmelt did not contribute significantly to the overall yearly discharge. Losses due to sublimation and evapotranspiration decrease the effect of snowmelt runoff. A large portion of the remaining available meltwater infiltrates to baseflow.

This study provides for the first time a better understanding of the snowmelt dynamics in this region of the world. The data base being developed in the Sundli Nala can be used to calibrate the hydrologic forecasting model being developed by the Indian CWC to manage the water resources for the Upper Yamuna River.

INTRODUCTION

The need to quantify the input of snowmelt runoff into total seasonal discharge in northern Indian rivers has been recognized for several decades. Previous attempts to estimate this input have concentrated on developing methods to correlate total seasonal discharge with snow cover area calculated for large watersheds. Studies of this sort include those by Duggal et al. (1981), Gupta et al. (1982), Ramamoorthi and Rao (1982), Ramamoorthi (1983) and Dey et al. (1984). The cooperative effort between the Central Water Commission of India, the United Nations, and the World Meteorological Organization has led to the first comprehensive collection of snow accumulation data for the Indian Himalayas, making snowmelt runoff studies feasible.

The locations for the meteorological sensors and snow surveys were carefully selected so that the data collected from the sites would fulfill the input requirements of the snowmelt subroutines of the Streamflow Synthesis and Reservoir Regulation (SSARR) model. The snowmelt subroutines are an integral part of the SSARR model (Figure 1). Field data were also collected to define basin characteristics and the pattern of snowmelt. These measurements ensured that detailed short-term and long-term snowmelt runoff could be predicted using a mass balance modeling approach.

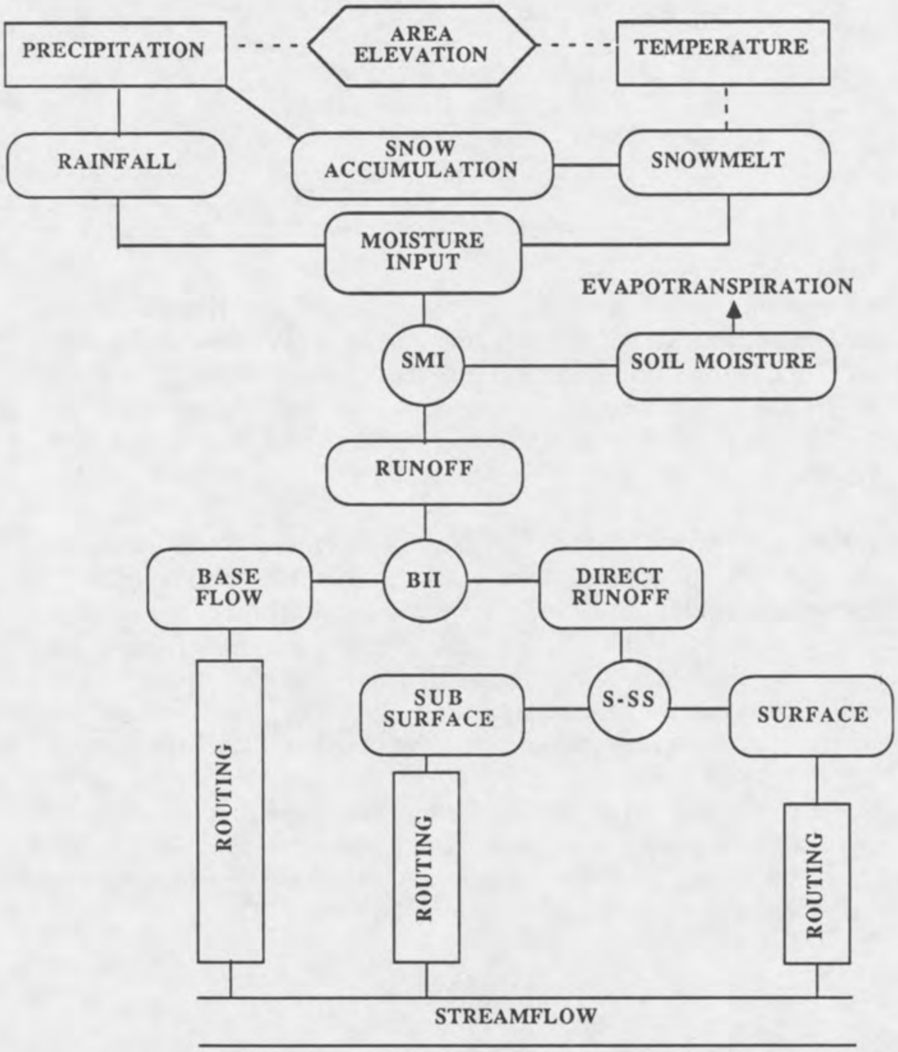

Figure 1. Schematic diagram of the SSARR model.

BACKGROUND

In August 1979 the Government of India approved a Pilot Project titled "Improvement of River and Flood Forecasting Systems in India" in cooperation with the World Meteorological Organization/ United Nations Development Programme (WMO/UNDP). The primary purpose of the project was to modernize India's existing flood forecasting system through the use of a remote sensing system for collecting meteorological and hydrological data. The project started in April 1980. With this start came the revitalization of snow hydrology in India.

To carry out the acquisition and use of the snow data in flood forecasting, a Snow Hydrology Division (SHD) was established in the Central Water Commission (CWC) in May, 1984. The SHD immediately developed a Snow Hydrology Pilot Project that involved training CWC personnel on data collection procedures and remote sensing instruments, and installing and maintaining these sensors.

OBJECTIVES

The primary objectives of this study were to examine the quality, consistency and reliability of the data for the Sundli Nala watershed; to compare the observed discharge with the predicted discharge; to provide data on snowmelt runoff dynamics and basin characteristics; and to evaluate the use of SSARR to model long-range discharge predictions in the basin during its snowmelt season.

STUDY AREA

The Sundli Nala Basin, a 4.86-sq-km watershed near the town of Jubbal in the Himachael Pradesh Province, was chosen as the initial study site. The Sundli Nala watershed is a tributary to the Pabar river, part of the Upper Yamuna River system (Figure 2). This watershed has an elevation range of 2000–3556 m. The vegetation cover is primarily coniferous forest with canopy closure ranging from 20% to 80%. Approximately 10% of the watershed is privately owned, and cover varies from clear-cut grazing meadows to apple orchards. Steep slopes account for the thin undeveloped soil cover, which is subject to rapid erosion. Bedrock consists of a well-fractured metamorphic gneiss, common to a large area of the Lesser Himalayan Range.

The Sundli Nala watershed was chosen as it is representative of a large number of watersheds in the Himachael Province. It is also close to a main highway and medical facilities. The average yearly snowfall is estimated at 30-45 cm at 1828 m, where Jubbal is located, and is believed to reach in excess of 300 cm at the highest elevations of the Sundli Nala watershed. The average annual discharge has been estimated at about 0.15 m^3/s, but the maximum over the last 40 years is thought to be around 50 m^3/s (Rangachari, 1986).

Figure 2. Location map of the Sundli Nala watershed.

DATA COLLECTION

Meteorological and hydrological data were collected in the watershed for the four winters between 1984 and 1988. With the exception of discharge measurements and the snow surveys, all data were collected at the meteorological station, located within the Sundli Nala watershed at an elevation of 2400 m. The hydrometeorologic parameters collected were daily temperature, precipitation, humidity, discharge, snow depth, snow water equivalent, wind speed and direction, and weekly snow course information from 17 snow courses (Figure 3).

Precipitation measurements were taken with a prototype Indian rain gauge and a conventional tipping bucket recorder system. The tipping-bucket data were collected

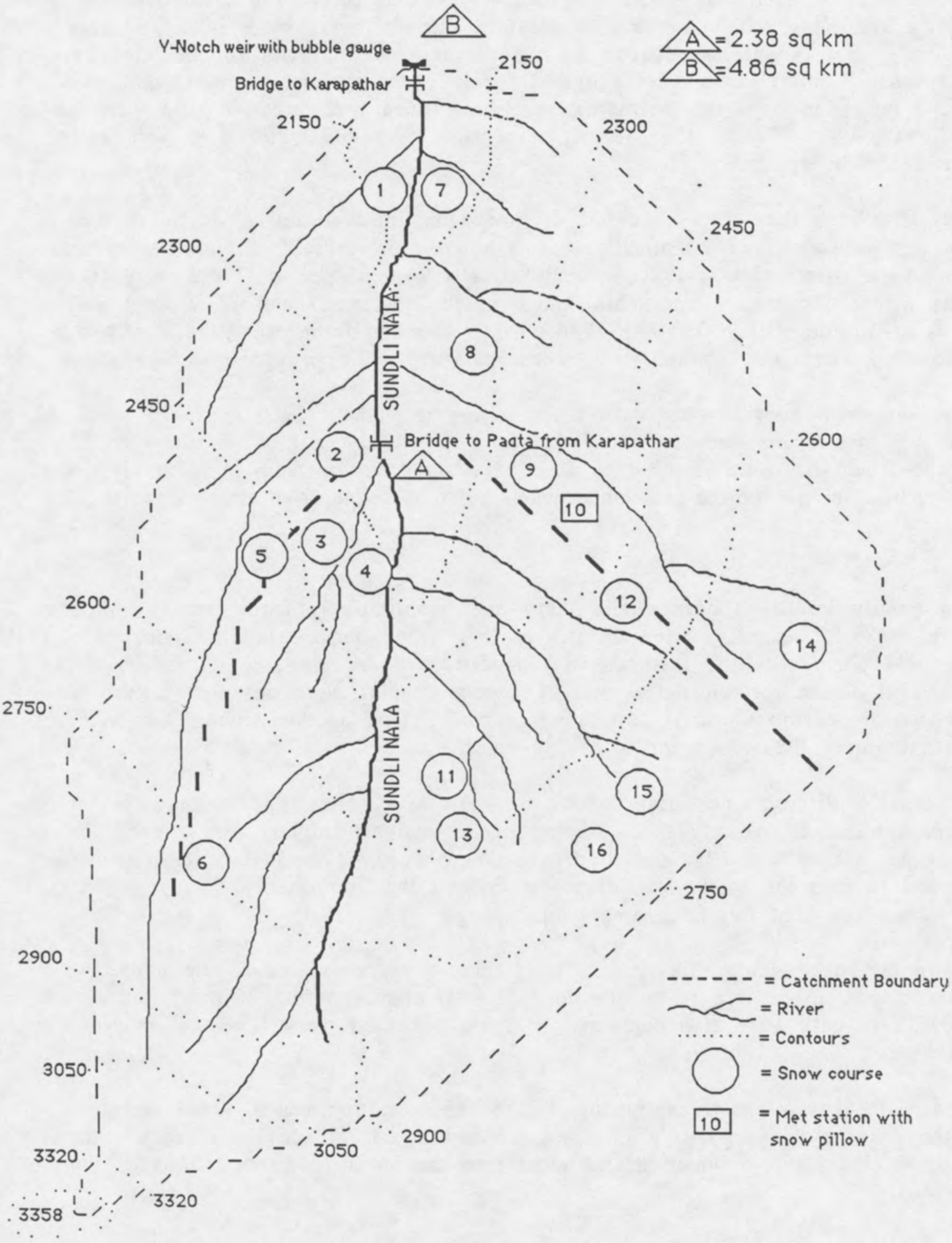

Figure 3. Hydrometerological site at Jubbal.

for the last two snow seasons. Precipitation data were also calculated from snow depth measurements taken at the meteorological site. Water equivalent of the snowpack was determined from the stainless steel snow pillow installed before the 1986–87 snow season. Daily minimum and maximum temperature measurements were obtained from thermometers. Hourly data were also available from a thermograph for the last three snow seasons. Humidity data were acquired for the four seasons from a hygrothermograph and wet- and dry-bulb thermometers. Wind speed and direction data were obtained for the 1986–87 and 1987-88 winter seasons. Net radiometer data were collected and are being interpreted.

Daily discharge data were recorded at three-hour interval during daylight hours over all four seasons from a manually read V-notch weir. Initially a bubble gauge was used to record stream flow data continually over a 24-hour period. There were some problems with the operation and maintenance of the system. Therefore, a float system was installed at the weir before the 1986–87 snow season to measure the hourly rise and fall of the water level in the river. These data are being converted to flow rates.

Seventeen snow courses were established in the watershed. Each consisted of 5 or 10 sampling sites. These snow courses were sampled weekly. All of the snow courses were located below the elevation of 2750 m. The snow survey team made at least one transect to the summit of the watershed when ablation began to occur.

Data quality

Data quality improved both qualitatively and quantitatively from the 1984-85 season to the 1986-87 season. As the snow hydrology group became familiar with all of the sensors, field procedures and methods were modified, increasing the reliability of the data collected at the meteorological station. Inconsistencies were observed in the data between sensors during the first two snow seasons. These inconsistencies were corrected by recalibrating the sensors on a weekly basis.

The greatest discrepancies occurred in precipitation data during the snow season. Precipitation was collected in both a tipping bucket and an ordinary rain gauge. The tipping-bucket sensor was expected to provide more accurate results as it contained a heating coil to melt the snow. Due to power failures the tipping-bucket gauge often missed events recorded by the ordinary rain gauge.

All tipping-bucket and ordinary rain gauge data were compared to the daily snow depth and snow pillow data to ensure that the best approximation of precipitation was obtained. These data were also compared to those collected from a nearby meteorological station.

Snow water equivalent measurements by the snow survey teams were used to estimate the water budget in the basin. They defined the differences in snow accumulation with elevation and provided useful input into the elevation band options of the SSARR model.

Low snow accumulations were recorded in the study basin over the four years of operation. At the meteorological site (elevation 2400 m) the maximum snow depth recorded in the past four years was 70 cm. The 1987-88 season had the lowest maximum snow depth observed for the four seasons at 10 cm. The yearly quantity of snow was significantly less than what was expected, based on the experiences of the local inhabitants around Jubbal. Large snow events were recorded in late February and early March for several of the seasons; however, the air and ground temperatures were too high for snow to accumulate.

Observed changes in discharge

The Sundli Nala basin is characterized by a thin soil cover and steep slopes, causing the response time for precipitation events to be extremely rapid. It was thought that sharp rises would be present in the discharge data as the snow melted.

The snow survey data indicate that snowmelt begins immediately after each precipitation event. Recorded daily air temperatures rarely remain below freezing for more than a few days per season at the 2400-m level. Large elevation differences (2000 to 3556 m) in the watershed greatly influence the timing of the maximum melt period. Therefore, the melting pattern is correlated with orographic effects. Also, warm daylight temperatures, high winds and low humidity cause a large portion of the moisture to be evaporated or sublimated before it reaches the weir.

SSARR MODEL RESULTS

The latest version of SSARR (1986) consists of two separate snowmelt runoff routines, the Integrated Snowband Watershed Model and the Depletion Watershed Model (U.S. Army Corps of Engineers, 1986). For the latter the temperature index approach and snowband option were utilized. The Integrated Snowband Model uses climatological data to compute the snowpack volume and extent, which makes it useful for volume forecasting. The Temperature Index Method of the Depletion Curve Model utilizes daily temperature and an elevation-area curve for the basin to determine whether snow will accumulate, remain constant or melt in each elevation zone. It is similar to the Integrated Snowband Watershed model. Daily input requirements for the SSARR models are average or minimum and maximum temperature, precipitation and discharge.

To calibrate the SSARR snowmelt routines, the basin characteristics and snowmelt dynamics for the Sundli Nala watershed were defined. Initially, basin characteristics such as lapse rates and surface, subsurface and baseflow storage times were estimated based on data published by the snow hydrology team for the study site, as well as example basins in the SSARR manual. Typical relationships were estimated from examples in the SSARR manual and included soil moisture versus runoff percent, input rate of precipitation versus the amount of runoff routed to surface and subsurface flow, respectively, and the baseflow infiltration versus the percent of runoff routed to baseflow.

Snowmelt dynamics were determined from the snow course and snow depth measurements at the study basin. Parameters derived from this data set included melt rates and snow water equivalent values throughout the snow season.

The hydrometeorological data from the 1986-87 winter season were run through the Integrated Snowband Model. The results indicated that discharge during the snowmelt season was extremely overestimated during late January and early February, while rain events at the end of the season were well modeled (Figure 4).

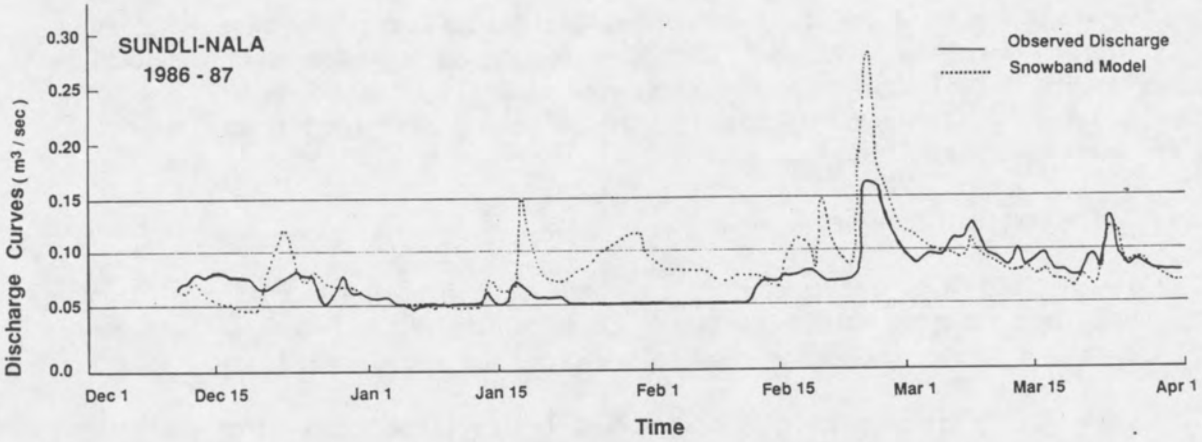

Figure 4. Initial SSARR discharge prediction versus actual discharge for the 1986–87 data.

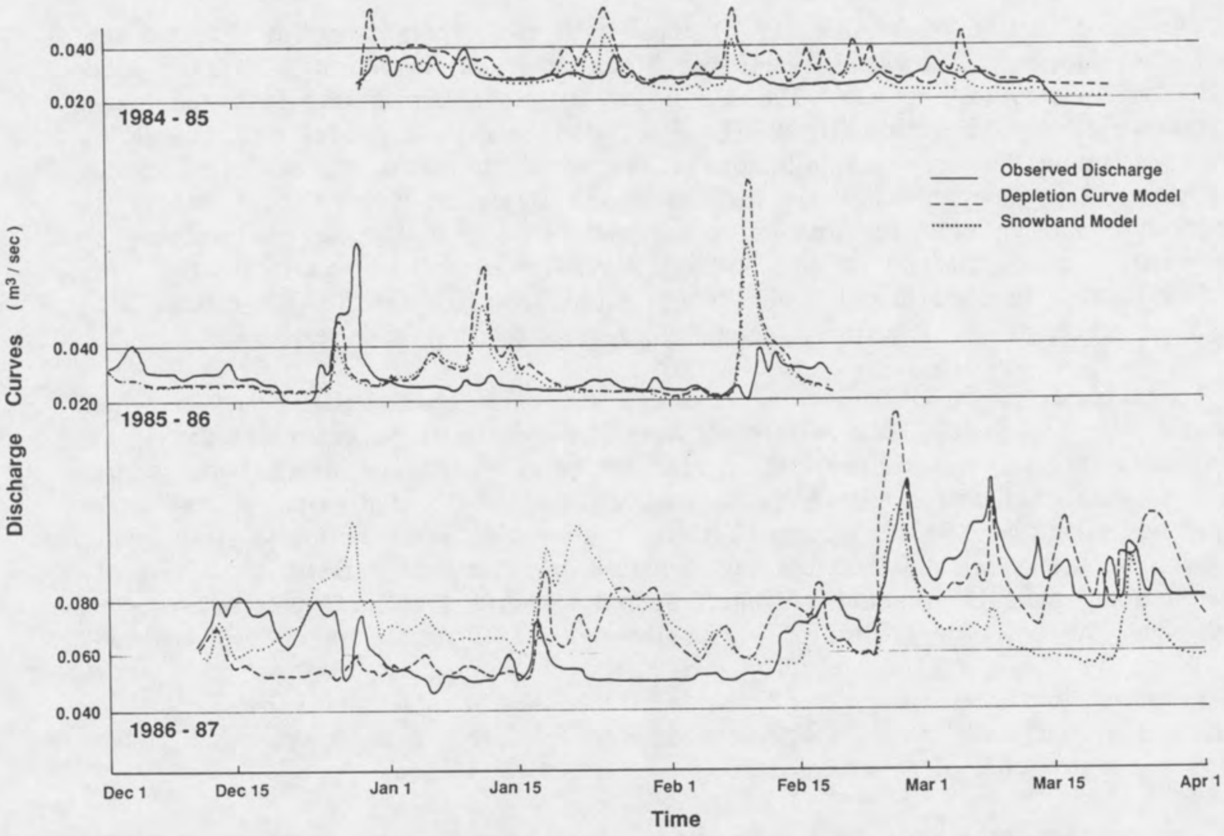

Figure 5. Final SSARR discharge prediction versus actual discharge for the 1984–1987 data.

Field work was completed in the fall of 1987 to check that basin characteristics were logically estimated. All relationships that were derived for the model were discussed with the snow hydrology field teams to ensure that they were reasonable. Both the Integrated Snowband Watershed Model and the Depletion Curve Watershed Model were then recalibrated with slight changes, particularly in the snowmelt and evapotranspiration rates, using data from the 1984-1987 snow seasons. This resulted in a closer fit of the models to observed discharge (Figure 5). However, there are still large discrepancies between the observed and predicted discharge during the snowmelt runoff period. It is postulated that the discrepancies are related to the frequency of the discharge data (every 3 hours during daylight hours) rather then SSARR calibration error. Further simulation using continuous recorded discharge data for the 1988-89 winter season will allow this to be verified.

CONCLUSIONS

The sensor evaluation study being conducted by WMO and the CWC in the Snow Hydrology Division is the first step in understanding sensor performance and the quality of the snow data being obtained in this sector of the world. The test, evaluation, and training program was successful, and a cadre of technical engineers and technicians are available to conduct the field evaluation and model verification for larger basins. The data collection, management and SSARR model calibration are well understood by CWC.

Two options of the SSARR (Streamflow Synthesis and Reservoir Regulation) model were used to develop a long-range prediction of snowmelt for the Sundli Nala Basin. After calibration, both options synthesized the observed discharge quite well using the raw data gathered by the snow hydrology group. In calibrating the SSARR model it was apparent that to simulate the lack of rise in discharge during ablation, the sublimation and evapotranspiration must be quite high, the melt rate must be low, and a large amount of the snowmelt runoff must be routed to baseflow. This is contradictory to the rapid response of the basin during rainfall as shown by the discharge data (Figure 5).

The initial results from the modeling effort were encouraging. However, several high-snowfall events will be required to create a complete snow data base to calibrate the SSARR model for the Lesser Himalayan region.

FUTURE WORK

Snow data collection activities will continue at the Sundli Nala watershed. Other sites will be selected in the Pabar and Upper Yamuna River Basin to extend the results and experience learned in the Sundli Nala. Remote-sensing satellite data can be used to provide snow data over large basins. Calibration of the SSARR model will be extended to include all snow-covered areas of the Yamuna River Basin.

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