Chapter 10
Multisubbasin Modeling

10-1. General

a. The foregoing chapters have described the various components of the watershed-runoff process. This chapter describes how these components are combined into a river basin model, as shown in Figure 10-1. The components can be thought of as building blocks for a comprehensive river basin analysis model or detailed pieces of a smaller watershed model. Those components may include small, component watersheds (subbasins) which are integral pieces of the larger basin; river reaches which connect the subbasins; confluences of rivers; lakes; and various man-made features. There are many man-made features in a river basin which affect the rate and volume of runoff. Some of the main features are reservoirs, urbanization, diversions, channel improvements, levees, and pumps. The multisubbasin model refers to the collection of all these natural and man-made components which describe the runoff process in a river basin.

b. This chapter describes the components of a river basin and provides criteria for subdividing basins into these components. Once the river basin model is built, it too must be calibrated and verified. Even though each of these components may have been individually calibrated as described in the previous chapters, the whole model must also be calibrated. The synergistic effect of all the components acting together may produce different results than their individual calibrations. This can be due to the spatial variation in precipitation and runoff, and/or nonlinearities in the river routing process. Thus, methods for calibrating and verifying a river basin model are also provided here.

10-2. General Considerations for Selecting Basin Components

a. General considerations for selecting the size and location of basin components are discussed in this paragraph. More detailed hydrologic, hydraulic, and project engineering and management criteria for sizing and locating basin components are given in paragraph 10-3. There are three general considerations for selecting and sizing basin components: where is information needed; where

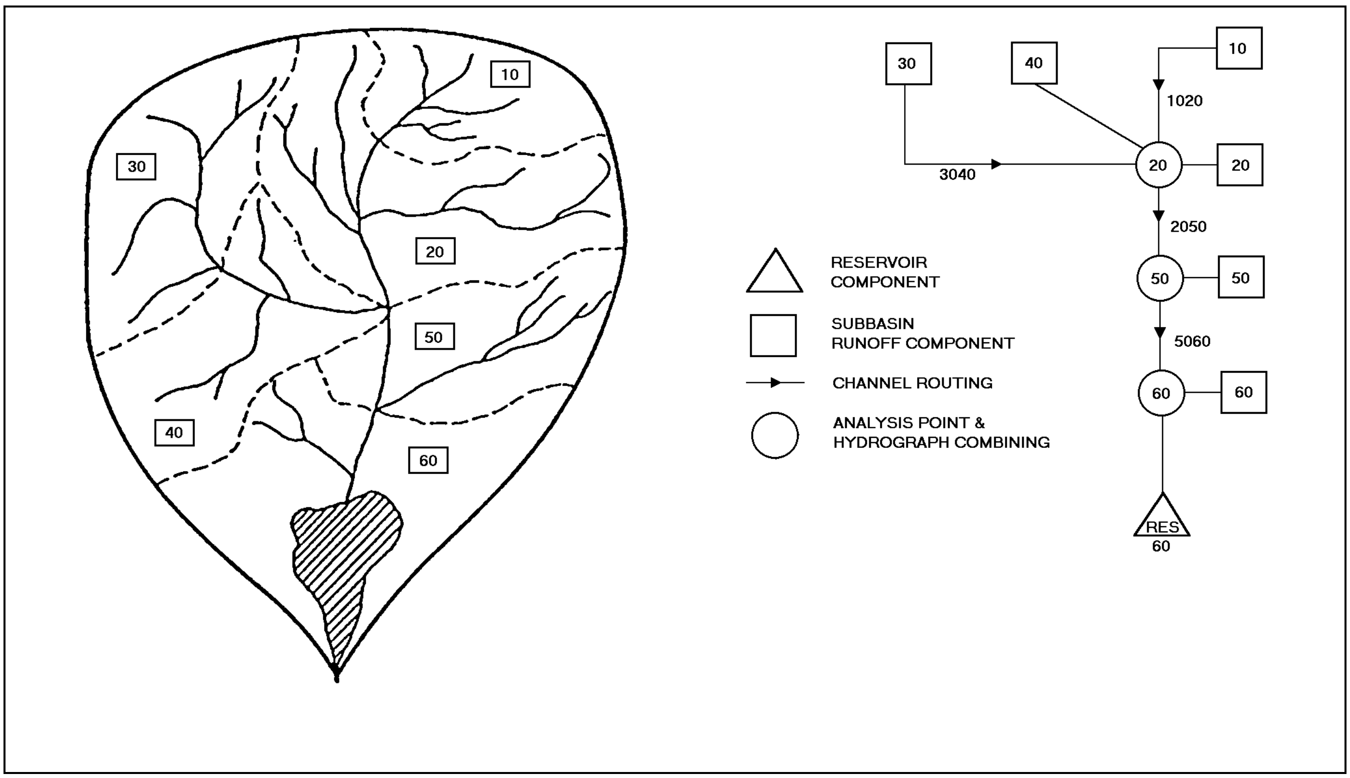

Figure 10-1. Components of a river basin model

are data available; and where do hydrologic/hydraulic conditions change?

b. The first consideration addresses why the analysis is being made. It includes input from all study team members such as economists, engineers, and environmentalists. Typical places where information is needed are locations subject to flood damage, sites where projects are proposed, wetlands, and archeological sites. The entire study team should be involved in identifying these information needs.

c. The second consideration addresses how much information one has to perform the analysis. Data availability is key to successful modeling. Thus, the basin model must be structured to take advantage of available data. Some of the primary types of information which influence basin subdivision are stream gauges, precipitation gauges, river-geometry surveys, and previous studies. By subdividing a river basin at these data locations, the model can be calibrated much more easily.

d. The third consideration addresses where hydrologic and hydraulic processes change so that they can be adequately represented by the basin components. Hydrologic modeling assumes that uniform conditions prevail within each of the basin components. The term “lumped parameter” refers to that condition where the same process is assumed to occur equally over the entire component. Some examples are a watershed with a mixture of urban and rural areas and a river which goes from a narrow canyon into a broad floodplain. One cannot assume that the same hydrologic or hydraulic parameters can describe the runoff process in areas where the physical processes are quite variable. One of the keys to successful hydrologic modeling is to select basin components which are “representative” of the heterogeneous processes of nature.

10-3. Selection of Hydrograph Computation Locations

Subbasins, channel reaches, and confluences are the general locations where hydrographs are computed. Subbasins are usually part of all the other basin component decisions. That is, whenever a computational point is identified in a basin, the local tributary watershed runoff is also computed at that point. For example, the land surface runoff characteristics of a basin may be constant, but the river hydraulic characteristics may change in the middle of that basin. In that case, two subbasins for land surface runoff may be used so that the upstream runoff can be added to the hydrograph before routing through the downstream reach. Too large a subbasin may “average out” important watershed and river dynamics. Too small a subbasin increases data handling and processing expenses.

a. Hydrologic criteria. Variation in precipitation and infiltration are two important hydrologic criteria. A detailed explanation of both criteria follows.

(1) Precipitation variation. The subbasin runoff computation process involves determination of subbasin-average precipitation and infiltration, then transformation of the resulting moisture excess into streamflow at the outlet of the subbasin. Thus, subbasins should be sized to capture variations in precipitation and infiltration. It would be desirable to have a recording precipitation gauge in every subbasin, but usually there are many more subbasins needed than there are precipitation gauges. The main consideration must be that there are enough subbasins to capture the spatial variation in precipitation.

(2) Infiltration variation. Infiltration characteristics of the land surface are a major part of subbasin selection. The desire is to have a subbasin with uniform infiltration characteristics. Thus, forested areas should be separated from grasslands, urban from rural, agricultural from natural, etc. Different soil types also have different infiltration characteristics. The general consideration is land use. Where land use changes, infiltration characteristics change. The problem is that watersheds are not made up of uniform land uses. The objective is to select areas which are “representative” of a particular infiltration condition. This average infiltration consideration becomes especially difficult in urban areas which are inherently a mixture of many land uses. The basic concept is the same: subdivide the watershed into like-watershed responses. The urban case requires consideration of additional features such as:

(a) presence of storm drains,

(b) roof downspouts directly connected to the street,

(c) large parks or shopping centers, and

(d) local drainage requirements.

Oftentimes these conditions will change with different land developers and city/county ordinances. In the urban case, it is often desirable to compute runoff from pervious and impervious areas separately within the same subbasin.

This procedure allows infiltration characteristics to vary, capturing the two main land-use characteristics in an urban subbasin.

(3) Runoff variation. The land-use condition also determines the rate of runoff. Land slope is also a major factor determining the rate of runoff. These land-use and slope conditions are represented by different unit hydrograph or kinematic wave land surface runoff parameters. Because only one set of parameters may be specified for a subbasin, it is important to have them "representative" of the average subbasin characteristics. Ideally, a subbasin would have similar land use, soils, slope, and stream-network patterns. Urbanization obviously can make drastic changes to the runoff network.

b. Hydraulic criteria. Natural channel variation and man-made variations are two important hydraulic criteria. A detailed explanation of both criteria follows.

(1) Natural channel variation. Hydraulic criteria refer to where the river or stream channel changes in a significant enough manner to affect the routing processes. Examples of these hydraulic controls are constrictions in the channel, major changes in the slope of the channel, broadening of the channel into a floodplain, and confluence with tributaries. Because only a single routing method can be used in a single river reach, that reach should have reasonably uniform hydraulic characteristics. Tributaries are important because many of the river routing processes are nonlinear and depend upon the magnitude of the flow. Thus, where tributaries increase the flow significantly, separate routing reaches should be incorporated upstream and downstream of the tributary.

(2) Man-made variations. Manmade structures and modifications of the river channels usually have a major impact on the flow routing process. Examples of man-made features are bridges, floodplain encroachments, diversions, pumps, dams, weirs, culverts, levees and floodwalls, and channel clearing and cleaning. All of these changes to the natural river system usually have a major impact on the routing process; and thus, channels where these variations occur should be modeled separately.

c. Information needs criteria. Information needs are dependent on the purpose of the project. If flood damage reduction is a project purpose, then flood damage locations (cities, towns, industrial sites, etc.) must be included as a hydrograph computation point. Such points do not enhance the hydrologic/hydraulic computations, but they are necessary to provide the flow and stage information for computing flood damage. The same is true for any other project purpose which depends on river flow/stage for its evaluation.

d. Data availability criteria. Data are necessary to calibrate the river basin model to observed historical events. Data are usually insufficient, so every gauge location must be carefully reviewed and used to the fullest extent possible. Stage or flow gauging stations are the most important for determining hydrograph computation points.

(1) A subbasin/river reach break point will usually be made at every stream gauge so that the computed hydrograph can be compared with the observed hydrograph at that location.

(2) Sometimes special river basin subdivisions will be made differently than the general river basin model to make use of the data for calibration of subbasin runoff parameters. That is, the total area contributing to a gauge may be used as a single subbasin for the purposes of calibrating watershed runoff parameters to different sized basin areas. Those special, large basins are only used for the subbasin parameter calibration and regionalization needs; those large subbasins are disaggregated back into their logical components for the generalized river basin model.

e. General criteria.

(1) These considerations must also take into account the practical engineering economy of the analysis and the purpose for which the study is being made. There is always a tradeoff between a detailed representation of a river basin and the practical information needs and resources available for the study. For instance, the surcharging of a culvert may be critical to local information needs in an urban area, but it may have very little effect on the peak discharge farther downstream in a large river basin. Thus, the watershed modeler's job is to weigh these information needs against the watershed and river dynamics to obtain a representation of the basin which provides the needed information within a reasonable cost and time.

(2) The river basin modeler should be careful to include all major components in the river basin model. That is, do not lump together too large of an area just because data are not available for a particular area of the river basin. A logical physical network of subbasins and river reaches should still be maintained even though data are not available. One example is to treat major

tributaries as separate components rather than lump them in with the local tributary area of the main river. Building a logical basin model will help identify where additional data are needed, and then it will be ready to include the data when available.

10-4. Calibration of Individual Components

The first step in the calibration of the river basin model is the calibration of the individual components where observed precipitation runoff data are available; such as, calibration of the subbasin infiltration, runoff transformation, base-flow parameters, and calibration of the river reach flood routing parameters, as described in the preceding chapters. Obviously, not all of the subbasins and routing reaches in the river basin will have gauged events for this calibration. Thus, it is common to take calibration results from gauged basins and regionalize that data for use in ungauged areas. The regionalization process relates the best estimate of the parameters from the gauged locations to readily measurable basin characteristics. That relationship (usually a regression equation) is then used in the ungauged area where the same basin characteristics can be measured and the relation used to estimate the parameters. The ungauged area analysis and regionalization process are described in Chapter 16. In performing regional analysis, it is imperative to have the parameters make good physical sense and not to use the regional equations outside the range of the data from which they were derived.

10-5. Calibration of Multisubbasin Model

The river basin model must be calibrated as a whole because the individual runoff and routing processes were calibrated for the gauged subbasins only. Also, the nonlinearities of the runoff and routing processes will cause differences from the individual component calibrations. The river basin model is calibrated using the observed precipitation data and streamflow measurements at all locations in the basin. The primary points of comparison are at gauges on the main stem of the river. Several subbasins, routing reaches, and confluences will undoubtedly have been used to compute a hydrograph at the gauge location. Several considerations and methods are necessary to calibrate the basin model. The timing, magnitude, and volume of the hydrograph must be calibrated. Sometimes one or the other is more important depending on the purpose of the study; e.g., peak flow is important for channel design, and volume is important for reservoir analysis.

a. Analysis of components. There are several components of the multisubbasin model. A detailed analysis of these components follows.

(1) General. The total flow at a gauge location is the result of several upstream processes. Sometimes the individual upstream components of the basin are routed to the gauge location to compare their relative contribution to the total hydrograph. Caution must be exercised to be sure that nonlinearities in the upstream routing processes do not adversely affect the component parts when routed individually. The component parts should be evaluated for timing, magnitude, and volume with respect to the observed hydrograph. Any inconsistent results should be traced back to their origin. The source of the problem may be in a precipitation gauge, runoff conversion processes, or the routing. At this point, it is hydrologic detective work to determine and resolve the sources of inconsistencies. Do not be too quick to blame poor results on data; check the river basin model formulation first, and be sure that the tributary drainage area is correct.

(2) Analysis of volume errors. Volume errors are the result of incorrect precipitation, detention and retention storage, and infiltration calculations. Check basin average precipitation assumptions with other gauges in the area. Check the infiltration method assumptions for the ungauged portions of the tributary basin.

(3) Analysis of timing errors. Timing errors can be the result of almost every part of the precipitation-runoff process. The precipitation and infiltration rates and patterns can cause differences in timing. More commonly, the unit hydrograph or kinematic wave land surface runoff and channel routing parameters are reviewed first. The channel routing parameter sensitivity can be easily analyzed by looking at the routed components separately. Always compare physically based estimates of travel times with the model results.

(4) Analysis of magnitude errors. Errors in peak flow can be caused by inaccurate precipitation intensities, incorrect subbasin runoff parameters, incorrect timing of tributaries, or the wrong amount of attenuation in the channel routing reaches. Precipitation distributions should be reviewed to ensure that periods of high intensity have not been averaged out by weighing the measurements of more than one recording gauge. Unit hydrograph and kinematic wave parameters should be checked with

respect to physical characteristics of the basin. Routing reaches should be reviewed for unreasonable amounts of attenuation.

b. Consistency checks. In performing the analyses of components, it is easy to independently change the individual parameters to obtain the desired result. But, such change should not be made without maintaining consistency with respect to all like land uses, soils, channels, etc. throughout the river basin. For example, if the infiltration rate is changed in one subbasin to improve the fit with the observed flows, then a corresponding change must be made in all subbasins with the same or similar land use and soil types. Consistency in runoff and routing parameters must be maintained throughout the entire river basin. Oftentimes a compromise is reached where the change helps in one location but increases the error in another location.

10-6. Verification of the Multisubbasin Model

Verification is the name of a procedure for independent checking of the parameters selected for the basin components, that is, checking the performance of the model with data not used in calibration. Independent checks of the parameters can also be made with simple measures of the physical process.

a. Other storm runoff data not used in calibration. Reserving some data for verification analysis only is always hard to do because there never seem to be enough data for adequate calibration. Good verification results give high credibility to the model and, thus, should be performed if at all possible. Floods selected for verification should be of the size and type for which the project is being designed. If the verification results are not good, then further calibration of the model must be made using the verification flood event in addition to the previous calibration data. Any changes in the parameters must be justified with respect to all storms and the physics of the process.

b. Physics of the runoff process. The physics of the runoff and routing processes are often used to help with the calibration of the basin components. They are equally helpful in checking the river basin model results. Approximate travel times in subbasin and routing reaches can be calculated by Manning's equation. Saturated soil infiltration rates can be checked with modeled losses. Runoff per unit area (e.g., cfs per square mile) can be calculated for various points in the basin and checked for consistency with respect to precipitation. Volume checks can be made to verify overall continuity of moisture input, outflows, and water still in the system. Each one of these measures helps build confidence in the model's representation of the basin and helps gain insight into the hydrologic and hydraulic processes of the basin.