

Bhutan's Glacial Lake Outburst Flood (GLOF) Iridium®-Based Early Warning System



On October 7, 1994 a glacial lake outburst flood (GLOF) occurred on the Glacial Lake of Luggy in the Kingdom of Bhutan, sending a flood wave down the Phochhu and Punatsangchhu Rivers, claiming 22 lives and causing massive property and livestock damage. Although major flooding had occurred in the past, the 1994 GLOF was the catalyst for the government of Bhutan to establish an Early Warning System giving downstream inhabitants sufficient time for evacuation.

Located in the eastern Himalayas, the Kingdom of Bhutan is bordered by China's glacial Tibetan Plateau in the North, the Indian States of Sikkim in the West, Assam and West Bengal in the South, and Arunachal Pradesh in the East. Elevations in this mountainous terrain range to over 7000 meters.

Bhutan's glacier lake-fed rivers carry large volumes of water during the monsoon season. Glacial lakes, which form behind unconsolidated glacial debris (moraine) as the glaciers melt, will periodically produce a GLOF when the water previously dammed up by moraine or glacier suddenly breaks through its barrier.

In 2001 the International Center for Integrated Mountain Development (ICIMOD) identified 24 of Bhutan's glacial lakes as potentially dangerous. Eight of these lakes are in the headwaters of the Punakha-Wangdu Valley.

After the 1994 event, Bhutan implemented a basic early flood warning system at strategic points in the Phochhu sub-basin . In 2004 simple staff gauges were installed at four glacial lakes and at their confluence in the headwaters of the Phochhu River. Currently, the System depends upon two personnel from the Hydro-Met Services Division to manually read the gauges and report results via HF radios to the control station in Wangdu. When radio communication fails, they use a Thuyara Satellite phone.

In order to provide a more comprehensive, reliable solution to the problem, the Early Flood Warning Project was funded by the Global Environment Facility of the United Nations Development Programme (GEF-UNDP) . It has three components: 1) lowering the water level

of Thorthormi Lake, 2) installation of an Early Warning System along Punatsangchhu Valley, and 3) strengthening of disaster management and community awareness.

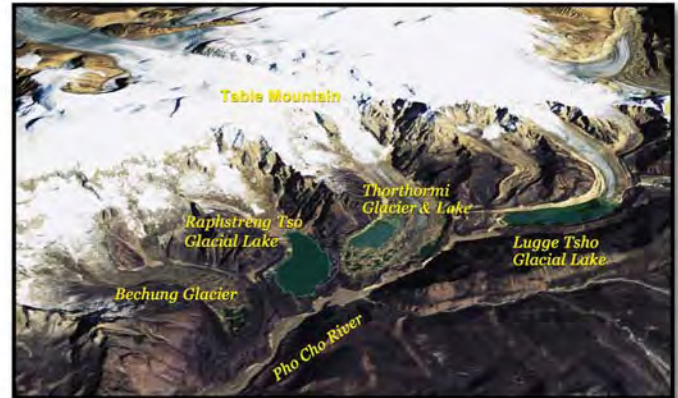
Sutron Corporation, a worldwide leader in providing real time data collection, remote monitoring systems and hydrological/meteorological monitoring equipment, was awarded the Project to provide the Early Warning System in March of 2010. Testing, training and installation are well underway and the System will be operational in mid-2011.

Uniquely Effective Solution: *Iridium® Communications*

Sutron chose Iridium® Satellite Communications as the telemetry back-bone for Bhutan's GLOF Early Warning Project . Iridium®'s fully-meshed Constellation of 66 satellites enable worldwide continuity of service, regardless of how remote any location is. The satellites fly in formation in near-polar orbit, in six orbital planes, 11 satellites per plane, evenly spaced around the planet. Each Iridium® Satellite completely circles the Earth once every 100 minutes, and from horizon to horizon across the sky in about ten minutes.

Sutron recommended the Iridium® System as the most economical, the most reliable and the best suited system for Bhutan's remote, rugged terrain and extreme climate conditions. Other communications were ruled out for the following reasons:

- ▶ INSAT (over India) - communications are only one-way.
- ▶ VSAT - not economical.
- ▶ HF radio communications - reliability issues.
- ▶ Line-of-sight (LOS) radio - required several repeater stations across remote, rugged terrain and was too costly in both time and money.

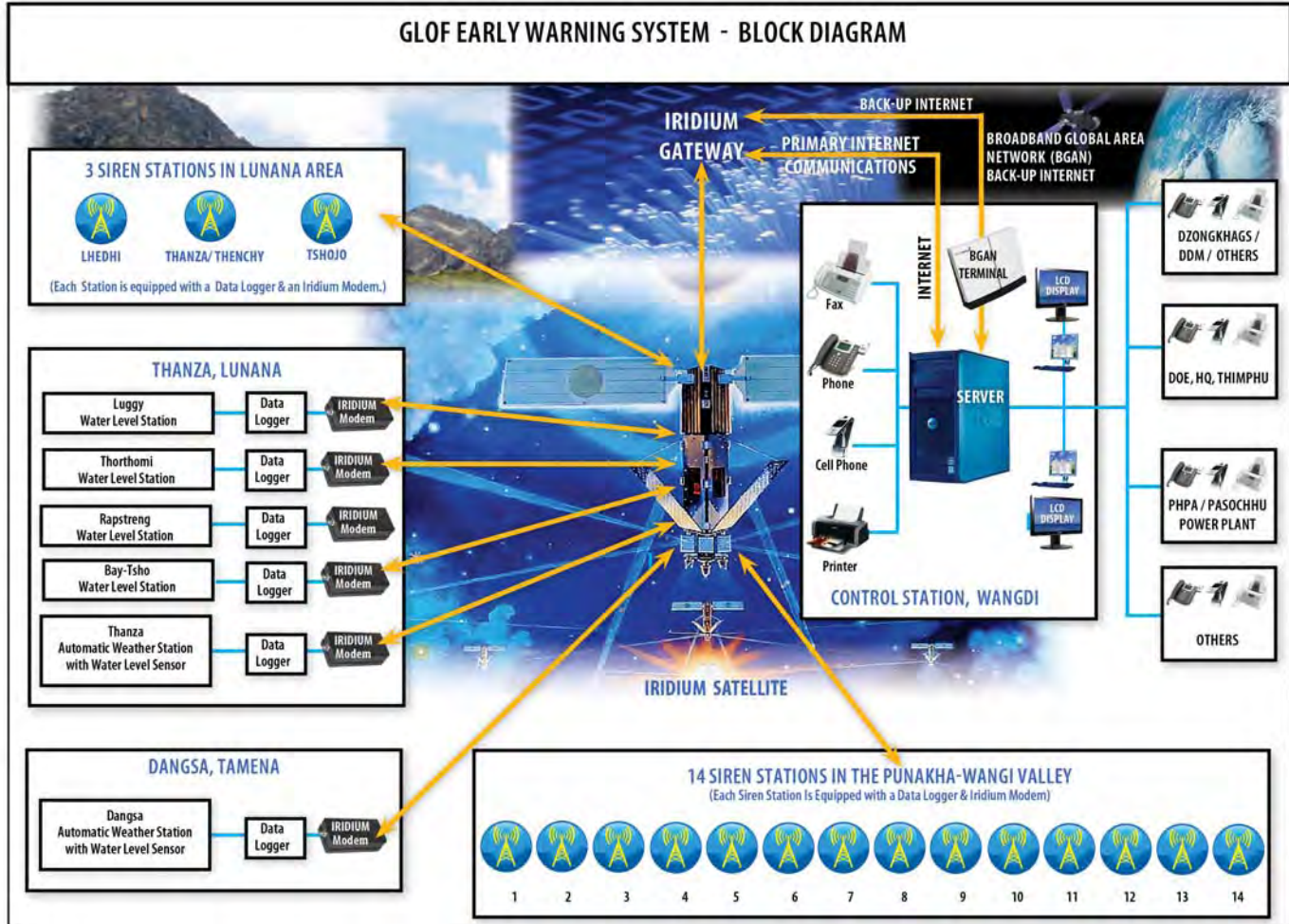


Iridium® provides two-way communications, essential for the functions of siren control, data on demand, station diagnostics and maintenance.

Sending Data from Remote Glacial Lakes & Siren Control

When a remote hydro-met station sends data via its Iridium® modem, it connects to the Iridium® Satellite that is overhead at the time of transmission. Data traffic is routed among Iridium® Satellites to reach the Satellite above the Iridium® Earth Gateway, which downlinks the data to the Internet. Data is immediately available through the internet at the Control Station

in Wangdu. Because the Iridium® Constellation uses Low Earth Orbit (LEO) satellites, any data delays are virtually unnoticeable.



Early Warning System Components - *Critical Redundancy at 14,000 Feet Elevation*

The Early Warning System Sutron is providing consists of one Central Control Station, 17 Siren Stations and 6 Hydro-Met Monitoring Stations: 4 stations monitoring water level (AWLS) and 2 stations monitoring water level and weather combined (AWS). The System is divided into two geographical areas: the Upper Sites near the glacial lakes, the source of the GLOF, and the Lower Sites of the Punakha-Wangdu Valley where the majority of the population is located.

Four AWLS and one AWS are located at elevations reaching 14,000 feet (4267.2 m), accessible only by traveling by pack animal for nine days. There are no easy maintenance visits to these

stations. Therefore, Sutron's system had to employ two-way communications, remote diagnostics and back-up sensors and dataloggers.



Automatic Water Level Stations (AWLS)

Automatic Water Level Stations at the glacial lakes of Luggy, Thorthormi, Rapstreng and Bay Tsho measure river levels every 15 minutes (from November to February) and every five minutes (March to October) and transmit data every hour. When a parameter threshold, user-selectable, for river stage or rate of change is detected, an Iridium® message is instantly transmitted to the Control Station for immediate activation of the upper sirens and for verification prior to lower sirens activation. Water Level Stations house a durable, reliable XLite Datalogger, Iridium® modem, AC/DC power supply for future connection, and Sutron's Dual Orifice Constant Flow Bubbler with Logger, for double simultaneous sensor measurements and data back-up. The Stations are powered by a 50 watt solar panel and a 100AH 12 volt battery and solar regulator.



Automatic Weather and Water Level Stations (AWS)

Automatic Weather and Water Level Stations located at Dangsa and Thanza measure weather parameters and river levels every 15 minutes and transmit data every hour. Like the AWLS, user-selected alarm parameters trigger an instant Iridium® message to the Control Station for verification and siren activation. The AWS house a reliable XLite Datalogger, Iridium® modem, AC/DC power supply for future connection, Sutron's Dual Orifice Constant Flow Bubbler with Logger, barometric pressure sensor, ultrasonic wind sensor, solar radiation sensor, air temperature and relative humidity sensor, a total precipitation gauge (Thanza), and a tipping bucket rain gauge (Dangsa). The stations are powered by a 50 watt solar panel with a 100AH 12 volt battery and solar regulator.

Siren Stations

The Siren Stations are located near population centers, usually above the villages on the side of the mountain for maximum projection. Siren Stations transmit diagnostics such as battery voltage and siren status to the Control Station once a day. The Siren Stations include an XLite Datalogger, Iridium® modem, an AC/DC power supply for future connection, and a Whelen OA-1 siren with siren amplifier. To ensure continuous operations, the stations are powered by two 80 watt solar panels with two 75AH 12 volt batteries connected in series to produce a 24 volt power supply for the siren.



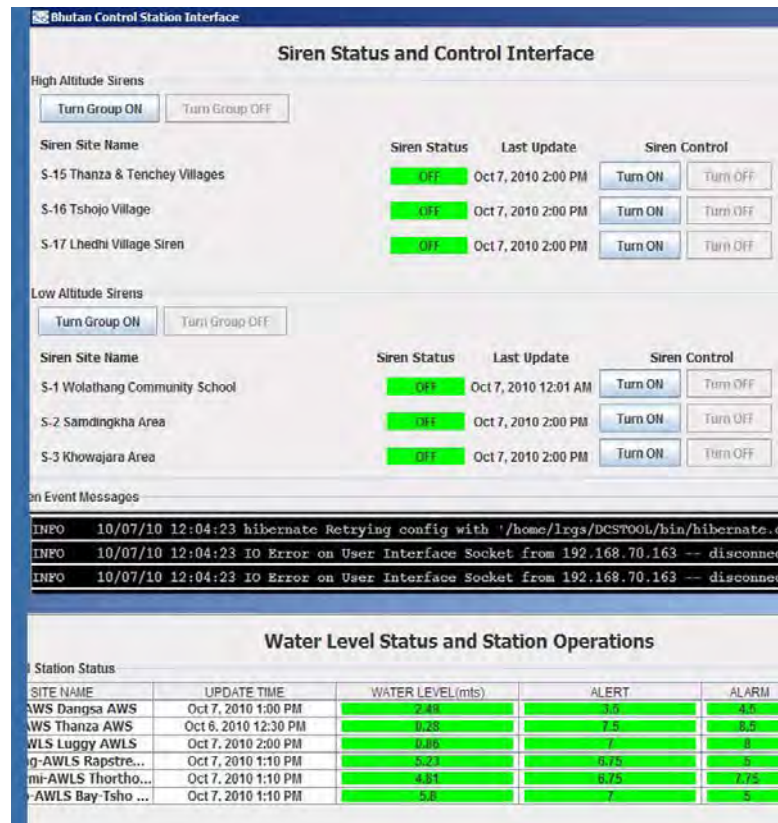
Siren Station Overlooking the Punakha Dzong, Bhutan

The Control Station

The Wangdu Control Station includes a server and two work stations. Data from the remote stations flows into the custom database via Iridium® satellite telemetry. Control Station operators will view the latest reported data from any of the 23 stations using custom software, data bases, and graphical interfaces developed by Sutron for the Kingdom of Bhutan. Designated users (power company, disaster management agency, etc) will be given access to a custom System Web Page in order to view river stage and weather data. In addition to managing scheduled and on-demand data collection, Control Center Staff will oversee siren activation. Since travel times in the river for the upper villages vary from 20 minutes to 60 minutes, the upper three sirens will activate immediately upon exceedence of the user-selected thresholds. Before activating the 14 lower sirens, the Control Center Staff will verify that a GLOF event has happened. They will de-activate the sirens if they confirm that a false alarm has been detected.

Project Status and Future Systems

Construction and installation of the GLOF Early Warning System for the Punakha – Wangdu Valley has made excellent progress for the lower sites and will resume in the spring for the upper sites. Equipment for the 23 remote stations has been assembled and tested. The Control Center software has been developed, integrated and tested. Installation of the Stations will begin shortly for the lower Stations and in the spring for the Upper Stations. The GLOF Early Warning System will be fully operational in 2011.



Bhutan Control Station Interface

Siren Status and Control Interface

High Altitude Sirens

Turn Group ON Turn Group OFF

Siren Site Name	Siren Status	Last Update	Siren Control	
S-15 Thanza & Tenchey Villages	OFF	Oct 7, 2010 2:00 PM	Turn ON	Turn OFF
S-16 Tshoje Village	OFF	Oct 7, 2010 2:00 PM	Turn ON	Turn OFF
S-17 Lhedni Village Siren	OFF	Oct 7, 2010 2:00 PM	Turn ON	Turn OFF

Low Altitude Sirens

Turn Group ON Turn Group OFF

Siren Site Name	Siren Status	Last Update	Siren Control	
S-1 Wolathang Community School	OFF	Oct 7, 2010 12:01 AM	Turn ON	Turn OFF
S-2 Samdingkha Area	OFF	Oct 7, 2010 2:00 PM	Turn ON	Turn OFF
S-3 Khowajara Area	OFF	Oct 7, 2010 2:00 PM	Turn ON	Turn OFF

on Event Messages

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INFO 10/07/10 12:04:23 hibernate Retrying config with '/home/lrgs/DCSTOOL/bin/hibernate.c
INFO 10/07/10 12:04:23 IO Error on User Interface Socket from 192.168.70.163 -- disconnect
INFO 10/07/10 12:04:23 IO Error on User Interface Socket from 192.168.70.163 -- disconnect
  
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Water Level Status and Station Operations

Station Status	SITE NAME	UPDATE TIME	WATER LEVEL(mts)	ALERT	ALARM
	AWS Dangsa AWS	Oct 7, 2010 1:00 PM	2.48	3.5	4.5
	WS Thanza AWS	Oct 6, 2010 12:30 PM	0.25	1.5	2.5
	WLS Luggy AWLS	Oct 7, 2010 2:00 PM	0.05	1	2
	g-AWLS Rapstre...	Oct 7, 2010 1:10 PM	5.23	6.75	8
	mi-AWLS Thortho...	Oct 7, 2010 1:10 PM	4.21	6.75	7.75
	r-AWLS Bay-Tsho ...	Oct 7, 2010 1:10 PM	5.8	7	8

Graphical User Interface for Station Status & Control

The success of this project is attributable to the foresight and hard work of the Bhutanese government, the generosity of the donors, the technical expertise of Sutron and and the local knowledge of our partner in Bhutan, USD Enterprises. It is anticipated that this system will be the first of many early warning systems for the Kingdom of Bhutan.