Section 7-1

Calibration of Initial Headwater Area

<u>Selection Criteria</u>

The following criteria, not in any particular order, should be used for selecting the initial headwater area to calibrate within a river basin:

- The period of observed streamflow data should be as long as possible, ideally covering most or all of the period of record used for the historical data analysis. This long period is needed for two reasons. First, besides needing a period to calibrate the models at the location, it is also important to have some independent periods to validate the results. Second, many times it is helpful to make comparisons between calibrations at other locations within the basin and the initial headwater area and since the streamflow data for the other locations may have varying periods of record, the initial headwater point needs a long record to insure that there are overlaps with the other sites.

- The physical characteristics of the drainage area should have been basically stable over time, i.e. no substantial land use, vegetation cover, or agricultural changes and the streamflow data should be consistent. In addition, the initial headwater should be physiographically representative of the total river basin, or at least the portions of the basin that produce significant runoff.

- The networks used to estimate the model input variables, especially precipitation, should have good coverage. Noise in the input data, especially precipitation, makes it more difficult to determine the proper parameter values, thus the mean areal inputs need to have a minimal amount of random error.

- If there is a wide variation in the amount of annual runoff over the river basin, especially if there are drainages with small amounts of runoff, the initial headwater area should be a drainage with average to above average runoff relative to the other parts of the river basin.

- There should be minimal complications. There should be no significant reservoirs or large lakes that dampen out the hydrograph response. Diversions, if any, should be small and should have observed data that can be used to adjust the streamflow to natural conditions. The amount of irrigated acreage should have little, if any, effect on flow. There shouldn't be any power plants or other controls that cause substantial noise at low flows. Glacier contribution to runoff should be avoided if possible.

Using these criteria, all of the headwater gages within the river basin should be evaluated and the one that comes the closest to meeting the criteria should be used as the initial area for calibration.

Periods of Record

As mentioned in Chapter 7, besides calibrating the models for the initial headwater area, a validation should be done on a separate period of the record at that location. If a careful validation is done on the initial headwater, it is probably not necessary to run separate validations at the other locations within the river basin. Guidelines for selecting the period to use for calibration are as follows:

- The calibration period should contain as much variety in hydrologic conditions as possible. There should be events with very high flows and there should be extended dry periods with very low flows. Ideally there should be significant runoff events at all times of the year and under different initial soil moisture conditions. There should be years with both much above and considerably below normal volumes of runoff. If snow is a factor, there should be years with both very large and abnormally small amounts of snow cover and ideally snowmelt periods at various times during the snow season. However, it is probably best to not include the flood of record, the minimum flow of record, or other extremes within the calibration period. It would be better to save these events and periods for validation so that you can see if the calibrated models can extrapolate beyond the conditions experienced during calibration.

- The calibration period typically needs to be about 10 years long, at least in the areas where lumped, conceptual models generally provide satisfactory results. Experience has shown that a period of about 10 years is needed in order to determine stable values of the model parameters. When the models are calibrated using shorter periods, the parameters are more likely to vary depending on the period used. In regions where lumped models give marginal results, the calibration period may need to be longer in order to get a sufficient number of events and variety of conditions to determine the parameter values. In regions where the results are typically unsatisfactory, even the full period of record is likely not going to be adequate for determining the parameters with any degree of certainty.

- If possible, it is a good idea to have the calibration period for the initial headwater overlap with periods when most of the other streamgages within the basin also have observed daily flow records. In this case the same period can be used at most locations for calibration and observed discharges will be available to adjust the instantaneous flows that are routed downstream.

The periods to use for validation should be as long as possible and, as mentioned above, ideally will contain some extreme events and situations to test the extrapolation capabilities of the calibrated models. Essentially the entire period with observed mean daily flow data, except for the calibration period, will be used for validation.

Initial Model Parameter Values

Initial parameter values for the snow and Sacramento models can be obtained in one of two ways for the initial headwater area.

- If an adjacent river basin has been already calibrated, the initial snow and Sacramento model parameters should be obtained from the headwater area within the previously calibrated basin that is the most hydrologically similar to the initial headwater in the current river basin. This nearby headwater should have good data, minimal complications, and its calibration results have met the objectives so that you are quite confident in the parameter values. In this case the strategy for calibrating this initial headwater will be the same as for other headwaters and locals with minimal complications within the river basin, i.e. only change those parameters that clearly need to be altered. By following this procedure parameter values should not only end up being consistent from one area to another within a river basin, but should show realistic variations across the entire RFC area.

- If no adjacent river basin has been previously calibrated or if there is a considerable difference in hydrologic conditions between this initial headwater area and any drainage that has been previously calibrated in the region, then the initial snow and Sacramento model parameters can be derived from available information. Guidelines and methods have been developed to derive initial parameter values by analyzing hydrographs and from physical or climatic information. Section 7-4 contains guidelines for determining initial parameter values for the SNOW-17 model. Section 7-5 describes techniques for deriving initial parameter values for the Sacramento model. Even if the initial parameters are obtained from a previously calibrated drainage, it is a good idea to read and understand the material in these sections. The information included should help in understanding the function of each parameter, assist in knowing how to isolate the effects of the parameters, and give some insight into a reasonable range of values.

Initial parameter values for the channel response model that is used to convert the runoff entering the channel system to a discharge hydrograph at the gaging location should always be determined directly for each drainage area. The channel network for each drainage is unique and the response function for one area should not be used for another. Section 7-6 discusses how the unit hydrograph technique is used in conjunction with the Sacramento model and methods for deriving an initial estimate of the unit hydrograph ordinates.

Calibration Strategy

Once initial parameters have been determined for each of the models, the next step is to adjust the parameter values so that the simulation results meet the calibration objectives. The calibration of a conceptual model by making interactive adjustments to model parameters is completely dependent on having the proper knowledge of the function and how to isolate the effects of each parameter. The function of each parameter is determined by understanding the structure of the model. Knowing the model structure will also help in understanding what conditions must exist in order to select the portions of the simulation results to examine to determine if changes should be made to the value of a given parameter. It is critical for a person to gain a reasonable understanding of how to isolate the effects of each model parameter if they are going become competen t at calibrating conceptual models. Without a reasonable proficiency in knowing the effects of each parameter on model response, interactive calibration becomes a very inefficient process with little probability of the user ever determining the proper parameter values. Without this knowledge the user would be better off using an automatic calibration method. Section 7-7 contains a discussion of how the major snow model parameters affect model response. Section 7-8 contains a similar discussion for the Sacramento model. An understanding of these 2 sections and the structure of each model is an absolute prerequisite to interactive calibration.

When using the interactive trial and error method of calibration, it is best to follow a proven strategy for determining which parameters need to be modified rather than just randomly looking at various portions of the record and making parameter changes. Even though a step by step strategy is outlined, it cannot be followed in a cookbook fashion. The steps give a general pattern to follow, but the user must remain somewhat flexible. Some general items to consider concerning calibration in general and in particular when using the recommended strategy are:

- Be reasonably bold when making parameter changes. Finding the proper value will take less time if the changes to parameter values are fairly large. If you overshoot, it is much easier to estimate your next trial value than if you only make a sight incremental change.

- Model parameter values are selected to produce the best results over a number of events or occurrences of a given situation and should not be assigned based on a single event. The random errors that occur for individual events during calibration can hopefully be minimized operationally by improved data estimates or run-time modifications to model computations.

- Remove large errors in parameter values whenever they are detected. The first step in the strategy involves removing large errors that exist at that point in the process, but during later steps significant errors in other parameters may become apparent. When these errors are causing enough noise in the simulation results that they make it difficult to determine the proper value of the parameters currently being worked on, the parameters causing this noise must be modified, at least to the degree that their effect is not interfering with the current step.

- One should periodically return to previous steps to recheck the results. Parameter changes in subsequent steps may necessitate adjustments, usually small, to parameters values determined during an earlier step.

- Remember to periodically check the statistics mentioned in chapter 7. These statistics help to identify trends in the simulation and assist in determining the periods, and possibly the parameters, to examine.

- Change the duration and scale of the ICP displays depending on which flow components and parameters are being examined. Long durations, typically one or two years, and a semi-log scale are used when working on low flow components and parameters, while shorter periods, generally in terms of months, and an arithmetic scale are used when examining storm events or snowmelt runoff periods.

The recommended strategy for calibrating an individual watershed is as follows:

1. Remove large errors. If certain initial parameters or some of the input data are considerably in error, there will be a large discrepancy between the simulated and observed hydrograph. These problems need to be corrected before proceeding in a more step by step fashion through the parameters. The amount of noise caused by these errors make it very difficult to isolate the effect of individual parameters and to determine which parameters need to be modified and by how much. The aim at this point is not to totally correct these errors, but to get the simulation results at least in the right ballpark.

Large timing errors should typically be corrected first, since they can also be a source of volume discrepancies. The most common large timing problems that exist at this point in the process are:

- Large error in the percolation rate for the Sacramento model such that there is way too much storm runoff and not nearly enough baseflow or vice versa. This problem can usually be corrected by changing the LZFSM and LZFPM parameters by the same ratio such that the PBASE term in the percolation equation is increased or decreased until the split between storm runoff and baseflow is more reasonable.

- Large error in the amount of surface runoff generated by the Sacramento model such that major storm events are way over or under simulated. This problem is generally corrected by changing the UZFWM parameter upwards or downwards.

- Improper channel response function is being used for the Sacramento model (see discussion in Section 7-6). This occurs when the unit hydrograph contains the timing effects of interflow, as well as surface runoff. This problem is corrected by removing interflow from the unit hydrograph being used.

There could also be large timing errors associated with snowmelt runoff, however, if the initial parameter guidelines are followed and the temperature data are reasonably unbiased, this should not be a problem. There could be timing problems with the snowmelt during the largest snow years due to the approach recommended for determining the SI snow model parameter, but this is to be expected at this point.

In general, for most watersheds the overall volume error should be no more than about 10%. For watersheds with small amounts of annual runoff, especially those with less than an average of 5 inches per year, the initial volume error may be greater. If the initial volume error is larger than expected, it is important to look carefully at the components of the water balance to determine if there is a problem that needs to be corrected before proceeding with the calibration. The most likely problems are biased precipitation or evaporation data or streamflow data that haven't been corrected for diversions or other gains or losses. In some cases the tension water capacities of the Sacramento model could be off so far that the ratios of conte nts to capacity remain too large or too small and thus result in an error in the amount of computed actual evaporation. This is most likely in a arid or semi-arid region. In some cases the problem is merely that the unit hydrograph ordinates do not represent the specified drainage area (this should result in a warning from the UNIT-HG operation if the correct drainage area was entered). Any significant volume errors need to be corrected before proceeding with the calibration.

In some regions, especially the northeastern United States, there may be frequent errors in determining the form of precipitation, i.e. rain versus snow. This not only affects the model response at the time of the precipitation event, but also will affect the volume of snow available for melt at a later date. The amount of noise in the simulated results caused by this problem will make it very difficult to determine appropriate parameter values. When this occurs, the data for individual events, typically temperature, need to be modified so that the form of precipitation is generally correct before proceeding with the calibration. Suggestions for how to correct the form of precipitation are included in Section 7-4 under the “Form of Precipitation” section.

2. Obtain a reasonable simulation of baseflow. In order to obtain the best results from the Sacramento model, it is important to properly calibrate all components of the model. At many forecast points one may be primarily interested in high flows, however, the structure of the model makes it impossible to maximize the ability to predict high flows when low flows are not reasonably modeled. Contrary to the thoughts of some people, the model doesn’t need multiple sets of parameters (e.g. one for simulating floods and another for extended predictions involving all flow levels). The simulation of the various flow components are all interconnected, thus the percolation of water into the lower zones and the computation of baseflow must be correct in order to get a good reproduction of storm runoff. A proper calibration should yield parameter values that will not only reasonably simulate low flows, but will also provide the best simulation of high flows.

Since many of the low flow parameters are involved in the percolation equation, it is necessary to concentrate on this part of the model first to obtain a good foundation before focusing on upper zone soil moisture and storm runoff. The aim of this step initially is not to finalize the parameters that control baseflow, but to get the simulated hydrograph to generally match the observed under low flow conditions. Then as the calibration proceeds, you will periodically return to this step and make refinements to the parameter values.

When working on getting a reasonable reproduction of low flows, it is best to start with primary baseflow. Section 7-5 discusses the importance of determining in advance which portions of the observed hydrograph are to be modeled with each of the available runoff components and that the identification of primary baseflow is critical to a successful simulation. That section also describes situations when it is difficult to isolate primary baseflow. The periods when primary baseflow is the only source of runoff or at least predominates are examined to determine if the LZPK and LZFPM parameters need to be modified. Next supplemental baseflow periods are examined to check the values of LZSK and LZFSM. Changes to all the se parameters will alter the PBASE term in the percolation equation and thus not only affect the amount of water going to the lower zone and baseflow, but also modifying the amount available for storm runoff. Thus, if the overall volume is in the right ballpark, the total volume of storm runoff should become more reasonable as the simulation of baseflow improves. Another parameter to examine at this point is PFREE. In some cases it may be necessary to make some crude adjustments to the shape of the percolation curve, i.e. parameters ZPERC and REXP, at this stage of the process, but the refinement of the shape of the percolation curve occurs in a later step.

When working on getting a reasonable reproduction of low flows, one should recognize whether there are periods when baseflow is drawn down due to evaporation from riparian vegetation or from irrigation withdrawals. Both of these causes of low flow draw down have a similar effect on the hydrograph. Knowledge of the basin is required to decide which is most likely the cause. Such periods should not be used when making adjustments to the main parameters that control low flow. After other low flow periods are being simulated in a reasonable fashion, one can then try various values of the RIVA parameter or introduce the Consumptive Use operation (CONS_USE) to see how well the draw down periods can be modeled. RIVA should then be set back to zero or the CONS_USE operation removed and these periods ignored until the final step.

3. Adjust major snow model parameters, if snow is included. Once the baseflow simulation is reasonably good, the major snow model parameters should be checked to determine if adjusments are needed to the volume and timing of snowmelt. The major snow model parameters are MFMAX, MFMIN, SCF, UADJ, SI, and the areal depletion curve. The minor snow model parameters generally should not need to be adjusted during calibration, but in a few cases modifications to these parameters may be necessary. It is most important to check the snow model parameters at this point in areas where snowmelt runoff is significant and especially when there is an extended melt season. If snowmelt events are infrequent and generally occur over a short period, it may be necessary to wait and adjust snow model parameters at the same time as the Sacramento model parameters that primarily affect storm runoff (step 5). If form of precipitation problems were not corrected in step 1 and it is now apparent that noise resulting from the mistyping of winter events is making it difficult to determine the proper parameter values, then the data should be corrected as described in Section 7-4. If mistyping of precipitation is infrequent and random, it should not be necessary to correct the data in order to determine the snow model parameter values.

If it is necessary to use snowmelt parameters (primarily MFMAX and MBASE) that are considerably different from those suggested in Section 7-4 or if snowmelt occurs consistently early or late in spite of the changes that are made to the parameters, it is quite likely that the temperature estimates are invalid. There may be other reasons for discrepancies at the beginning of the snowmelt season as discussed near the end of Section 7-7, but significant overall timing problems or unreasonable parameter values are a good indication that the computation of the MAT values should be reexamined using the guidelines in Section 6-4. Especially in mountainous areas, the initial MAT estimates may need to be redone because of difficulties in determining the temperature versus elevation relationship due to scatter in the station data or the use of improper lapse rates.

4. Adjust tension water capacities. This step involves finding periods that isolate the effect of tension water deficits in both the upper and lower zones of the Sacramento model, i.e. the UZTWM and LZTWM parameters. The idea is to determine whether the deficits are generally too large, too small, or about right, thus indicating how the parameters should be modified. During this step is also a good time to check the value of the PCTIM parameter. Fast response runoff during periods when upper zone tension water deficits exist can only be modeled by constant impervious area runoff.

5. Adjust parameters that primarily affect storm runoff. This involves altering the value of UZFWM to get the proper division between surface runoff and interflow, changing UZK to get the correct timing of interflow, determining if ADIMP is needed and if so, finding the best value, and refining the shape of the percolation curve over a large range of LZDEFR values primarily by adjusting the ZPERC and REXP parameters. When making adjustments to the percolation rates in the Sacramento model, it is best to look at the entire curve and determine what changes are necessary and then select parameter values that will produce the curve that is needed. A procedure for evaluating the entire percolation curve is described in Section 7-8.

6. Make final parameter adjustments. This typically includes looking at the following:

- If riparian vegetation evaporation effects exist, determine the final value of the RIVA parameter or if there are irrigation withdrawals, add the CONS_USE operation and make the necessary adjustments to its parameters.

- Refine the timing of major peaks, mainly those that produce surface runoff, by modifying the shape of the channel response function (unit hydrograph).

- Adjust ET-Demand curve values to improve the seasonal bias pattern (if it can be deduced that ET errors are the cause of any trend in the seasonal bias). When making modifications to mean monthly ET-Demand values, the monthly PE adjustment curve should be examined to make sure that the values are realistic and that abrupt changes do not occur from one month to another.

- Raising or lowering the entire percolation curve to improve the flow interval bias pattern by changing LZFSM and LZFPM by the same ratio.

Indeterminate Parameters

It needs to be recognized that depending on the conditions that exist within a given watershed and the types of events that occur within the calibration period of record, there may be some parameter values that cannot be reliably determined. This occurs when the parameter is never or rarel y activated during the calibration period. It is important to understand when this occurs since it may affect the operational ability of the model to extrapolate to conditions outside the range of what was included in the calibration period. Parameters for which reliable values sometimes cannot be determined are:

Snow Model:

- SI – If bare ground occurs as soon as snowmelt begins during every year, i.e. there is no significant period when the area remains at 100 percent snow cover, it is impossible to determine the value of SI other than to know that it is greater than the maximum average areal water equivalent that occurred during the calibration period.

- UADJ – If few or no significant rain-on-snow events with warm temperatures occur, it is not possible to obtain a reliable value of the UADJ parameter.

Sacramento Model:

- UZFWM – If surface runoff never occurs, it is impossible to determine the proper value of UZFWM other than to say that it has to be great enough that the model will never generate surface runoff. When there are only a few events with surface runoff, the value of UZFWM generally contains much uncertainty in watersheds where the distribution of rainfall is highly variable during these large storms.

- LZTWM, UZTWM, and PFREE – In very wet regions where significant soil moisture deficits never occur, at least during the calibration period, it is not possible to determine the value of the tension water capacities or PFREE. In some areas there are sufficient dry spells to estimate the UZTWM parameter, but none of sufficient length to determine LZTWM or get a good estimate of PFREE. Also in semi-arid regions, there may never be sufficient moisture to fill the lower zone tension water, thus it is not possible to know the proper value for this parameter. In very dry regions there is not enough runoff to be confident in any of model parameter values.

- ZPERC and REXP – If the vast majority of events occur over a limited range of lower zone moisture conditions, it is very difficult to obtain unique values for ZPERC and REXP. Various combinations of these parameters can result in similar percolation rates over a small range of soil moisture. This is especially common in wet regions.

<u>Special Situations</u>

There are some special situations that can exist when calibrating watersheds that need some additional discussion. This includes watersheds with multiple zones, glaciers, and frozen ground.

- Multiple Zones – It is important to maintain a realistic relationship between parameter values from one zone to another within a watershed whether the drainage is subdivided based on elevation zones, travel time zones, or some other breakdown. There are 2 basic recommended approaches:

- Start with the same values for all parameters for each zone. Then keep the parameter values the same as the calibration progresses except when there are events that clearly allow one to determine unique parameter values for a given zone. These could be rain events where the precipitation only occurs over one of the zones or snowmelt runoff periods where all or most of the melt is coming from one zone.

- Start with parameter sets that have different initial values for some parameters and then maintain the ratio or difference in these parameters between the various zones as parameter values are modified. The initial differences can be based on relationships, either objective or subjective, between parameters based on soils, vegetation, or climatic conditions or based on differences in parameter values from previously calibrated watersheds that most likely represent one zone or another. The initial relationship between the parameters for each zone are only modified during the calibration if there are a number of events that clearly allow for a unique determination of certain parameter values for a given zone. ICP contains a feature (included with the Selected Parameters option under the Edit menu) that allows the user to maintain the ratio or difference (fixed for each parameter) between zones when changing parameter values for the snow and Sacramento models. When this feature is on, the parameters in all zones are altered to maintain the ratio or difference whenever the value for any one zone is changed.

• Glaciers – A separate zone is typically used to model glacier effects. One glacier zone should be sufficient unless possibly the glacier covers most of the drainage and covers a wide range of elevations. Two general modeling approaches have been used to simulate the streamflow response from the glaciated area:

- Use the snow model to simulate the accumulation and melt that occurs on the glacier surface and the GLACIER operation to model the time delays that take place as the water moves through the glacier. The GLACIER operation allows for a variable withdrawal rate of any liquid water passing through the glacier that is a function of the amount of inflow at the glacier surface in the recent past. This results in little outflow and a storage buildup when rain or meltwater first enters the glacier. As warmer weather persists and passages within the glacier open up, there is a much faster response to surface inflow and the water in storage is released. This results in both a delay and dampening effect.

- Use the snow model to simulate the accumulation and melt at the surface, plus some of the delay that occurs when water passes through the glacier and use the Sacramento model to handle the variation in attenuation rates of this water. In this case a user specified seasonal melt factor variation is used in the snow model to artificially produce some of the delay between when rain or melt occurs and when the water reaches the streamgage. Only certain portions of the Sacramento model are used, primarily those that control the attenuation of water through the system by dividing it into the various components, surface, interflow, and supplemental and primary baseflow. The following Sacramento model parameters can be set to zero for a glacier; PCTIM, ADIMP, RIVA, PFREE, and the ET-Demand values. The tension water capacities can be set to a non-zero value and the storage initially set to the capacity, which will not change during the run since the evaporation rate is zero.

In both cases the initial water equivalent of the snow cover should be set to a very large value (typically 30,000 mm has been used) and the initial liquid water storage should be equal to the PLWHC parameter multiplied by the initial water equivalent (i.e. liquid water storage should be full at the start of the run). During the calibration it is important to monitor the change in the water equivalent to insure that any increase or decrease in glacier ice is reasonable compared to any available mass balance studies for glaciers in the region.

The main advantage of using the GLACIER operation is that it is a more conceptually correct approach. The snow model is being used as it was intended and the GLACIER operation is attempting to model the effects of the glacier on storing and attenuating the surface melt and rain water. The main advantage of using the Sacramento model is that it allows for more runoff components. The GLACIER operation allows for a variable withdrawal rate which can produce values that are similar to interflow and supplemental and primary baseflow rates in the Sacramento model. The GLACIER operation cannot pass water through the glacier as quickly as surface runoff occurs in the Sacramento model. High intensity rains on some glaciers in the late summer when passages through the ice are fully open show a surface runoff type response. The GLACIER operation cannot mimic this type of response.

• Frozen Ground – Extensions to the Sacramento model are used in an attempt to model the effects of frozen ground. The algorithms consist of an indicator of the amount of frost in the soil (either a frost index as in the preliminary frozen ground model or frost depth in a new procedure being developed) and then a modification of portions of the Sacramento model, typically percolation and interflow withdrawal rates, based on the amount of frost. Frozen ground mainly has a significant effect on streamflow in somewhat open regions where there are cold periods with little snow cover during portions of the winter and percolation rates are quite different for frozen and non frozen soil. Regions where dense forests and/or significant snow cover exist provide enough insulation to prevent substantial frost from developing except at far northern latitudes where permafrost occurs. Regions where percolation rates are very low even when the soil is not frozen or where permafrost exists (percolation rates remain similar throughout the year), typically don't require the use of the frozen ground algorithms.

When deciding whether to include the frozen ground algorithms, it is a good idea to start the calibration without considering frozen ground and concentrate on events during the summer and fall, plus spring events during years with a substantial snow cover over most of the winter accumulation period. The frozen ground algorithms can be included and the amount of frost displayed, but the effect of the frost on the Sacramento model should be turned off (done in the preliminary frozen ground model by setting the SATR parameter to zero). Thus, one can see when the algorithms could change the response of the Sacramento model and a decisio n can be made as to whether the inclusion of frozen ground is needed and should likely improve the results.

Use of Other Data during Calibration

The primary observations used to compare against model simulated results during calibration are mean daily flow data, however, there are other observations that should also be used when they are available. This includes other types of flow data and snow observations.

- There are two types of streamflow data that should be used whenever possible besides mean daily discharges. These are instantaneous discharges and peak flows.

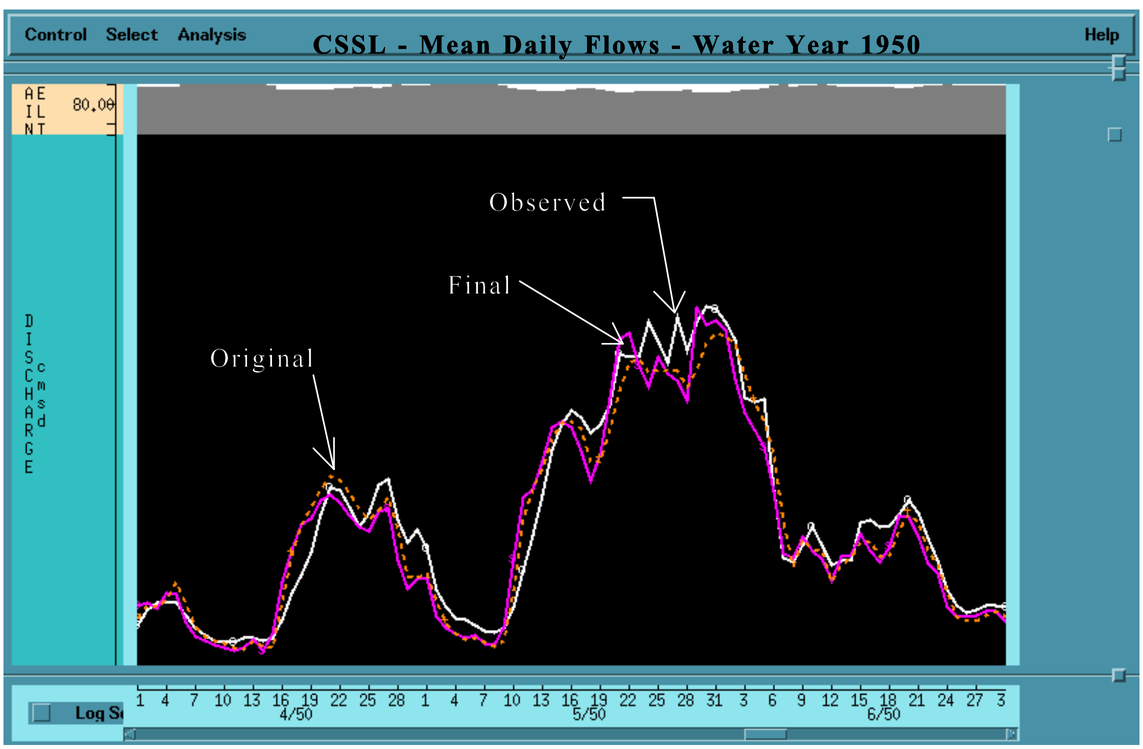
  - Instantaneous discharge data are very helpful for faster responding watersheds and when there is a significant diurnal variation in flows during snowmelt periods. The instantaneous discharges are not needed on a continuous basis, just during selected storm events and snowmelt periods. When the storm hydrograph from a watershed doesn’t peak for 2 to 4 days or more, generally mean daily flows are adequate for determining the parameters that control storm events (primarily UZFWM and possibly ADIMP) and the shape of the unit hydrograph, however, for areas that peak sooner, instantaneous discharges are often needed to refine these parameters. The same is true of watersheds with snowmelt periods that last for more than a few days. Mean daily flow data will not indicate the magnitude of diurnal fluctuations that may exist. This can only be determined by examining instantaneous discharge data.

  To illustrate the situation involving diurnal variations in streamflow during snowmelt we will use data from the Central Sierra (CSSL) and Upper Columbia (UCSL) Snow Laboratories. These data were collected in the late 1940's and early 1950's as part of the Snow Investigations conducted by the Corps of Engineers and the Weather Bureau [*Snow Hydrology*, 1956]. The watersheds used are both small (CSSL watershed is 3.96 mi^2 and the UCSL watershed is 8.09 mi^2), thus any damping of the response due to the channel system is minor. The original calibrations for both of these watersheds were done using only mean daily flow data.

  Figure 7-1-1 shows the simulation of mean daily flows for the 1950 snowmelt period for CSSL. This figure includes the original calibration, based only on daily flows, which had no surface or variable impervious runoff during snowmelt periods, and the final calibration, which used observed 6 hour instantaneous discharges to determine model parameters and as a result generated both of these runoff components. As can be seen the mean daily flow simulations in both cases are quite good. Figure 7-1-2 shows the instantaneous flow simulations from the original calibration that show a much more damped response than what actually occurred. Figure 7-1-3 shows a much more realistic reproduction of the instantaneous flows after the UZFWM value was reduced to produce surface runoff during high intensity snowmelt periods and the ADIMP parameter was used to generate fast response runoff when snowmelt rates were lower. The simulated instantaneous dischar ges are delayed somewhat from the observed because a 6 hour time interval is being used , whereas a hourly interval would be more appropriate for such a small, quick responding watershed, however, the amplitude is quite reasonable. Without instantaneous flow data one would not know which parameter set was most appropriate.

Figure 7-1-4 shows the simulation of mean daily flows for the original calibration from th e UCSL. Figure 7-1-5 shows the simulation of instantaneous discharges at a 6 hour

Figure 7-1-1. Simulation of mean daily flows for CSSL.



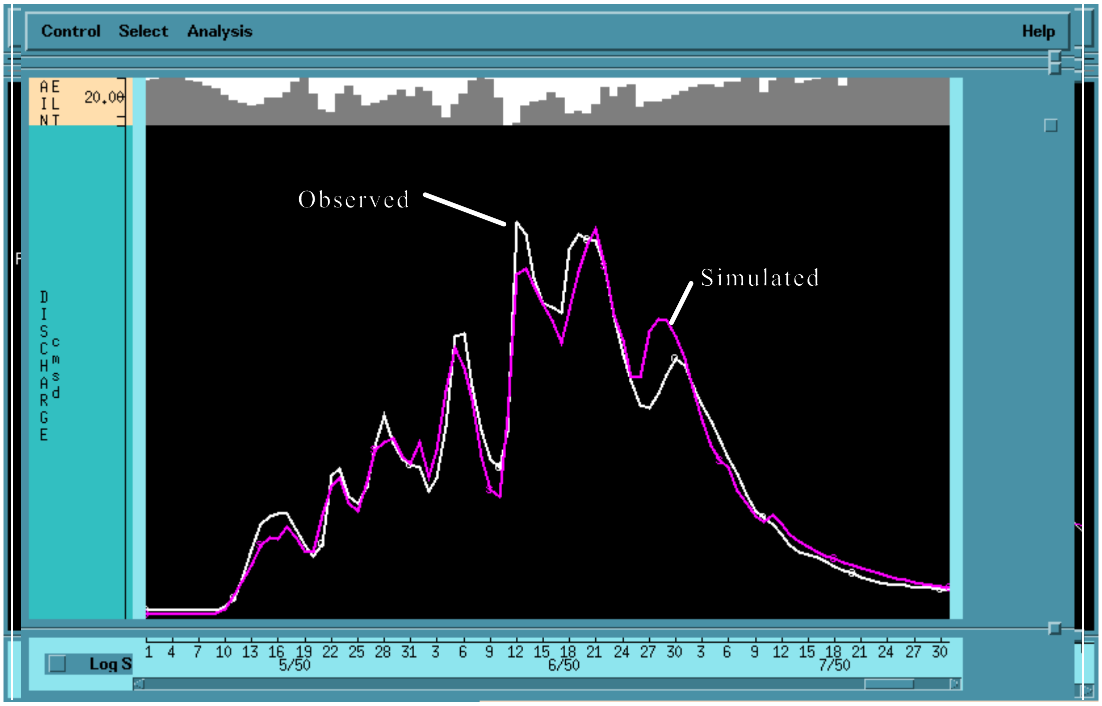


Figure 7-1-2. Simulation of instantaneous flows from the original calibration for CSSL.
Figure 7-1-3. Simulation of instantaneous flows from the final calibration for CSSL.

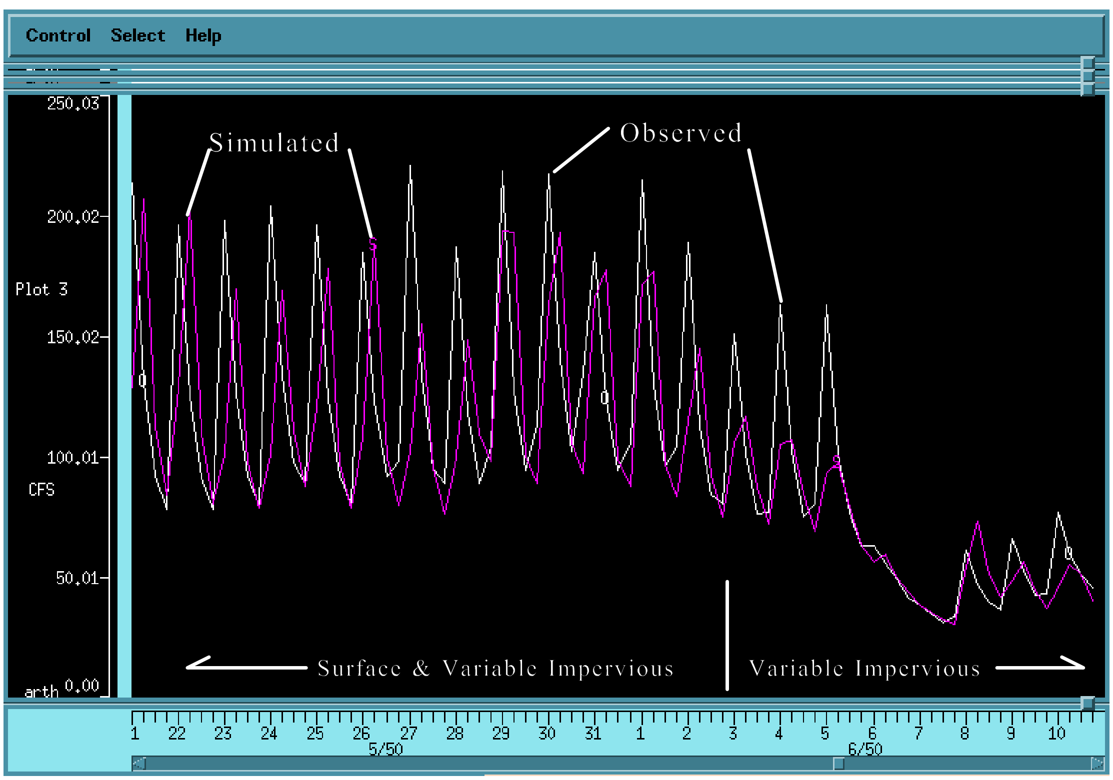
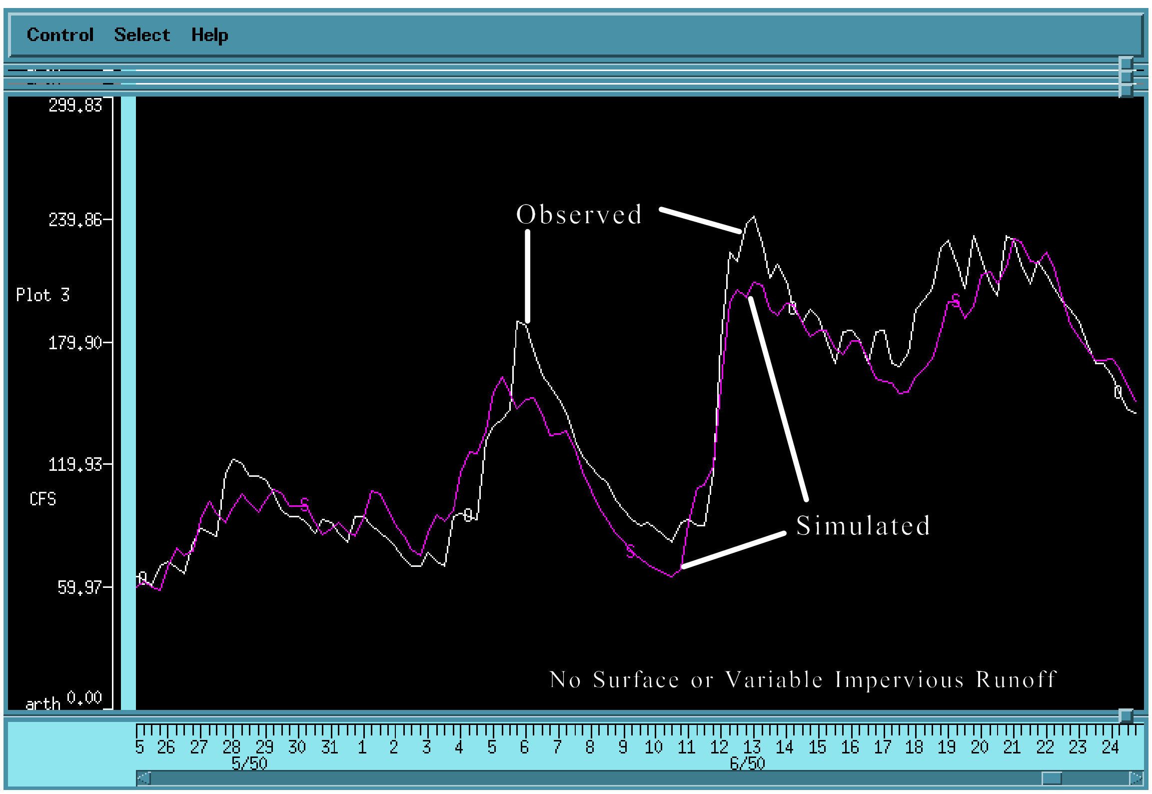


Figure 7-1-4. Mean daily flow simulation for the original UCSL calibration.
Figure 7-1-5. Instantaneous discharge simulation from the original UCSL calibration.
interval for this same parameter set. In this case the instantaneous flow simulation is qu



ite realistic based on only using mean daily flows for calibration, however, one wouldn't know for certain unless some observed instantaneous discharge data were available for ex amination.

File Edit Search Preferences Shell Windows Help

/home/eaa/calb_report/figures/peakflow.temp line 4, col 61, 3421 bytes

PEAKFLOW DISCHARGE AND TIMING ERROR SUMMARY

OBSERVED PEAK Q(CFS)	H(FT)	DATE	FLAG Q H	SIMULATED PEAK Q(CFS)	DATE	TIMING ERROR(DAYS)	DISCHARGE ERROR(CFS)	DISCHARGE RATIO (SIM/OBS)
3620.0	8.1	3/19/1968	6	3150.0	3/20/1968	-1	-470.0	0.87
3420.0	8.1	1/26/1979	6	2610.0	1/27/1979	-1	-810.0	0.76
2580.0	7.2	4/ 7/1987	6	2910.0	4/ 7/1987	0	330.0	1.13
2300.0	6.7	6/ 7/1982	6	2300.0	6/ 8/1982	-1	0.0	1.00
1960.0	6.4	4/ 2/1993	6	1890.0	3/31/1993	2	-70.0	0.96
1780.0	6.3	6/ 3/1984	6	1690.0	6/ 1/1984	2	-90.0	0.95
1780.0	6.1	2/12/1970	6	1530.0	2/12/1970	0	-250.0	0.86
1690.0	6.0	3/27/1969	6	1620.0	3/27/1969	0	-70.0	0.96
1590.0	5.9	3/23/1972	6	1530.0	3/24/1972	-1	-60.0	0.96
1420.0	5.6	3/29/1978	6	1470.0	3/29/1978	0	50.0	1.04
1360.0	5.5	3/16/1986	6	1340.0	3/16/1986	0	-20.0	0.99
1260.0	5.5	3/13/1983	6	1470.0	3/13/1983	0	210.0	1.17
1250.0	5.4	3/15/1977	6	1540.0	3/15/1977	0	290.0	1.23
1160.0	5.2	2/ 4/1973	6	1370.0	2/ 4/1973	0	210.0	1.18
1030.0	5.0	1/28/1976	6	1590.0	1/29/1976	-1	560.0	1.54
1030.0	5.0	2/26/1975	6	1160.0	2/26/1975	0	130.0	1.13
1020.0	4.8	3/23/1980	6	1240.0	3/23/1980	0	220.0	1.22
899.0	4.5	3/17/1971	6	614.0	3/18/1971	-1	-285.0	0.68
857.0	4.5	2/27/1981	6	1430.0	2/27/1981	0	573.0	1.67
830.0	4.7	3/23/1974	6	1140.0	3/23/1974	0	310.0	1.37
779.0	4.3	4/23/1991	6	703.0	4/23/1991	0	-76.0	0.90
775.0	4.3	4/ 5/1990	6	717.0	4/ 5/1990	0	-58.0	0.93
739.0	4.3	5/13/1989	6	688.0	5/13/1989	0	-51.0	0.93
692.0	4.1	3/28/1988	6	960.0	3/28/1988	0	268.0	1.39
614.0	4.0	11/24/1991	6	870.0	11/24/1991	0	256.0	1.42
403.0	3.4	2/13/1985	6	484.0	2/14/1985	-1	81.0	1.20
MEAN: 1417.0	5.4			1462.0		-0.1	45.3	1.09

(OBSERVED DISCHARGE EVENTS ONLY)

"*" INDICATES SIMULATED PEAK ON SEARCH WINDOW BOUNDARY, WHICH PROBABLY IS NOT THE TRUE PEAK.

DISCHARGE RMS ERROR = 296.500 (CFS)
TIMING RMS ERROR = 0.760 (DAYS)
AVERAGE PERCENT ERROR (AVEOBSQ-AVESIMQ)/AVEOBSQ = 3.2 %
CORRELATION COEFFICIENT (DISCHARGE) : R = 0.936
BEST FIT LINE: OBSQ = A + B * SIMQ : A = -227.600(CFS) B = 1.120

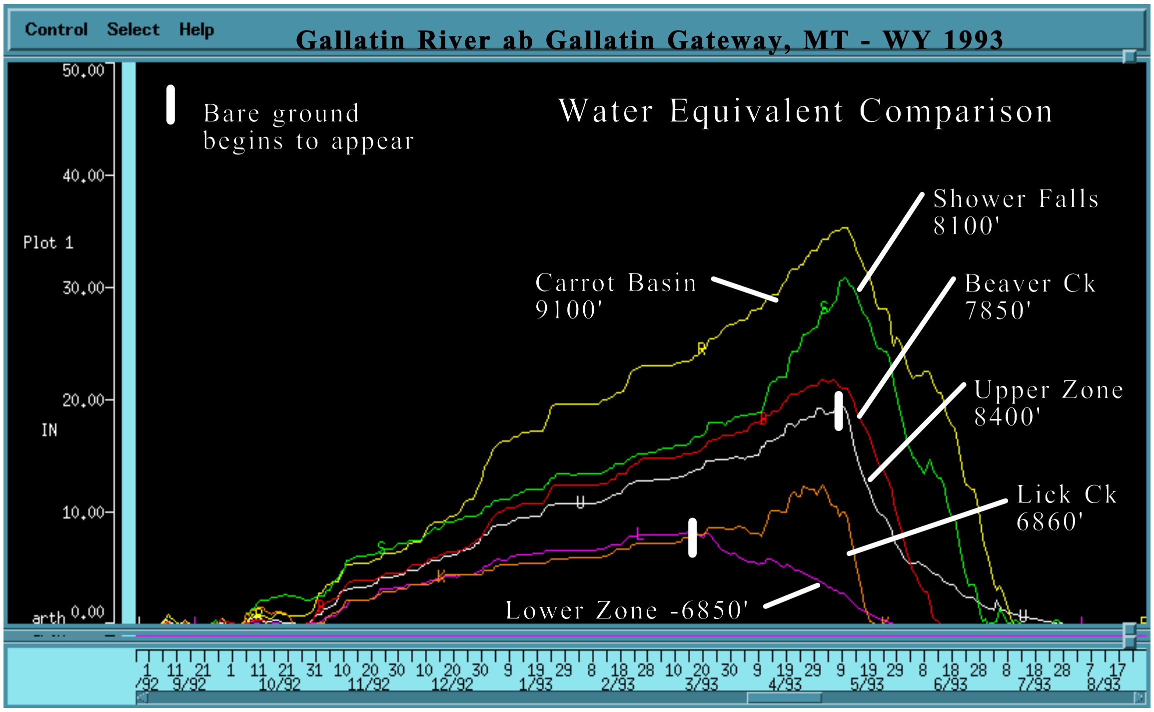
Figure 7-1-6. Sample display from the PEAKFLOW operation.

- Peak flow data are helpful to determine how well the magnitude of the instantaneous peaks are reproduced, especially when instantaneous discharge data are not available at all or only for a small portion of the calibration period. These data are most valuable for fast responding streams, but can also be helpful when diurnal flow variations occur during snowmelt. The current PEAKFLOW operation tabulates a comparison of observed and simulated peaks by calculating the difference between the values and their ratio as shown in Figure 7-1-6. There is also a timing comparison, but only in terms of which day the peak occurred since the archived records don't contain the time of the observed peak during the day. It is somewhat difficult to use this tabular summary directly, since if mean daily flows are over or under simulated, the peaks on those days should also be similarly affected (i.e. if the highest daily flows are somewhat under simulated, it should be expected that the peaks should show a similar tendency, however, there is no tabulation of the daily flow bias just for the days with observed peak flow data). It would be better to compare the ratios of the observed peak to the observed mean flow for each peak flow day to the same ratios for simulated discharges. This would more clearly indicate whether the instantaneous flow simulations had a similar diurnal pattern as the observed discharge data.

• Snow observations can be used to verify the snow model computations by assisting to discern the actual form of the precipitation and to confirm whether the simulation of the snow cover is reasonable. Snow data that can be used for these purposes are snowfall, water equivalent and depth, and possibly areal extent of cover.

- Snowfall data – Data on new snowfall can be helpful in the determining if the form of precipitation selected by the snow model is correct or whether it needs to be modified. Section 7-4 includes of discussion of problems associated with the model determining the correct form of precipitation under certain conditions. This section also shows how snowfall data can be used along with streamflow response and possibly water equivalent or depth data to check whether the form of precipitation needs to be changed.

- Water equivalent and depth data – Comparisons can be made between the mean areal w ater equivalent computed by the model and point or flight line observations of water equi



valent to determine if the model computations are reasonable. There is always the probl em that point or even flight line measurements only represent a small portion of a drainag e area and thus there will seldom be a one to one correspondence between computed and measured values. Even so, observations of water equivalent can provide information as to how realistic are the model calculations. It is especially helpful to have several obser vations of water equivalent scattered through the area and at a range of elevations in the mountains. Generally the more observations, the more likely that one can realistically a ssess the model performance. In the mountains the model computations should typicall y show a pattern that is similar to snow course or SNOTEL observations during the accu mulation period. During the melt period the observation sites should go bare before the mean areal water equivalent goes to zero. The model water equivalent will exhibit a mo re gradual decrease once bare ground begins to show up in portions of the watershed, whi le point measurements will go abruptly to zero. In flatter terrain where the time from co mplete cover to no snow conditions occurs over only a few days, this effect is less appare nt. Figure 7-1-7 shows a water equivalent comparison for the Gallatin River above Gall atin Gateway, Montana. Model water equivalents for the upper and lower zones are plot ted along with data from 4 SNOTEL sites.

If no water equivalent data are available, comparisons can be made between modeled wat er equivalent and observed depth of snow on the ground. When doing this one must re member that the density of the snow cover changes throughout the snow covered period, t hus the relationship between water equivalent and depth is ever changing. In spite of thi s, depth data can be helpful to assess whether the model results are reasonable.

Figure 7-1-7. Water equivalent comparison for Gallatin River ab. Gallatin Gateway, MT.

- Areal extent of snow cover – Areal extent observations derived from satellite data are available for many western mountain areas for more recent years. The satellite estimates are available for entire watersheds and specific elevation bands. These observations can be compared against the areal extent of snow cover computed by the model, however, one must be aware that there should not be a one to one correspondence between the model areal extent and direct observations. The reason for this is that the areal depletion curve in the model implicitly includes other factors than just the areal snow cover as discussed in Section 7-4. The model should be using an areal extent that is less than that observed during the period when bare ground exists, with the largest discrepancies occurring in areas with the most rugged terrain. Thus, if one takes this difference between model and actual areal extent into account, the observations should be helpful in assessing whether the model results are reasonable.

Validation of Results

As indicated previously it is a good idea to validate the calibration results for the initial headwater watershed on other portions of the period of record. If done properly, this will test the extrapolation capabilities of the calibration results and determine if "curve fitting" occurred during the calibration (i.e. parameters were tweaked just to improve goodness of fit statistics). As mentioned earlier, the validation period should ideally include events that are outside the range of what occurred during the calibration period, i.e. the flood and low flow of record would be in the validation period. Ideally statistics for the calibration and validation periods should be similar, though typically the calibration period statistics are slightly better as some degree of "curve fitting" is hard to avoid. A variety of statistics can be used to compare the results during the calibration period and one or more validation periods. These can include:

- Root mean squared errors, both daily flows and monthly volumes,
- Differences and standard deviations of monthly mean flows to test seasonal variations,
- Autocorrelation functions of observed flows and simulation residuals,
- Frequency distributions of observed and simulated flows, and
- Histograms of high flow peaks and their simulation errors.

Some possible causes of validation problems, i.e. differences in results between the calibration and validation periods, besides "curve fitting" include:

1. Calibration period is not adequate either because the validation period contains events that excite certain model components for the first time or events that seldom occurred during calibration occur during the validation period under somewhat different conditions (e.g. surface r

unoff may have occurred once during calibration with a certain spatial rainfall pattern, but occurs with a different rainfall pattern during the validation period). Also certain problems present, but unnoticed in calibration, may be amplified in validation.

2. Factors external to the models are changing over time, i.e. the observed flow data are not consistent due to changes in factors such as reservoir releases, agricultural practices, and vegetation and land use changes.

If these problems occur the suggested actions are as follows:

Case 1. Use the entire period of record to refine the calibration so that all possible model components are used and so that the maximum number of occurrences of specific situations are included in determining the most likely value of each parameter. This should only involve modifications to those parameters whose values were based on few, if any, events during calibration. Parameters whose values are based on only a few events or control components that were never used will contain a high degree of uncertainty. Parameters that sometimes fall into this category were mentioned in the section on Indeterminate Parameters in this section. For all parameters, but especially these, a subjective estimate of the degree of uncertainty (e.g. ± percentage of the parameter value to represent the standard deviation of the uncertainty) should be made for operational use.

Case 2. The observed flow data should be made consistent over both periods of record or another watershed should be selected for the initial calibration. This case should not occur if the selection criteria for the initial headwater area were followed.

If a thorough validation is done for the initial headwater area within the river basin, validation is probably not necessary for the other drainages in the basin. Using the strategy recommended in this chapter, the parameter sets for all the other drainages in the river basin will be closely tied to the parameters determined for the initial headwater area.