Chapter 3

Hydrometeorological Monitoring Networks

Earth data observations are an essential component of flash flood early warning systems. Multi-sensor hydrometeorological monitoring networks, composed of gauge, radar, and satellite sensors collect rainfall, temperature, and other data that are used by forecasting models to produce flash flood guidance and threat information. Hydrometeorological monitoring networks and associated communications are critical to the success of any flash flood early warning system.

What Is in This Chapter?

This chapter should be read by persons who need to understand a key component of any flash flood early warning system—the capability to provide real-time and historical awareness of hydrometeorological conditions. The chapter reviews the various types of observation sensors that are used to form a multi-sensor network and associated technologies for communicating that data for analysis. The various sections in the chapter are:

- **Hydrometeorological sensors** for flash flood forecasting. These include rain gauges, river/streamflow gauges, radars, and satellites
- **Communications requirements** for collecting sensor data
- **Backup communications** for collecting data and distributing warnings by local/provincial forecast offices and National Meteorological and Hydrological Service (NMHS) centers
- **International Data Observation and Information Collection,** including the role of the Global Telecommunications System (GTS)

Hydrometeorological Sensors

Gauge Networks

The purpose of gauge networks is to provide accurate, real-time hydrometeorological measurements to facilitate bias adjustment of radar and satellite precipitation estimates, provide rainfall input to hydrologic and flash flood models, and support general weather forecasts and flash flood forecasts. It is not possible to fully understand rainfall, stream flow, or other weather and climate phenomena without ground truth data. But be aware, gauges are prone to errors and typically cannot spatially represent the localized nature of convective rainfall. Thus, "ground truth" is an elusive quantity that we can only estimate using gauge networks. We therefore need gauge reports that are as accurate, reliable, and timely as possible. This is essential to the success of a flash flood early warning system. Chapter 5 provides examples of a few of the many ALERT (Automated Local Evaluation in Real Time) networks in the United States.

Gauge networks are often composed of several independent networks that are deployed throughout a region of interest to create a real-time data stream of earth data measurements for various applications. Since it is quite common for several independent gauge networks to already exist in a flash flood-prone region, the creation of a hydrometeorological network can be primarily an exercise in integrating and automating available gauge infrastructure (see the discussion on Integrated Flood Observing and Warning Systems (IFLOWS) in Chapter 5).

Data sharing agreements enable various gauge operators to create a single gauge network from several smaller networks, and therefore benefit from the records and infrastructure that is available to both. Protocols that address institutional sensitivities regarding proprietary information should be negotiated to maximize the utility of available infrastructure. That process involves negotiation about data access, ownership, and maintenance, as well as development of processes for ensuring timely delivering of reliable gauge data to the flash flood forecasting center.

The exploitation of existing gauge infrastructure is especially important for forecast model calibration. By using the historical record of past rainfall and flash flood events, computer forecast models can be tuned to local flash floods patterns. Without such records, it can take several years to accumulate enough data to calibrate those models to reflect the specific character of flash floods in a region.

Of course, when gauge infrastructure is inadequate or unavailable, new gauges can be installed to fill gaps in coverage or replace old technologies. But because gauges in new locations require time to accumulate a historical record that can be used for forecasting and model calibration, it is always preferable to continue using existing gauge locations in order to exploit that record. Real-time automated gauges are recommended to assure rapid sampling and transmission of critical observations to a forecast center.

Gauges are important for many reasons, including:

- Hazard assessment and warning support. (Locate gauges immediately upstream of or within at-risk population centers.)
- Radar bias calibration (Select gauges at different elevations and throughout the radar coverage area.)
- Satellite rainfall bias correction.
- Numerical forecast model calibration.

As a general rule, the distribution of automated precipitation and stream flow gauges in areas of primary concern should be maximized as budgets allow, particularly if fine-scale flash flood forecasting and use of hydrologic models is a priority. Stream flow gauges should sample both large and small basins in order to improve hydrologic model calibration and validate hydrologic model simulations. Rain gauges for radar calibration should have at least a 15-minute sampling rate and their distribution should be representative of the region, both horizontally and vertically.

Rainfall Gauges

For flash flood applications, rainfall gauges will consist of a precipitation measurement device, data collection platform (DCP), power supply and management unit, and communication device. These can be coupled with a range of common weather sensors that measure temperature, humidity, barometric pressure, and other standard weather parameters like wind speed and direction.

Precipitation measurement devices employ a variety of technologies, although the most common types are the "weighing gauge" and the "tipping bucket". Weighing gauges operate by capturing water in a collection system and recording the weight of that water. These gauges are more costly and require routine maintenance, but are more accurate than tipping bucket gauges. Tipping bucket gauges operate by capturing a small volume of water in one of two small buckets as shown in Figure 3.1. Once the rain is captured, the bucket tips and empties. The occurrence of this "tip" is recorded, and precipitation volumes and rates are transmitted as the number of tips and the rate at which they occurred. Tipping-bucket rain gauges tend to underestimate precipitation during periods of intense rainfall and in cases of frozen precipitation. All gauges tend to underestimate in high winds. But compared to weighing gauges, tipping bucket gauges are less expensive and demand significantly less maintenance. However, like all automated gauges, there is still a maintenance cost associated with them. There are numerous commercially available options for either of these gauge types.

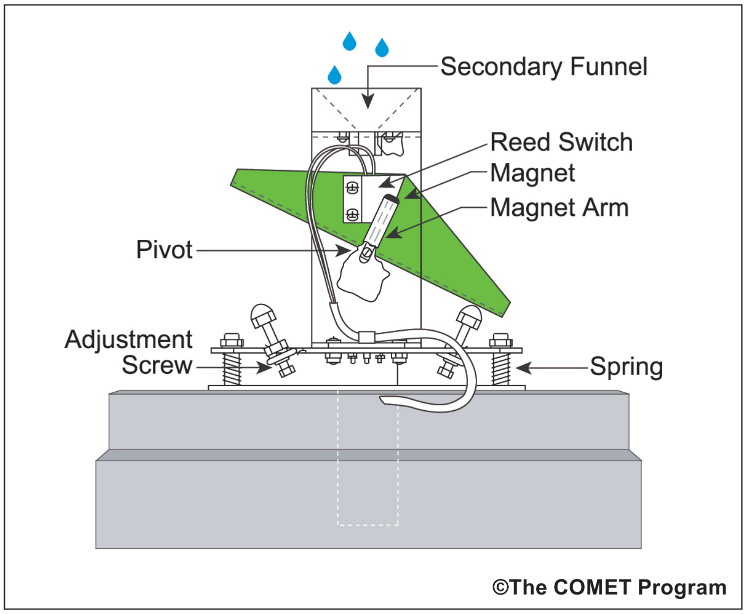

Figure 3.1 Schematic of a typical tipping bucket mechanism

The data collection platform records output from the gauge and stores it for remote query by a data acquisition program. All major meteorological instrumentation companies offer options for DCP. (The specific type is best left to the implementation engineer and implementing partners in order to facilitate integration into the existing network.)

Communications devices (discussed later in this chapter) for collecting gauge data should ideally use either telephone networks for communication (landline or low-power cellular), UHF/VHF radio, or GOES DCPs for data transmission.

Streamflow Gauges

As with rainfall gauges, stream flow gauges consist of some form of measuring device — in this case for water surface elevation measurement— a DCP, a power supply and management unit, and a communication device. Streamflow gauges estimate discharge by measuring the water surface elevation in the channel. This is then compared to a table or graph known as the stage-discharge relationship or rating curve, which is comprised of manual discharge measurements and the corresponding water surface height, to obtain an instantaneous estimate of stream flow. Because stream flow measurements must be made manually in order to establish rating tables, it is especially important to maintain existing gauges. Numerous options for water surface measurement and for stage-discharge relationship table creation exist from commercial suppliers. Options include web-cams aimed at permanently mounted staff gauges, acoustic depth sensors, and traditional manometers.

Tip

When upgrading existing stream flow gauges to real-time reporting, it is usually possible to add a rainfall gauge to the same DCP. This allows expansion of the precipitation observation network with minimal cost – only that of the precipitation measurement device.

Important Points to Remember about Gauge Networks

- Accurate, reliable, and timely gauge data is essential to the success of a flash flood early warning system
- The establishment of a hydrometeorological network for flash flood support can often be an exercise in integrating and automating already existing networks.
- Tipping-bucket rain gauges tend to underestimate precipitation during periods of intense rainfall, but they are less expensive than weighing gauges.
- All gauges have a maintenance cost, although the cost associated with tipping bucket gauges is less than that associated with weighing gauges.

Weather Radar Networks

A primary function of a weather radar network is to provide high-resolution, real-time gridded rainfall estimation over a region of interest. Weather radars are powerful tools for hydrometeorological monitoring and forecasting because of their ability to characterize precipitating clouds over a large area as opposed to the point measurement of an *in situ* gauge. Radar can detect the formation of clouds, track their movement and evolution, probe their internal structure, and make quantitative estimates of the amount of precipitation they produce at the surface.

The primary measurement of a weather radar (henceforth, "weather radar" will be referred to simply as "radar") is reflectivity, which is directly proportional to the amount of electromagnetic energy scattered back to the radar by cloud and precipitation particles (e.g., raindrops, snowflakes, hail). Radar reflectivity can span several orders of magnitude and thus is usually measured on a decibel scale (i.e., dBZ). The largest values of radar reflectivity are associated with the most intense precipitation. Quantitative precipitation estimates (QPE) from radars are usually facilitated by employing power-law relationships (relationships between two variables such that one is proportional to a power of the other) between precipitation rate and radar reflectivity.

Some weather radars now also transmit and receive energy at two different polarizations (usually horizontal and vertical). These so-called "polarimetric" radars provide several additional measurement parameters that focus on the contrast between signals at the two polarizations. This information can be used to unambiguously:

- Detect radar artifacts, e.g., features caused by radar beam blockage, anomalous propagation, bright band, etc.
- Correct radar attenuation caused by heavy rain shafts, increasing distance from the radar, etc.
- Identify hydrometeor types
- Enhance QPE capabilities

Polarimetric radars provide more accurate rainfall estimates for little additional cost according to studies by NOAA's National Severe Storm Forecast Laboratory.

Design Criteria

There is a range of strategic and tactical criteria that must be considered in deploying modern weather radar systems. This section provides a detailed analysis of the strategic criteria—primarily the terrain and precipitation characteristics of the region—before providing general recommendations regarding site selection and system procurement. Discussions of cost-benefit analysis are not included, however.

Rainfall Intensity

Flash floods tend to occur in regions prone to intense rainfall, and therefore it is essential to understand local rainfall intensity patterns when considering the deployment of a radar network. In particular, the issue of radar signal attenuation must be addressed. Attenuation of radar signals increases as radar wavelength decreases and as rainfall intensity, path length through rainfall, and mean raindrop size increase. The primary negative impact of attenuation is the artificial lowering of radar reflectivity, which leads to underestimates of rainfall intensity. As mentioned above, there are polarimetric techniques for correcting attenuation. However, if the radar signals are attenuated down to the noise floor, that is, when signal and noise have about the same strengths, correction is not possible.

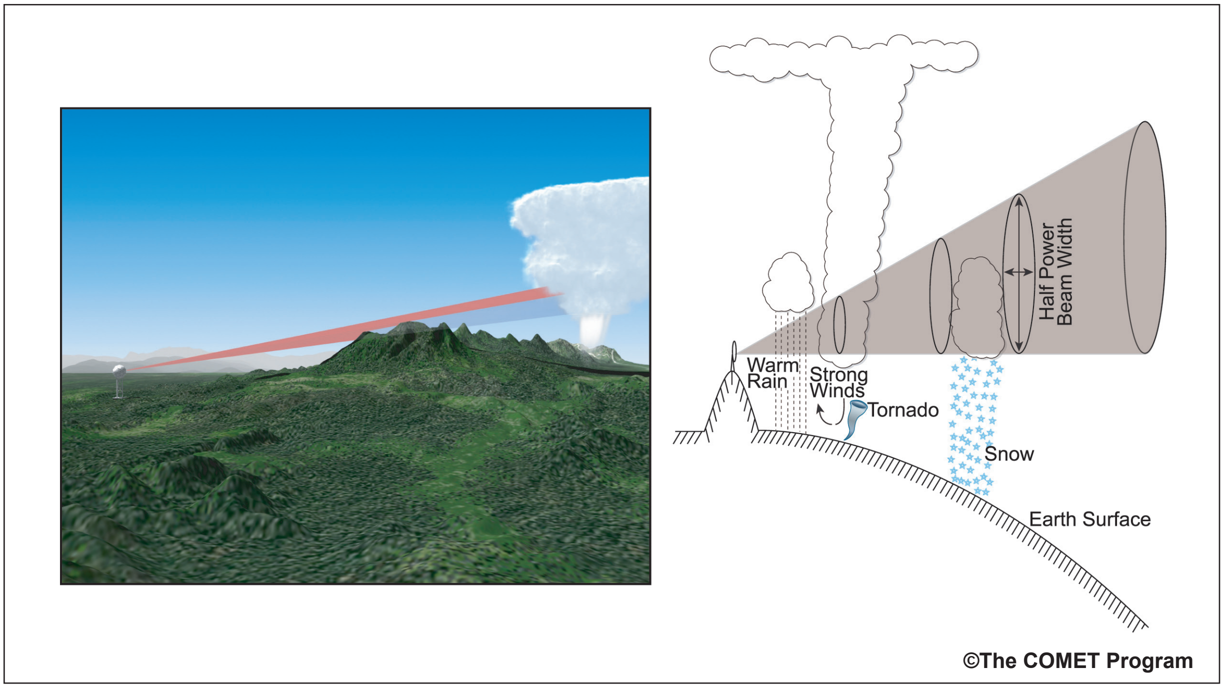

Figure 3.2 Challenges associated with deploying a radar in complex terrain

Topography

Topography is another challenge that needs to be factored into radar network planning. For optimal sampling of precipitation, it is best for the radar beam to be as low to the ground as possible without being blocked by terrain. This objective is often difficult to achieve in a region with a mixture of mountain ridges and adjacent valleys, which sometimes requires the radar beam to be well above the floor of many valleys. It is also critical that the beam does not extend to levels above where most of the precipitation is forming.

As described in National Research Council (2005) pages 133-135, if a radar station is placed in a valley location, its horizon will likely be blocked by adjacent mountains. In contrast, if a radar station is placed on a mountain ridge, its horizon will likely be clearer but sampling in valley locations will be compromised. While this dilemma usually involves a trade-off based upon various priorities, in certain situations it can be advantageous to employ both wide range "surveillance" and gap-filling radar stations in order to capture condition below and above mountain ridges. That is, a combination of C-band (~5 cm wavelength) and S-band (~10 cm wavelength) "surveillance" radars and shorter-range (< 40 km), X-band radars (2.5 to 4 cm wavelength) may be most effective in a region of complex terrain.

Range

The range of desired coverage is another important consideration. The number of stations needed to achieve adequate network coverage is not only a factor of attenuation and terrain, it is also influenced by range. With increasing range the horizontal and vertical dimensions of any radar beam increases, reducing its ability to resolve atmospheric phenomena. In addition, the angle at which the radar energy is transmitted and the earth's curvature effectively raise the radar beam farther above the earth's surface with increasing range. At a certain height, the radar beam will miss a significant portion of the precipitation particles that form at or slightly above the cloud base. (See Figure 3.2)

Logistics

Another key consideration in planning a radar network is to assess the logistical suitability of potential station locations. Relevant logistical issues might include existing infrastructure, power, communications, access, security, local obstructions, radio frequency licensing, and radio frequency interference to name a few. Table 3.1 provides a checklist of logistical

Table 3.1 Logistical Considerations for Radar Network Deployment

Considerations	Questions to Ask
Property Ownership/ Land Title / Zoning	Who owns the proposed station site? Does it have zoning that would permit radar operations? Will the owner provide an easement or unrestricted access? What rental fees or other expenses would be levied?
Current Use	Is the current use of the property compatible with radar operations? Is there enough free space for a station and supporting infrastructure? (Check with radar vendors to determine station footprint and space requirements.) Are there any obstructions, natural or manmade, that might restrict radar beam swath today or in the future?
Existing Energy & Communications Infrastructure	What electrical and gas services are available at or near the site? Are data and voice telecommunications available, by land or wireless links? How robust is this infrastructure, and are redundant lines of communication available? Is there enough space for a diesel generator or gas-powered backup power supply and associated fuel storage tank?
Existing Routes of Access	Is the site accessible throughout the year, especially during flood/debris flow seasons? Is it accessible via an alternate route if the primary route is impassible? Can large vehicles travel safely to and from the station?
Existing Support Facilities	Is there on-site accommodation and office space for the station operator? Are there neighboring accommodations or markets?
Security	Is the site secure from vandalism, theft or terrorism? If not, can it be secured affordably?
Safety	Are there populations within the beam swath that may be at risk from microwave energy or any other hazards?
Visibility	If a microwave link is required for communications, is there a clear line-of-sight/signal path between the site, repeater stations, and the forecasting center? Also, can the visual impact of the radar station to the surrounding community be minimized without compromising its performance?
Proximity	How close is the site to the personnel that will need to access the station in an emergency or on a regular basis?
Electromagnetic Interference	Are there sources of signal interference that could impact radar performance or other critical functions such as data transmission?
Radio Frequency Licensing	What are local and national regulatory requirements for signal propagation and spectrum access?
Installation versus Operations	How do the above factors impact the cost of installing the station in the short-term versus the cost of operating the station over the long-term? This comparative analysis is critical to fully understanding trade-offs and finding the optimal site(s) for the radar network.

considerations and questions to ask prior to finalizing the radar station site location(s). Site selection often requires reaching compromise amongst competing factors and should be seen as an interactive process among the NMHS, radar system vendors, government regulators, and local citizens.

Important Points to Remember about Weather Radar

- Weather radars are powerful tools because of their ability to provide high spatial and temporal resolution precipitation data over a large area as opposed to the point measurement of an *in situ* gauge.
- Attenuation of radar signals increases as radar wavelength decreases and as rainfall intensity, path length through rainfall, and mean raindrop size increase. This leads to underestimates of rainfall intensity, especially by shorter wavelength radars.
- A combination of "surveillance" radars and shorter-range radars may be most effective in regions of complex terrain.
- The height above the ground of the radar beam makes rainfall estimates at long ranges less accurate. This is a greater problem in mountainous terrain.

Satellite Networks

The mission of meteorological satellites is generally twofold: collection of observational data such as infrared and visible imagery, and dissemination of this data and other products that are uplinked from the meteorological service that controls the satellite. Additionally, these satellites perform a communications role in relaying data from various Data Collection Platforms (DCP) such as streamflow and rain gauges.

Estimating Precipitation

In many regions without sufficient radar coverage, satellite data are the primary means for making precipitation estimates. Several different satellite instruments are used in this process. Infrared sensors are probably the most familiar, with broad and consistent coverage from geostationary satellites. However, when clouds are present, infrared sensors observe only the temperature of the cloud tops. In contrast, passive microwave sensors on polar orbiting satellites observe emissions from water and ice *within* clouds to produce more reliable quantitative precipitation estimates, but they do so with less frequency. Finally, space-based active microwave (or radar) sensors have a role in the overall precipitation monitoring mission, producing the highest accuracy in both the vertical and horizontal dimensions.

Combining polar-orbiting microwave data and geostationary visible and infrared data provides opportunities to maximize the advantages of each system. Each polar-orbiting satellite sensor views a location on the earth once every 12 hours. However, multiple satellites currently operated jointly by the U.S. and Europe can provide passive microwave rain rate products for any given location every 3 to 4 hours on average.

Data from geostationary satellites arrives every half hour or even more often. Lacking microwave sensors, geostationary satellites can provide timely storm locations, but cannot produce reliable rain rates. Thus, researchers have developed synergistic precipitation products that combine the accuracy of the microwave rain rates with the temporal advantages of geostationary data. These high resolution products have been developed with an eye toward numerical modeling data assimilation, model validation, and climate studies, but they are growing in popularity with operational weather forecasters.

> **Tip**
>
> The Tropical Rainfall Measuring Mission (TRMM), launched in 1997, was conceived as a satellite mission to study tropical rainfall for climate studies and is the precursor to the Global Precipitation Measurement (GPM) mission. The two most important missions are an onboard precipitation radar (or PR) and the TRMM microwave imager (or TMI).

For example, the Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis (TMPA) combines microwave estimates of precipitation with geostationary satellite infrared estimates. Microwave rain rates are used to "calibrate" the GOES estimates. The NOAA CPC Morphing Technique (CMORPH) product is constructed entirely from passive microwave precipitation estimates. At times and locations when polar-satellite microwave data are unavailable, CMORPH propagates the microwave estimates in the time gaps using trends observed in geostationary infrared data. This propagation is referred to as "morphing." To compute estimates using the Naval Research Laboratory Blended technique (NRL-Blended), passive microwave data from polar-orbiting satellites and TRMM radar data are used to calibrate the geostationary infrared data where the microwave and infrared data overlap. This information is retained and used to produce rain rates for continuing calibration of newly received geostationary satellite data. The NOAA/NESDIS (National Environmental Satellite, Data, and Information Service) Self-Calibrating Multivariate Precipitation Retrieval (SCaMPR) algorithm is yet another rain rate estimation technique that calibrates predictors from GOES data to rainfall rates from microwave instruments. The goal is to produce estimates at the frequency of GOES data but with an accuracy that is closer to that of the intermittently-available microwave rainfall rates. SCaMPR is an experimental algorithm that is run in real time by the Center for Satellite Applications and Research (STAR), the applied science arm of NESDIS.

Processing Satellite Data

While a description of satellite ground reception equipment is beyond the scope of this document, it is important to remember that processing equipment needs to also include an ability to produce real-time, national estimates of rainfall from satellite data for operational use. The NOAA/NESDIS Center for Satellite Applications' Hydro-Estimator algorithm has automatically produced operational real-time rainfall estimates since 2002 from GOES-11 and -12 Imager band 4 (IR window) data. The final products are digital fields of instantaneous rainfall rate every 15 minutes (see Chapter 8 for additional details.)

Gridded rainfall estimates from GOES imagery are the primary source of precipitation data for several national and regional flash flood forecasting systems, since many countries cannot afford weather radar networks. The Central America Flash Flood Guidance system described briefly in Chapter 5 and more extensively in Chapter 8 is one example.

Important Points to Remember about Satellite Data

- Satellite estimates of precipitation can be partially corrected by coincident rain gauge "ground truth" data.
- Gridded rainfall estimates are the primary source of precipitation information for areas that lack radar networks and networks of rain gauges.
- Rainfall estimates can be computed for the entire planet by making use of both Polar Orbiting and Geostationary satellites.

Communications Requirements

Robust communications between the hydrometeorological observation networks and the forecast center are crucial to the success of a flash flood early warning system. Without the timely, reliable transmission of data from each sensor to the forecaster (and into numerical models), it is not possible to assess and act upon flash flood threats. Some earth observations, especially data from international networks, are available in real time through internet and satellite downlinks. Data from local monitoring networks typically depend upon fixed or wireless communications, the internet, radio telephony, UHF/VHF radio, or GOES DCPs for data transmission. Principal factors in determining what types of communication to employ include:

- Data rate
- Power availability (power from mains vs. autonomous/self-powered)
- Guarantee of data transmission (private network vs. shared data line)
- Location and availability of telecommunication infrastructure (satellites in field of view)
- Availability of funding

Two-way communications with a gauge network can be advantageous. Such a capability can be used to:

- Update software or calibration values at the station
- Interrogate the system for faults
- Change the sampling rate
- Carry out various housekeeping functions that would otherwise wait for a site visit

This allows the system to be flexible and improves overall reliability.

In adopting a communication system for a gauge installation, one consideration has to be its reliability under severe environmental conditions. For example, for flash flood warning, some of the rain gauges may have to be positioned in a slide-prone region to provide an acceptable early warning. In the event of a landslide, the first losses are often the Public Switched Telephone Network (PSTN), mobile telephone links, and electrical power. Under such circumstances, satellite links may be the only option. Additionally, some form of uninterruptible power supply (UPS) is necessary. This often takes the form of a battery back-up system with an adequate reserve capacity of several hours. A number of manufacturers, including gauge and data logger manufacturers, produce relatively inexpensive ready-to-use communications systems suitable for gauges.

Tip

Critical data should be collected from multiple networks via multiple communications paths.

The method of communication depends largely on the distance the data must be transmitted. For short distances a radio link is often convenient. For countrywide links, subscriber trunk dialing or dedicated telephone lines of the Public Switched Telephone Network (PSTN) are an effective medium. Where fixed lines are not practical, the growth in the use of mobile phone links using General Switched Messaging (GSM) technology and General Packet Radio System (GPRS) protocols has extended the potential for long-distance communication. Both the fixed and mobile telephone systems give access to the internet through an Internet Service Provider (ISP), which can greatly enhance the transmission of data. For example, many of the GPS stations of the global network of the International Global Navigation Satellite System Service report through the internet.

All forms of telephony are merging into one with telephone links that will make the connection method transparent to the user.

In general, broadband refers to telecommunication in which a wide band of frequencies is available to transmit information. Thus information can be multiplexed and sent on many different frequencies or channels within the band concurrently, allowing more information to be transmitted in a given amount of time (much as more lanes on a highway allow more cars to travel on it at the same time).The advantages of broadband technology are:

- A continuous two-way connection allowing high-speed data sampling and near-real-time data retrieval. Remote gauge diagnostics and the ability to reprogram the system remotely are available.
- Timing drift and operator setup error are eliminated by having accurate time available from Network Time Protocol servers on the internet.
- Data delivery costs are known up front, because the subscription costs are paid monthly or yearly.
- Real-time data collection allows malfunctions to be found and fixed more rapidly.
- Fixed-line broadband systems can also allow backup access through a dial-up modem.

The disadvantages of broadband technology are:

- A LAN interface is required; this is often difficult to add to existing systems.
- A land line is necessary for non-satellite broadband systems.
- A DCP serial port is generally not available, so interfacing is more difficult.
- Power requirement for broadband modems is quite high (~1 amp); this can create problems where main power is not available.

As already noted, for more remote areas, mobile satellite links provide a viable alternative. There are now upward of 30 orbiting satellite systems in operation dedicated to data transmission, some on a global basis.

Backup Communications

A local/provincial forecast center, and ideally an NMHS should employ backup communications for the collection of data and information needed to detect natural hazards. Two types of backup communications should be employed by centers:

- Alternative communication paths for critical data to reach a center
- Backup communications as part of a “service backup” provided by another center

Alternate communication paths for data collection and product dissemination are needed within a center. In the event of the failure of one of a center’s primary communication links, information can be rerouted through a secondary connection.

Functionality backup by another center means that procedures are in place for an office to assume the functions of another if the latter has lost all communications links. Typically, a center should have connections to at least two other centers.

Commercial satellite systems may offer forecast centers a diverse dissemination mechanism for warning information and thus supplement primary WMO Global Telecommunications System (GTS) connectivity (see next section). In this regard, a suitable commercially provided service could be used as backup to GTS circuits.

Many other meteorological satellite systems are operated in polar orbits for observational data collection, and many perform the additional service of collecting data from Data Collection Platforms (DCP) such as stream flow and rain gauges. The role of implementing more than one satellite receiving system should be explored by a NMHS to provide maximum overall system reliability. Although not common, unexpected outages of satellite systems do occasionally occur and can sometimes result in total loss of a satellite platform. Data reception from more than one satellite system will help ensure very high reliability in the unlikely but possible occurrence of loss of one satellite service combined with a loss of terrestrial communications at a warning center.

International Data Observation and Information Collection

As mentioned earlier in this chapter, NMHS receipt of data from local monitoring networks typically depends upon fixed or wireless communications, the internet, radio telephony, UHF/VHF radio, or GOES DCPs for data transmission. At the same time, the primary international data collection pathway for a NMHS is the Global Telecommunications System of the World Meteorological Organization. WMO GTS is the backbone system for global exchange of data and information in support of multi-hazard, multipurpose early warning systems, including all meteorological and related data; weather, water and climate analyses and forecasts; tsunami-related information and warnings, and seismic parametric data. The GTS distributes a wide range of earth data observations with standardized data formats and content. Data and information are routed using a message switching system (MSS) consisting of hardware and software systems. An overview of the GTS is given in Figure 3.3.

> **Tip**
>
> *The Global Telecommunication System (GTS) is defined as:* "The coordinated global system of telecommunication facilities and arrangements for the rapid collection, exchange and distribution of observations and processed information within the framework of the World Weather Watch."
>
> – ***WMO No 49 Technical Regulations***

The structure of the GTS makes use of terrestrial communications circuits to disseminate data, products, and bulletins over a tiered network. The three

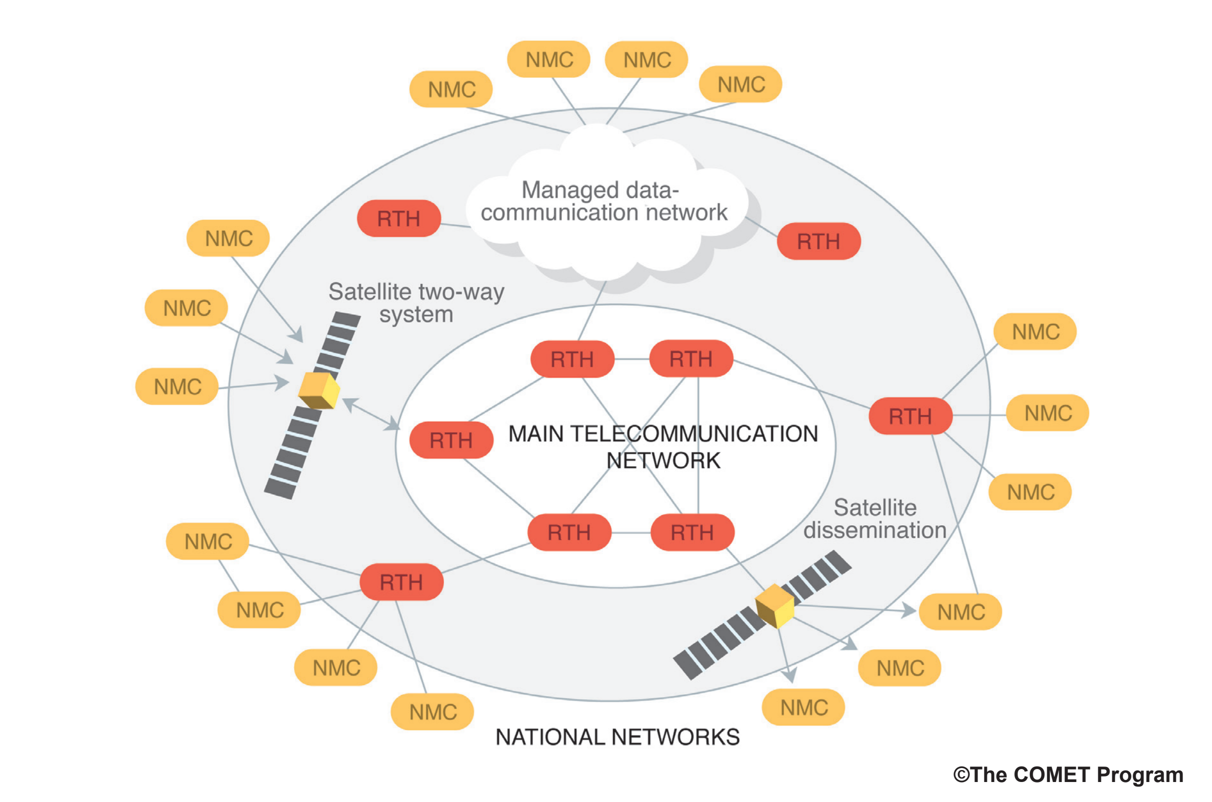

Figure 3.3 Basic structure of the WMO Global Telecommunications System

tiers of the GTS are the World Meteorological Centers (WMC), the Regional Telecommunications Hubs (RTH), and the National Meteorological Centers (NMCs).

The Main Telecommunication Network (MTN) links together three World Meteorological Centers (WMCs) (Melbourne, Moscow and Washington) and 15 Regional Telecommunication Hubs (RTHs) (Algiers, Beijing, Bracknell, Brasilia, Buenos Aires, Cairo, Dakar, Jeddah, Nairobi, New Delhi, Offenbach, Toulouse, Prague, Sofia and Tokyo). This core network has the function of providing an efficient, rapid and reliable communication service between the Meteorological Telecommunication Centers (MTCs).

The Regional Meteorological Telecommunication Networks (RMTNs) are an integrated network of circuits covering the six WMO regions — Africa, Asia, South America, North America/Central America & the Caribbean, South-West Pacific, and Europe plus the Antarctic— and interconnecting the MTCs, thus ensuring the collection of observational data and regional selective distribution of meteorological and other related information to Members. Until the integrated network is completed, HF-radio-broadcasts may be used in order to meet the requirements of the internet for the dissemination of meteorological information.

The National Meteorological Telecommunication Networks (NMTNs) enable the National Meteorological Centers (NMCs) to collect observational data and receive and distribute meteorological information on a national level.

WMO is building on its GTS to achieve an overarching WMO Information System (WIS), enabling systematic access, retrieval, dissemination, and exchange of data and information to all WMO and related international programs. WIS will also be able to provide critical data to other national agencies and users dealing with many sectors including disaster risk management.

Important Points to Remember about Communications Requirements

- Robust communications between the observation networks and the forecasting center are key to the success of a flash flood early warning system.
- In adopting a communication system for a gauge installation, one consideration has to be its reliability under severe environmental conditions.
- Alternate communication paths for data collection and product dissemination are needed within an NMHS to ensure 24/7 operations.
- WMO GTS is the backbone system for global exchange of data and information in support of multi-hazard, multipurpose early warning systems.

Vendor Specifications

The Association of Hydro-Meteorological Equipment Industry web site is:
http://www.hydrometeoindustry.org.

Additionally, a list of vendors is posted on NOAA's website:
http://www.nws.noaa.gov/im/more.htm.

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