Section 8-1

Guidance for Using MODs with the SNOW-17 and SAC-SMA Operations

Introduction

This section provides some guidance for using the main MODs that are directly associated with t he SNOW-17 and SAC-SMA operations in a manner that reduces the chance of adding a bias to future forecasts and thus preserving the benefits of calibration. For the SNOW-17 operation the MODs discussed are:

- .MFC (used to change the melt rate under non-rain situations)
- .UADJ (used to change the melt computations during rain-on-snow periods)
- .WECHNG (used to change the mean areal water equivalent)
- .AESCCHNG (used to change the areal extent of snow cover)

For the Sacramento model the MODs included are:

- .SACBASEF (used to change the amount of water in lower zone free water storages)
- .SACCO (used to change any of the Sacramento model state variables)

Though this discussion provides a brief description of exactly what happens when each MOD is applied and provides recommendations for their use, the focus, as mentioned, is on using these MODs in a manner that doesn't bias the state variables and thus cause problems during subseque nt forecasts, including extended predictions.

.MFC MOD

The Melt Factor Correction (.MFC) MOD is used to multiply the non-rain melt factor by a constant for the period specified. This MOD can be used to change the melt rate for computational intervals within both the observed data period and out into the future. The primary reason for the .MFC MOD is that the relationship between air temperature and surface energy exchange varies depending on meteorological conditions. The normal seasonal variation in this relationship is specified when the SNOW-17 model is calibrated. However, the scatter about the seasonal melt factor curve is ignored during calibration as only the average relationship is being established. Operationally there is a need to remove this variability in order to improve forecast accuracy. During most periods the calibrated melt factor provides a very reasonable estimate of snowmelt, however, under certain situations the actual melt rate can be substantially different than the normal rate. Comparisons between energy balance melt computations and the SNOW-17 model have identified those meteorological conditions that produce the largest errors in temperature index based melt calculations [*Anderson*, 1976]. These include:

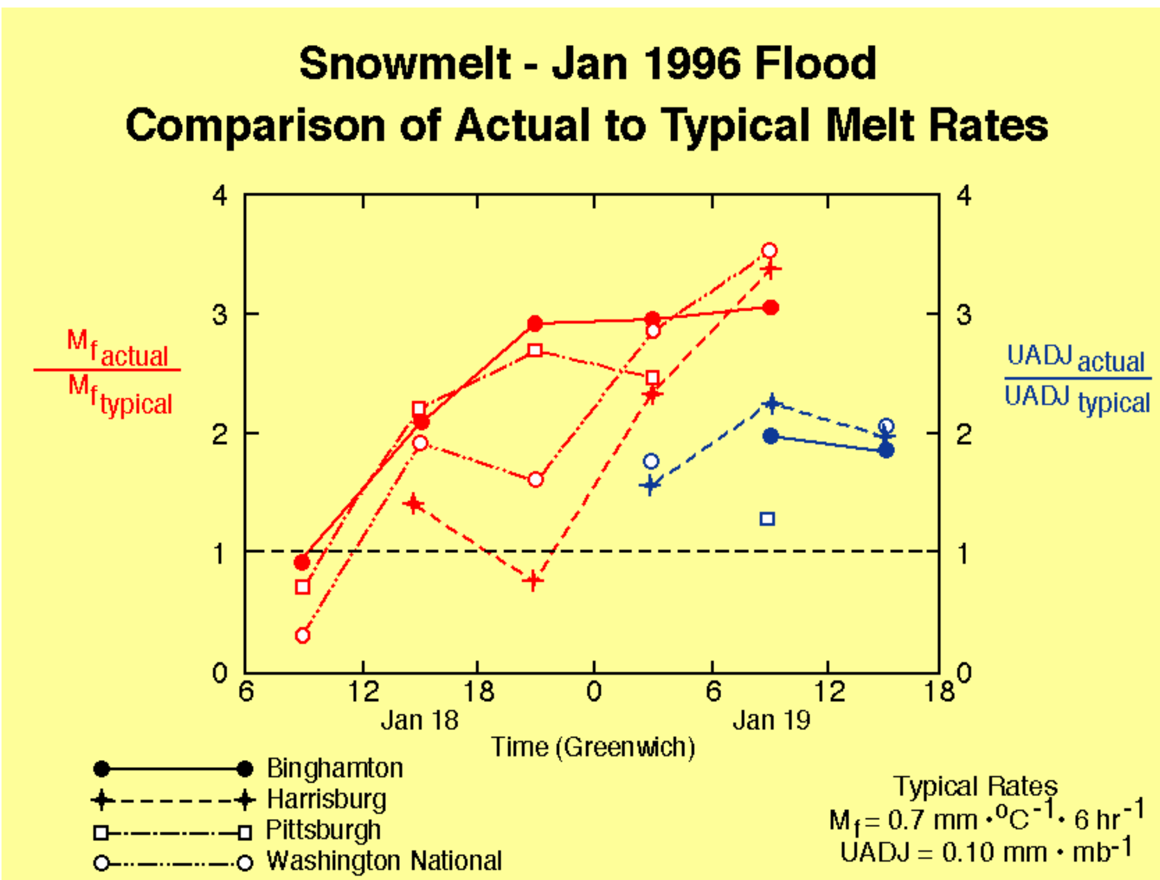
- Periods with high dew-points and high wind speeds - During such periods the turbulent transfer terms in the energy balance, i.e. the latent and sensible heat terms, transfer more energy than under normal conditions causing the melt rate to increase. In this case a .MFC value greater than 1.0 would be needed.

- Periods with much above normal temperatures and calm winds - Under these conditions the turbulent transfer terms are negligible, but the calibrated melt factor is computing more melt than would normally be expected at that time of year. This results in too much melt and thus the need for a .MFC value of less than 1.0.

- Periods with clear skies, but much below normal temperatures during the height of the melt season - Under these conditions there is a significant amount of solar radiation and the snow surface has aged so that the albedo is low enough for much of the radiation to be absorbed, however, the air temperature is indicating that not much melt should be occurring. In this case the .MFC value would need to be greater than 1.0.

Even though the forecaster can recognize these situations and realize that the melt rate needs to be modified, the problem is to determine the magnitude of the adjustment. If an error in the melt rate is the only cause for the simulated hydrograph to differ from the observed, the forecaster can interactively determine a correction that will bring the two hydrographs into line. However, even in this case there may be difficulties as the meteorological conditions could be changing from one time interval to the next. Thus, it may be possible to determine the average correction over several intervals, but the variation from one interval to another would be difficult to assess. The problem is compounded when there are multiple causes for the simulation errors or when trying to decide the correction to use when abnormal melt conditions are forecast for the next few days. This all indicates that a tool is needed to provide the forecaster with guidance as to when the .MFC MOD is needed and what is a physically realistic value for any corrections.
While it is difficult to obtain the data necessary to calibrate and apply an energy balance model o

n a routine basis, especially for complex forested areas in the mountains, it is likely that energy balance computations could be used to provide guidance for using the .MFC MOD. One possible procedure for doing this can be demonstrated using the January 1996 flood event in the northeastern United States [*Office of Hydrology*, 1998]. This event was characterized by extreme melt rates caused by high dew-points and winds and significant orographic precipitation. For this event energy budget melt values were computed for selected synoptic stations in the northeast. Dividing the melt computed from the energy balance by the air temperature minus MBASE gives the melt factor needed for each interval to reproduce the energy balance melt amount. The normal melt factor could be determined by calibrating the SNOW-17 model for each of these stations using observed temperatures and water equivalents. Then the ratio of the energy balance melt factor to the normal melt factor, which is the .MFC value, could be computed. Figure 8-1-1 shows how the ratio of the actual (energy balance) melt factor over the typical (calibrated) melt factor, i.e. the .MFC MOD, would have varied throughout this event for several synoptic stations in the northeast (in this case the normal melt rate was assumed to be 0.7 mm/°C/6 hr rather than based on a calibration of the sites - a typical melt rate for an open site in this part of the country for mid January).



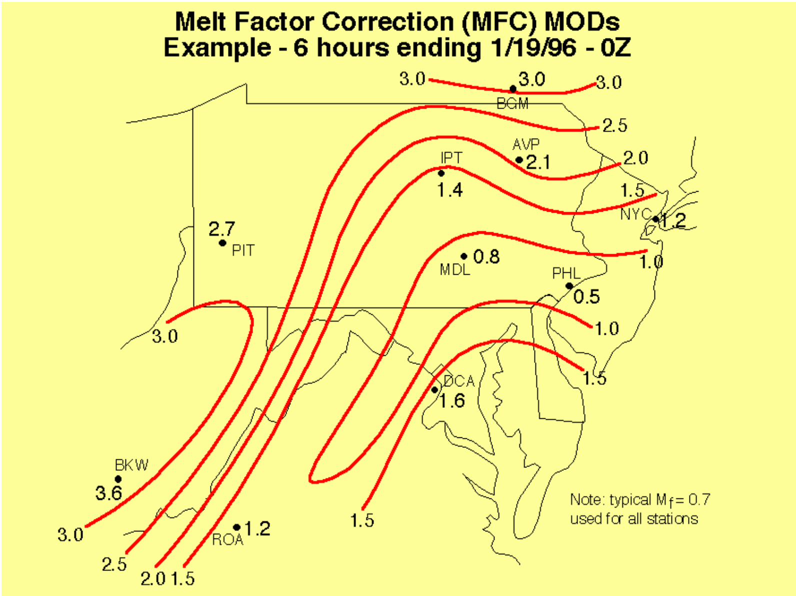


Figure 8-1-1. Variation c

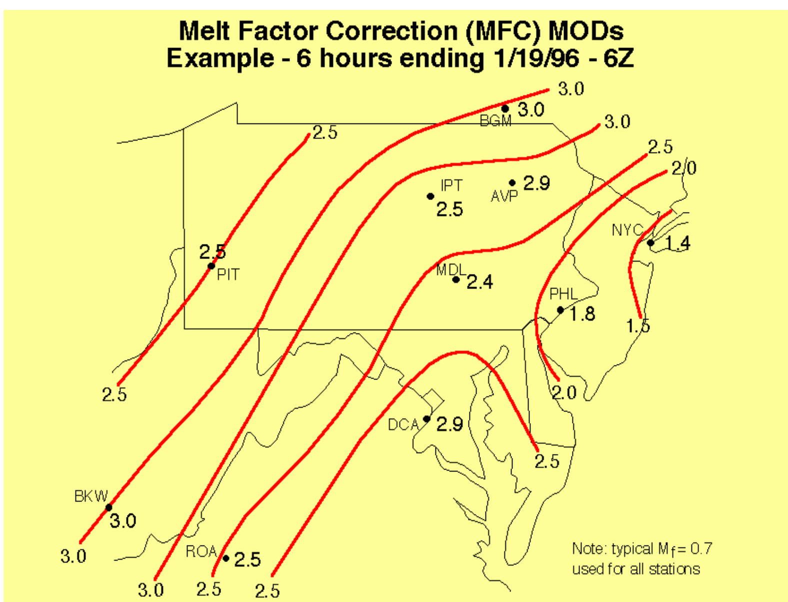
The next step in th e procedure would be to map the .MFC values computed for each synoptic station (any station wi th the data needed for energy balance computations and observed water equivalent data could be used). This should give an indication of how the correction varies spatially. Isocorrection line s could be then drawn using meteorological observations or predictions as a guide. This is illus trated in Figures 8-1-2 and 8-1-3 for two successive 6 hour periods during the 1996 event. By 0 Z high winds and dew-points existed in West Virginia,

Figure 8-1-2. Variation in .MFC values for period ending at 0Z on Jan. 19,1996.

Figure 8-1-3. Variation in .MFC values for period ending at 6Z on Jan. 19,1996.

western Pennsylvania, and New York resulting in much above normal melt rates for these areas.

Just east of the mountains conditions were very stagnant, though quite warm and humid, producing below normal melt conditions.



By 6Z the high winds covered most of the region.

The last step in the procedure would be to extract .MFC values for any particular watershed. This assumes that the .MFC values computed for an open site are appropriate to use for an entire watershed with mixed cover. This seems like a fairly reasonable assumption.

In the future estimates of the appropriate melt factor corrections could possibly be obtained from the Snow Data Assimilation System (SNODAS) being developed by NOHRSC [*Carroll et al.*, 2001]. SNODAS utilizes downscaled fields of meteorological data from numerical weather mo dels and gridded precipitation estimates to drive a distributed energy and mass balance snow mo del. The resulting snow model states can be updated using satellite, airborne, and ground-based snow observations. The procedure was first run for the central and eastern U.S. in the spring o f 2001 and continuously for the conterminous U.S. for the winter of 2110-2002. SNODAS is st ill in the evolutionary stage. Adjustments are being made to many of the algorithms and data fi elds. It will probably take a few more years for the system to reach a stable configuration. A period would then be needed to develop the relationships between melt factors derived from the SNODAS energy budget calculations and those from the SNOW-17 model. These relationshi ps could then be applied to SNODAS derived melt factors to identify when abnormal melt rates a re likely to occur and to obtain realistic estimates of the magnitude of any corrections. Alternat ively, the relationships might be used to adjust SNODAS energy exchange estimates prior to dire ctly overriding the SNOW-17 computed values.

If some method is not used to determine a physically realistic estimate for melt factor corrections , there is good chance that the correction applied will be too large or too small. In either case, t he resulting water equivalent at the end of the correction period will be off (assuming it was corr ect to begin with) and subsequent forecasts will contain too little or too much snow, thus produci ng a bias.

.UADJ MOD

The wind function correction (.UADJ) MOD is used to multiply the UADJ parameter (wind function term) in the rain-on-snow melt equation by a constant for the period specified. This MOD can also be applied to future intervals as well as the observed data period. It should be noted that the .UADJ value only affects the turbulent transfer terms in the rain-on-snow melt equation. The longwave radiation and heat of rainwater terms are not altered.

The primary reason to use the .UADJ MOD is to account for variations in wind speed during rain-on-snow periods when the temperature is enough above freezing so that significant melt occurs. Since .UADJ is only used when rain is occurring, there is always the question as to whether simulation errors are due to melt computations or whether the estimate of the amount of rain is in error. As with the .MFC MOD, energy budget computations could be used to determine a reasonable value for the wind function correction. Figure 8-1-1 shows .UADJ values derive by comparing the wind function derived from the energy budget to a typical value for an open site for several synoptic stations when rain was occurring during the 1996 northeastern U.S. flood event. Computations of .UADJ values at synoptic stations, or other sites with the data needed for energy balance calculations, could be used as a guide for determining watershed corrections. However, wind adjustments might be more difficult to extrapolate in regions with substantial terrain and forest cover than melt factor corrections. As with the .MFC MOD, improper wind function adjustments will affect the resulting water equivalent and cause some bias in subsequent forecasts. In the future relationships could be derived to possibly adjust SNODAS computations of melt during rain-on-snow periods for use within the SNOW-17 model.

.WECHNG MOD

The Water Equivalent Change (.WECHNG) MOD is used to change the mean areal water equiv alent at a specified time during the period of observed data. When the water equivalent is modi fied with this MOD, the areal extent of snow cover is assumed to remain the same. This results in the areal depletion curve being shifted when the change is made when some bare ground exist s. This is illustrated in Figure 8-1-4. In order to change both the water equivalent and the frac tion of the area cover by snow, both the .WECHNG and .AESCCHNG MODs must be used. In this figure TWE is the total water equivalent, i.e. the sum of ice and liquid water in the snow co ver, and A_s is the areal extent of the snow cover.

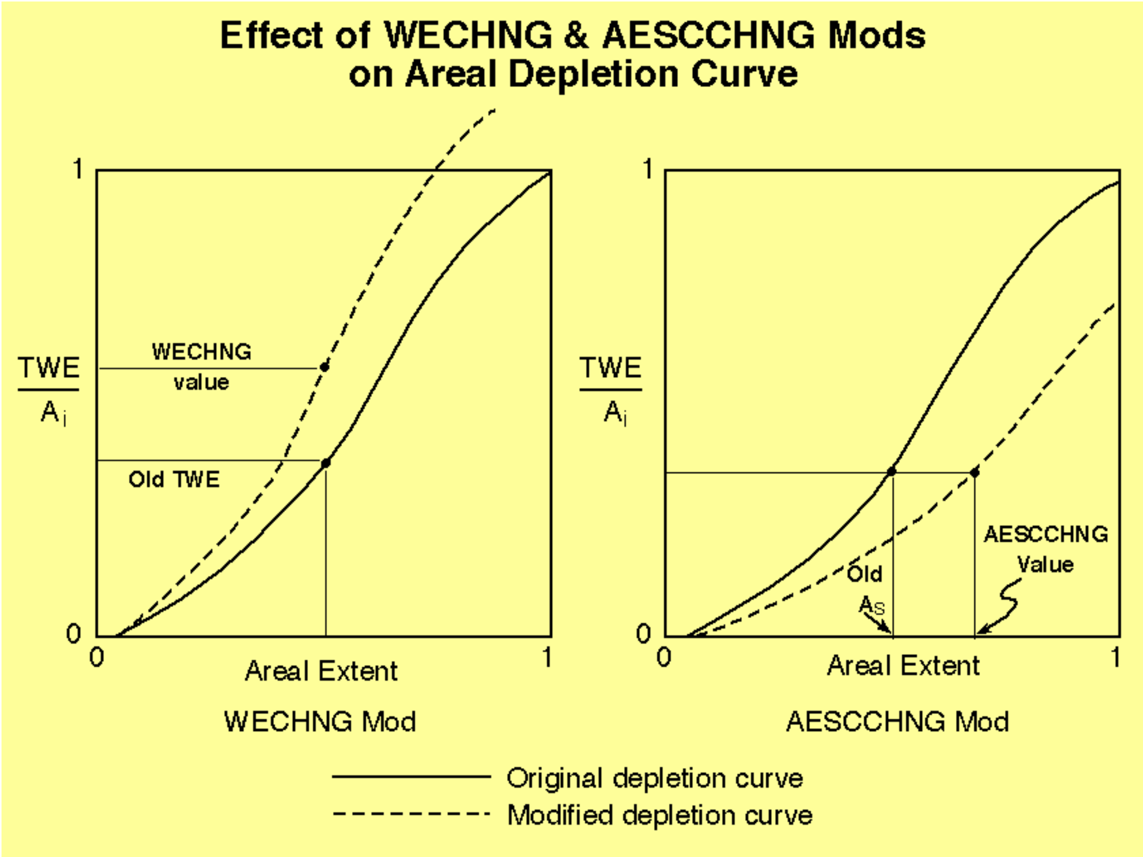


Figure 8-1-4. Effect of .WECHNG and .AESCCHNG MODs on the areal depletion curve.

The water equivalent typically needs to be modified because the snow cover accumulated by the model can be in error due to inaccurate precipitation input. This is caused by variations in catch deficiencies from normal and by storm dynamics that produce a different areal distribution than the typical pattern indicated by the isohyetal analysis. Also snowmelt computations may have been in error due to abnormal lapse or melt rates. The updated value of the water equivalent is normally based on water equivalent observations from snow courses, airborne gamma flight lines, or special surveys. The updated areal water equivalent derived from the observations can be directly substituted for the model value or each estimate can be given some weight. This depends on the relative uncertainty of each value. In many cases this is a subjective decision.

In flat terrain it may be okay to assume that there is a one-to-one relationship between the observations and the model's areal estimate. This is more likely if there are sufficient observations scattered over the area. The problem that can occur in very flat areas, like portions of the upper midwest, is that during the melt period significant water can pond in fields before ice at the outlet melts and allows the water to drain. In this case airborne gamma observations may include both snow and ponded water. If such observations are used directly, it could resulted in a biased estimate of areal water equivalent.

In mountainous terrain it is highly unlikely that even a weighted average of the observations can be used directly without first determining the relationship between the weighted average and model estimates. Generally the relationship between available observations and model values will vary from one time of the year to another. Thus, separate relationships need to be derived for each date that observations are typically available. In order to determine the relationship between the observations and the water equivalent generated by the model, first a reasonably long, stable historical record of observations must exist. Second, there needs to be a model simulation using historical gage data for an overlapping period.

The simplest updating procedure would be derived by plotting the observed water equivalent fro m a single site or a weighted average of several sites in and near the area against the model estimate for the same historical date. The average relationship derived from this plot could then be used to update the model whenever real time observations are available from those sites. The procedure can be evaluated by using the relationship to update the water equivalent during the historical period and then determine whether the resulting snowmelt runoff volume is an improvement over the simulation with no updates.

A more complex procedure is the Snow Estimation and Updating System (SEUS) based on the methodology proposed by Day [1990]. This system was in use by the western RFCs for awhile, but is no longer supported by the NWS. A replacement for SEUS was develop for use in the Pacific Northwest [*RTi*, 2000]. This procedure develops regression equations between fraction of normal values of observed and simulated water equivalents for various times during the snow season. The procedure is based on fraction of normal values to make it independent of the network of observations. This avoids having to recalculate regression equations every time a new station is added or deleted from the network. In addition, the procedure avoids having to estimate missing data since the estimated fraction of normal is based only on the stations which actually report. Based on tests on selected basins to evaluate the effect of this updating procedure on hydrograph simulations, it was decided to weight the estimate derived from the observations and the model simulated value equally.

In the future output from SNODAS may be used for determining water equivalent updates for SNOW-17. SNODAS could prove to be especially beneficial in the central and east regions of the country where the historical water equivalent network is quite sparse. SNODAS has the capability to use snow depth values, as well as water equivalent, to update model states. As with most updating procedures, relationships will need to be established between the SNODAS mean areal water equivalents and those produced by the SNOW-17 model in order to make sure that a bias is not introduced when the water equivalent is modified.

The key is to carefully evaluate any procedure for updating water equivalent as improper changes can have a large effect on the volume of snowmelt runoff and thus result in a significant bias. At least for mountainous areas, an objective procedure must be based on derived relationships between historical observations and model estimates.

.AESCCHNG MOD

The Areal Extent of Snow Cover Change (.AESCCHNG) MOD is used to change the areal extent of snow cover at a specified time during the period of observed data. When the areal extent of the snow cover is modified with this MOD, the mean areal water equivalent is assumed to remain the same. This results in the areal depletion curve being shifted. This is illustrated in Figure 8-1-4. In order to change both the water equivalent and the fraction of the area cover by snow, both the .WECHNG and .AESCCHNG MODs must be used.

The areal extent of snow cover may need to be changed because of variations in accumulation and melt patterns from normal or due to errors in the model simulation of water equivalent or melt. The most routine observations of the areal extent of snow cover are those obtained from satellite data by NOHRSC. At least in the past, aircraft were used in some regions to observe the snow line in the mountains and thus derive an estimate of the areal cover. Again, as with most observations, areal extent of the snow cover observations generally can't be used directly to update the snow model. It could be that in open, flat terrain the observed and simulated values of snow cover have a one-to-one relationship, however, this is certainly not the case in the mountains and even in watersheds with reasonably level terrain, but varying vegetation patterns. The main reason is that the snow model implicitly uses the areal depletion curve to account for variations in melt rates and other factors in addition to areal cover as discussed in Chapter 7-4 and illustrated on Figure 7-4-3. Thus, in most areas a relationship between the areal extent observations and the model computed values would have to be derived before the satellite estimates could be used to update the snow model. This hasn't been done to this author's knowledge. Such a relationship may not be linear as suggested by Figure 7-4-3. In order to derive the relationship an overlapping period with stable satellite observations and historical model simulated values must be available. In mountainous areas with multiple zones, the satellite estimates must correspond to the elevations used to divide the watersheds. If satellite observations are used to update the areal extent in the snow model without first defining the relationship with the simulated snow cover values, it is very likely that a bias will result, especially in mountainous regions.

.SACBASEF MOD

The Sacramento Baseflow (.SACBASEF) MOD is used to multiply the contents of both lower zone free water storages, i.e. LZFSC and LZFPC, by the same constant. This MOD allows the user to increase or decrease baseflow and maintain the relative division of water between the two storages. Generally this is the preferred method of modifying the amount of baseflow. A proper calibration should provide for a reasonable allocation of baseflow between supplemental and primary components. When there are low flow errors in a historical simulation, it is typically because baseflow is too high or too low, not the relative magnitudes of the two components.

When the .SACBASEF MOD is applied, it will take some period of time before the baseflow reaches the desired level, i.e. the change in the amount of baseflow doesn't appear instantaneously, but gradually over a number of time intervals. This is because baseflow, like all runoff generated by the Sacramento model, must pass through the channel response function, typically a unit hydrograph, before reaching the drainage outlet. Thus, the transition time is dependent on the number of ordinates in the unit hydrograph.

The decision as to whether baseflow needs to modified is generally based on comparing the simulated and observed hydrographs during a low flow period. When applying the .SACBASEF MOD there are several things to watch out for and situations to avoid. These include:

- The only flow components making up the simulated hydrograph should be primary and supplemental baseflow (supplemental flow can be zero if this storage is completely drained). There should be no other sources of runoff prior to when the hydrograph is being analyzed for a period equal to the length of the unit hydrograph. Currently there is not a graphical display of runoff components in IFP analogous to the ICP display shown in Figure 7-8-1, though this information can be obtained in a tabular form (PRINTSMA technique). In many cases during a recession it is assumed that the simulated hydrograph can be brought in line with the observed by changing baseflow, when in reality, other runoff components are still contributing to runoff. This can especially be the case near the end of a long snowmelt season. It appears that the hydrograph is in a baseflow recession, when snowmelt from a small portion of the area is still producing interflow and possibly impervious runoff.

- Baseflow modifications shouldn't be made during periods when there is evaporation from riparian vegetation. Such evaporation occurs when the RIVA parameter is greater than zero, there is a reasonable level of ET-Demand, and tension water deficits exist. The algorithms in the Sacramento model for handling riparian evaporation are quite simple, thus the simulation errors during such periods are much more likely to be the result of problems with computing the loss due to riparian vegetation than the amount of water in the lower zone free water storages. You probably just need to live with the simulation errors that exist under these conditions.

- It is probably unwise to modify baseflow at locations where problems can exist with the ratings, especially at low flows. This is certainly the case during the winter in northern region

s. River ice can significantly affect the rating curves in these area, thus it may be very likel y that the observed flow values are in error. Observed flows are also likely to be in error at other locations where the channel is not well defined at low water levels.

If care is taken when using the .SACBASEF MOD, this should be the best way to correct for sim ulation errors during baseflow periods. This MOD takes advantage of the calibrated relationshi p between supplemental and primary baseflow and thus, in general, is less likely to result in bias ed values of the related storages than if the lower zone free water contents were modified indepe ndently.

.SACCO MOD

The Sacramento Carryover (.SACCO) MOD is used to change the value of any of the Sacramento model state variables at a specified point in time. The contents of any of the 6 moisture storages, UZTWC, UZFWC, LZTWC, LZFSC, LZFPC, and ADIMC, can be modified. Tension water can be changed by either specifying a new content or deficit. The MOD also allows for modifying the value of the frost index used in the frozen ground algorithm associated with the Sacramento model.

One tool that can be helpful when using the .SACCO MOD is the tabulation summary of moisture contents that can be generated by the WATERBAL operation after a calibration is complete. This table shows the average, high, and low values for each of the 6 moisture storages for each month and thus can be used to avoid making changes to the contents that are outside of the range experience during the historical simulation.

Following are some guidelines for using the .SACCO MOD in a manner that will avoid generating biased values.

- LZFSC and LZFPC - The preferrable method for making changes to these contents is to use the .SACBASEF MOD. If only primary baseflow exists and the situations mention under the .SACBASEF discussion are not present, then the effect of using the .SACCO MOD to change the baseflow would be the same as using the .SACBASEF MOD, however, it is much easier to compute a multiplying factor than to calculate the content that would be needed to produce the desired amount of baseflow. When both supplemental and primary components are contributing to the baseflow, it very difficult to assess how to change the contents of each storage based on the short period of time that is typically displayed operationally (normally less than a week of observed data are being processed). This makes it is very difficult to change these two storages independently. It is much preferred to use the relationship between these two runoff components that was established during the calibration and rely on the .SACBASEF MOD to make run time modifications to the contents. On most watersheds the contents of the supplemental, and especially the primary, storage will affect the amount of low flow that is produced for a considerable time in the future.

- UZFWC - It is not recommended that the forecaster attempt to modify this value. The contents of the upper zone typically change quite rapidly, especially when water is entering the model. The UZFWC value could possibly be changed to increase or decrease the amount of interflow during the first few days of a recession, but even then it is difficult to determine a new value since the upper zone free water storage is losing water both as interflow and percolation. The only saving feature if UZFWC is modified, is that the effect will only last for a short time since this zone typically drains within a few days though the effect of altering the percolation amount would persist much longer.

- UZTWC, LZTWC, and ADIMC - Tension water deficits develop over some period of time during periods of dry weather and substantial evaporation. Potential errors in the size of the se deficits are caused, in part, by biased evapotranspiration estimates due to abnormal weather conditions or vegetation activity. The errors can also be due to biased estimates of precipitation for the events, frequently convective, that occur during the period that the deficits develop.

Streamflow observations can't be used to determine if a problem exists in the size of the tension water deficits until a substantial runoff event occurs. This could be a rain storm after a dry period or the beginning of snowmelt for a year when the summer moisture deficiency wasn't satisfied by fall rains. In both of these cases the tension water deficits may only be a portion of the reason why the streamflow response is not simulated correctly. In the case of the rain event, the amount of rainfall for the storm could be incorrect. In the case of the snowmelt situation a number of factors can affect the simulation at the beginning of the melt season as discussed at the end of Section 7-7. These factors need to be taken into account when making modifications to the conditions prior to such events.

Tension water deficits could also possibly be adjusted based on soil moisture observations. There have been studies that showed favorable comparisons between the Sacramento model tension water deficits and soil moisture measurements. In order to properly use the soil moisture data to update the tension water contents, relationships would have to be established using an overlapping period of stable soil observations and historical model simulations. The problem in many cases would be in finding a sufficient record of moisture observations to develop the relationships. The soil moisture data would not have to be available in real time in order to be used for updating as tension water deficits develop slowly. It would be sufficient if the data were available within a day or two after the observations were made.

If the tension water contents are suspected to be in error prior to any runoff events and there is not an objective procedure for updating the values, extreme care is advised when making any changes. This is because these deficits, especially the lower zone deficit, can affect the amount of runoff produced over a considerable time into the future. Thus, any change can have a significant impact on an extended flow prediction, especially in times of drought. The range in the contents during the historical simulation should certainly be used to avoid a completely unreasonable modification.

Typically if the upper or lower zone deficits are altered and the ADIMP parameter is being used to produce direct runoff, the value of ADIMC should also be adjusted.