Flash-Flood Warning for the Upper Sutlej River Basin, Northern India

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ABSTRACT

Through a collaborative effort of several governmental agencies in India and the United States, a pilot flash-flood warning system is being implemented for the upper Sutlej River basin in northern India. The Sutlej River is prone to extreme flash floods resulting from localized cloud bursts, the failure of debris dams or sudden glacial melt. Hence, floods can be independent of weather and, therefore, difficult to forecast. As a result, a flood-warning system is needed to measure, transmit, and forecast water levels in order to assist in flood mitigation. A data-collection and telemetry network was installed along the river and a simple flood-routing model is being implemented. Direct communications with local authorities, the army, and other stakeholders are being established. These combined efforts will reduce the vulnerability of citizens in the upper Sutlej River basin to flash floods, improve warning capabilities of the Central Water Commission (CWC) of India, and increase long-term collaboration between Indian and American hydrologists and meteorologists.

INTRODUCTION

Approximately 16 percent of the world's population lives in India on about 2.45 percent of the earth's land. The country is subject to a variety of natural hazards, including droughts, flash floods, widespread flooding from monsoonal rains, severe thunderstorms, cyclones, tsunamis, landslides, and earthquakes. In 2003, the Government of India (GOI) and the United States Agency for International Development (USAID) initiated the Disaster Management Support (DMS) project as

a collaborative effort to reduce the vulnerability of the Indian population to a variety of natural hazards. The DMS project includes implementation of a pilot flood-warning system for the upper Sutlej River basin in northern India. The purpose of this paper is to provide background information on the DMS project, and to describe upper Sutlej flash-flood warning demonstration project, including background on the basin and recent floods.

CLIMATE FORECASTING SYSTEMS COMPONENT OF THE GOVERNMENT OF INDIA – USAID DISASTER MANAGEMENT PROJECT

The Climate Forecasting Systems (CFS) component of the DMS project supports the use of climate and weather forecasts as tools to enhance early warning of floods and other hazards, promote better decisionmaking at the local level, and enhance allocation of scarce natural resources. Through a set of demonstration projects that are being implemented during 2005 – 2007 and peer-to-peer interactions, improvements are being made in the capacity of GOI agencies to predict the occurrence of hydrometeorological events and to develop more effective plans at the national, state, and local levels to mitigate the adverse effects of these events. CFS activities promote dialogue and cooperation among various Indian agencies, including the CWC, Indian Meteorological Department (IMD), government ministries and departments at the national and state levels, and universities and research institutes for climate hazards.

The CFS component of the DMS project includes five subprojects: (1) tropical cyclone forecasting and warning; (2) local severe storms, including flash floods; (3) extreme temperatures; (4) flood forecasting, including flood inundation mapping; and (5) forecast communications. Pilot early-warning and disaster preparedness systems, which directly reduce vulnerability at the local level, are being implemented through these subprojects. The systems incorporate the needs of users through institutionalized dialogue among interested stakeholders.

SUTLEJ RIVER FLASH-FLOOD WARNING AND MITIGATION PILOT PROJECT

As a sub-project of the CFS, the CWC, National Weather Service (NWS), and U.S. Geological Survey (USGS) are implementing a demonstration flash-flood warning project for the upper Sutlej River Basin in northern India. The objective of the project is to develop a prototype flash-flood warning system to provide national and local authorities with sufficient warning to mitigate the effects of the extreme flash floods that occur frequently in the upper Sutlej Basin. Experiences from this project can then be transferred to other river basins in India.

Study Area

The Sutlej River (fig. 1), also known as the Langqên (Chinese) and Satlej (Indian) River, is the principal tributary of the Indus River. The river flows approximately west-northwest from China, and west-southwest from approximately the India – China border to the Indus River. The Sutlej River flows from China into the Indian state of Himachal Pradesh, and subsequently into the state of Punjab before joining

the Indus River in Pakistan. After being joined by four other rivers in Punjab, the Sutlej is sometimes known as the Panjnad (five rivers) River. The flash-flood warning project is being conducted entirely within Himachal Pradesh, upstream from the city of Simla (also known as Shimla; fig. 1).

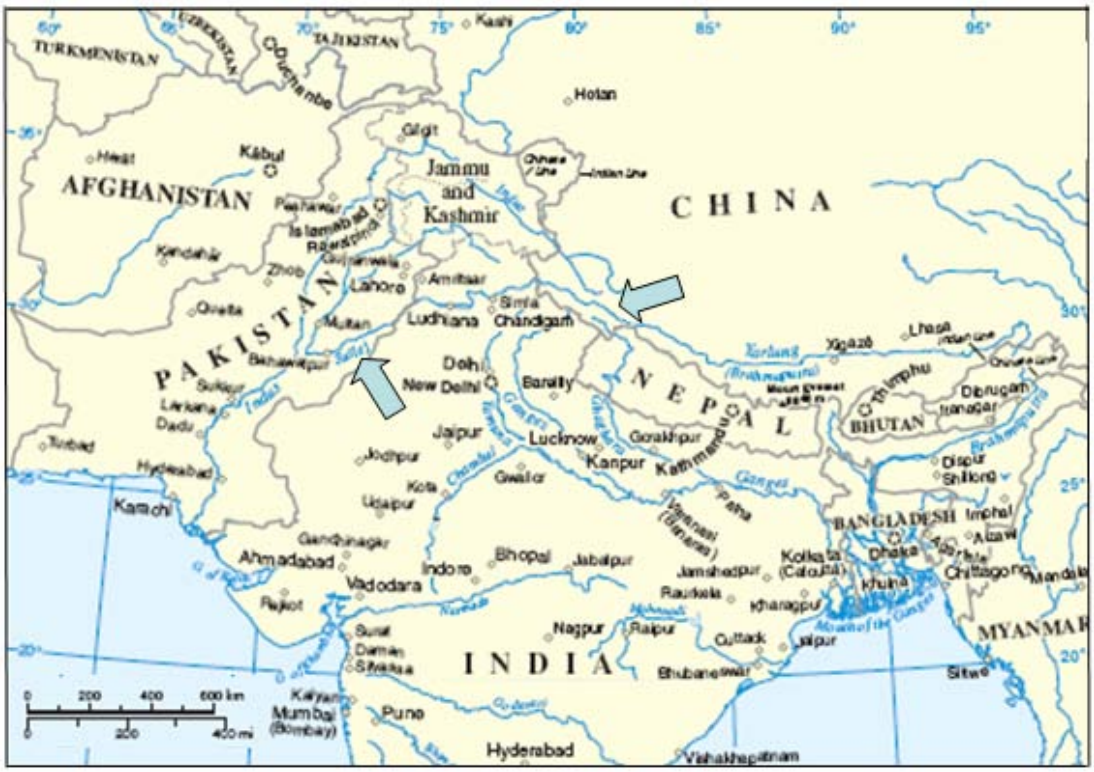

Figure 1. Location of Sutlej River in India; block arrows indicate Sutlej River. (Source: United Nations, 2001).

The source of the Sutlej River is in China where elevations in some locations of the basin are as high as 6,700 m (meters). The total area of the basin downstream to Rampur (fig. 2) is 51,000 km^2 (square kilometers), of which about 37,000 km^2 is in India. The average slope of the river between the India – China border and the confluence of the Baspa River with the Sutlej is about 12 m/km, although slopes can be as high as 45 m/km. The walls of the river valley between Khab and Rampur are quite steep, with typical slopes of 45 – 50 degrees. In some locations, the river valley narrows to only 50 – 150 m in width, with valley slopes as great as 70 degrees. The climate is generally arid, and little vegetation grows along the Sutlej River valley. Some of the higher mountain plateaus above the treeline are, however, covered in alpine grasses.

Sutlej River streamflow has been measured at Khab since1972 (fig. 3) and at Rampur since 1963. Flows are strongly bi-model throughout this reach; for example, flows typically range from about 70 – 130 m^3/s (cubic meters per second) in the winter to 400 – 1,500 m^3/s in the summer at Rampur. Much of the flow in the Sutlej is derived from glacial meltwater and snowmelt. The upper part of the Sutlej basin is not

affected by the monsoon, but snowfall occurs in the higher elevations. Monsoonal rains, which typically occur between early July and late August affect flows in the basin downstream from about Karchhan. Suspended- sediment concentrations can be elevated during periods of high flow, with concentrations as high as 43,000 mg/L (milligrams per liter) reported.

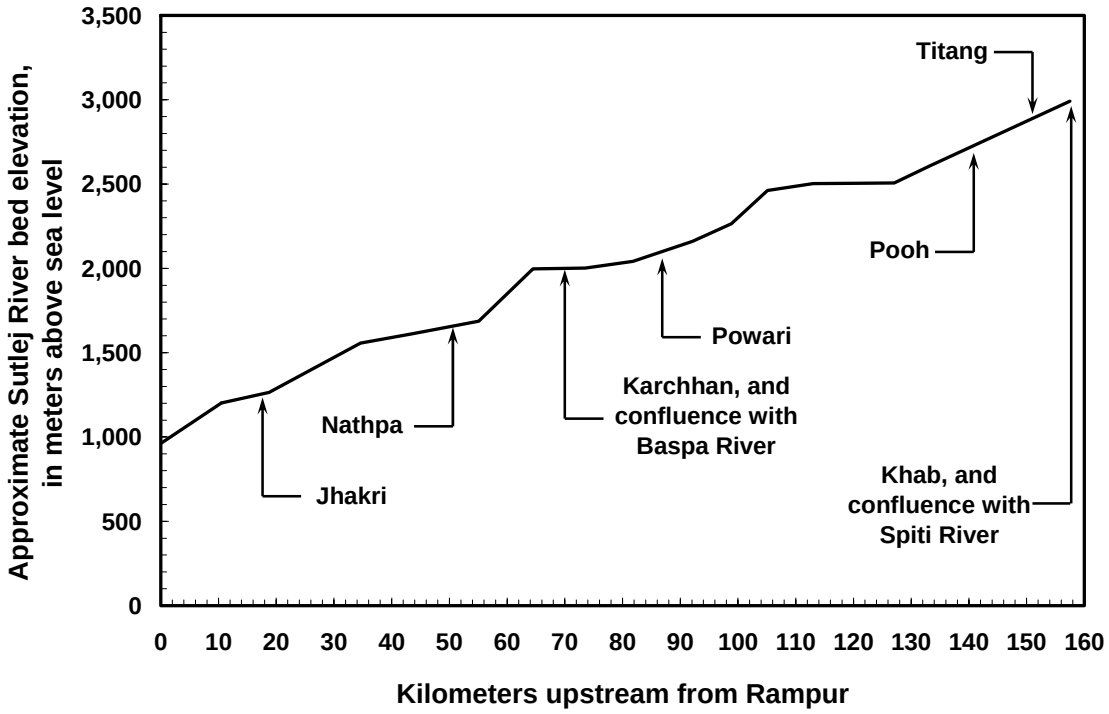

Figure 2. Approximate Sutlej River bed elevation and locations of selected towns and tributaries along the Sutlej River between Rampur and Khab.

The hydropower potential of rivers in Himachel Pradesh is estimated to be more than 11,000 megawatts (MW), which is more than a third of the hydropower potential of the entire nation. Much of this hydropower potential is in the Sutlej basin. One of the first of many planned hydropower projects in the Sutlej basin was completed in 2004. The Nathpa-Jhakri project includes a low dam (approximately 60 m high) that diverts flow in the Sutlej through a pair of 27-km long tunnels to a powerhouse near Jhakri. The facility can generate about 1,500 MW of electricity and supplies power to Himachel Pradesh and to Delhi.

The project must be shut down when suspended sediment concentrations exceed about 4,000 mg/L to avoid damage to the turbines. (The project was closed more than 2 weeks, as of August 10, 2006, because of high sediment levels, resulting in an income loss of more than one billion Rupees and power shortages in parts of the country.) In addition, floodgates at the dam must be opened to pass floodwaters. The process of shutting down the tunnels and opening the floodgates requires about 2 hours. Hence, not only is a flash-flood warning system needed to provide local officials with information for emergency response but also to protect the Nathpa-Jhakri project infrastructure.

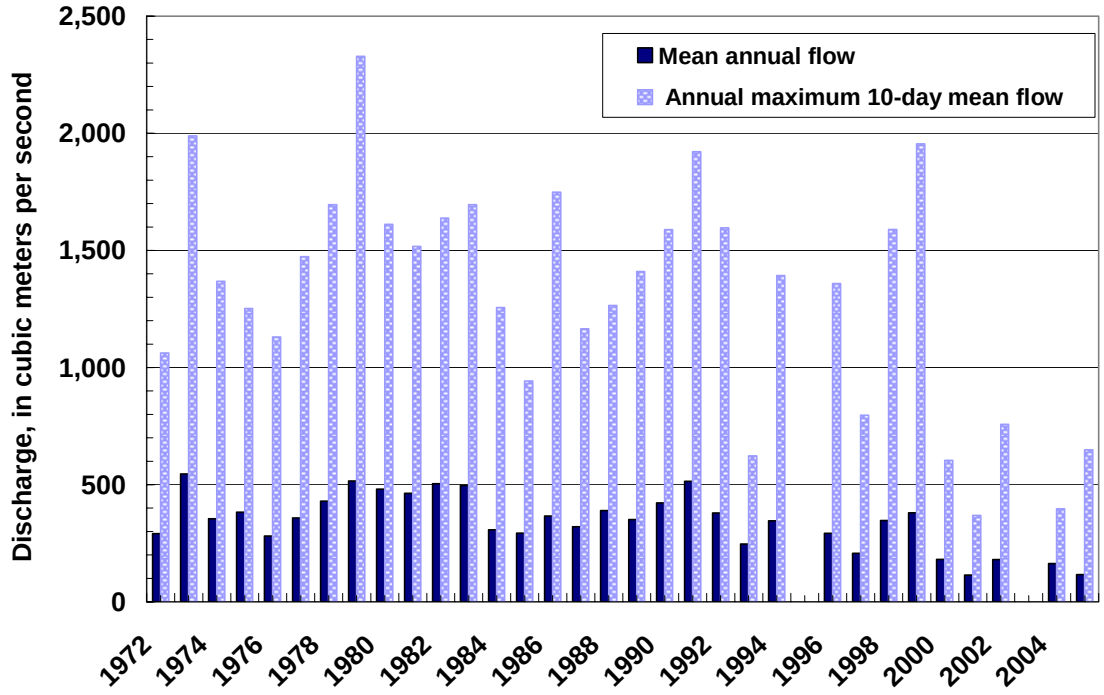

Figure 3. Mean annual and annual maximum 10-day mean flow for the Sutlej River at Khab, 1972 – 2004.

Recent Flooding in the Basin

The Sutlej River valley in Himachal Pradesh is subject to flooding from sudden and localized cloud bursts, glacial meltwater, debris dam failure, and monsoonal rains. Floods in 2000 resulted in more than 150 deaths in the Sutlej basin. The estimated peak discharge at Rampur was about 5,000 m^3/s, or more than twice any peak discharge measured at the site between at least 1972 and 2000.

The Sutlej River basin also is subject to frequent landslides that are triggered by a combination of steep slopes, the absence of vegetation, excessive rainfall, the freeze-thaw cycle, and in some cases, seismic events. These landslides can partially or completely block flows in the river. For example, a landslide in 2004 dammed the Pareechhu River, a tributary to Sutlej River in an extremely remote area of China (fig. 4), forming a fairly large lake. At its largest, the surface area of the lake was about 193 hectares, and the total length of the lake was about 5 km.

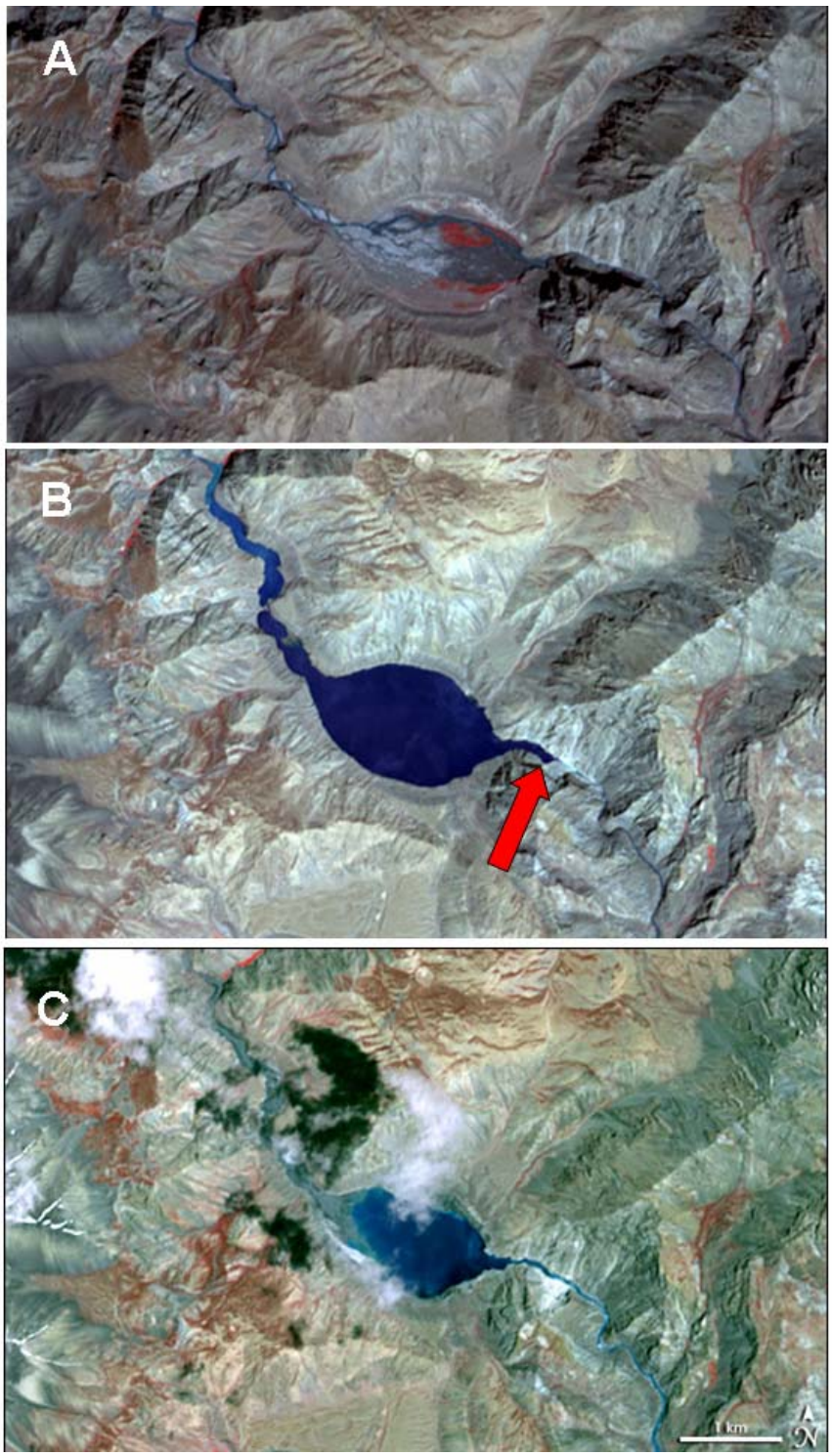

Figure 4. Lake formed by debris dam on the Pareechhu River, a tributary to the Sutlej River in China: (A) October 1, 2003, prior to landslide; (B) September 1, 2004, after formation of debris dam (indicated by red arrow) and near the end of the summer snowmelt period; and (C) July 2, 2005, after failure of debris dam and partial draining of the lake. The river flows west to east (source: National Aeronautics and Space Administration, 2006).

In late June 2005, the debris dam failed, resulting in severe flooding along the Sutlej in India. Reports vary, but water levels near Rampur were reported to have risen more than 15 m in a few hours. The estimated peak flow at Rampur was about 4,500 m^3/s, or almost as high as the flood of 2000. The leading edge of the flood traveled from Khab to Rampur, a distance of 157.5 km, in 305 minutes, or a speed of almost 32 km/hr. The flood caused severe damage to the National Highway through the Sutlej River valley and resulted in the loss of at least 10 bridges and 10 jhullas (ropeways). Areas of the Sutlej valley were cut off from surface transportation, and hydroelectric generation at the 1,500 MW Nathpa-Jhakri Project was halted because of high sediment levels in the river.

Flash-Flood Warning System

Scientists from NOAA and USGS are working with CWC to implement the flash-flood warning system for the Sutlej River. This system is needed because of the nature of flooding in the Sutlej, where floods can occur suddenly and without any obvious relation to a weather event. Information from the system will be provided directly to local emergency management officials for public protection and evacuation, and to authorities at the Nathpa-Jhakri hydropower project to protect the hydropower turbines and to safely pass floodwaters at the Nathpa dam. As additional hydropower projects are installed in the Sutlej River basin, this flash-flood warning system will become increasingly important both for protection of new facilities and as a prototype for other areas.

The flash-flood warning system consists of four water-level sensors, communications equipment, decision-support software, and a control room at Shimla. Sensors have been installed at Khab, Powari, Nathpa, and Rampur. Water level is measured using bubbler-type sensors. The sensor nozzles are placed in the river and the control units are placed on the banks above the elevation of the expected maximum flood. The multiple sensors provide redundancy, as well as information on the speed of the flood wave. Units in the river have been hardened to provide protection from the large rocks that can be carried by floodwaters.

Data are transmitted by satellite to the CWC Earth Station at Jaipur and received at Shimla through V-Sat link. Observers also are on standby at each of the four gauges during floods in order to provide backup information.

The decision-support software includes a very rudimentary flood-routing model that will be used to estimate the arrival time of the flood wave, the arrival time of the peak, the magnitude of the peak, and the duration of the flooding. Limited data are available to construct the routing model, so a hydrologic routing approach is being used. The flood-routing model will be regularly updated with new data during a flood as data are received from the field. Forecasts will be provided for each of the gauge sites downstream from Khab, and perhaps for Sunni, which is about 40 river km downstream from Rampur.

Data and forecasts will be automatically transmitted to local emergency management authorities, the military, and officials at the Nathpa-Jhakri hydropower project. Rapid delivery of information is necessary because of the speed at which flood waves move in the Sutlej River. The mode of information transmittal from CWC to others remains to be finalized. Future activities include close coordination with the Indian Meteorological Department to utilize weather forecasts during the monsoon season for providing statements of expected river conditions to local officials.

SUMMARY

Through collaborative efforts of the CWC, NWS, and USGS, a flash-flood warning system is being implemented for the flood-prone upper Sutlej River basin. The Sutlej River flows through an extremely steep valley, carries a high sediment load, and is subject to flash floods. The Sutlej River basin also is subject to frequent landslides that are triggered by a combination of steep slopes, the absence of vegetation, excessive rainfall, the freeze-thaw cycle, and some seismic events. These landslides can partially or completely dam flows in the river. Failure of the dams can be unexpected and catastrophic, such as the flood that occurred in 2005. Flood forecasting based solely on weather forecasts is inadequate in this situation. Hence, a flash-flood warning system based on near real-time observations, a simple flood-routing model, and enhanced communications is being jointly implemented in the Sutlej River by GOI and US agencies. The system will automatically provide data and forecasts to local emergency management authorities, the military, and officials at the Nathpa-Jhakri hydropower project so that flood responses can be implemented. These efforts will reduce the vulnerability of citizens in the upper Sutlej River basin to floods, improving warning capabilities of the CWC, and increase long-term collaboration between GOI and US hydrologists and meteorologists.

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