Chapter 14
Period-of-Record Analysis

14-1. General

Period-of-record analysis is seeing increasing interest and usage due to the continuing decrease in the costs of computer processing and the increased availability of hydrologic models with continuous simulation capability. As used in this document for flood-runoff analysis, period-of-record analysis refers to applying a precipitation-runoff model to simulate a continuous period of record of streamflow, including the detailed simulation of flood events. This method requires a relatively sophisticated hydrologic model capable of simulating throughout the hydrologic cycle; it implies a more complete model calibration effort; and, it requires extensive data and data processing. Because of these factors, it is not an inexpensive approach to flood-runoff analysis and therefore not an economical application in many situations. However, certain engineering applications, e.g., the detailed evaluation of the effects of urbanization in a basin, are readily suited to this type of analysis.

14-2. Simulation Requirements

Because period-of-record analysis requires the continuous and detailed simulation of stream flow from precipitation, additional modeling requirements are required beyond those normally associated with the simulation of discrete storm events. Previous chapters in Part II of this manual have described the processes associated with individual flood analysis, including precipitation/runoff transformation and routing techniques. These techniques are also applicable to continuous simulation. Beyond these, however, are several additional factors that must be treated in a continuous modelling effort, summarized as follows:

a. Evapotranspiration.

b. Lake and reservoir evaporation.

c. Long-term subsurface simulation.

d. Distributed watershed formulation.

e. Interception.

f. Data processing requirements.

These factors were described in detail in Chapter 8.

14-3. Model Calibration

The process of deriving characteristics, equation constants, weighting factors, and other parameters that serve to define the model for a particular watershed is termed “calibration.” (Strictly speaking, “calibration” is distinguished from “verification,” as described below.) In continuous simulation, the calibration process is generally more rigorous and complex than is model development for discrete storm analysis, in that more parameters are usually involved in a continuous model; a much greater amount of hydrometeorological data is involved; the fitting of the model requires a greater number of hydrologic factors (i.e., short- and long-term volumes, year-to-year carryover of volume, low-flow streamflow reproduction--as well as peak flow and flood-runoff timing); and more rigorous statistical procedures are usually employed to ensure that an unbiased fitting of the model is achieved.

a. Calibration process. The following is an outline of the steps typically followed in calibrating a continuous simulation model.

(1) Data development. The data base development for the model can be a time-consuming process, requiring careful attention. Although digital sources now exist for easy downloading of streamflow, precipitation, temperature, and snow data, these sources may not include an adequate frequency of observations. For example, a small basin may require hourly observations, for satisfactory simulation, that are not readily available from common data sources. Calibration of a continuous simulation model typically employs from 5 to 30 or more years of continuous records, so the data processing task is relatively large if a frequent timestep is required. The presence of poor quality data can be a problem. Prechecking the data by such techniques as graphics display or by double-mass curve analysis and other station cross-checking procedures is desirable. The use of a data management system such as HECDSS is useful in this regard.

(2) Station selection. The choice of which precipitation and temperature stations best represent the basin-wide meteorological input might take several iterations through the entire calibration process. However, reasonably appropriate choices can be made prior to calibration through intuitive inspection of station location and characteristics, use of normal annual isohyetal maps, simple correlations of precipitation with runoff, etc.

(3) Initial model parameters. The initial choice of model parameters is not a critical concern since adjustments will be made during calibration. However, those parameters that have physical relevance should be determined to reduce the possibilities for future adjustment as the calibration proceeds. Table 14-1 lists the model parameters that are typically encountered in continuous simulation models and indicates those factors that can be determined by independent analysis. For other parameters that need to be empirically determined, the initial value might be based upon known factors in previous simulation studies, by examples given in user manuals, or by default values in the computer program.

(4) Water balance. A desirable, if not essential, part of the calibration process is to make an independent estimate of the basin's water balance. This calculation would yield annual, or perhaps monthly, estimates of basin precipitation, evapotranspiration, and soil moisture that can be helpful in calibrating the model.

(5) Parameter adjustment. Trial simulation runs are made and model output is compared with observed streamflow and runoff data as described in paragraph 13-3. Based upon those comparisons, parameter adjustments are then made to improve the fit of the model. This process requires an experienced and knowledgeable person, both in the use of the model and understanding basic hydrologic principles. Adjustments are made first to those factors which have the greatest impact on the model fit, then proceeding to variables with lesser sensitivity. The process may be expressed as three basic steps (each having several trials) as follows:

(a) Achieve fit of runoff volumes throughout the year (monthly water balance). This process primarily involves adjustment of precipitation weighting, loss-rate functions, and evapotranspiration factors. Calibration fit is usually judged by comparing monthly and annual runoff volumes.

(b) Develop hydrograph shape. This step involves working with runoff distribution and routing factors, particularly in the lower-zone components. If snow is a factor, then temperature and snow accumulation/ablation factors may need to be adjusted.

(c) Refine hydrograph fit. This final step involves working with surface runoff factors and other parameters to refine the hydrograph shape.

(6) Table 14-1 describes this priority order in more detail and gives relative sensitivity of the variables. Most of the parameters in a continuous simulation model represent a physical process. It is imperative that parameter values remain physically reasonable throughout the calibration process to keep the fit from being a local optimization that will not work when extrapolated to new data. The verification step described below is highly desirable to ensure that the fit is a general solution, not one unique only to the calibration data used.

b. Calibration comparison tools. Continuous simulation models use and create an immense amount of data, particularly if a long period of record is involved. Judging the fit of the final streamflow output alone is difficult, but reviewing the intermediate output such as soil moisture levels, snow pack, and runoff component hydrographs, makes the task more difficult. Accordingly, it is almost mandatory that special techniques be employed to facilitate comparisons of calibration runs and make model adjustments. These techniques are preferably built into the computer program being utilized. The following are examples of tools that are typically employed:

(1) Tabular summaries:

(a) Monthly and annual volume summaries in units of runoff volume and in inches.

(b) Summary tabulations of model internal computations.

(2) Graphical displays:

(a) Hydrographs of observed and computed streamflow.

(b) Hydrographs of model internal component output (e.g., soil moisture, subsurface flow).

(c) Flow-duration curves, observed and computed streamflow.

(d) Scatter-plots, monthly runoff volumes.

(e) Period residuals (observed - computed flow) or accumulated errors versus time.

(3) Statistical calculations:

(a) Statistical summaries of monthly volumes.

(b) Root-mean square error of period deviations (computed minus observed).

Table 14-1
Model Calibration - Parameter Sensitivity

Parameter	Relative Sensitivity	Major Effects	Principal Calib. Tool	Calibration Priority	Independent Evaluation	Physical Attribute/ Connection
Precipitation/Temperature						
Precipitation station weight	H	V	X	1	X	Thiessen Polygon/NAP Map
Temperature station adjustment	M	S		2	X	Station data/observed flows
Elevation-distribution of precipitation	M	V		2	X	NAP Map
Evapotranspiration function	M	V		1	X	Observed evap.; empirical formulas
Intercept function	L	V		1	X	Maps (vegetation cover)
Lapse rate	M	S		2	X	Theoretical, observed temperature
Snow						
Melt-rate factor change	M	S	X	2		
Snow conditioning	L	S		3	X	Theoretical, observed equations
Runoff Distribution						
Precipitation excess function	H	V	X	1		Soil maps, observed flows
Lowest zone distribution	L	S		1		
Base flow distribution	H	S	X	2		
Subsurface/surface distribution	M	S		2		
Routing Function						
Lowest zone	L	S		2		
Baseflow	M	S	X	2		
Subsurface flow	H	S	X	3		
Surface flow	H	S	X	3		
Initial Conditions						
Snow water equivalent	L	V		1	X	Snowpack readings
Snow condition	L	S		1	X	Snowpack readings
Soil moisture	L	S		1	X	Observed flows, observed precip.
Base flow	L	S		1	X	Observed flows
Surface flow	L	S		1	X	Observed flows
Legend:	L=Low M=Medium H=High	V=Volume S=Hydrog shape		1=Water balance 2=Hydrog shape 3=Refined fit		

COMMENTS

- "Relative Sensitivity" indicates degree to which parameter affects model output.
- "Major Effects" indicates which aspect of the output is primarily affected.
- "Principle Calibration Tool" indicates which parameters are usually adjusted to achieve first-cut calibration.
- "Calibration Priority" suggests the order in which parameters are typically adjusted.
- "Independent Evaluation" indicates those parameters that are typically determined independent of the calibration process, because they are more physically based. Adjustments may be required, however, in fine-tuning the model.

c. Verification. After calibration of the model is complete, it is good practice to then simulate an independent period of record and compare the results with observed data. This procedure will help to ensure that the calibration is not unique and limited to the data set employed for calibration.

14-4. Applications

It is important in approaching a possible application of period-of-record analysis to be certain that it is a necessary and appropriate approach to solving the problem, since the commitment of time and resources is relatively high. On the other hand, this type of analysis is available as a potentially powerful tool in hydrologic analysis and forecasting for types of applications that may not be obvious. To assist in the decision-making on applications, and for providing references if similar studies are undertaken, the following actual and potential applications are described:

a. Extension of streamflow records. In situations where weather records in a basin have a longer period of record than streamflow stations, continuous simulation would be a logical method of extending a record of streamflow, particularly if a continuous flow record is desired (as opposed to, say, just peak flows). The model used would be calibrated and verified on the observed data and extended as meteorological data permit.

b. Derivation of ungauged streamflow records. This application is quite feasible and has been utilized in the profession. Since the effort involved is not small, it is likely that it would not be used in ordinary planning investigations but might be appropriate for special situations, e.g., cases with legal or controversial ramifications. The method relies on the fact that most likely adjacent basins will have similar subterranean characteristics, so that if a detailed simulation model is developed on a basin with streamflow data, subsurface and groundwater characteristics can be transferred to the ungauged basin with a relatively high degree of confidence. Surface characteristics also can be based upon the gauged basin but are likely to be modified as necessary by observable factors such as slope, terrain, etc.

c. Analysis of basin modifications. The assessment of urbanization effects and other changes in the physical characteristics of a river basin are quite well suited to period-of-record analysis with a continuous simulation model. The model can be calibrated by relating observed physical conditions (past records might likely exist reflecting either no development or partial development) to observed hydrometeorological data. Then, the period of record of hydrometeorological data can be simulated utilizing the observed or forecasted physical conditions to be evaluated. The resulting flows will be a large sample of data for statistical representation, reflecting a consistent level of basin development. The model used in this type of analysis would have to be capable of representing the physical changes involved; i.e., increase in impervious area, changes in runoff response, etc.

d. Interior runoff analysis. A stochastic analysis may be required in the planning and design of interior drainage facilities for leveed areas, particularly when the relative timing and magnitude of the main river and the interior runoff are important in determining the economics of the project. Although the main river would likely have an adequate record of streamflow data, most interior drainage areas do not. By using continuous simulation, the rainfall-runoff calculation required for the interior area can be performed and conveniently joined with the main channel streamflow, which would either be derived by the rain-runoff model or based upon observed streamflow data.

e. Long-term runoff forecasting. Continuous simulation has been used to produce long-term forecasts of streamflow for operational purposes. In a technique called “extended streamflow prediction” (ESP), the NWS and others have combined period-of-record weather records for a given future period of up to several months with current basin hydrologic conditions to produce a statistical representation of future conditions. The procedure is best suited for the Western interior river basins with large winter snowpacks, where a snowpack in January plays a relatively large role in determining runoff in May and June. The statistical analysis produced by the period-of-record simulation reflects the variations in subsequent precipitation and temperature combined with the current snow conditions. Successive forecasts made as springtime approaches have less and less variance.