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Instrumentation, Telemetry and Remote Sensing

1 IMPORTANCE OF HYDROLOGIC MEASUREMENTS

Hydrologic measurements are made to obtain data on hydrologic processes. These data are used to better understand these processes and as a direct input into hydrologic simulation models for design, analysis, and decision making. A rapid expansion of hydrologic data collection worldwide has become a routine practice to store hydrologic data on computer files and to make the data available in a machine-readable form, such as on magnetic tapes or disks. These two developments, the expansion and computerization of hydrologic data, have made available to hydrologists a vast array of information, which permits studies of greater detail and precision than was formerly possible. Recent advances in electronics allow data to be measured and analyzed as the events occur, for purposes such as flood forecasting and flood warning.

Hydrologic processes vary in space and time, and are random, or probabillistic, in character. Precipitation is the driving force of the land phase of the hydroologic cycle, and the random nature of precipitation means that prediction of the resulting hydrologic processes (e.g., surface flow, evaporation, and streamflow) at some future time is always subject to a degree of uncertainty that is large in comparison to prediction of the future behavior of soils or building structures, for example. These uncertainties create a requirement for hydrologic measurement to provide observed data at or near the location of interest so that conclusions can be drawn directly from on-site observations.

2 HYDROLOGIC MEASUREMENT SEQUENCE

Although hydrologic processes vary continuously in time and space, they are usually measured as point samples, measurements made through time at a fixed location in space. For example, rainfall varies continuously in space over a watershed, but a rain gage measures the rainfall at a specific point in the watershed. The resulting data form a time series, which may be subjected to statistical analysis.

In recent years, some progress has been made in measuring distributed samples over a line or area in space at a specific point in time. For example, estimates of winter snow cover are made by flying an aircraft over the snow field and measuring the radiation reflected from the snow. The resulting data form a space series. Distributed samples are most often measured at some distance from the phenomenon being observed; this is termed remote sensing. Whether the data are measured as a time series or as a space series, a similar sequence of steps is followed.

The sequence of steps commonly followed for hydrologic measurement is shown in Figure 1, beginning with the physical device which senses or reacts to the physical phenomenon and ending with the delivery of data to a user. These steps are now described.

Sensing: A sensor is an instrument that translates the level of intensity of the phenomenon into an observable signal. For example, a mercury thermometer senses temperature through the expansion or contraction of the volume of mercury within a thin tube; a storage rain gage collects the incoming rainfall in a can or tube. Sensors may be direct or indirect.

A direct sensor measures the phenomenon itself, as with the storage rain gage; an indirect sensor measures a variable related to the phenomenon, as with the mercury thermometer. Many hydrologic variables are measured indirectly, including streamflow, temperature, humidity, and radiation. Sensors for the major hydrologic variables are discussed in the subsequent sections of this chapter.

Recording: A recorder is a device or procedure for preserving the signal produced by the sensor. Manual recording simply involves an observer taking readings off the sensor and tabulating them for future reference. Most of the available rainfall data are produced by observers who read the level in a storage rain gage each day at a fixed time (e.g., 9 A.M.). Automatic recording requires a device which accepts the signal from the sensor and stores it on a paper chart or punched tape, or an electronic memory including magnetic disks or tapes.

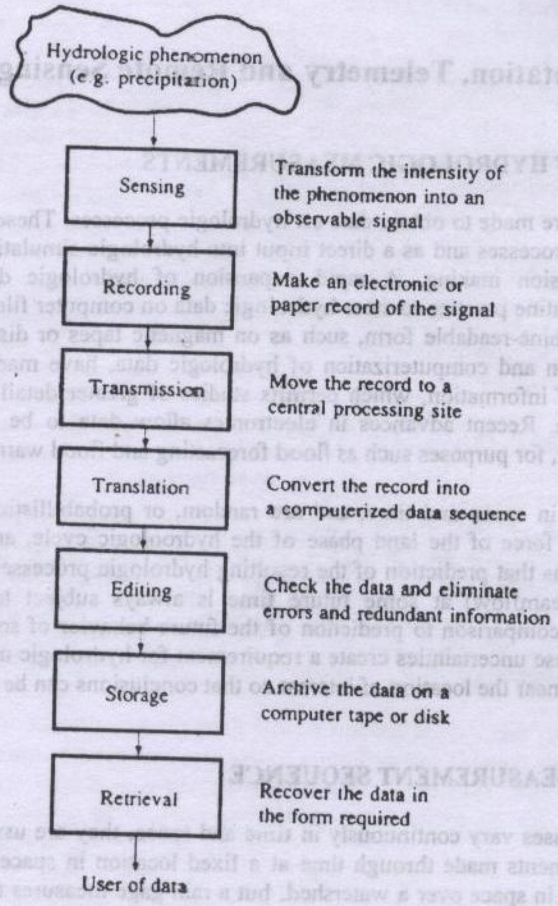

Figure 1

The hydrologic measurement sequence

Transmission: Transmission is the transfer of a record from a remote recording site to a central location. Transmission may be done routinely, such as by manually changing the chart or tape on a recorder at regular intervals (from one week to several months in duration) and carrying the records to the central location. A rapidly developing area of hydrology is real-time transmission of data through microwave networks, satellites, or telephone lines. The recorder site is "polled" by the central location when data are needed; the recorder has the data already electronically stored and sends them back to the central location immediately. Microwave transmitters operate with relatively short-wavelength electromagnetic waves (10^{-1} to 10^{-3} m) traveling directly over the land surface with the aid of repeater stations; satellite data transmission uses radio waves (1 to 10^4 m in wavelength) reflected off a satellite whose position is fixed relative to the earth's surface. Microwave and satellite transmission of data are valuable for producing flood forecasts and for providing continuous access to remote recording sites which are difficult to reach by land travel.

Translation: Translation is the conversion of a record from a field instrument form into a computerized record for permanent electronic storage. For example, translators are available which read 16-track hydrologic paper tape records and produce an electronic signal in a form readable by computers. Cassette readers and chart followers are other devices of this type.

Editing: Editing is the procedure of checking the records translated into the computer to correct any obvious errors which have occurred during any of the previous steps. Common errors include mistakes in the automatic timing of recorded measurements and information lost in transmission and translation, which is filled in by directly analyzing the record made at the recorder site.

Storage: Edited data are stored in a computerized data archive. Such archives contain many millions of hydrologic data systematically compiled into files indexed by location and sequenced by the time of measurement.

Retrieval: Data are retrieved for users either in a machine-readable form, such as magnetic tape or diskette, or as a paper printout.

3 TELEMETRY SYSTEMS

Historically, many gauges were read periodically by an individual making the rounds of installations. This served well when the purpose of the data was to establish a base record of some variable such as rainfall. But today, under many circumstances, it has become necessary to make continuous recordings of rainfalls, streamflows, and evaporation rates and to have these data available for the real-time operation of water management systems and for forecasting hydrologic events. Some examples of activities requiring real-time hydrologic data are managing reservoirs, issuing flood warnings, allocating water for various uses such as irrigation, monitoring streamflows to ensure that treaties and pacts are honored, and monitoring the quality and quantity of water for regulatory and environmental purposes. Accordingly, gauging stations capable of electronically transmitting their data to a central location for immediate use have now become common. The advantages of such stations include providing information to users in a time frame that meets management needs, reducing the costs of collecting data, and providing a continuous and synchronous record of hydrologic events. **Figure 2** shows a stream gauge reporting station using radio transmission. **Figure 3** illustrates a satellite data collection and transmitting operation.

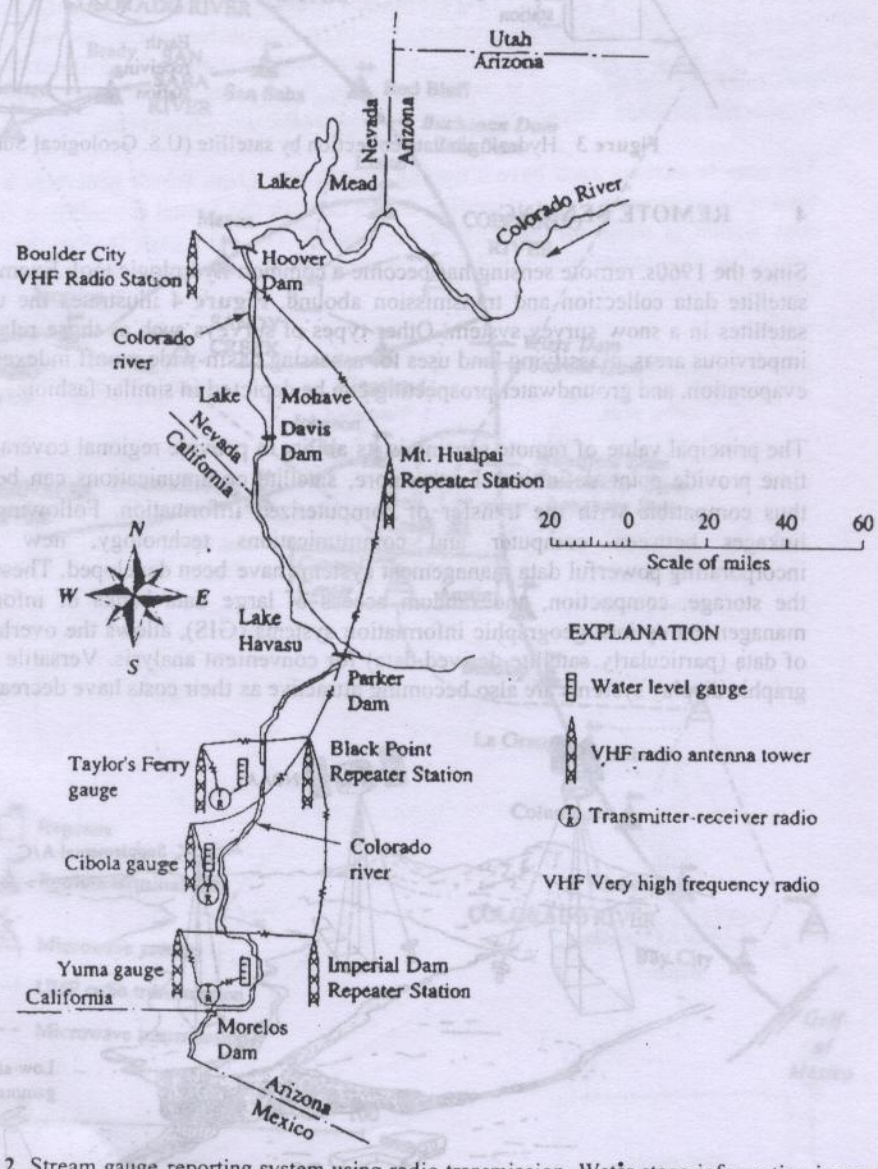

Figure 2 Stream gauge reporting system using radio transmission. Water stage information is requested from the gauging stations by VHF radio signal. In turn, this water stage information is obtained from the stream gauges and automatically encoded and transmitted to the Boulder City receiving station. All downstream releases from Hoover Dam are determined and integrated with this streamflow information in controlling the flow of the lower Colorado River. (U.S. Bureau of Reclamation.)

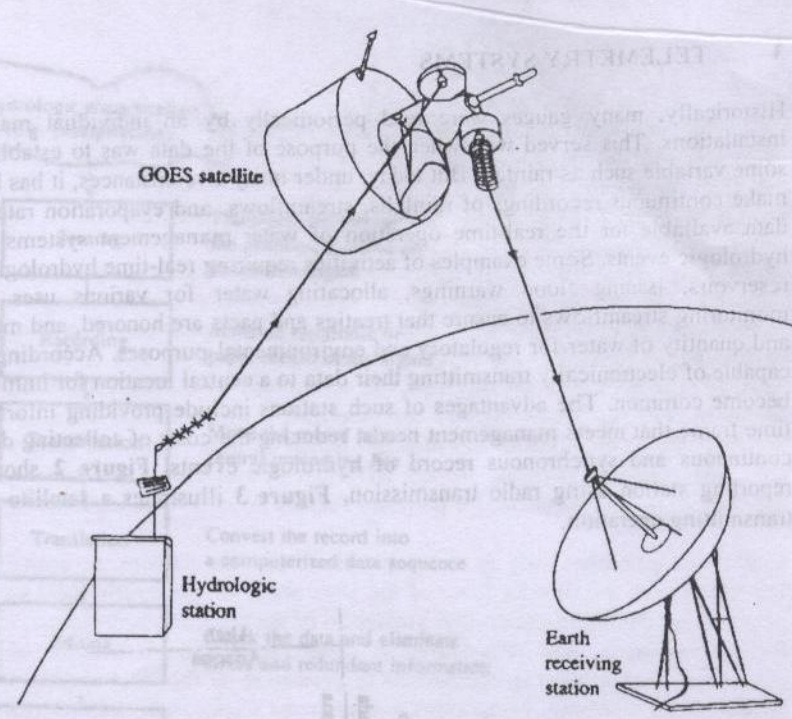

Figure 3 Hydrologic data collection by satellite (U.S. Geological Survey)

4 REMOTE SENSING

Since the 1960s, remote sensing has become a common hydrologic tool. Examples of aircraft and satellite data collection and transmission abound. **Figure 4** illustrates the use of aircraft and satellites in a snow survey system. Other types of surveys such as those related to determining impervious areas, classifying land uses for assessing basin-wide runoff indexes, determining lake evaporation, and groundwater prospecting can be depicted in similar fashion.

The principal value of remote sensing is its ability to provide regional coverage and at the same time provide point definition. Furthermore, satellite communications can be digitized and are thus compatible with the transfer of computerized information. Following the evolution of linkages between computer and communications technology, new software systems incorporating powerful data management systems have been developed. These systems facilitate the storage, compaction, and random access of large data banks of information. One data management option, geographic information systems (GIS), allows the overlaying of many sets of data (particularly satellite-derived data) for convenient analysis. Versatile color pictorial and graphic display systems are also becoming attractive as their costs have decreased.

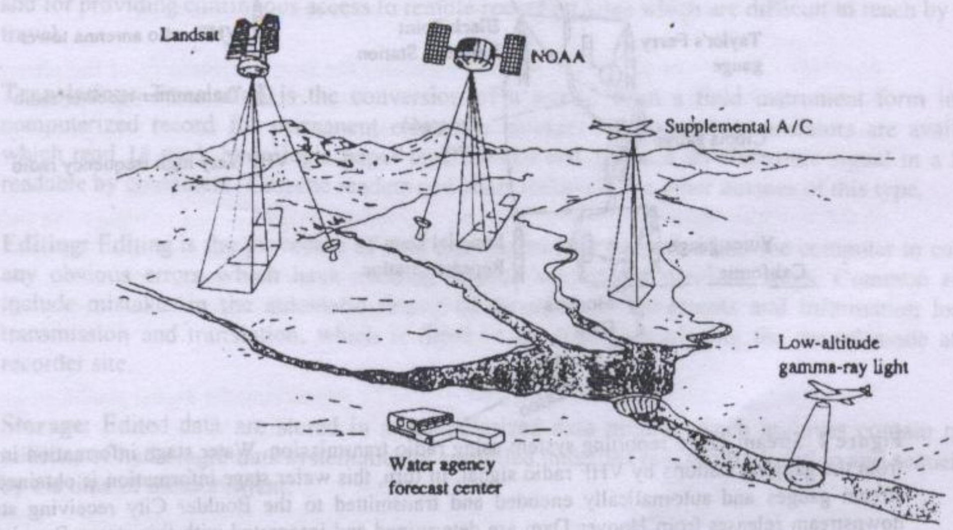

Figure 4 Satellite snow survey system (after Calabrese and Thome, 1981)

With the advancement of satellite technology, the use of satellites as remote sensor platforms has spread. Currently available sensors can operate in a multitude of electromagnetic radiation wavelengths and the information content of their signals can include surface temperatures, radiation, atmospheric pollutants, and other types of meteorological data. As remote sensors are improved to permit the attainment of greater radiometric and geographic resolution, and as computer image-enhancing techniques become more sophisticated, it is certain that this powerful water management tool will see even greater and more diversified use.

5 REAL-TIME DATA COLLECTION SYSTEMS FOR RIVER-LAKE SYSTEMS

Real-time data collection and transmission can be used for flood forecasting on large river-lake systems covering thousands of square miles, as shown in **Figure 5** for the lower Colorado River in central Texas. The data collection system used there is called a Hydrometeorological Data Acquisition System (Hydromet, EG&G Washington Analytical Services Center, Inc., 1981) and

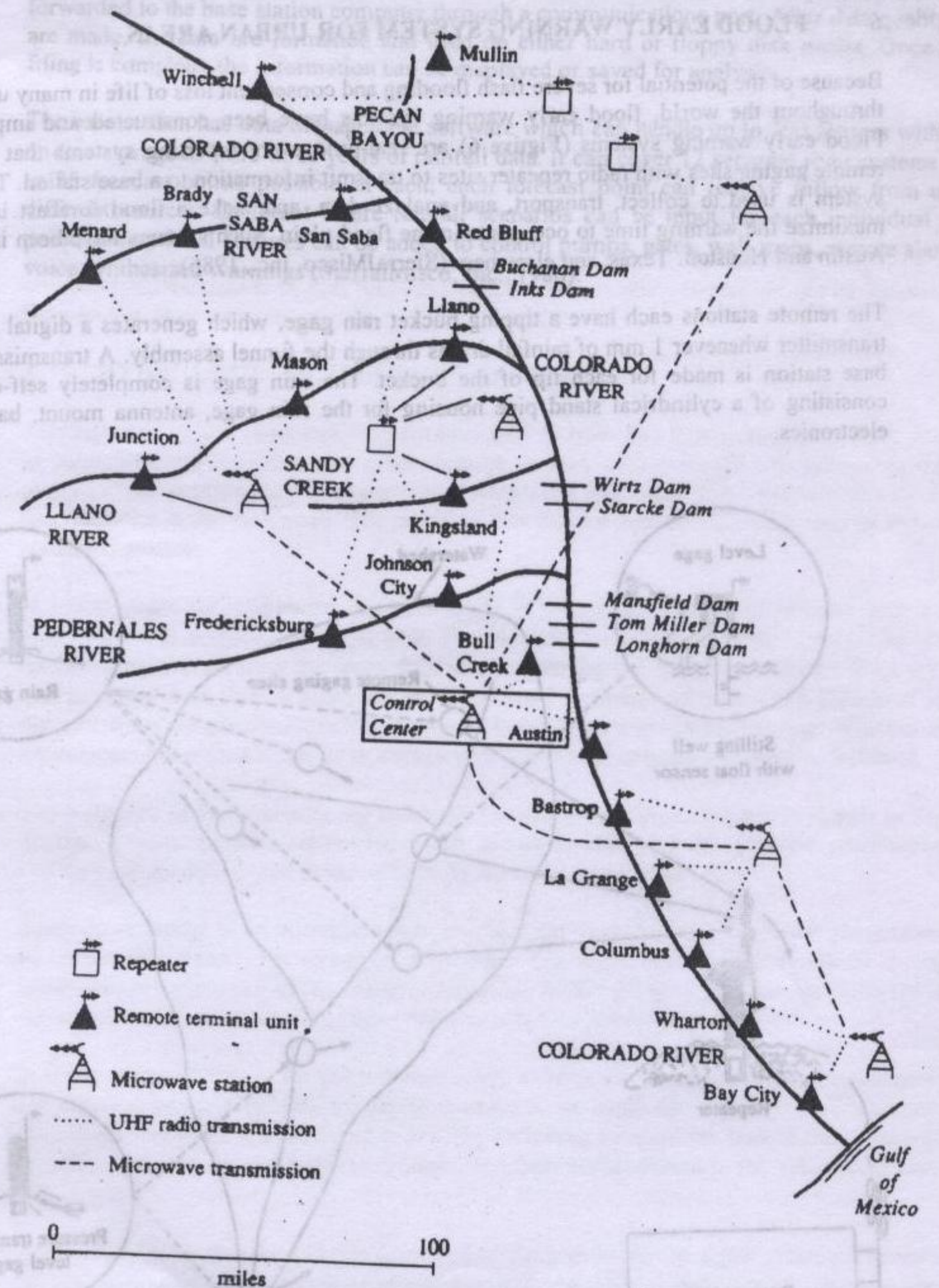

Figure 5 Real-time data transmission network on the lower Colorado River, Texas. Water level and rainfall data are automatically transmitted to the control center in Austin every 3 hours to guide releases from the dams. During floods data are updated every 15 minutes.

is used to provide information for a flood forecasting model. This information is of two types: (a) the water surface elevations at various locations throughout the river-lake system, and (b) rainfall from a rain gage network for the ungaged drainage areas around the lakes. The Hydromet system consists of (a) remote terminal unit (RTU) hydrometeorological data acquisition stations installed at U.S. Geological Survey river gage sites, (b) microwave terminal unit (MTU) microwave-to-UHF radio interface units located at microwave repeater sites, which convert radio signals to microwave signals, and (c) a central control station located at the operations control center in Austin, Texas, which receives its information from the microwave repeating stations. The system is designed to automatically acquire river level and meteorological data from each RTU; telemeter this data on request to the central station via the UHF/microwave radio system; determine the flow rate at each site by using rating tables stored in the central system memory; format and output the data for each site; and maintain a historical file of data for each site which may be accessed by the local operator, a computer, or a remote dial-up telephone line terminal. The system also functions as a self-reporting flood alarm network.

6 FLOOD EARLY WARNING SYSTEM FOR URBAN AREAS

Because of the potential for severe flash flooding and consequent loss of life in many urban areas throughout the world, flood early warning systems have been constructed and implemented. Flood early warning systems (**Figure 6**) are real-time event reporting systems that consist of remote gaging sites with radio repeater sites to transmit information to a base station. The overall system is used to collect, transport, and analyze data, and make a flood forecast in order to maximize the warning time to occupants in the flood plain. Such systems have been installed in Austin and Houston, Texas, and elsewhere (SierraJMisco, Inc., 1986).

The remote stations each have a tipping bucket rain gage, which generates a digital input to a transmitter whenever 1 mm of rainfall drains through the funnel assembly. A transmission to the base station is made for each tip of the bucket. The rain gage is completely self-contained, consisting of a cylindrical stand pipe housing for the rain gage, antenna mount, battery, and electronics.

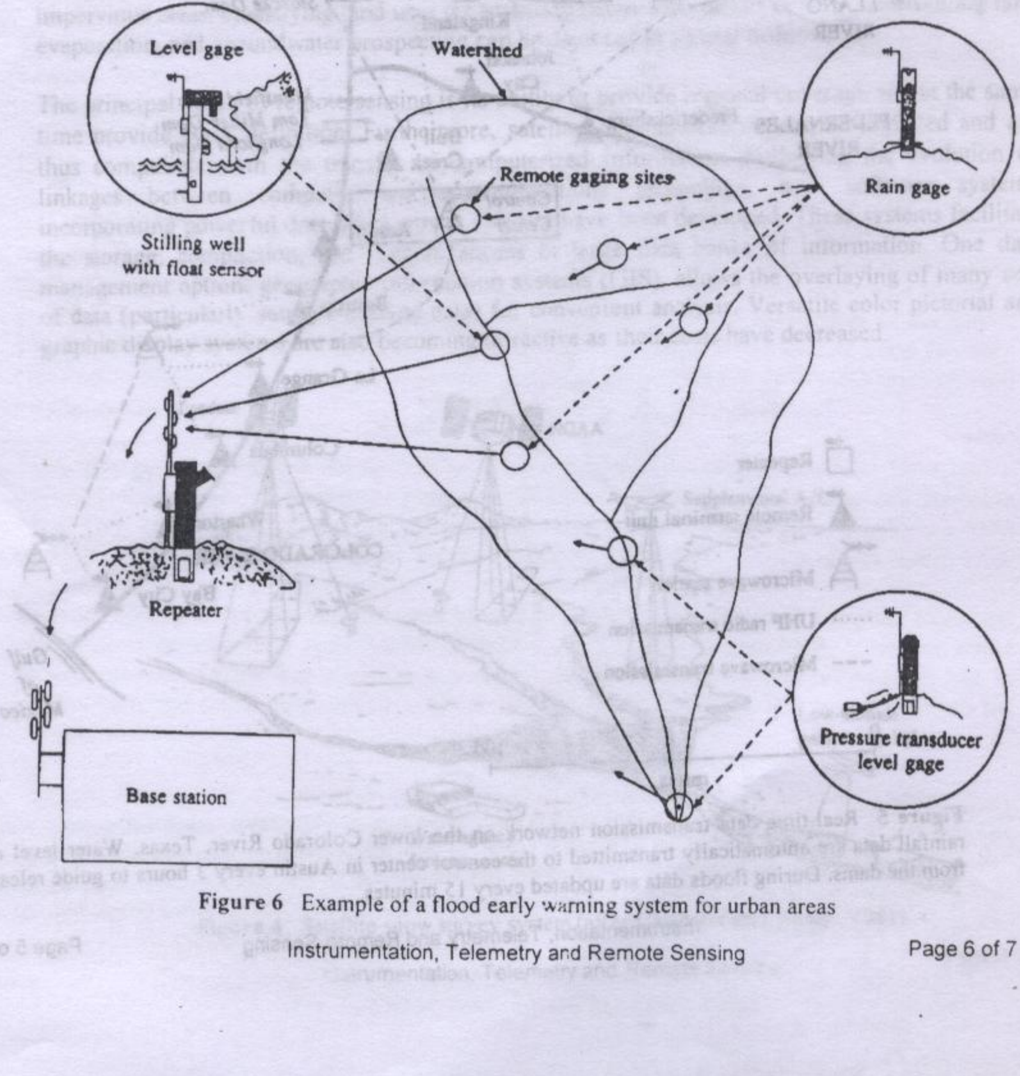

Figure 6 Example of a flood early warning system for urban areas

Some remote stations have both rainfall and streamflow gages. The remote stations can include a stilling well or a pressure transducer water level sensor. The pressure transducer measures changes of the water level above the pressure sensor's orifice. The electronic differential pressure transducer automatically compensates for temperature and barometric pressure changes with a one percent accuracy over the measured range.

Automatic repeater stations, located between the remote stations and the base station, receive data from the remote stations, check the data for validity, and transmit the data to the base station.

Incoming radio signals are transformed from radio analog form to digital format and are forwarded to the base station computer through a communications port. After data quality checks are made, the data are formatted and filed on either hard or floppy disk media. Once the data filing is complete, the information can be displayed or saved for analysis.

The base station has data management software which can handle up to 700 sensors with enough on-line storage to store three years of rainfall data. It can cover 12 separate river systems with up to 25 forecast points possible in each; each forecast point can receive inflow from up to 10 different sources. Different future rainfall scenarios can be input for each individual forecast point, and optional features can be added to control pumps, gates, wall maps, remote alarms, and voice synthesized warnings (SierraiMisco, Inc., 1986).