Chapter 5
Hydrologic Engineering Data

5-1. Meteorological Data

The extent of meteorological observations is determined by the data needs and use and the availability of personnel and equipment. Data usually recorded at weather stations include air (sometimes water) temperature, precipitation, wind, and evaporation. As indicated below, more extensive recording of various types of data is often made for special purposes. The primary source of meteorological data for the United States is the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center in Asheville, North Carolina. Data are available from NOAA in computer-readable form as well as published reports. NOAA publication "Selective Guide to Climatic Data Sources" is an excellent reference for data availability. Private vendor sources employing compact disc (CD) technology using NOAA records are also available.

a. Storm meteorology. The determination of runoff potential, particularly flood potential, in areas where hydrologic data are scarce can be based on a knowledge of storm meteorology. This includes sources of moisture in the paths over which the storm has traveled, as well as a knowledge of the mechanics of storm activity. Derivation of hydrologic quantities associated with various storms must take into consideration the type of storm, its path, potential moisture capacity and stability of the atmosphere, isobar, wind and isotherm patterns, and the nature and intensity of fronts separating air masses. These are usually described adequately in the synoptic charts that are prepared at regular (usually 6-hr) intervals for weather forecasting purposes and associated upper-air soundings. Where such charts are available, it is important that they be retained as a permanent record of meteorological activity for use in supplementing information contained in the regularly prepared hemispheric charts. These latter charts summarize the daily synoptic situation throughout the hemisphere but do not contain all of the data that are of interest or that would have direct bearing on the derivation of design criteria.

(1) NOAA monthly publication "Storm Data" (1959-present) documents the time, location, and the meteorologic characteristics of all reported severe storms or unusual weather phenomena. Synoptic maps are published by NOAA on a weekly basis in "Daily Weather Maps, Weekly Series" and on a monthly basis, "Synoptic Weather Maps, Daily Series, Northern Hemisphere Sea-Level and 500-Millibar Charts and Data Tabulations."

(2) Storm data including synoptic charts for selected historic storms are included in the "Hydrometeorological Reports" and "Technical Memorandum" prepared by the National Weather Service (NWS) Office of Hydrology in Silver Spring, MD. Other sources of meteorological data include the National Hurricane Center in Coral Gables, FL, and state climatologists as well as U.S. Geological Survey and Corps flood reports.

b. Precipitation. Monthly summaries of observed hourly and daily precipitation data are published by NOAA in "Climatical Data" and "Hourly Precipitation Data." Precipitation data are also available from NOAA in computer-readable media. Precipitation data for significant historic storms (1870's-1960's) are tabulated in "Storm Rainfall in the United States, Depth, Area, Duration Data."

(1) There are usually local, or state agencies, collecting precipitation data for their own use. These data could provide additional storm information. However, precipitation measurements at remote unattended locations may not be consistently and accurately recorded, particularly where snow and hail frequently occur. For this reason, records obtained at unattended locations must be interpreted with care. When an observer is regularly on-site, the times of occurrence of snowfall and hail should be noted to make accurate use of the data. The exact location and elevation of the gauge are important considerations in precipitation measurement and evaluation. For uniform use, this is best expressed in terms of latitude and longitude and in meters or feet of elevation above sea level. Of primary importance in processing the data is tabulating precipitation at regular intervals. This should be done daily for non-recording gauges with the time of observation stated. Continuously recording gauges should be tabulated hourly. The original recording charts should be preserved in order to permit study of high-intensity precipitation during short intervals for certain applications.

(2) Procedures to develop standard project and probable maximum precipitation estimates are presented in NWS hydrometeorological reports and technical memorandum. Chapter 7 of this manual provides an overview of hypothetical storms and their application to flood-runoff analysis.

c. Snowpack. Where snowmelt contributes significantly to runoff, observations of the snowpack characteristics can be of considerable value in the development of hydrologic design criteria. The observation of water equivalent (weight) of a vertical column sampled from the snowpack at specified locations and observation times is of primary importance. As the observations will ordinarily be used as an index for surrounding regions, the elevation and exposure of the location must be known. The depth of snowpack is of secondary importance, but some observations of the areal extent of the snowpack are often useful.

(1) An important element in processing snowpack observation data is the adjustment of observations at all locations to a common date, such as the first of each month during the snowpack accumulation season. Since these observations are often made by traveling survey teams, they are not made simultaneously. Also, they cannot always be made at a specified time because it is impossible to obtain accurate or representative measurements during snowstorms.

(2) Where continuous recordings of snowpack water equivalent by means of radioactive gauges or snow pillows are available, these can be used on a basis for adjusting manual observations at nearby locations. Otherwise, some judgment or correlation technique based on precipitation measurements is required to adjust the observations data to a uniform date at all locations. It is important to preserve the original records whenever such adjustments are made. However, data that are disseminated for use in design should be the adjusted systematic quantities.

(3) The primary agency for the collection and distribution of snowpack data is the Soil Conservation Service (SCS) (Department of Agriculture, Washington, D.C.). From January through May each year, the SCS publishes a monthly report titled, "Water Supply Outlook." These reports provide snowpack and streamflow forecast data for each state and region. The SCS also issues "Basin Outlook Reports," a monthly regional summary of snow depth and water content. Additionally, NOAA distributes an annual tabulation of snowpack data in their "Snow Cover Surveys." Climatoligcal precipitation data published monthly by NOAA also include information on snowfall and snow on the ground.

d. Temperatures. In most hydrologic applications of temperature data, maximum and minimum temperatures for each day at ground level are very useful. Continuous records of diurnal temperature variations at selected locations can be used to determine the daily temperature pattern fairly accurately at nearby locations where only the maximum and minimum temperatures are known. In applying temperature data to large areas, it must be recognized that temperatures normally decrease with increasing elevation and latitude. It is also important to preserve all of the original temperature records. Summaries of daily maximum and minimum temperatures should be maintained and, where feasible, published. The NOAA report series on "Climatography of the United States" by city, state, or region also provides information on daily and monthly normal temperatures.

e. Moisture. Atmospheric moisture is a major factor influencing the occurrence of precipitation. This moisture can be measured by atmospheric soundings which record temperature, pressure, relative humidity, and other items. Total moisture in the atmosphere can be integrated and expressed as a depth of water. During storms, the vertical distribution of moisture in the atmosphere ordinarily follows a rather definite pattern. Total moisture can therefore be related to the moisture at the surface, which is a function of the dew point at the surface. Accordingly, a record of daily dew points is of considerable value. Here, again, the elevation, latitude and longitude of the measuring station must be known. NOAA publication "Local Climatological Data" is a primary source for observed dew point, pressure, and temperature data.

f. Winds. Probably the most difficult meteorological element to evaluate is wind speed and direction. Quite commonly, the direction of surface winds reverses diurnally, and wind speeds fluctuate greatly from hour to hour and minute to minute. There is also a radical change of wind speed and direction with altitude. The speed and direction at lower levels is greatly influenced by obstructions such as mountains, and locally by small obstructions such as buildings and trees. Accordingly, it is important that great care is exercised in selecting a location and altitude for wind measurement. For most hydrologic applications, wind measurements at elevations of 5 to 15 m above the ground surface are satisfactory. It is important to preserve all basic records of winds, including data on the location, ground elevation, and the height of the anemometer above the ground. An anemometer is an instrument for measuring and indicating the force or speed of the wind. Where continuous records are available, hourly tabulations of speed and direction are highly desirable. Total wind movement and the prevailing direction for each day are also useful data. Daily wind data for each state are published in NOAA publications "Local Climatological Data" and "Climatological Data."

g. Evaporation. Evaporation data is usually required for reservoir studies, particularly for low-flow analysis. Reservoir evaporation is typically estimated by measuring pan evaporation or computing potential evaporation. There are several methods of estimating potential evaporation, based on meteorological information. Pruitt (1990) reviewed various approaches in an evaluation of the methodology and results published in "A Preliminary

Assessment of Corps of Engineer Reservoirs, Their Purposes and Susceptibility to Drought," (HEC 1990e).

(1) Evaporation is usually measured by using a pan about 4 ft (1.2 m) in diameter filled with water to a depth of about 8 in. (0.2 m). Daily evaporation can be calculated by subtracting the previous day's reading from today's reading and adding the precipitation for the intervening period. The pan should be occasionally refilled and this fact noted in the record. This volume of added water, divided by the area of the pan, is equal to the daily evaporation amount expressed in inches or millimeters. A tabulation of daily evaporation amounts should be maintained and, if possible, published. It is essential that a rain gauge be maintained at the evaporation pan site, and it is usually desirable that temperature, dew point (or wet-bulb temperature) and low-level wind measurements also be made at the site for future study purposes.

(2) NOAA Technical Report "NWS 33, Evaporation Atlas for the Contiguous United States" (Farnsworth, Thompson, and Peck 1982) provides maps showing annual and May-October evaporation in addition to pan coefficients for the contiguous United States. Companion report "NWS 34, Mean Monthly, Seasonal, and Annual Pan Evaporation for the United States" documents monthly evaporation data which was used in the development of the evaporation atlas. Daily observed evaporation data are published for each state in NOAA publications "Local Climatological Data" and in "Climatological Data."

h. Upper air soundings. Upper air soundings are available from NOAA National Climatic Data Center in Asheville, NC. The soundings provide atmospheric pressure, temperature, dew point temperature, wind speed, and direction data from which lapse rate, atmospheric stability, and jet stream strength can be determined. These meteorological parameters are necessary to a comprehensive storm study.

5-2. Topographic Data

a. Mapping. For most hydrologic studies, it is essential that good topographic maps be used. It is important that the maps contain contours of ground-surface elevation, so that drainage basins can be delineated and important features such as slopes, exposure, and stream patterns can be measured. United States Operational Navigation Charts, with a scale of 1:1,000,000 and contour intervals of 1,000 ft, are available for most parts of the world. However, mapping to a much larger scale (1:25,000) and smaller contour intervals in the range of 5-20 ft (1.5 to 6 m) are usually necessary for satisfactory hydrologic studies. The USGS 7.5 Minute Series (Scale 1:24,000), with a typical contour interval of 5 or 10 ft (1.5 or 3.0 m), provides a good basic map for watershed studies. The USGS publications "Catalog of Published Maps" and "Index to Maps" are excellent guides to readily available topographic data for each state. Reports by the USGS are available through Books and Open File Reports Section, USGS, Federal Center, Box 25425, Denver, CO, or by contacting the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161.

b. Digital mapping. Increasingly, topographic data are available in digital form. One form of computer description of topography is a digital elevation model (DEM). Geographic information systems (GIS) can link land attributes to topographic data and other information concerning processes and properties related to geographic locations. DEM and GIS representations of topologic data are part of a general group of digital terrain models (DTM). Some of the earliest applications in hydrologic modeling used grid cell (raster) storage of information. An example of raster-based GIS is the Corps' Geographic Resource Analysis Support System (GRASS). An alternate approach utilizes a collection of irregularly spaced points connected by lines to produce triangles, known as triangular irregular network (TIN). The use of DEM and TIN data and processing software is rapidly changing and may soon become the standard operation for developing terrain and related hydrologic models. A review of GIS applications in hydrology is provided by DeVantier et al. (HEC 1993).

c. Stream patterns and profiles. Where detailed studies of floodplains are required, computation of water-surface profiles is necessary. Basic data needed for this computation include detailed cross sections of the river and overbank areas at frequent intervals. These are usually obtained by special field surveys and/or aerial photography. When these surveys are made, it is important to document and date the data and resulting models, then permanently preserve the information so it is readily available for future reference. Observations of actual water-surface elevations during maximum flood stages (high-water marks) are invaluable for calibrating and validating models for profile computations.

d. Lakes and swamps. The rate of runoff from any watershed is greatly influenced by the existence of lakes, swamps, and similar storage areas. It is therefore important to indicate these areas on available maps. Data on the outlet characteristics of lakes are important because, in the absence of outflow measurements, the outflow can often be computed using the relationship between the amount of water stored in the lake and its outlet characteristics.

e. Soil and geology. Certain maps of soils and geology can be very useful in surface-water studies if they show characteristics that relate to perviousness of the basin. These can be used for estimating loss rates during storms. Of particular interest are areas of extensive sandy soils that do not contribute to runoff and areas of limestone and volcanic formations that are highly pervious and can store large amounts of water beneath the surface in a short time. Additionally, watershed sediment yield estimates will depend on similar information. The SCS soil survey reports are the primary source of soil and permeability data. State geologic survey or mineral resource agencies are also a useful source of geologic data.

f. Vegetal cover. Often the type of vegetation more accurately reflects variation in hydrologic phenomena than does the type of soil or the geology. In transposing information to areas of little or no hydrologic data, generalized maps of vegetal cover are very helpful. As with soil and geology, vegetation has a significant impact on sediment yield. In the arid southwest, time since the watershed last burned is a significant parameter in estimating total sediment yield for a storm event. The U.S. Forest Service, the Agricultural Stabilization and Conservation Service (ASCS) and, in western states, the Bureau of Land Management are sources of vegetal cover maps. State forest, agricultural agencies, or USGS topographic maps also provide information on vegetal cover.

g. Existing improvements. Streamflow at any particular location can be greatly affected by hydraulic structures located upstream. It is important, therefore, that essential data be obtained on all significant hydraulic structures located in and upstream from a study area. For diversion structures, detailed data are required on the size of the diversion dam, capacity of the diversion canal, and the probable size of flood required to wash out the diversion dam. In the case of storage reservoirs, detailed data on the relation of storage capacity to elevation, location, and size of outlets and spillways, types, sizes, and operation of control gates, and sizes of power plant and penstocks should be known. Bridges can produce backwater effects which will cause upstream flooding. This flooding may be produced by the approach roads, constriction of the channel and floodplain, pier shapes, the angle between the piers and the streamflow, or the pier length-width ratios.

5-3. Streamflow Data

The availability of streamflow data is a significant factor in the selection of an appropriate technical method for reservoir studies. It is important to be cognizant of the nature, source, reliability, and adequacy of available data. If estimates are needed, the assumptions used should be documented, and the effect of errors in the estimates on the technical procedure and results should be considered.

a. Measurement. Streamflow data are usually best obtained by means of a continuous record of river stage, supplemented by frequent meter measurements of flows that can be related to corresponding river stages. It is important that stage measurements be made at a good control section, even if a weir or other control structures must be constructed. Each meter measurement should consist of velocity measurements within each of several (6-20, where practical) subdivisions within the channel cross section. Velocity for a subdivision is usually taken as the velocity at a depth of 60 percent (0.6) of the distance from the surface to the streambed or as the average of velocities taken at 20 and 80 percent (0.2 and 0.8) of the depth at the middle of the subdivision. River stage readings should be made immediately before and after the cross section is metered. The average of these two stages is the stage associated with the measurement. The measurement is computed by integrating the rates of flow (m^3/s) in all subdivisions of the cross section.

(1) Measurements of stream velocity and computed streamflow are usually recorded on standard forms. When measurements have been made for a sufficient range of flows, the rating curve of flow versus stage can be developed. The rating curve can be used to convert the continuous record of stage into a continuous record of flow. The flows should be averaged for each day in order to construct a tabulation of mean daily flows. This constitutes the most commonly published record of runoff.

(2) For flood studies, it is particularly important to obtain accurate records of short-period variations during high river stages and to obtain meter measurements at or near the maximum stage during as many floods as possible. Where the river profile is very flat, as in estuaries and major rivers, it is advisable to obtain measurements frequently on the rising and on the falling stage to determine if a looped, or hysteresis, effect exists in the rating. The reason for this is that the hydraulic slope can change greatly, resulting in different rating curves for rising and falling stages.

b. Streamflow data sources. The USGS is the primary agency for documenting and publishing flow data in the United States. Daily flow data for each state are published in the USGS annual "Water Data Report." The USGS National Water Data Exchange (NAWDEX) computerized database identifies sources of water data. The National Water Data Storage and Retrieval System (WATSTORE) provides processing, storage, and retrieval of surface water, groundwater, and water quality data.

NAWDEX is only an index of the contents of WATSTORE. These programs will eventually be integrated into a National Water Information System, which will also combine the National Water-Use Information Program and Water Resources Scientific Information Center (Mosley and McKerchar 1993). Commercial data services have also provided convenient access to USGS daily and peak flow files on CD.

c. Flow conditions. Reservoirs substantially alter the distribution of flow in time. Many other developments, such as urbanization, diversions, or cultivation and irrigation of large areas can also have a significant effect on watershed yield and the distribution of flow in time. The degree that flows are modified depends on the scale and manner of the development, as well as the magnitude, time, and areal distribution of rainfall (and snowmelt, if pertinent). Most reservoir evaluations require an assessment based on a consistent flow data set. Various terms are used to define what condition the data represent:

(1) Natural conditions in the drainage basin are defined as the hydrologic conditions that would prevail if no regulatory works or other development affecting basin runoff and streamflow were constructed. The effects of natural lakes and swamp areas are included.

(2) Present conditions are defined as the conditions that exist at, or near, the time of study. If there are upstream reservoirs in the basin, the observed flow record would represent "regulated flow." Flow records, preceding current reservoir projects, would be adjusted to reflect those project operations in order to have consistent "present conditions" flow.

(3) Unregulated conditions reflect the present (or recent) basin development, but without the effect of reservoir regulation. Unlike natural conditions which are difficult to determine, only the effect of reservoir operation and major diversions are removed from the historic data.

(4) Without-project conditions are defined as the conditions that would prevail if the project under consideration were not constructed but with all existing and future projects under construction assumed to exist.

(5) With-project conditions are defined as the conditions that will exist after the project is completed and after completion of all projects having an equal or higher priority of construction.

5-4. Adjustment of Streamflow Data

The adjustment of recorded streamflows is often required before the data can be used in water resources development studies. This is because flow information usually is required at locations other than gauging stations and for conditions of upstream development other than those under which flows occurred historically. In correlating flows between locations, it is important to use "natural" flows (unaffected by artificial storage and diversion) in order that correlation procedures will apply logically and efficiently. In generating flows, natural flows should be used because general frequency functions, characteristic of natural flows, are employed in this process.

a. Natural conditions. When feasible, flow data should be converted to natural conditions. The conversion is made by adding historical storage changes (plus net evaporation) and upstream diversions (less return flows) to historical flows at the gauging stations for each time interval in turn. Under some conditions, it may be necessary to account for differences in channel and overbank infiltration losses, distributary flow diversions, travel times, and other factors.

b. Unregulated conditions. It is not always feasible to convert flows to natural conditions. Often, required data are not available. Also, the hydrologic effects and timing of some basin developments are not known to sufficiently define the required adjustments. An alternative is to adjust the data to a uniform basin condition, usually near current time. The primary adjustments should remove special influences, such as major reservoirs and diversions, that would cause unnatural variations of flow.

c. Reservoir holdouts. The primary effect of reservoir operation is the storage of excess river flow during high-flow periods, and the release of stored water during low-flow periods. The flow adjustment process requires the addition of the change in water stored (hold-outs) in each time step to the observed regulated flow. Holdouts, both positive and negative, are routed down the channel to each gauge and algebraically added to the observed flow. Hydrologic routing methods, typically used for these adjustments, are described in Chapter 9 of EM 1110-2-1417. The HEC Data Storage System (HEC-DSS) software (HEC 1995) provides a convenient data management system and utilities to route flows and add, subtract, or adjust long time-series flow data.

d. Reservoir losses. The nonproject inflow represents the flow at the project site without the reservoir and includes runoff from the entire effective drainage area above the dam, including the reservoir area. Under nonproject conditions, runoff from the area to be inundated by the reservoir is ordinarily only a fraction of the total precipitation which falls on that area. However, under project conditions infiltration losses over the reservoir area are usually minimal during a rainfall event. Thus, practically all the precipitation falling on the reservoir area will appear as runoff. Therefore, the inflow will be greater under project conditions than under nonproject conditions, if inflow is defined as total contribution to the reservoir before evaporation losses are considered. In order to determine the amount of water available for use at the reservoir, evaporation must be subtracted from project inflow. In operation studies, nonproject inflow is ordinarily converted to available water in one operation without computing project inflow as defined above. This is done in one of two ways: by means of a constant annual loss each year with seasonal variation or with a different loss each period, expressed as a function of observed precipitation and evaporation. These two methods are described in the following paragraphs.

(1) Constant annual loss procedure consists of estimating the evapotranspiration and infiltration losses over the reservoir area for conditions without the project, and the evaporation and infiltration losses over the reservoir area with the project. Nonproject losses are usually estimated as the difference between average annual precipitation and average annual runoff at the location, distributed seasonally in accordance with precipitation and temperature variations. These are expressed in millimeters of depth. Under project conditions, infiltration losses are usually ignored, and losses are considered to consist of only direct evaporation from the lake area, expressed in millimeters for each period. The difference between these losses is the net loss due to the project. Figure 5-1 illustrates the differences between nonproject and project losses.

(2) The variable loss approach uses historical records of long-term average monthly precipitation and evaporation data to account for the change in losses due to a reservoir project. This is accomplished by estimating the average runoff coefficient, the ratio of runoff to rainfall, for the reservoir area under preproject conditions and subtracting this from the runoff coefficient for the reservoir area under project conditions. The runoff coefficient for project conditions is usually 1.0, but a lower coefficient may be used if substantial infiltration or leakage from the reservoir is anticipated. The difference between preproject and project runoff coefficients is the net gain expressed as a ratio of precipitation falling on the reservoir. This is often estimated to be 0.7 for semi-arid regions. This increase in runoff is subtracted from gross reservoir evaporation, often estimated as 0.7 of pan evaporation, to obtain a net loss.

e. Other losses. In final project studies it is often necessary to consider other types of project losses which may be of minor importance in preliminary studies. Often, these losses cannot be estimated until a project design has been adopted. The importance of these losses is dependent upon their relative magnitude. That is, losses of 5 m^3/s might be considered unimportant for a stream which has a minimum average annual flow of 1,500 m^3/s. Such losses, though, would be significant from a stream with a minimum average annual flow of 25 m^3/s. Various types of losses are discussed in the following paragraphs.

(1) The term "losses" may not actually denote a physical loss of water from the system as a whole. Usually, water unavailable for a specific project purpose is called a "loss" for that purpose although it may be used at some other point or for some other purpose. For example, water which leaves the reservoir through a pipeline for municipal water supply or fish hatchery requirements might be called a loss to power. Likewise, leakages through turbines, dams, conduits, and spillway gates are considered losses to hydropower generation, but they are ordinarily not losses to flow requirements at a downstream station. Furthermore, such losses that become available for use below the dam should be added to inflow at points downstream from the project.

(2) Leakage at a dam or in a reservoir area is considered a loss for purposes which are dependent upon availability of water at the dam or in the reservoir itself. These purposes include power generation, pipelines from the reservoir, and any purpose which utilizes pump intakes which are located at or above the dam. As a rule, leakage through, around, or under a dam is relatively small and is difficult to quantify before a project is actually constructed. In some cases, the measured leakage at a similar dam or geologic area may be used as a basis for estimating losses at a proposed project. The amount of leakage is a function of the type and size of dam, the geologic conditions, and the hydrostatic pressure against the dam.

(3) Leakage from conduits and spillway gates is a function of gate perimeter, type of seal, and head on the gate, and it varies with the square root of the head. The amount of leakage may again be measured at existing projects with various types of seals, and a leakage rate computed per meter of perimeter for a given head. This rate may then be used to compute estimated leakage for a

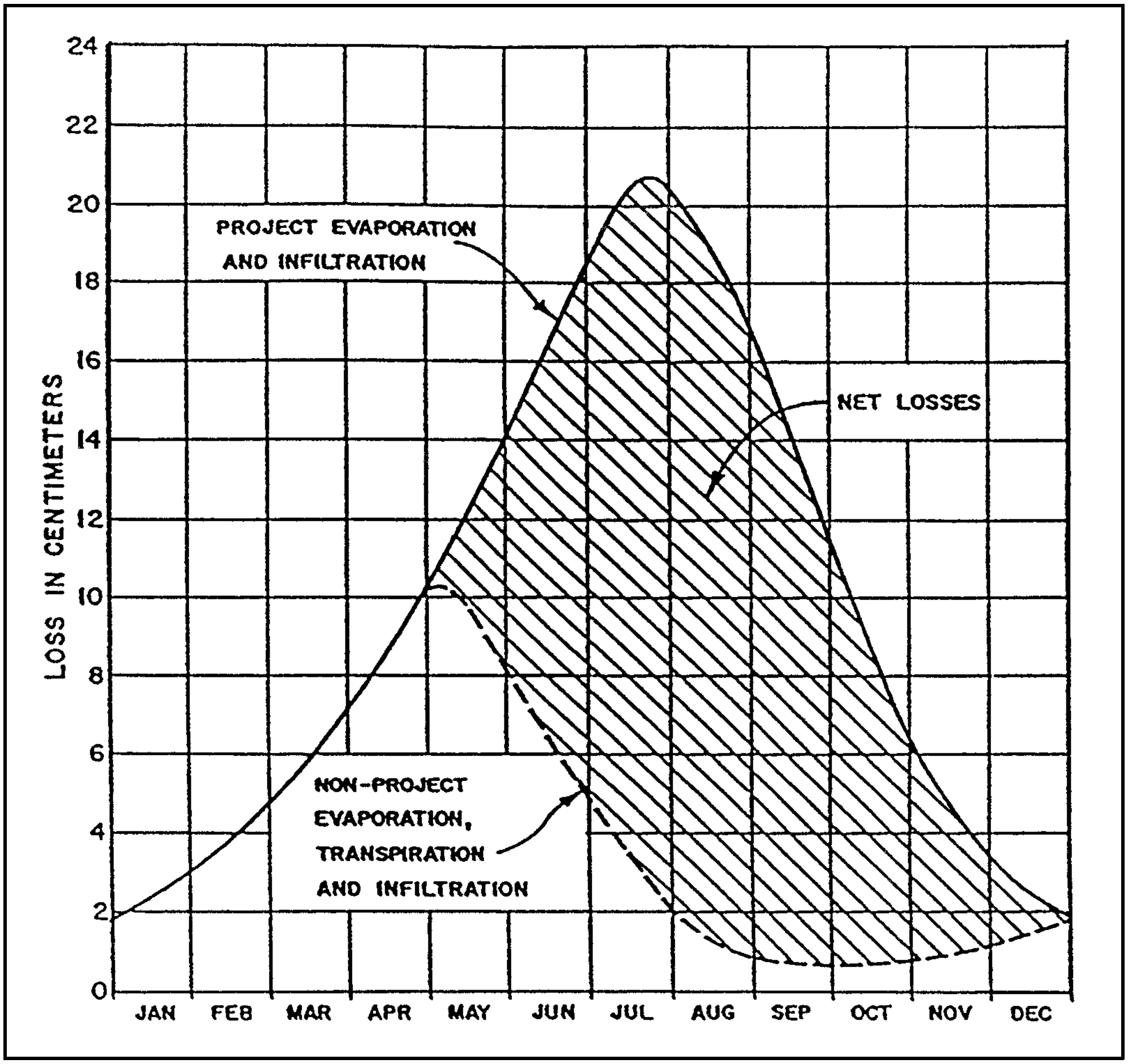

Figure 5-1. Project and nonproject reservoir losses

proposed project by using the proposed size and number of gates and the proposed head on the gates.

(4) If a proposed project will include power, and if the area demand is such that the turbines will sometimes be idle, it is advisable to estimate leakage through the turbines when closed. This leakage is a function of the type of penstock gate, type of turbine wicket gate, number of turbines, and head on the turbine. The actual leakage through a turbine may be measured at the time of acceptance and during annual maintenance inspections, or the measurements of similar existing projects may be used to estimate leakage for a proposed project. An estimate of the percent of time that a unit will be closed may be obtained from actual operational records for existing units in the same demand area. The measured or estimated leakage rate is then reduced by multiplying by the proportion of time the unit will be closed. For example, suppose that leakage through a turbine has been measured at 0.1 m^3/s, and the operation records indicate that the unit is closed 60 percent of the time. The average leakage rate would be estimated at 0.1×0.6 or 0.06 m^3/s.

(5) The inclusion of a navigation lock at a dam requires that locking operations and leakages through the lock be considered. The leakage is dependent upon the lift or head, the type and size of lock, and the type of gates and seals. Again, estimates can be made from observed leakage at similar structures. Water required for locking operations should also be deducted from water available at the dam site. These demands can be computed by multiplying the volume of water required for a single locking operation

times the number of operations anticipated in a given time period and converting the product to a flow rate over the given period.

(6) Water use for purposes related to project operations is often treated as a loss. Station use for sanitary and drinking purposes, cooling water for generators, and water for condensing operations have been estimated to be about 0.06 m^3/s per turbine at some stations in the southwestern United States. Examining operation records for comparable projects in a given study area may also be useful in estimating these losses. If house units are included in a project to supply the project's power requirements, data should be obtained from the designer in order to estimate water used by the units.

(7) The competitive use of water should also be considered when evaluating reservoir losses. When initially estimating yield rates for various project purposes at a multiple-purpose project, competitive uses of water are often treated as losses. For example, consider a proposed project on a stream with an average minimum usable flow of 16 m^3/s. The reservoir of this project is to supply 1.5 m^3/s by pipeline for downstream water supply and 2.0 m^3/s for a fish hatchery in addition to providing for hydroelectric power production. The minimum average flow available for power generation is thus, 16 - (1.5 + 2.0) = 12.5 m^3/s. Care should be exercised in accounting for all such competitive uses when making preliminary yield estimates.

f. Missing data.

(1) After recorded flows are converted to uniform conditions, flows for missing periods of record at each pertinent location should be estimated by correlation with recorded flows at other locations in the region. Usually, only one other location is used, and linear correlation of flow logarithms is used. It is more satisfactory, however, to use all other locations in the region that can contribute independent information on the missing data. Although this would require a large amount of computation, the computer program HEC-4 *Monthly Streamflow Simulation* accomplishes this for monthly streamflow (HEC 1971).

(2) Flow estimates for ungauged locations can be estimated satisfactorily on a flow per basin area basis in some cases, particularly where a gauge exists on the same stream. In most cases, however, it is necessary to correlate mean flow logarithms (and sometimes standard deviation of flow logarithms) with logarithms of drainage area size, logarithm of normal seasonal precipitation, and other basin characteristics. Correlation procedures and suggested basin characteristics are described in Chapter 9 of EM 1110-2-1415.

g. Preproject conditions. After project flows for a specified condition of upstream development are obtained for all pertinent locations and periods, they must be converted to preproject (nonproject) conditions. Nonproject conditions are those that would prevail during the lifetime of the proposed project if the project was not constructed. This conversion is made by subtracting projected upstream diversions and storage changes and by accounting for evaporation, return flows, differences in channel infiltration, and timing. Where nonproject conditions will vary during the project lifetime, it is necessary to convert to two or more sets of conditions, such as those at the start and end of the proposed project life. Separate operation studies would then be made for each condition. This conversion to future conditions can be made simultaneously with project operation studies, but a separate evaluation of nonproject flows is usually required for economic evaluation of the project.

5-5. Simulation of Streamflow Data

a. Introduction. The term "simulation" has been used to refer to both the estimation of historic sequences and the assessment of probable future sequences of streamflow. The former reference concerns the application of continuous precipitation-runoff models to simulate streamflow based on meteorologic input such as rainfall and temperature. The latter reference concerns the application of stochastic (probabilistic) models that employ Monte Carlo simulation methods to estimate the probable occurrence of future streamflow sequences. Assessment of the probable reliability of water resource systems can be made given the assessment of probable future sequences of flow. Statistical methods used in stochastic models can also be employed to augment observed historic data by filling in or extending observed streamflow records.

b. Historic sequences from continuous precipitation-runoff models. Many different types of continuous simulation runoff models have been used to estimate the historic sequence of streamflow that would occur from observed precipitation and other meteorologic variables. Among the most prominent are the various forms of the Stanford Watershed Model (Mays and Tung 1992) and the SSARR Model used by the North Pacific Division (USACE 1991). For a further description of the application of the models see EM 1110-2-1417 Section 8.

c. Stochastic streamflow models. Stochastic streamflow models are used to assess the probable sequence of future flows. As with any model, a model structure is assumed, parameters are estimated from observed data, and the model is used for prediction (Salas et al. 1980). Typically, stochastic streamflow models are used to simulate annual and/or monthly streamflow volumes. Stochastic streamflow models have not been successfully developed for daily streamflow.

(1) Although many different structures have been proposed in the research literature, regression is most commonly used as the basis for stochastic streamflow models. The regressions involve both correlation between flows at different sites and the correlation between current and past flow periods, termed serial correlation. The correlation between sites is useful in improving parameters estimates from regional information. The serial correlation between periods is important in modeling the persistence, or the tendency for high flow or drought periods. A random error component is added to the regression to provide a probabilistic component to the model.

(2) The model parameters are estimated to preserve the correlation structure observed in the observed data. If the appropriate correlation structure is preserved, then the regression residuals should closely approximate the behavior that would be expected from a random error component.

(3) Model prediction is performed via the application of Monte Carlo simulation. Monte Carlo simulation is a numerical integration technique. This numerical technique is necessary because the stochastic model effectively represents a complex joint probability distribution of streamflows in time and space that cannot be evaluated analytically. The simulation is performed by producing random sequences of flows via a computer algorithm that employs random number generators. These sequences of flows are analyzed to assess supply characteristics, for example the probability for a certain magnitude or duration of drought. The number of flow sequences generated is sufficient when the estimated probabilities do not change significantly with the number of simulations. For further explanation of this point, see "Stochastic Analysis of Drought Phenomena" (HEC 1985b).

d. Assessment of reliability with stochastic streamflow models. The advantage of using a stochastic streamflow model over that of employing only historic records is that it can be used to provide a probabilistic estimate of a water resource system's reliability. For example, the probability that a particular reservoir will be able to meet certain goals can be estimated by simulating the stochastic flow sequences with a reservoir simulation model. Once again, the number of flow sequences used are sufficient when the estimate of the probabilities stabilize.

e. Available software for stochastic streamflow simulation. HEC-4, "Monthly Streamflow Simulation" (HEC 1971), and LAST (Lane 1990) are public domain software for performing stochastic streamflow simulation. HEC-4 performs monthly stochastic streamflow simulation. LAST utilizes a more modern approach where annual and shorter time period (seasonal, monthly, etc.) stochastic streamflow can be co-simulated.

f. Extending and filling in historic records. Statistical techniques can be used to augment existing historic records by either "filling in" missing flow values or extending the observed record at a gauge based on observations at other gauges. The statistical techniques used are referred to as MOVE, maintenance of variance extension, and are a modification of regression based techniques (Alley and Burns 1983, and Salas 1992). MOVE algorithms have been instituted because the variance of series augmented by regression alone is underestimated. The MOVE technology is only generally applicable when serial correlation does not exist in the streamflow records. However, monthly or annual sequences of streamflow volumes usually do exhibit a degree of serial correlation. In these circumstances, the information provided by the longer record station may not be useful in extending a shorter record station. For a discussion of the impact of serial correlation see Matalas and Langbein (1962) and Tasker (1983).