Telecommunication Systems for Real-time Hydrometeorological Data Collection and Transmission for the HKH Region

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Abstract
Telecommunication systems for real-time hydrometeorological data collection and transmission have matured greatly, both in the technologies used and the applications of real-time data. Some technologies are appropriate for small-scale monitoring systems that provide warning for local flash-flood prone communities, whereas others are appropriate for large-scale monitoring systems for water management and flood forecasting in international river basins. The Ganges-Brahmaputra-Meghna (GBM) Basin is one of the world's largest international river basins, with 1 percent of the world's land area, and 10 percent of the world's population. Applications appropriate to the GBM Basin for small-scale monitoring networks may include line-of-sight radio or land-line based telephony systems. Increasingly in some small-scale areas, cellular telephones may be appropriate. For monitoring hydrometeorology throughout the entire GMB basin, appropriate technologies include polar-orbiting and geostationary satellites and meteor burst, though there are important cost-of-access and institutional issues with respect to satellite-based systems. Reference is made to the United States and (a) the application of satellite-based technologies, where USGS and NOAA cooperate closely in monitoring hydrometeorology at 6,500 locations nationwide, and (b) a Department of Agriculture meteor burst system for monitoring snow and soil moisture, nationwide. A careful needs analysis is the basis for selecting the most appropriate technology.

Introduction

Telecommunication systems for real-time hydrometeorological data collection and transmission have matured greatly, both in the technologies used and in the applications of real-time data. This paper briefly summarises telecommunication technologies that have become well established throughout the world, largely viewed from the North American experience of the authors. The paper contains a limited discussion of experience in the Ganges-Brahmaputra-Meghna (GBM) Basin, which is based on documentation and verbal communication from colleagues. This paper presents only a brief description of the technologies and the applications, which are still quite dynamic and continue to evolve. Any prospective user is encouraged to carefully consider the requirements for tele-communication of real-time hydrometeorological data when considering applying one of the technologies discussed in the paper. Institutions – ranging from equipment manufacturers and water-management organisations to operators of meteorological satellite systems – all influence the evolution of hydrometeorological data tele-communications. In addition, the Internet sites listed in this paper provide access to current information on technologies, applications, and access policies to satellite systems, and to key scientists and engineers.

Telecommunications Technologies

Real-time hydrometeorological data are required to support numerous water-resources management applications – flood forecasting and warning, municipal and agricultural water supply, hydroelectric power generation, navigation, and environmental protection to name several – and well-established technologies exist to gather such data from automated hydrometeorological networks. There is no universal 'best' telecommunications technology because technology selection is affected by numerous factors, including geographical extent of the networks, meteorological conditions, river-response times, staff capacity, and cost. In the case of satellite-based technologies, institutional and international policies of the organisations that operate the satellites must also be considered. Finally, if real-time data sharing across institutional and international boundaries is part of the criteria for technology selection, then some technologies are more appropriate than others.

In a basin as large and as diverse as the Ganges-Brahmaputra-Meghna (GBM) Basin, numerous technologies are available to gather data from networks. Line-of-sight radio, extended line-of-sight radio (ELOS), telephone, satellite-based, and meteor burst technologies are candidate technologies and are briefly discussed below. The discussion in this paper focuses on the telecommunications aspects of automated data-acquisition systems.

At a typical network station, the sensor data is collected more times in one day than telecommunications and data transmissions convey data from the numerous data-collection cycles. For example, if data is collected at 15-minute intervals from four sensors and telecommunications occur at a three-hour interval, one transmission can convey 48 sensor measurements. Telecommunications can occur in a self-timed mode, wherein the automated network station initiates a transmission to a communications centre, or in an interrogated mode, wherein the automated network station responds to a data request from a communications centre. In the self-timed mode, the transmission may occur at a fixed-time interval – say once every three hours – or when hydrological conditions dictate – say when water levels exceed a predetermined limit or the rate of change of water level or precipitation exceeds selected rates. When hydrological conditions dictate data transmission, thresholds for transmission are programmable and are network-station specific. Finally, regardless of the telecommunications medium selected, they tend to share several common characteristics, such as the following.

Power – each network station typically telecommunicates data only several times a day and telecommunications equipment operates off batteries, recharged by solar panels.

Multiple Communications Media – most equipment suppliers allow multiple communications media at a network station, so that communications redundancy is allowed for.

Vandalism – vandalism of antennas and communications repeaters is a problem everywhere.

Frequency Authorisation – users of all of the radio-based technologies must secure permission to use radio frequencies from their national radio-spectrum management authorities; most countries are members of the International Telecommunications Union (ITU), an international organisation dedicated to promoting standards of communication, worldwide.

Quality assurance – review of real-time hydrometeorological data, using automated as well as human-based approaches, is important.

Annual operational and maintenance costs, which typically are in the range of 10-20 % of the costs needed to implement a hydrometeorological network, must be anticipated. Costs of satellite service can range from nothing to a significant expense in developing countries.

Line-of-sight Radio

As the name implies, this telecommunications technology is possible if the communications centre and the network station are within line of sight of each other. Local-area monitoring systems – such as those that are used for flash-flood monitoring and warning for a city, a small basin upstream of a reservoir, or an irrigation scheme – may be quite well served by line-of-sight radios. Such radios typically operate in the very high frequency (VHF) range – 132-174 Megahertz (Mhz) – or ultra high frequency (UHF) range – 390-512 Mhz.

If the communications centre and a network station are too far apart, and the curvature of the Earth, or mountains or other topographic highs obstruct the view, one or more intermediate repeater stations will be required. Repeater stations add cost and complexity to the network. However, one network station can act as a repeater station for another network station and the topology of network and repeater design can become quite complicated if the network covers a large geographical area or if the terrain is mountainous. This technology has become rather sophisticated over the years and line-of-sight radio networks can be operated in self-timed and interrogated modes, or combinations of the two. Moreover, one communications centre can support the operation of hundreds of network stations and the centre can reprogramme the operation of network stations remotely. Suppliers of line-of-sight radio systems continue to take advantage of improvements in microelectronics to make their systems more compact, cost effective, reliable, and flexible in their application. The number of repeater stations may be reduced significantly by the use of ELOS radio technology. ELOS systems operate in the very low end of the VHF spectrum and are compatible with the meteor burst radio technology discussed below.

Telephone-based Systems

As the name implies, this telecommunications technology relies on the indigenous telephone system, either the traditional landline or increasingly cellular infrastructure. Telephone-based telecommunications media can operate in the dial-up mode or use dedicated lines, and two-way communication between a communications centre and a network station can be supported. Careful consideration must be given to the reliability of the traditional telephone system, especially during flood emergencies when community-based switchboards in flood-at-risk communities can fail and disrupt communication between centres and network stations. Moreover, cellular telephone systems may give priority to voice communication over data communication during flood emergencies and the medium may be least accessible when it is needed most. Of course, dedicated lines and dial-up systems have cost implications that must also be considered. If the issues of reliability and cost can be resolved, suppliers of telephone-based systems provide flexible and reliable systems that are analogous to the systems discussed under line-of-sight radio.

Satellite-based Systems

Several satellite-based systems have come into common usage for real-time hydrometeorological data collection. Although there are commercially based systems such as INMARSAT (http://www.inmarsat.org/) that could be considered, this discussion is limited to government-operated systems. Government satellite systems that support telecommunications of hydrometeorological data are generally operated in support of global weather monitoring. Under the auspices of the World Meteorological Organization (WMO), the Coordination Group for Meteorological Satellites (CGMS) (http://www.wmo.ch/indexflash.html) coordinates planning for and operation of meteorological satellites, and publishes relevant information about them. The following information about these satellites is general in nature and the most up-to-date information can be found in CGMS reports which are available on the Internet at <http://www.eumetsat.de/> under 'Publications'.

Telecommunication of hydrometeorological data via meteorological satellites is very much affected by the orbits of the satellites, which are in either geostationary or near-polar orbits. Both types of satellite provide imagery of the Earth's surface and data on the status of the atmosphere, though this paper focuses only on telecommunication of data from hydrometeorological stations. Figure 1 is a schematic diagram of the orbits of typical hydrometeorological satellites operated by CGMS members.

Geostationary Meteorological Satellite Systems

These satellites orbit the Earth in the plane of the equator at an altitude of 36,000 kilometres. They orbit in the direction of the Earth's rotation, making one orbit around

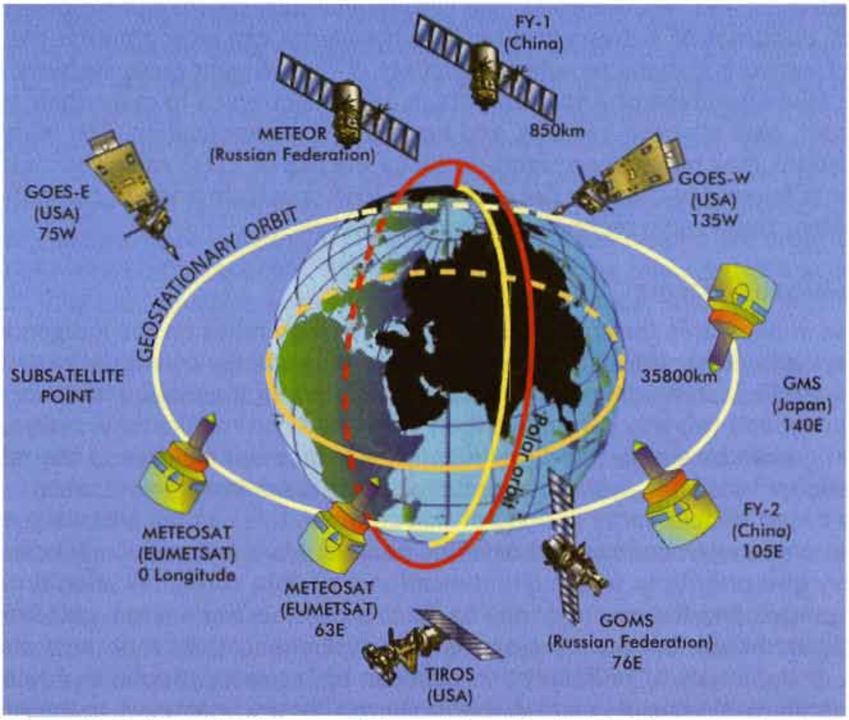

Figure 1: Schematic diagram of the orbits of typical hydrometeorological satellites operated by CGMS members (Source: WMO)

the Earth's centre each day, and appear to hover over fixed points on the equator. The National Oceanic and Atmospheric Administration (NOAA) (http://www.noaa.gov) operates two Geostationary Operational Environmental Satellites (GOES) that have sub-satellite points on the equator at 135° West Longitude (GOES-West) and 75° West Longitude (GOES-East). The European Meteorological Satellite Organisation (EUMETSAT) (http//www.eumetsat.de) operates Meteosat, with a sub-satellite point of 0° Longitude, and the Japanese Meteorological Agency (JMA) (http://www.jma.go.jp) operates the Geostationary Meteorological Satellite (GMS) with a sub-satellite point of 140° East Longitude. All of these systems support a data collection system (DCS) that provides capacity to telemeter environmental data from radios, called data collection platforms (DCPs). The DCS is a frequency division multiple access (FDMA) system that allows concurrent communications by DCPs on 100 or more discrete radio channels on each satellite. Each channel provides time division multiple access (TDMA), which permits many DCPs to use each channel by assigning fixed reporting times and intervals to each DCP. Some of the satellites reserve channels for Alert reporting, so that DCPs that are monitoring potentially hazardous conditions can report such conditions promptly when necessary, while still maintaining routine reporting on their assigned channels. The net result is that the DCS on the satellites can support tens of thousands of DCPs scatted over wide areas of the Earth.

The Indian Government operates a series of geostationary satellites (INSAT), that also supports a DCS and the Indian Meteorological Department (IMD) (http://www.imd.ernet.in/) also launched a geostationary meteorological satellite called METSAT in 2002 (http://www.spacedaily.com/news/020912145126.r84vpm67.html). More current information on these satellites, the full range of data collection they support, and policy related issues are available via the Internet sites included above, and CGMS reports.

Polar-Orbiting Satellite Systems

For many years, NOAA has operated two near-polar orbiting meteorological satellites. These satellites are in orbits that carry them above the Earth's surface at an altitude of about 850 kilometres. In contrast to geostationary satellites, which make one orbit daily, these satellites make about 14 orbits of the Earth each day, from the North Polar Region down over the equator to the South Polar Region and then up again on the far side of the Earth. The orbital planes of the NOAA satellites are sun synchronous, with one making early morning passes over areas of the Earth and the other making afternoon passes.

The Centre National d'Etudes Spatiales, the French National Space Agency (http://www.cnes.fr/) operates a tariff-based DCS called Argos that orbits on NOAA satellites (http://www.noaasis.gov/ARGOS/; http://www.argosinc.com). It is used extensively in support of marine applications. From a radio-communications perspective, the satellites are only in line-of-sight during several of these orbits and for periods that range from a few seconds to ten or more minutes, which means that radio communication via Argos is intermittent. DCP's in the Argos system are referred to as platform terminal transmitters (PTT) and operate in a random-access mode. In this mode, the PTTs merely transmit their data at random times and the data are relayed to communications centres when the satellites are passing by, or the satellites record the PTT data for later downloading to communications centres during a subsequent part of an orbit. Finally, the United States Department of Defense also operates similar satellites and their data are available to civilian users via NOAA. As is the case for geostationary satellites, more complete information about polar orbiting satellites is found in CGMS reports or agency Internet sites.

Meteor Burst Systems

For more than fifty years, a technology known as meteor burst has been used for telecommunication of data from network stations. Initially used for military purposes, this system is now well established for the telecommunication of environmental data. As shown in Figure 2, the system relies on reflecting radio signals off transitory ionised paths in the atmosphere, 90 to 100 kilometres above the Earth, that are left by micrometeorites as they disintegrate in the atmosphere. These ionised paths only persist for a fraction of a second, yet endure long enough to act as repeaters between communications centres and their network stations, which may be as far as 2,000 kilometres away. Typically, VHF radio communications systems use these ionised trails to interrogate and receive data from network stations. A communications centre will repeatedly poll a network station until, by chance – usually within a few minutes – an ionised trail is properly situated for contact to be made, at which time the network station attempts to use the same ionised trail to report its data to the communications centre. Hence there is a probabilistic nature to communication and many operators of meteor burst systems have developed complete statistics on the number of attempts that typically must be made before data collection from a network station can be expected. There is a natural variation in the density of micrometeorite trails, diurnally and seasonally, but for hydrometeorological data collection they are plentiful enough to satisfy many data-collection requirements. Meteor burst communication is also secure, in that it is difficult or impossible for a third party to monitor telecommunications between a communications centre and a network station.

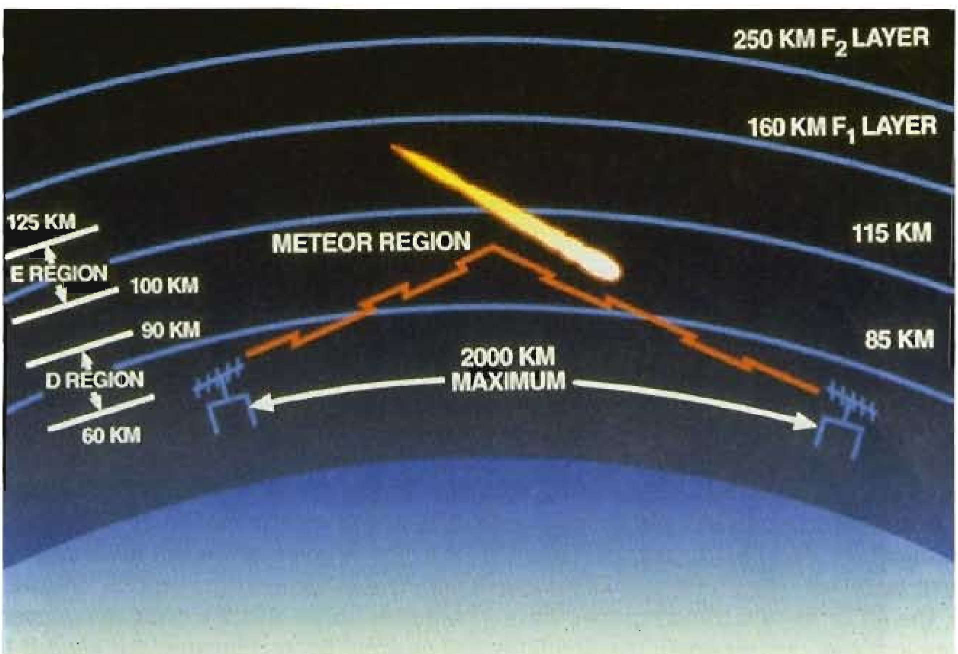

Figure 2: Operational geometry of meteor burst communications technology. (Source: adapted with permission from Meteor Communications Corporation)

Related Institutional Issues

Institutional issues are as important as technical issues with respect to telecommunications of hydrometeorological data. All of the radio-based systems require permission to broadcast from national radio-spectrum management authorities. As opposed to satellite systems, wherein users must negotiate agreements with operators to use the satellites, users of meteor burst technology can access micrometeorites, which are plentiful and free. Nonetheless radio-spectrum management authorities must grant permission to broadcast from meteor burst communications centres and network stations as well.

There are always numerous agencies in a country – and certainly in an international river basin – that collect hydrometeorological data. If these data are to be shared across institutional and national boundaries and their value maximised, data-exchange agreements must be negotiated that define the format, use, and limits of data. In the United States, for example, hydrometeorological agencies have agreed on a standard data exchange format, known as the Standard Hydrometeorological Exchange Format (SHEF) (http://www.nws.noaa.gov/oh/hrl/shef/version_1.3/index.htm). With SHEF, data can be exchanged among communications centres and their values made compatible with both sending and receiving organisations' data-processing systems. The WMO maintains a Global Telecommunications System (GTS) (http://www.wmo.ch/web/www/reports/nyoni_part2-2.html) that supports exchange of selected meteorological observations and products in defined formats from national hydrometeorological services via regional hubs to a main telecommunications network. Some of these links are high speed, though most are medium-speed to low-speed (teletype). Finally, in the case of satellite-based systems, two or more organisations can install 'digital direct readout ground stations' (DDRGS) that simultaneously monitor data being relayed from a satellite and enable them to receive data from DCP, lessening the need for data-sharing mechanisms, such as the Internet or the GTS.

Hydrometeorological Monitoring Applications

This paper briefly cites selected applications of several technologies that are used for the telecommunication of hydrometeorological data. The networks they support range from small, local networks that are well served by line-of-sight radio to national networks that are well served by geostationary meteorological satellite communication. Examples are cited from the United States and South Asia.

USGS Monitoring Network

The U.S. Geological Survey (USGS) stream-gauging programme provides streamflow data for a variety of purposes that range from current needs – such as flood forecasting by the National Weather Service (NWS) – to future or long-term needs – such as detection of changes in streamflow due to human activities or global warming. The development of data on the flow of the nation's rivers mirrors the development of the country. From the establishment of the first stream-gauging station operated by the USGS in 1889, this programme has grown to include 7,292 stations currently in operation. These stations do not represent a single 'network' of stations, but an aggregation of networks and individual streamflow stations that were established originally for various purposes, and that all use a uniform data-collection standard.

The data from about 6,500 of the USGS stations, whose locations are shown in Figure 3, are telemetered in real time to the NOAA GOES DCS. Use of the GOES DCS began in the early to mid 1970s and has gradually grown from about 1,000 stations in 1983 to about 6,500 stations today. Data from the network are received at the NOAA Ground Station at Wallops Island, Virginia, and then immediately retransmitted though a commercial satellite to 20 USGS Local Readout Ground Stations (LRGS) throughout the country. Real-time GOES DCS data are collected, analysed, quality assured, and stored in the National Water Information System (NWIS) and made available in real time to the public. These data are used by a wide range of people and agencies for public and private purposes, such as flood forecasting, water management, recreation, navigation, and water supply. The USGS also collects real-time groundwater and water quality data from selected stations.

The USGS updates the map in Figure 3 in real time and makes it available to the public on the Internet at http://water.usgs.gov/realtime.html. Anyone may access real-time date from any station on the map.

Snow Telemetry and Soil Climate Analysis Network

Since the 1930s, the US Department of Agriculture Natural Resources Conservation Service (NRCS) has been responsible for monitoring the snow pack in the Western United States, where agricultural and municipal water supply is highly dependent upon snowmelt. Beginning in 1976, the NRCS has operated the Natural Resources Conservation Service (NRCS) (http://www.wcc.nrcs.usda.gov/snotel/) to automatically collect data on meteorological and snow pack conditions in remote parts of the mountainous west. SNOTEL is managed from the National Water and Climate Center

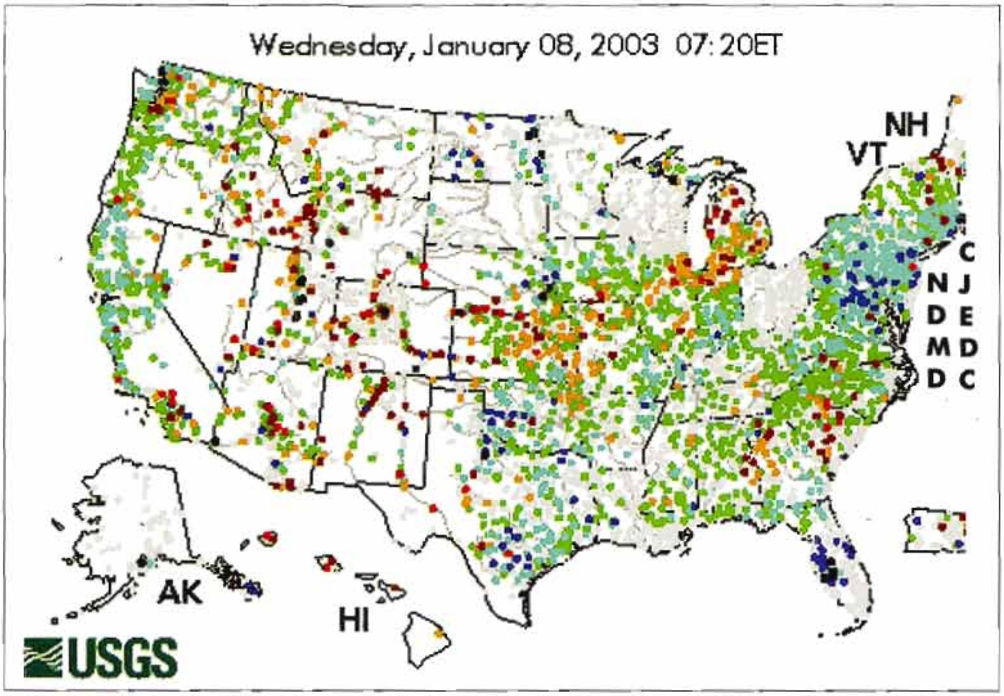

Figure 3: Location of real-time USGS hydrological stations, colour codes indicate streamflow conditions (Source: USGS)

(NWCC) (http://www.wcc.nrcs.usda.gov/) in Portland, Oregon and uses two master communications stations in Boise, Idaho, and Ogden, Utah, to gather data from 670 automated snow monitoring stations in 12 western states. The NRCS and the NWS collaborate on using SNOTEL and other data to prepare seasonal water-supply forecasts for these states. In more recent years, the NRCS has implemented the Soil Climate Analysis Network (SCAN) (http://www.wcc.nrcs.usda.gov/scan/index.htm) to monitor soil moisture and temperature at 72 network stations in 34 states, again using meteor burst technology. An added feature of meteor burst technology is that it can be operated in a line-of-sight mode; in Puerto Rico the stations operate as line-of-sight stations and use the same communications equipment as other meteor burst stations in the SCAN network. The NRCS intent, if funding becomes sufficient, is to increase the geographical coverage of SCAN to as many as 1,000 network stations. With this increased capacity, it could strengthen its capacity for drought monitoring, soil moisture accounting, calibrating satellite-based estimates of soil moisture, providing input to global circulation models, and supporting other water- and agriculture-related issues.

Selected Applications in the GBM Basin

Some selected applications of telecommunications of hydrometeorological network data in South Asia are described below. The list is only illustrative and far from complete.

Line-of-sight and Meteor Burst

An extended line-of-sight communications system has been installed in support of a community-based flash-flood warning system in Nepal. This system is intended to warn of the breakout of the Tsho Rolpa glacial lake in Nepal, which threatens as many as 6,000 downstream residents, a hydroelectric project, and other downstream infrastructure. Several of the monitoring stations will have redundant communications capacity to communicate also with a meteor burst master station over 600 km away in the western part of Nepal. This station provides meteor burst coverage to most of Nepal (written communication from Sandra Garl, Meteor Communications Corp).

Meteor Burst

Inflow forecasting for major reservoirs in the upper Indus Basin for the Water and Power Development Authority of Pakistan (WAPDA) was designed using meteor burst technology as the communications medium. Implemented in the early to mid 1990s, the system design included 20 hydrometeorological stations and a master station that communicated data to the WAPDA office in Lahore for processing. This system was later expanded to include 30 stations of a flood-forecasting network (written communication from Sandra Garl, Meteor Communications Corp; Bell et al 1994).

Geostationary Satellite-based Systems

Several satellite-based communications systems have been implemented in recent years in South Asia (written communication from Raul McQuivey, Sutron Corp), including the following.

- The Andhra Pradesh Hazard Mitigation and Emergency Cyclone Recovery Project (APHMECRP) installed 15 DCPs at remote strategic locations in India from 1997-2002. A follow-on phase includes the additional installation of 78 rainfall and water-level monitoring stations that telecommunicate their data via the INSAT satellite to two digital direct readout ground stations. Also instrumented were five remote stations that measure coastal parameters, including tide height, wind speed and direction, atmospheric pressure, rainfall, temperature, and humidity.

- A Snow and Avalanche Study Establishment project to forecast avalanche potential, which required 29 automated weather stations in high altitude areas that transmit their data via the INSAT
- A Central Water Commission of India project in support of flood forecasting that called for the installation of 55 automated hydrometeorological stations covering two river basins and four DDRGS receive sites – two in each of the Chambal and Mahanadi River basins

Discussion of a Phased-in GBM System

A telecommunications system for hydrometeorological data in the GBM basin – perhaps to be known as the GBM Hydrometeorological Telecommunications System (GBMHTS) – should be implemented via a multi-phased approach. Of course, the pre-implementation preparation for the GBMHTS would require general agreement among the many countries and institutions that would operate or receive data from the system. These players would have to come to consensus on a broad range of issues, such as:

- the geographical extent of the system;
- budget for capital costs, and operational and maintenance costs;
- staff capacity and capacity development requirements;
- density and distribution of hydrometeorological networks;
- data-reporting and sharing requirements;
- other general system attributes; and
- lessons learned from applications of telecommunications technologies in South Asia.

Within that broad agreement, a recommended approach would include the following four phases.

Initial phase: evaluation of communications strategy – Because this paper merely provides an overview of selected telecommunications media that could be appropriate for an international river basin as large and varied as the GBM, a technical team — comprising key player representatives — would have to come to a consensus on the communications medium to support the GBMHTS. This phase could include technical study tours to sites in South Asia, the United States, and other venues where telecommunications of data are well established. This phase would produce a GBMHTS Implementation Plan (GBMHTSIP), which would address implementing the system and maintaining it during a subsequent period of ten years or more.

Pilot phase – During this phase, a small subset of stations would be instrumented and real-world lessons learned. The GBMHTSIP would be revised, based on lessons learned.

Initial Implementation Phase – The first half of the GBBHTSIP would be implemented during this phase. At the end of this phase, the GBMHTSIP would be evaluated once again and finalised.

Final Implementation Phase – During this phase the system would be fully implemented.

Summary

This paper briefly discussed telecommunication systems for real-time hydrometeorological data collection and transmission, which have matured greatly, both in the technologies used and in the application of real-time data. It presented several telecommunications technologies that are being used over a wide range of geographic scales, ranging from the community level to continental scales. There is no universal 'best' technology, but one or more of the technologies discussed will likely be adequate to meet typical hydrometeorological requirements in the GBM, from flood forecasting to water-resources management. There is a large body of experience with these technologies throughout the world and the Internet provides ample access to this experience and to information about current applications. Finally, the authors suggest a possible approach to implementing a hydrometeorological telecommunications system for the GBM.

References

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