Section 7-7

Effect of Snow Model Parameters on Model Response

<u>Introduction</u>

A critical aspect of interactive trial and error calibration is to understand the unique effect that each parameter has on model response and how to isolate that effect. This understanding allows the person doing the calibration to make educated decisions as to which parameter values should be changed as opposed to random guesses. Without this understanding, interactive calibration becomes an exercise in futility.

This section describes the unique function of each of the major snow model parameters and also discusses things to examine when deciding which, if any, parameters should be changed when simulated and observed flows don't agree at the beginning of the snowmelt season. The unique aspects of each parameter are illustrated by hydrograph plots for the appropriate time periods with different values of the parameter being considered. These plots are generated by running the models with everything exactly the same except for the value of the parameter being discussed. Under such conditions the unique effect of each parameter can clearly be shown. The actual problem of deciding on which parameters to change becomes much more difficult during calibration because of noise in the data and the fact that typically multiple parameters need to be adjusted. The combination of the effects of multiple parameters not having the proper value make it much more difficult to determine which parameter values need to be altered. To have any hope of making the proper changes in a reasonable amount of time, one must know what periods to examine and what to look for to isolate the effects of each parameter. It is also helpful to have a systematic strategy for checking the parameters for possible changes. Such a strategy is outlined in Section 7-1.

Besides plots showing the effect of changing each of the parameters, panels that show how the model states are changing and other results of the model computations are included in many of the figures. These panels are extremely helpful in determining when the conditions occur that are needed to isolate the effects of the parameter. An explanation of the items included in these panels is in the next section. Even though two hydrograph plots are included on each figure to show the difference in response with different values of the parameter, the panels showing the model states and computations can only be included for one of the parameter values for a single zone. This value and zone are indicated next to the panels on each figure.

<u>Explanation of Panels Showing Model States and Computations</u>

Figure 7-7-1 illustrates the panels which are part of the ICP WY-PLOT display for the SNOW-17 operation. The plots on these panels are for a daily time interval. Instantaneous values such a water-equivalent are for the end of the day and mean, average, or total values such as energy exchange and air temperature are the mean, average, or total for the day.

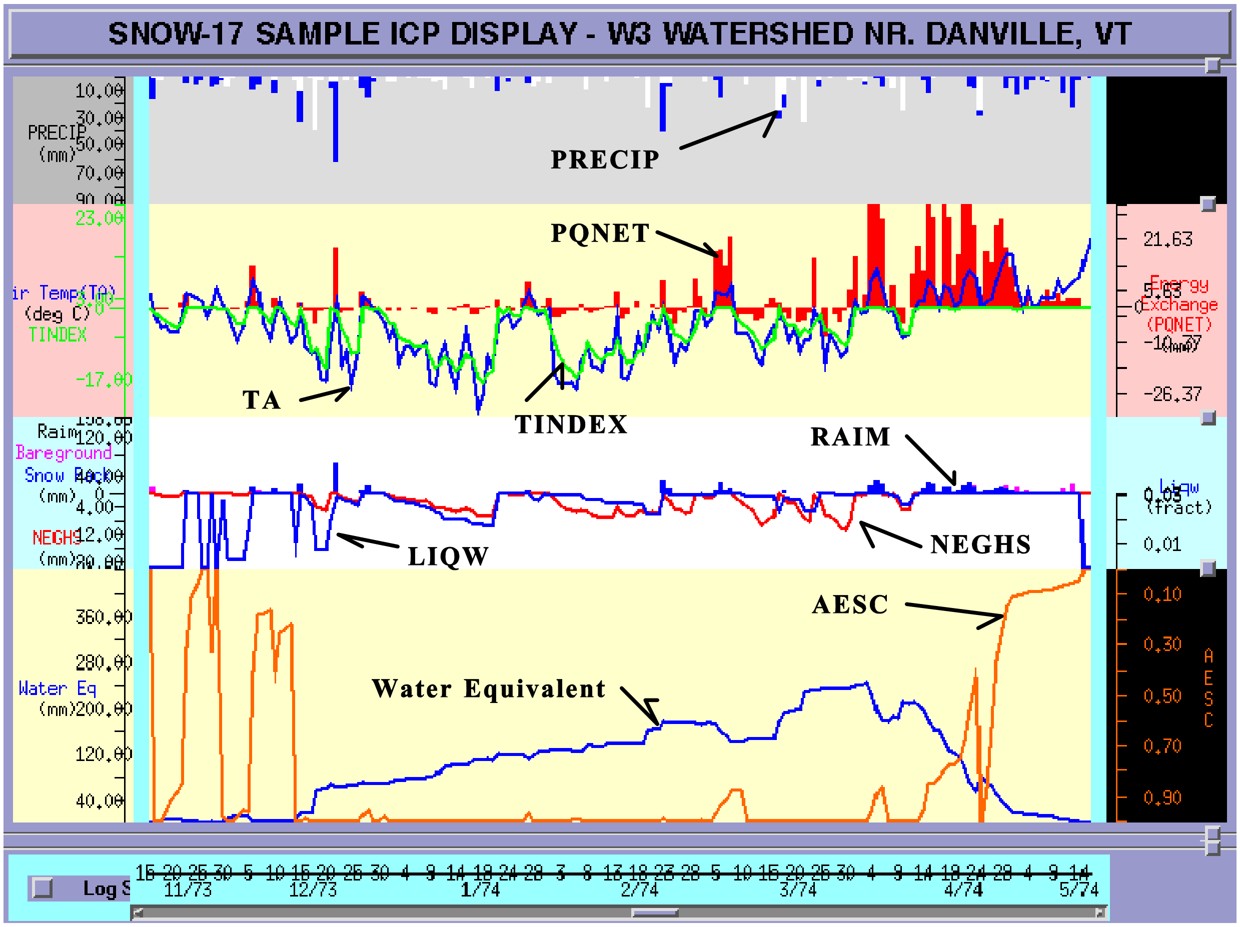


Figure 7-7-1. Sample ICP display for the SNOW-17 model.

• Top Panel – This panel shows the total amount of precipitation (PRECIP) for each day with the scale on the left side. The portion in blue indicates that the precipitation was rain, while the portion in white indicates snow. If the rain-snow elevation option is used, this panel will also contain the average elevation of the rain-snow line if it is within the elevation range of the zone. The rain-snow elevation scale will be on the right side.

• Second Panel from Top – This panel shows the average daily air temperature (TA) in blue and the average daily snow cover temperature index (TINDEX) in green with the scale on the left side. The gradient defined by these two variables indicates the direction of heat flow when the air temperature is below freezing. The panel also contains the total daily net energy exchange (PQNET) in red with the scale on the right side. The units of the energy exchange are mm (that is the energy needed to melt 1 mm of snow). The energy exchange is the combination of non-rain melt, rain-on-snow melt, and changes in the heat deficit of the snow cover during the day.

• Third Panel from Top – This panel shows the amount of liquid water (LIQW) in the snow cover in blue with the scale on the right side. The maximum amount of liquid water is contro lled by the PLWHC parameter. The brown line shows the heat deficit or negative heat storage (NEGHS) in the snow cover at the end of each day with the scale on the lower left side. The units for NEGHS are mm, i.e. the amount of melt or rain that is needed to return the snow cover to isothermal conditions at 0°C. This panel also shows the total amount of rain plus melt (RAIM) for each day with the scale on the upper left side. When the RAIM is in blue it indicates water that came from the snow cover (either melt or rain water that passed through the snow), while when RAIM is in magenta, it indicates rain on bare ground.

Bottom Panel – This panel shows the total amount of water equivalent in blue with the scale on the left side. This is the sum of the ice portion of the snow cover, any liquid water, and water moving through the snow at the end of each day. The panel also shows the computed areal extent of the snow cover (AESC) in brown with an inverted scale on the right side (bottom of plot is 100% cover and the top is bare ground).

Major Snow Model Parameters

This section describes the unique effect of each of the major snow model parameters. Examples are included for a watershed with a single zone and for most parameters, examples are also shown for watersheds with multiple elevation zones.

SCF – The snow correction factor is the only snow model parameter that controls the amount of snow that accumulates and thus the volume of snowmelt runoff. This is assuming that significant errors in the form of precipitation have been corrected. The effect of SCF shows up in the later part of the snowmelt season, i.e. when either too much or too little snow may remain and thus continues the snowmelt period beyond when it should end or cause melt to stop too soon. This is the period to examine to determine if there is a problem with the amount of snow. The higher the value of SCF the more snow will accumulate and the longer snow will remain and vice versa.

Figure 7-7-2 shows the effect of changing the value of SCF on the volume of snowmelt runoff for a watershed with only one zone. There is no difference during the period when there is 100% cover with both values of the parameter. The difference occurs during the later part of the melt season when the increase in the amount of snow with SCF=1.4 results in more runoff volume. Once the snow is gone, the difference in response between the two values disappears over time. There is some difference in runoff from the large rain event near the end of May, since the soil is more saturated at that time when SCF=1.4 due to a longer period of snowmelt, but by the rain event in mid June, the difference is minimal.

Figure 7-7-3 shows the effect of changing SCF for just the upper elevation zone of a mountain watershed for a year with a large enough amount of snow that the upper area remains at 100% cover for some period of time after melt begins and there is no significant rain during the snowmelt season. The figure also shows what portion of the runoff is

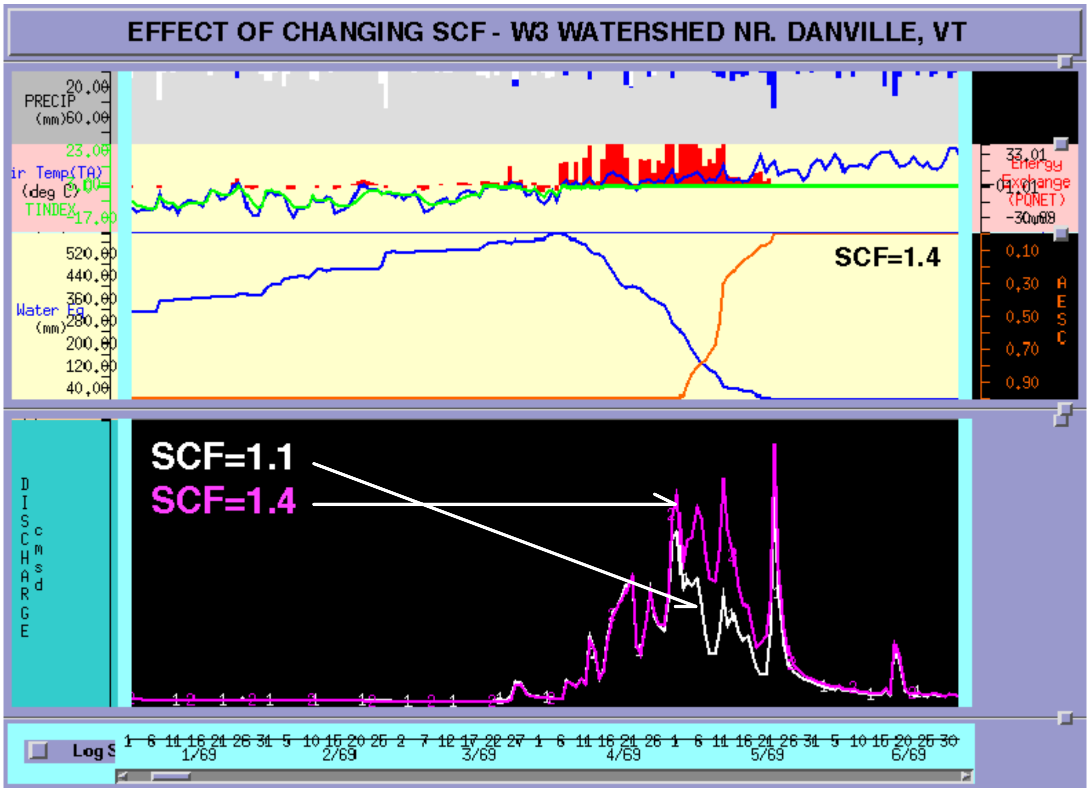
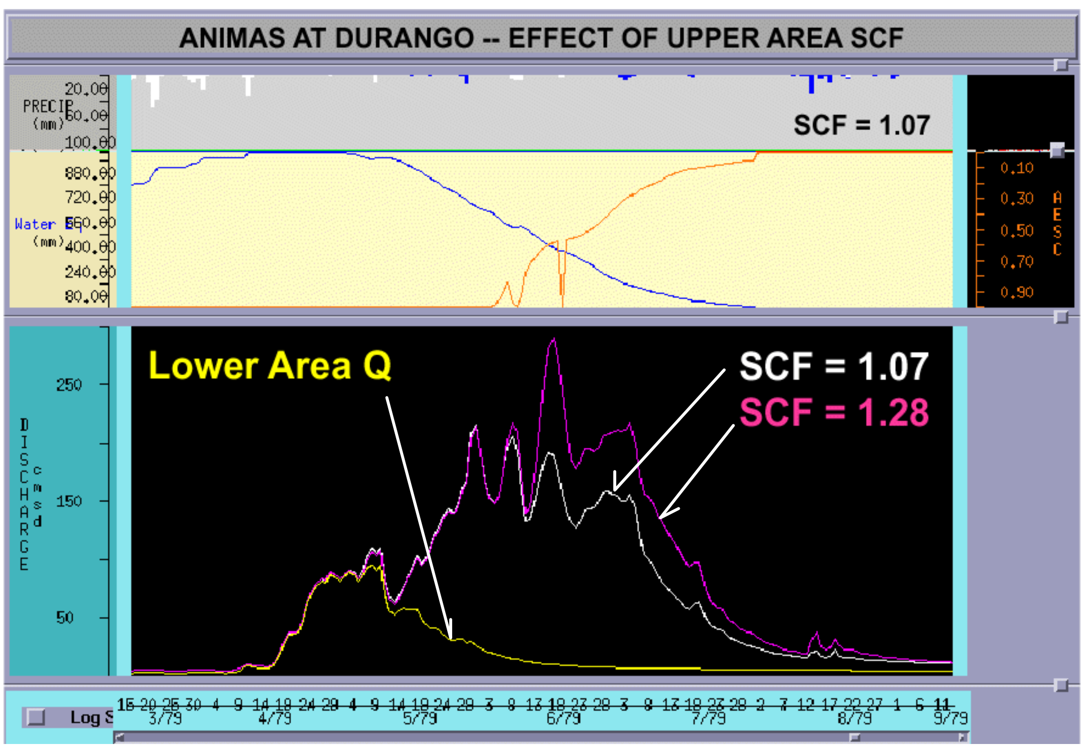


Figure 7-7-2. Effect of changing SCF for a watershed with one zone.

Figure 7-7-3. Effect of changing SCF for an upper elevation zone.



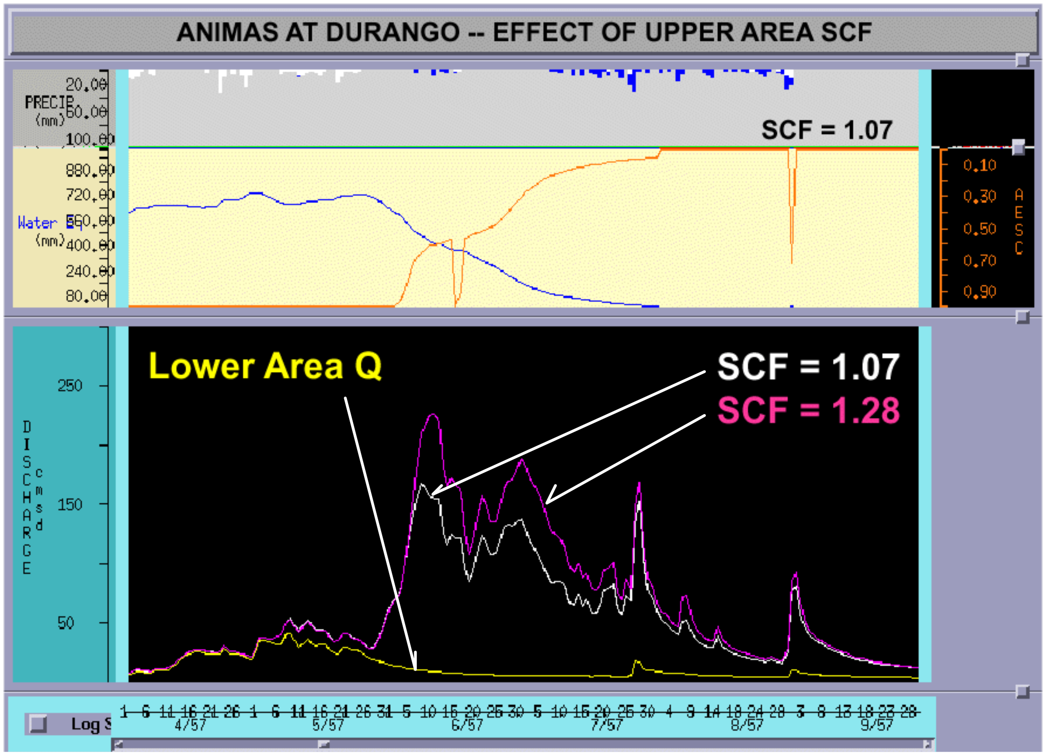
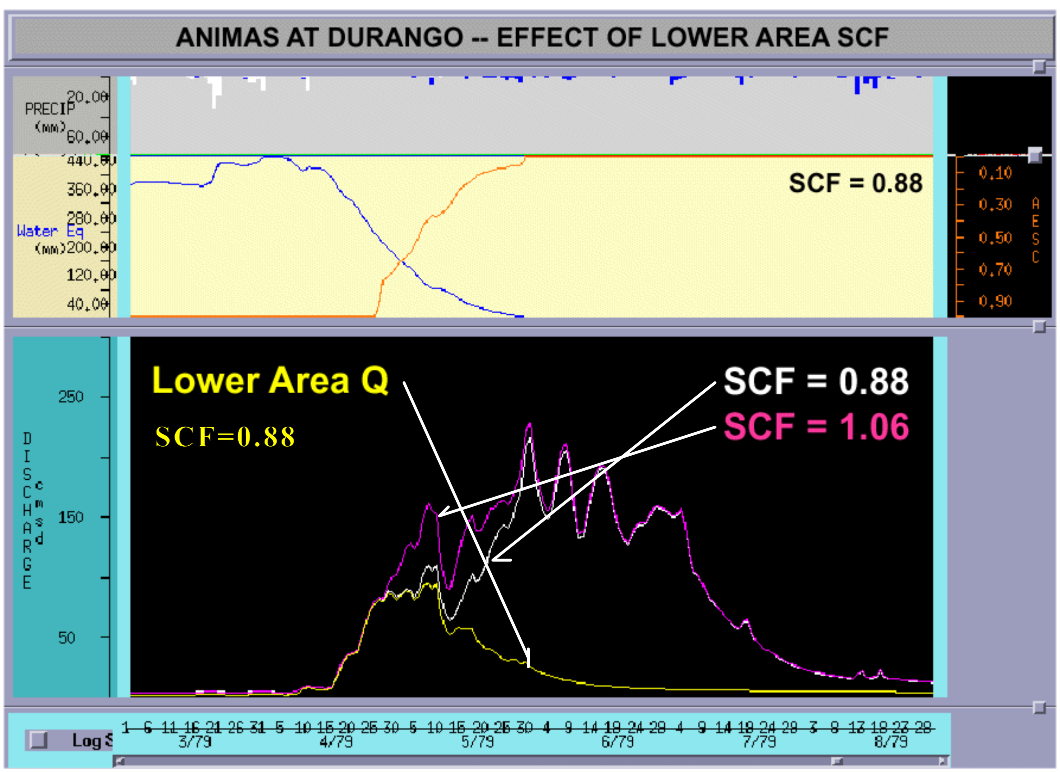


Figure 7-7-4. Effect of changing upper zone SCF with rain near the end of melt.

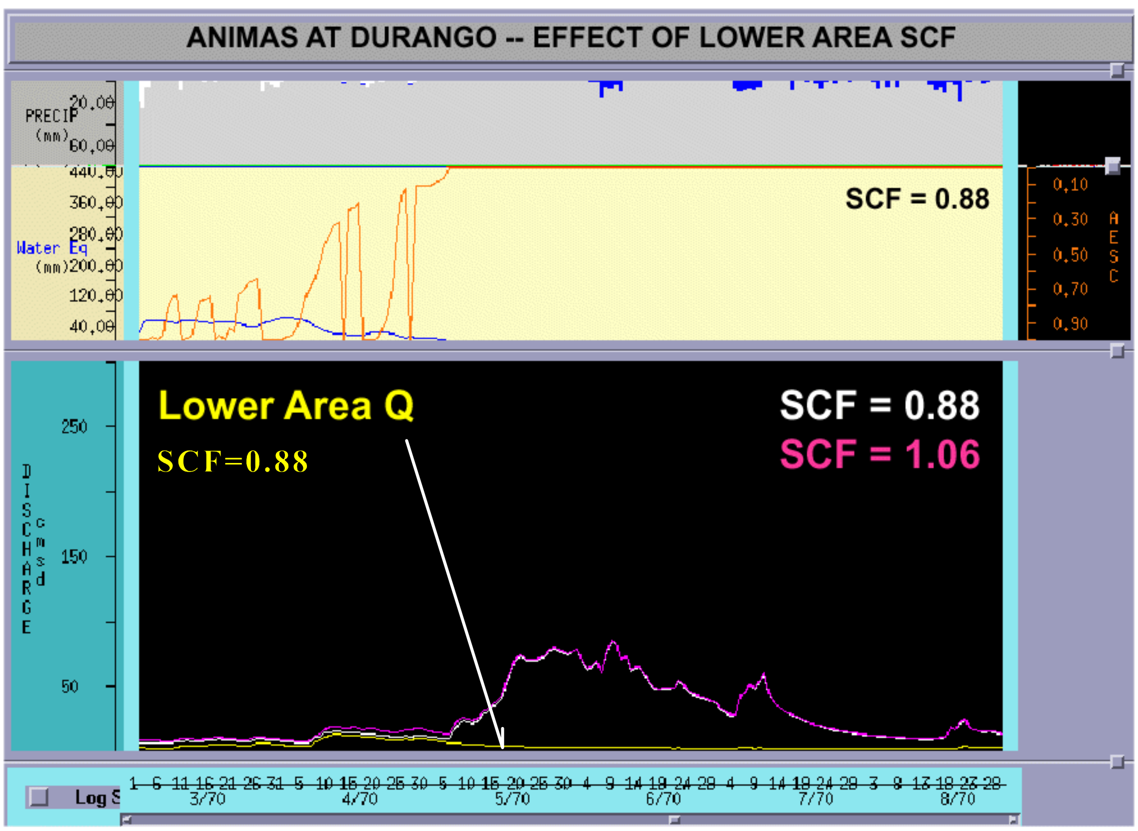
Figure 7-7-5. Effect of changing SCF for a lower elevation zone.



produced by the lower zone. It is very important when working with watersheds with multi ple elevation zones to known the contribution of each zone. The response to snowmelt is the same as in the previous figure since the upper zone melts off last and there are several weeks with 100% cover after melt begins. Figure 7-7-4 shows the same case for another ye ar for the same watershed. During this year the upper zone only remains at 100% cover for a short period after melt begins and the lower zone contribution is much less than in the previ ous example. Also during this year there is a significant amount of rain late in snowmelt se ason and for some time thereafter. Again the primary effect of changing SCF is to alter the amount of snow accumulation and thus the volume of runoff from snowmelt. There is some effect on the amount of runoff from the rain events, but this is small and diminishes with ti me. Figure 7-7-5 shows the effect of changing SCF for the lower zone for the same year as shown in Figure 7-7-3. This is a year when there is substantial volume of snowmelt runoff f rom the lower zone. Again by increasing the value of SCF, the volume of snowmelt runoff is increased, however, since the lower zone melts off well before the upper zone, the effect sh ows up toward the early part of the snowmelt season for the entire watershed. Figure 7-7-6 illustrates the effect of changing the lower zone SCF value on a year with little snowmelt run off from the lower zone. In this case since the snowmelt runoff volume from the lower zone is minimal, the effect of changing SCF for this zone has little effect on the hydrograph.

Figure 7-7-6. Effect of changing lower zone SCF during a low snow year.

To repeat, the unique effect of the SCF parameter is to control the amount of snow accumulat



ion and thus the volume of runoff from snowmelt. It is the only snow model parameter who se primary effect is to control the runoff volume.

Under the SCF parameter initial value discussion in Section 7-4 it was mentioned that when average annual precipitation is based on the water balance (determined by adding an estimate of actual annual ET to mean annual runoff) that the result could be too much rain and not enough snow. If this appears to be the case for such watersheds, the PXADJ factor in the SNOW-17 operation can be decreased below 1.0 to reduce the amount of rain and then SCF increased as necessary to obtain the correct amount of snow cover runoff.

<u>MFMAX and MFMIN</u> – These two parameters determine the maximum and minimum value of the non-rain melt factor. MFMAX has more effect when most of the melt occurs after March 21st, while MFMIN has more effect on melt that occurs prior to that date. The non-rain melt factor is used to determine the melt rate when the area is completely covered by snow, thus the effect of these parameters can be isolated when non-rain melt is occurring and there is 100% or nearly complete areal snow cover. SCF and the areal depletion curve have no effect when there is 100% cover and UADJ is only used when there is rain-on-snow melt occurring. A variety of factors can affect when the onset of melt occurs and the response during the very early part of the melt season (these will be discussed later in this section), thus it is best to examine the period after melt is well underway and there is still complete or nearly complete areal cover to determine if the non-rain melt factor should be altered. Since the non-rain melt factor varies seasonally and melt can occur at different times, one technique that may prove useful is to plot the seasonal melt factor variation and then note when the results would be improved by changing the melt factor up or down and when it should be left the same. After examining a number of years, hopefully there will be a pattern to the suggested changes and a new seasonal melt factor curve can be drawn and new values of MFMAX and MFMIN determined for the next iteration.

Figure 7-7-7 shows the effect of changing both MFMAX and MFMIN. In this case MFMAX has the most effect since almost all the melt occurs after March 21st. The overall effect of changing these melt factors is to cause more melt to occur early in the melt season and thus less later because the snow will be gone sooner. To isolate the effect of these parameters the period to examine is from after melt begins to when bare ground begins to show, i.e. from late March until about the 21st of April. There is a difference in the hydrographs later in the melt season, but this is not the period to use to determine if the non-rain melt factor needs to be adjusted as other snow model parameters can also affect this later period.

Figure 7-7-8 shows the effect of changing MFMAX for both elevation zones of a mountain watershed during a big snow year when there is significant snowmelt runoff from the lower elevation zone. Again the overall effect of increasing MFMAX is to cause more melt to occur early in the melt period, in this case for both elevation zones. Figure 7-7-9 shows the same change for a small snow year when there is little snowmelt runoff from the lower

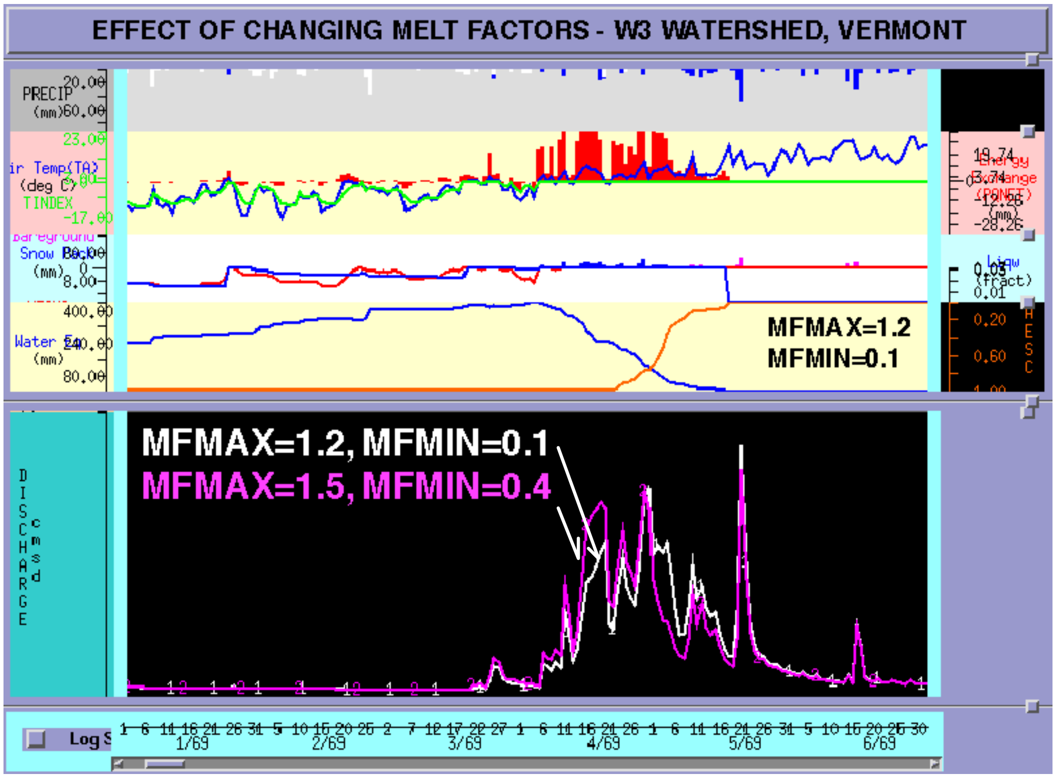


Figure 7-7-7. Effect of changing MFMAX and MFMIN for a watershed with one zone.

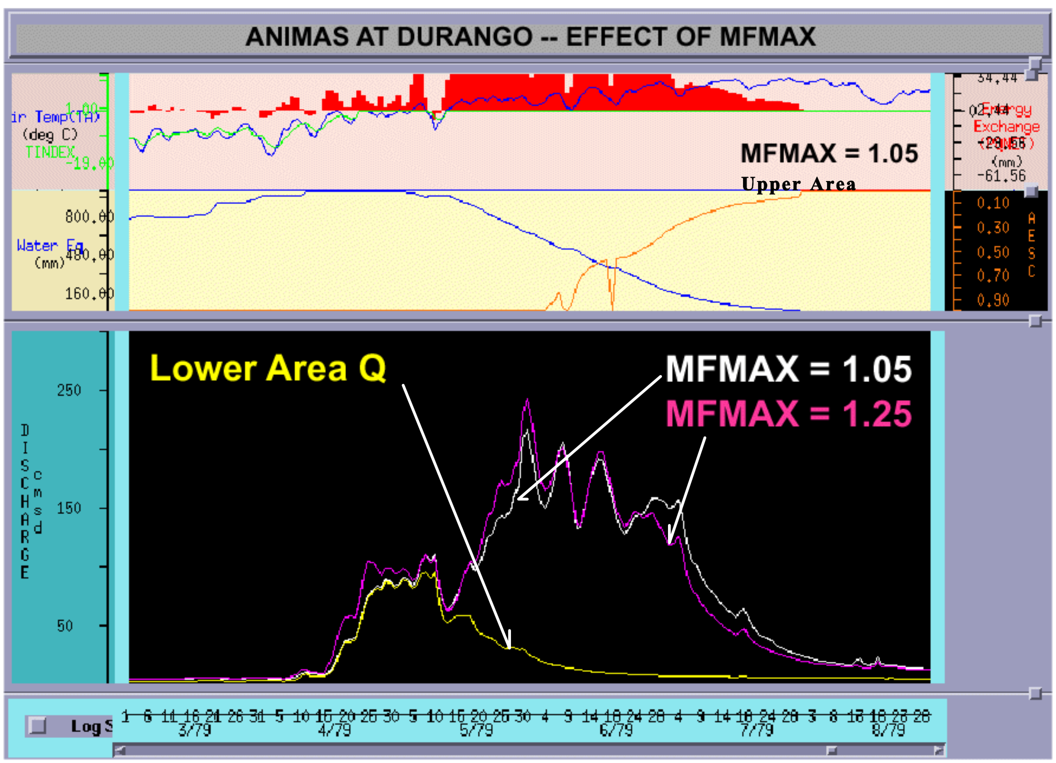


Figure 7-7-8. Effect of changing melt factors for 2 elevation zones during a big snow year.

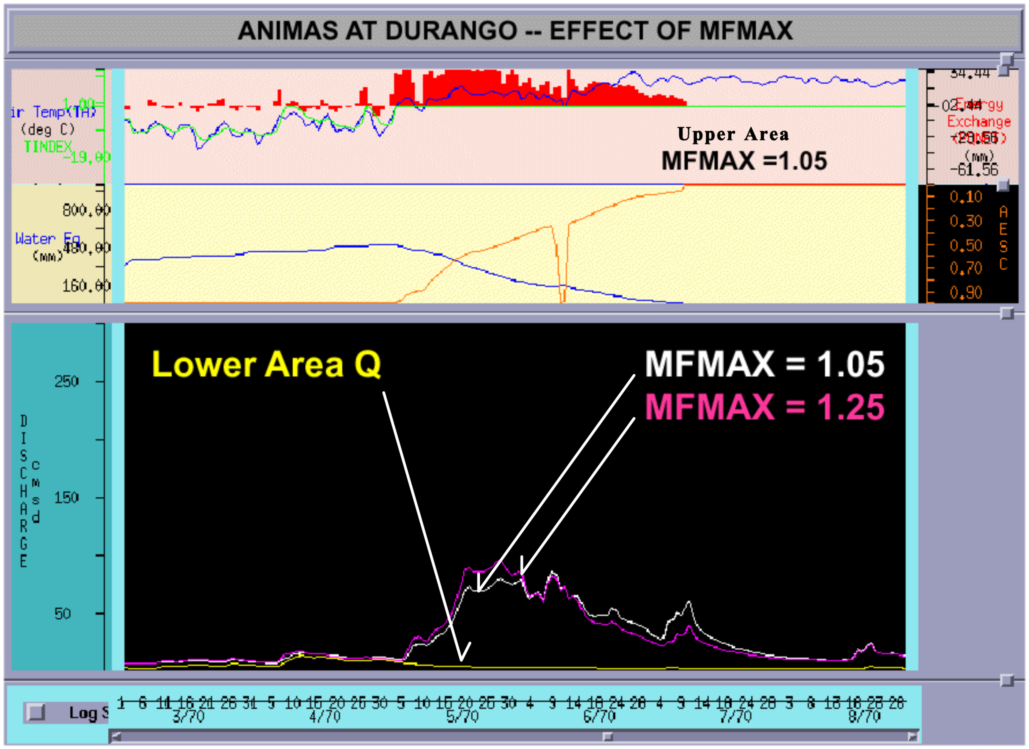
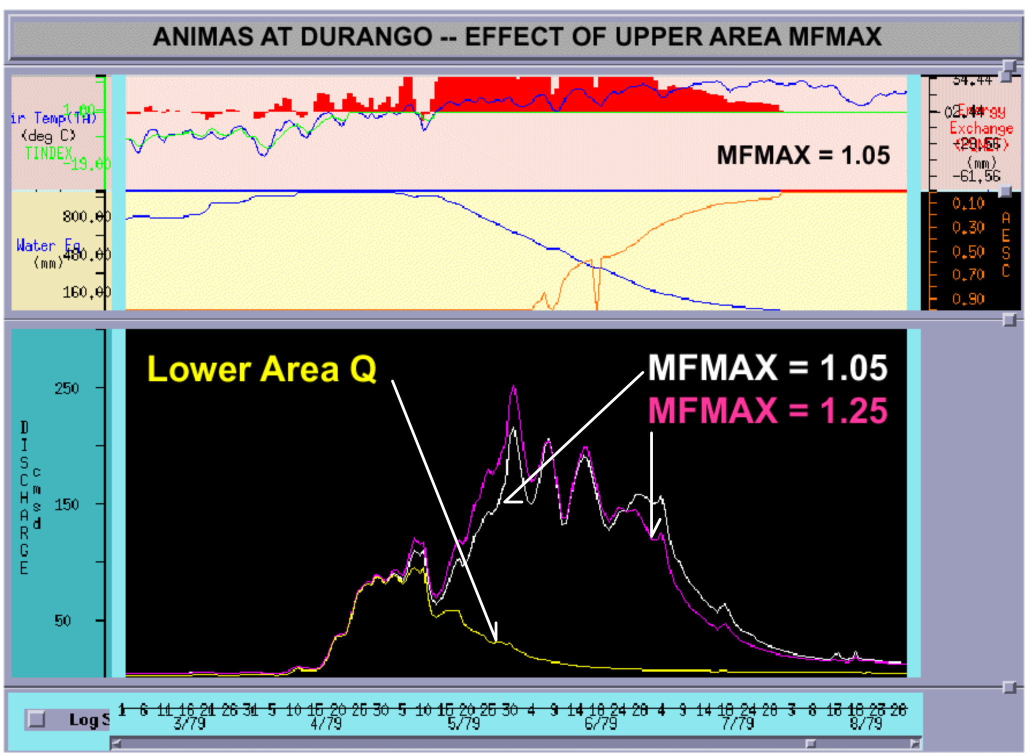


Figure 7-7-9. Effect of changing MFMAX for 2 elevation zones for a small snow year.

Figure 7-7-10.   Effect of changing MFMAX for the upper elevation zone only.



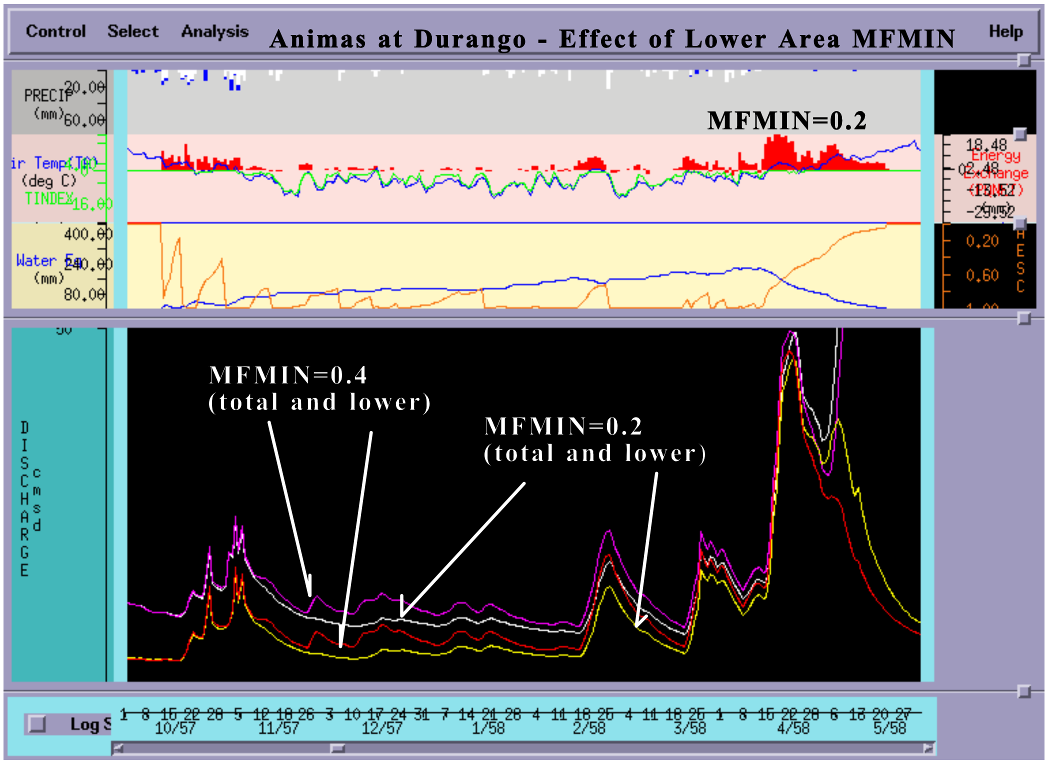


Figure 7-7-11. Effect of changing MFMIN for the lower elevation zone.

elevation zone. In this case the effect of increasing MFMAX for the lower zone is not notic eable since this zone produces little runoff. For lower elevation zones the effect of changing snow model parameters will only be visible during years when these zones have sufficient snow to produce a significant amount of runoff. Figure 7-7-10 shows the effect of changing only the MFMAX parameter for the upper elevation zone during a large snow year. In this case the timing of the melt from the upper zone is affected which again underscores the importance of knowing where the runoff is coming from when multiple zones are being used. Figure 7-7-11 shows the magnified effect of changing the MFMIN parameter for the lower elevation zone for this same watershed. Increasing the MFMIN value causes more melt during mid winter periods when the temperature goes above freezing at the lower elevations. Changing MFMIN for the upper zone wouldn't affect these periods since the temperatures remain below freezing at the higher elevations. In many watersheds in the intermountain west, MFMAX is the most important melt factor parameter since most melt occurs in the spring, however, in some cases there is some winter melt at lower elevations which allows for checking the value of MFMIN for the lower zone. The value of MFMIN for the upper zone is fairly insensitive for these watersheds.

To repeat, the unique characteristic of the non-rain melt factor parameters is that they determine the melt rate when there is 100% snow cover, thus the effects of MFMAX and MFMIN can be isolated once melt has really started and the area is completely, or nearly completely, covered by snow.

<u>SI</u> – The SI parameter determines when and for how long the area remains at 100% areal cover. During small snow years, typically bare ground shows up as soon as significant melt occurs. During large snow years, most areas remain at or near 100% areal cover for some period of time after melt begins. Thus, the effect of SI can generally be isolated by examining the snowmelt patterns during years with different amounts of snow accumulation. In Section 7-4 it was recommended that the initial value of SI be set to a value greater than any mean areal water equivalent that will occur during the period of record. If this is done, the initial run will show bare ground showing up as soon as melt begins for all years. Then one can examine the larger snow years to see if more melt is needed for some period into the snowmelt season. By tabulating the water equivalent values above which more melt is needed, one can determine a reasonable guess at a value of SI to try.

Figure 7-7-12 shows the effect of SI on a large snow year. When SI=999, bare ground shows up as soon as the snow begins to melt. When SI=200, the watershed remains at 100% areal cover until the mean areal water equivalent drops below 200 mm. This causes the entire area to contribute melt until the water equivalent (WE) drops below 200 mm. Figure 7-7-13 shows the same parameter combination for a small snow year. In this case there is almost no change in the response since the mean areal water equivalent barely exceeds 200 mm and thus, in both cases bare ground shows up soon after melt begins.

Figure 7-7-14 shows the effect of SI for the upper zone on a watershed with 2 elevation zones during a large snow year. When using a value of SI=600 mm, the melt continues over 100% of the area until the water equivalent reaches the SI value near the middle of June. When SI=999, the areal cover begins to deplete as soon as outflow is initiated from the snow cove r in the upper zone in early May. This causes the mean areal melt to be less than what would occur if the zone had remained completely covered. Figure 7-7-15 shows the effect of SI for the upper zone during a small snow year. In this case there is no difference in the response since the mean areal water equivalent never exceeds 600 mm. Figure 7-7-16 shows the effect of using a value of SI that causes both zones to remain at 100% areal cover for a significant time after melt begins during a large snow year. This increases the snowmelt contribution from both zones during this period.

To repeat, the effect of the SI parameter can be isolated by examining the early part of the melt season, i.e. the same period as used to isolate MFMAX and MFMIN, only in the case of SI one is looking for differences in response between large and small snow years. SI allows for 100% of the area to contribute for some period during years with a large snow accumulation, but not during small snow years.

Areal Depletion Curve – The areal depletion curve controls the amount of snowmelt once bare ground begins to appear. Thus, it is the timing of snowmelt whenever the mean areal water equivalent is less than SI that is examined to determine if the shape of the areal depletion curve should be altered. The best way to determine how the curve should be changed is to plot the areal depletion curve and then go through each of the years in the

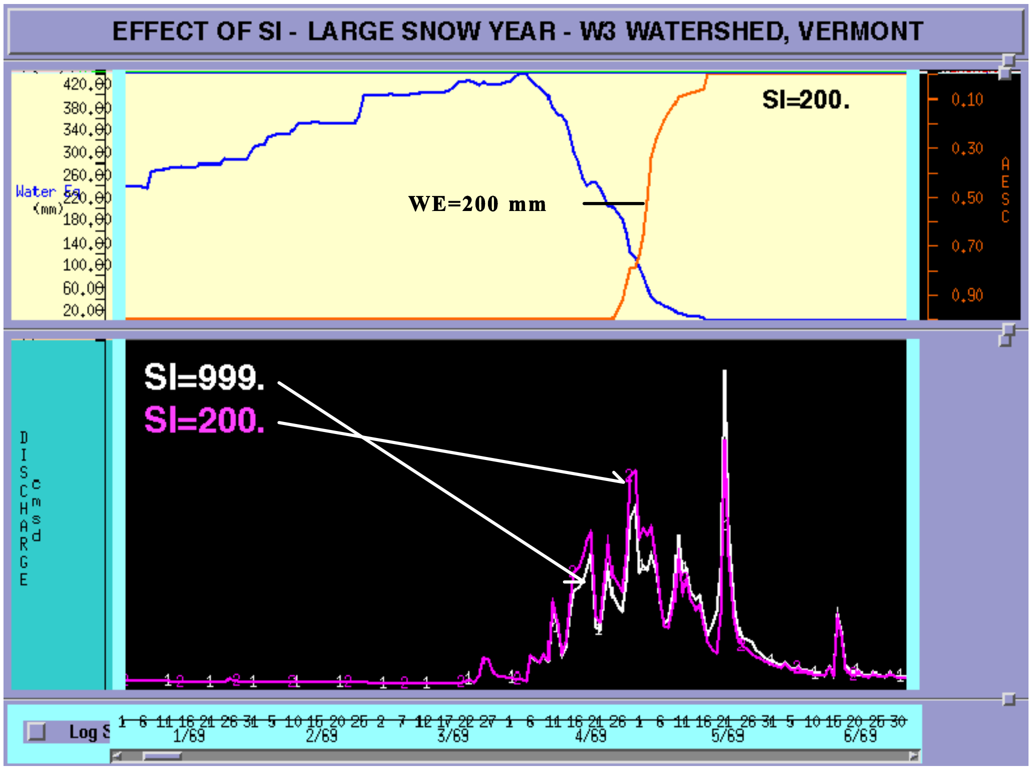
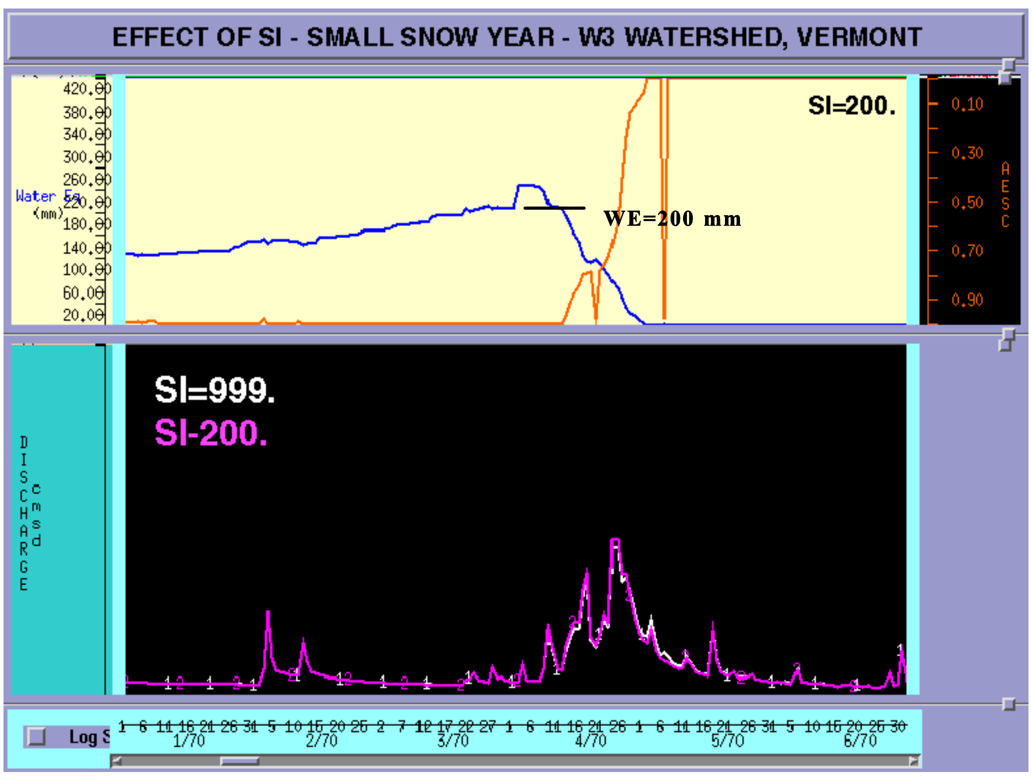


Figure 7-7-12. Effect of SI on a large snow year for a single zone watershed.

Figure 7-7-13.   Effect of SI on a small snow year for a single zone watershed.



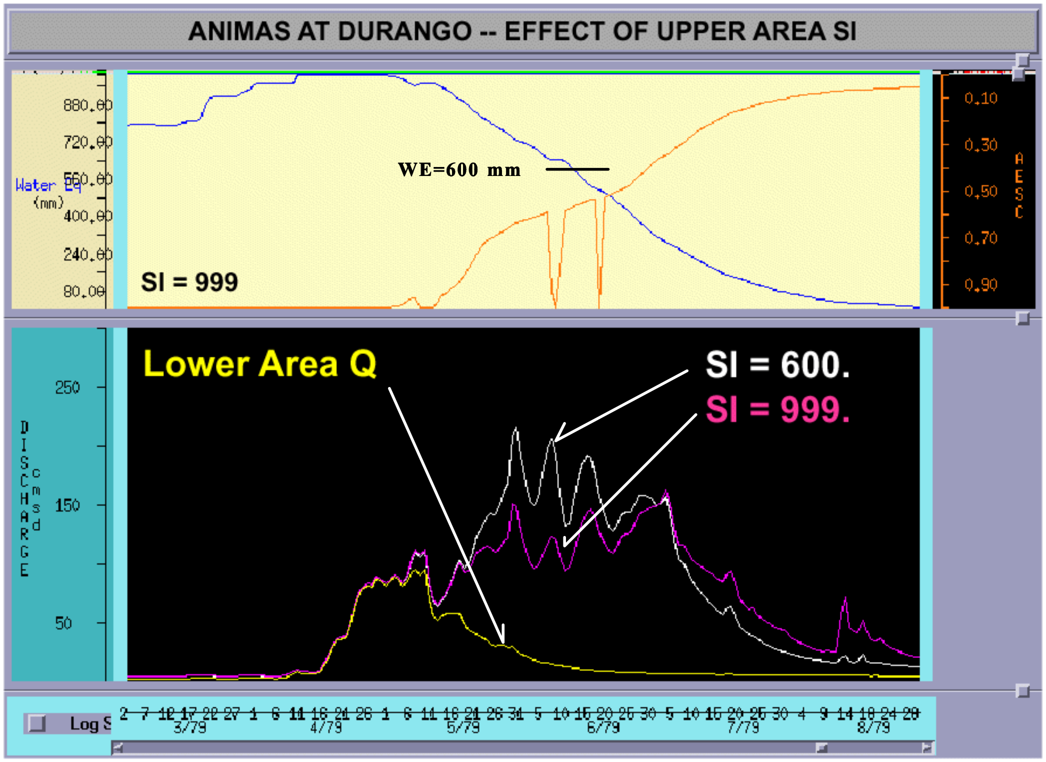


Figure 7-7-14. Effect of changing SI for a upper zone for a large snow year.

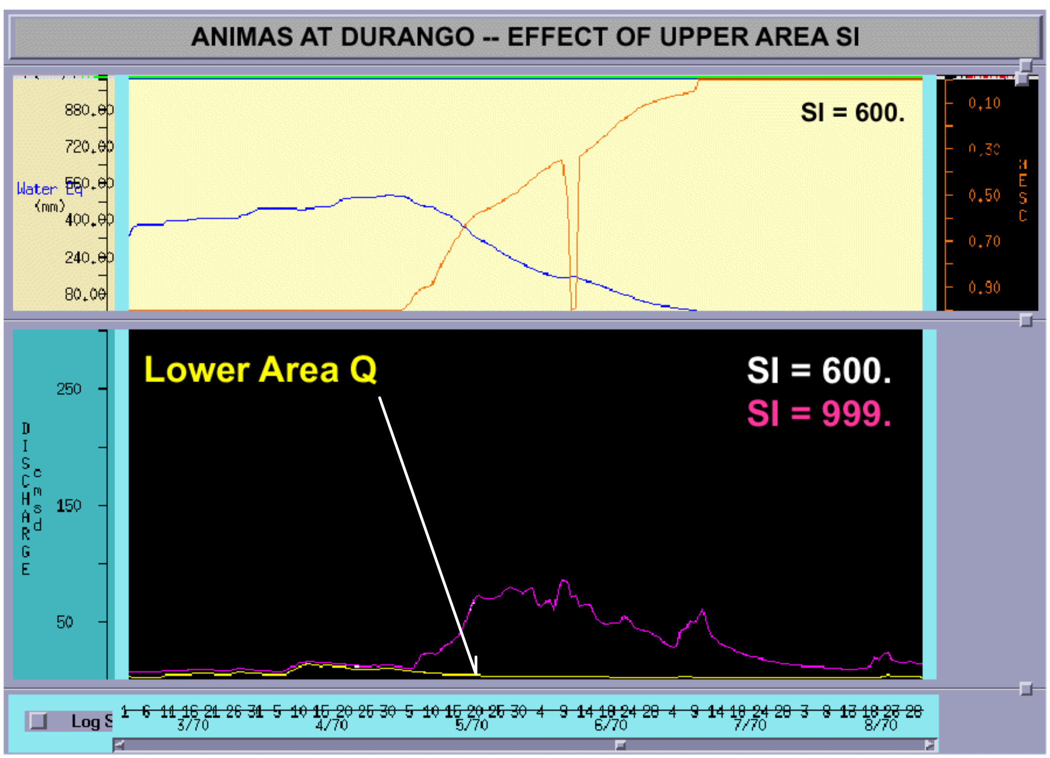


Figure 7-7-15. Effect of changing SI for a upper zone for a small snow year.

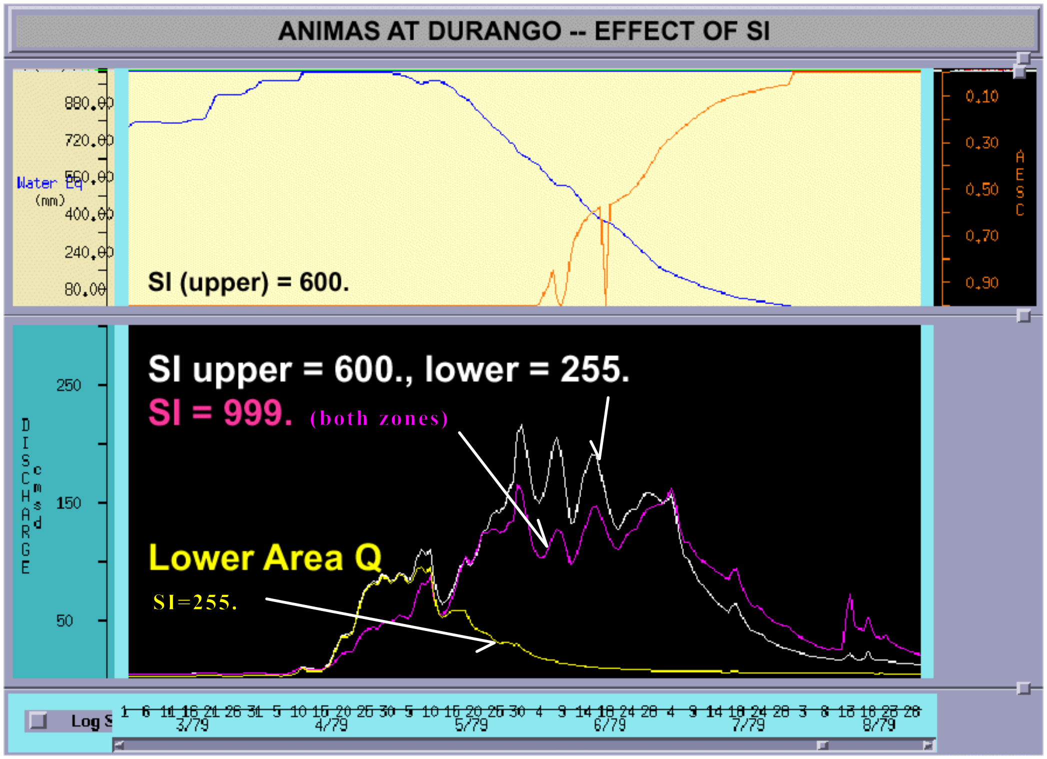


Figure 7-7-16. Effect of changing SI for both elevation zones during a large snow year.

calibration period and note what portion of the curve is being used at different times when some bare ground exists. If more melt is needed at a given time, it suggests that the areal cover should be increased for that WE/A_i ratio and vice versa. Hopefully a pattern will develop that indicates how the overall shape of the curve should be changed. In the following examples the sample initial value curves, curves B and C as shown on Figure 7-4-4, are used to illustrate the effect of changing the shape of the areal depletion curve.

Figure 7-7-17 shows the effect of changing the depletion curve for a watershed with no elevation zones. There is no difference in the hydrographs prior to when bare ground first begins to show. After that the ‘B’ curve melts off the snow quicker because the areal extent of the snow cover is significantly greater than for the ‘C’ curve for WE/A_i ratios above 0.4.

Figure 7-7-18 illustrates the effect of changing the areal depletion curve for the upper zone of a mountain watershed during a large snow year. Again the hydrographs are the same until bare ground begins to show up in the upper area. Again the ‘B’ curve melts off the snow quicker at first than the ‘C’ curve, however, due to the shape of the ‘B’ curve when only a little snow remains, there is still some snow left in this case in mid August to augment the summer rains that occur then. Figure 7-7-19 illustrates changing the areal depletion curve for both elevation zones for the same large snow year. Both zones remain at 100% cover for some period after melt begins. Changes to the depletion curve for the lower

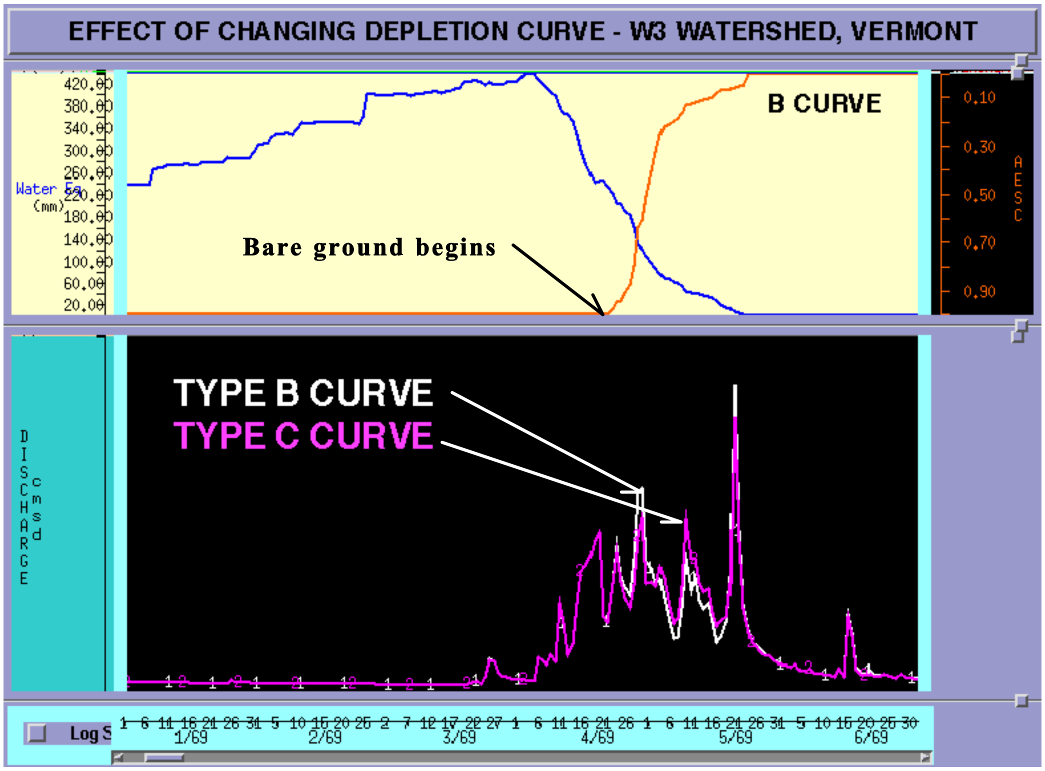
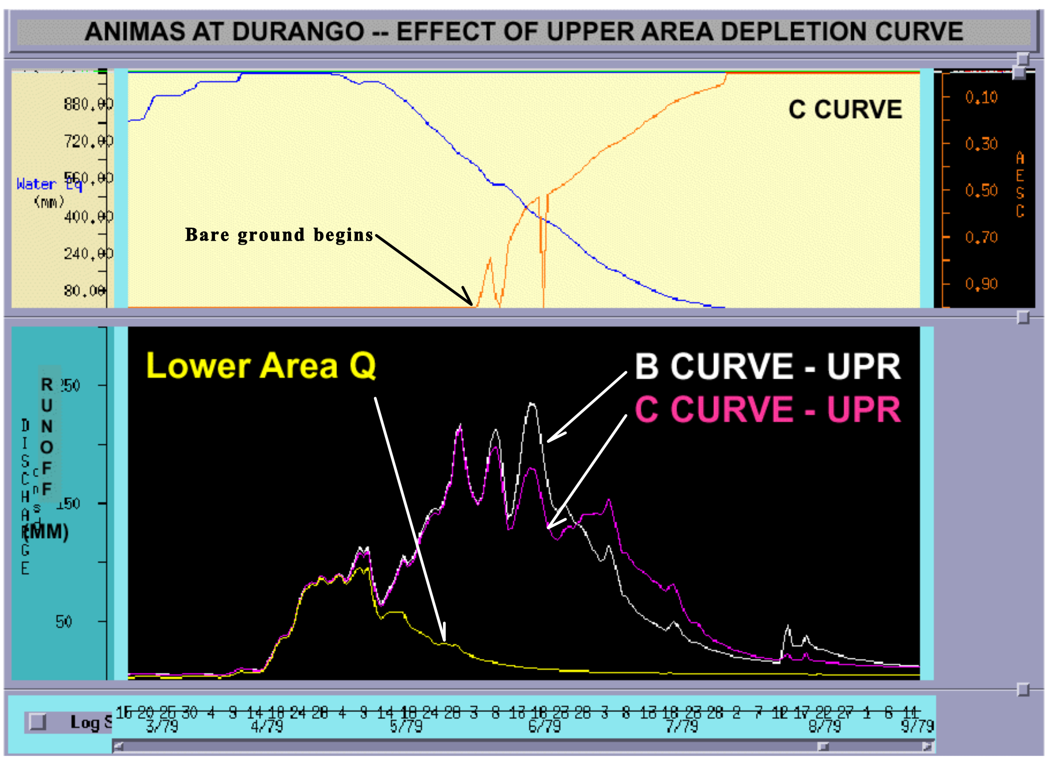


Figure 7-7-17. Effect of different depletion curves on a watershed with a single zone.

Figure 7-7-18. Effect of changing depletion curve for an upper elevation zone.



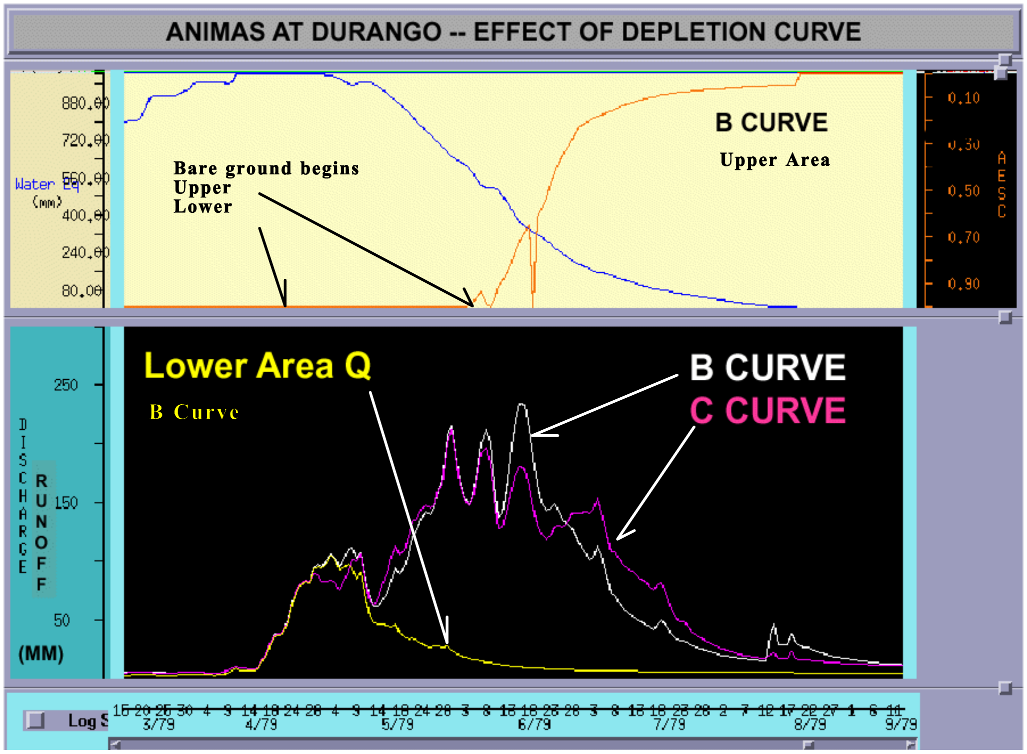
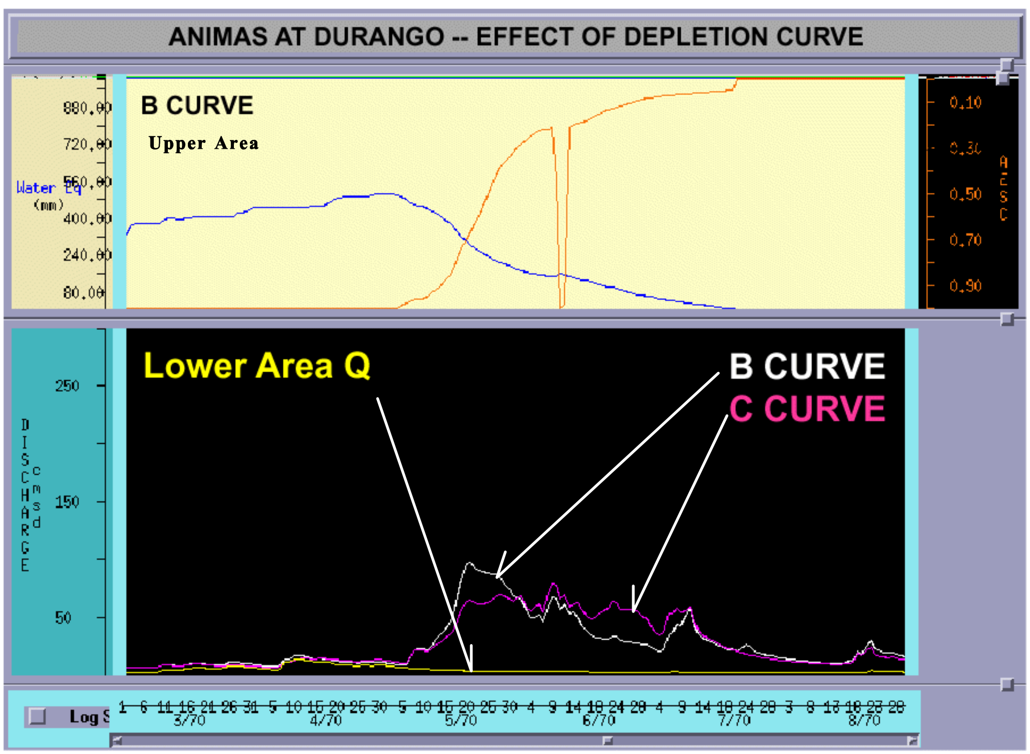


Figure 7-7-19. Effect of changing depletion curve for both elevation zones.

Figure 7-7-20.   Effect of changing depletion curve for both zones for a small snow year.



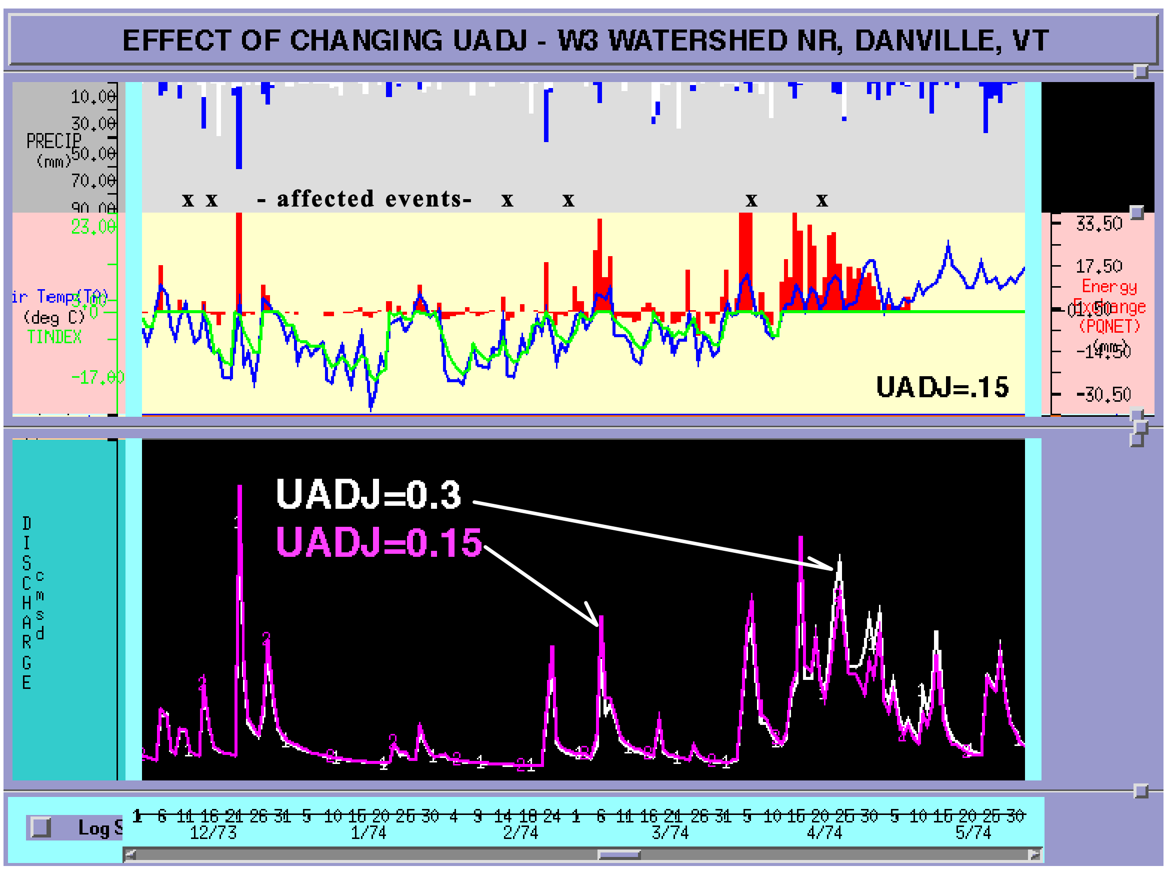
zone persist long enough so that the portion of the hydrograph when the upper area is compl etely covered is affected. Figure 7-7-20 shows the effect of changing the depletion curve f or this same watershed for a small snow year. During this year bare ground begins to show up as soon as active melt begins since the water equivalent for neither area exceeds SI, thu s the entire melt season is affected. Only the upper zone shows much effect to the depletio n curve changes because very little runoff is generated from the lower area.

<u>UADJ</u> – The rain-on-snow melt equation is only used when the rainfall rate exceeds 2.5 mm in a 6 hour period. Thus, to isolate the effect of the UADJ parameter, the rainfall rate mu st exceed that value. Also to have a significant amount of melt produced during rain perio ds, the air temperature must be well above freezing. If the temperature during rain is just b arely above freezing, very little melt will be generated. It should be emphasized that the a mount of rain is not a factor in isolating the effect of UADJ, but only that sufficient rain occ urs to use the rain-on-snow melt equation when the air temperature is well above freezing.

Figure 7-7-21 shows the effect of UADJ during a year with a number of rain-on-snow event s. Increasing the value of UADJ resulted in more melt during many of the rain events as n oted on the figure. Since these events were mostly in the winter, the additional snow

Figure 7-7-21. Effect of changing UADJ.

melted with UADJ=0.15 resulted in less snow being available for the main melt season in A



pril. For a few of the rain-on-snow events there was little difference in the amount of melt computed because the air temperature was barely above freezing. These were the 3 events occurring between the 6th and 16th of December and the 2 events in late January.

Table 7-7-1 summarizes the primary effect of each of the major snow model parameters. It is critical to understand the primary effect of each of these parameters in order to isolate the periods to examine to determine if changes are needed to their values.

Parameter	Primary Effect
SCF	Controls volume of snowmelt runoff
MFMAX, MFMIN	Controls melt when at or near 100% areal cover
SI	Controls when 100% cover exists during large snow years
Depletion curve	Controls melt when areal cover less than 100%
UADJ	Controls melt when rain falls and the temperature is warm

Table 7-7-1. Summary of primary effect of major snow model parameters.

<u>Discrepancies at the Beginning of the Snowmelt Season</u>

Various parameters and conditions can affect when the onset of snowmelt runoff occurs after a long accumulation period. This section attempts to discuss those items that should be examined when snowmelt runoff starts too early or too late. The things to consider include:

- <u>Snow Cover Heat Deficit</u> – If the size of the heat deficit is too large or too small prior to a snowmelt period, this can result in the onset of runoff to occur a few days late or early. Typically the size of the heat deficit is only sufficient to cause the onset of runoff to be off by a period of days and not weeks. A significant heat deficit will only exist prior to melt when there has been an extended period of very cold weather followed by a quick warm up to melt conditions. A significant heat deficit cannot develop when temperatures are not well below freezing or when the temperature warms up slowly, even though remaining below freezing, after an extremely cold period. Also a large heat deficit cannot build up in a shallow snow cover because there is not enough heat storage capacity. The size of the computed heat deficit is controlled by the TIPM and NMF parameters. To develop a significant heat deficit, the value of TIPM should be fairly low, typically 0.05 or 0.1, in order to maintain a large gradient between the air temperature (assumed snow surface temperature) and the antecedent temperature index (TINDEX, indicates the temperature at some distance within the snow cover) during a long cold period. When the temperature at the snow surface is considerably less than the internal snow temperature, then the larger the value of NMF, the faster the heat deficit will grow. Thus, if the size of the heat deficit is thought to be the cause of problems at the onset of snowmelt runoff, then one should try changing the TIPM and NMF parameters. It should also be recognized that even though small TIPM values and large NMF val ues will cause a significant heat deficit to develop during an extremely cold period, this same combination will cause the heat deficit to more rapidly diminish during a warm up. Thus, in order to have a large heat deficit that will affect melt computations and the timing of runoff, there must be a rapid transition from an extremely cold period to melt conditions.

Liquid Water Storage – The amount of liquid water that goes into storage within the snow cover when significant melt first occurs can have an effect on the onset of snowmelt runoff. If too much of the melt is held within the snow cover as liquid water, the runoff will be delayed and vice versa. For regions with a relatively deep snow cover during most winters, it is physically unrealistic to use a liquid water holding capacity for ripe snow (PLWHC parameter) outside the range of 0.02 to 0.05. In these regions liquid water storage is seldom the cause of problems related to the onset of snowmelt runoff. However, in regions with generally shallow snow cover, especially in the plains and north central regions, the overall amount of liquid water that can be held in the snow can be considerably greater than 5% due to the slush layer that typically builds up at the snow-soil interface. In these regions a PLWHC value of 0.15 to 0.30 is quite common and the PLWHC parameter is a likely candidate for correcting problems at the onset of runoff from melt.

Ice Blocking the Channel System – In some regions, especially portions of the north central area and parts of Alaska, ice may build up and block portions of the channel system, especially drainage outlets and culverts. This results in the initial melt water ponding in fields and low lying areas until the ice melts and frees the outlet. By neglecting this situation, computed snowmelt runoff appears sooner than what is observed. Currently there is no explicit way to model this effect. A separate procedure or modification to a channel response or routing model would be the most physically realistic way to address the problem. The use of a larger than normal PLWHC may implicitly account for some portion of this condition.

Soil Moisture Conditions – Soil moisture conditions can have a significant influence on runoff at the beginning of a snowmelt period in many regions. Two soil moisture model situations typically can cause problems during such periods. First, the magnitude of the tension water deficits when melt begins will have a large effect on the timing and the amount of the initial runoff. In some regions it is common during years with a dry summer and fall for large tension water deficits to still exist when melt begins. During other years the deficits will be full going into the winter and remain full until melt begins. If the tension water deficits are too large when melt starts, generally the onset of runoff will be delayed longer than it should and vice versa. Thus, it is important to check the size of the tension water deficits prior to snowmelt especially if problems exist with the onset of runoff from the melt.
Percolation problems can also affect the timing of runoff at the onset of snowmelt though these problems typically continue well into the melt season. If the percolation rate is too large when melt begins, too much water will initially go into lower zone storages, while if the rate is too low, the water will run off too quickly. Generally if a reasonable baseflow simulation is obtained prior to working with the snow model parameters this will not be a significant problem though if the lower zone deficiency ratio in the Sacramento model moves over a large range during the melt season, there could be a problem with the percolation rate for the

drier conditions that exist when melt begins.

Temperature Bias – If snowmelt occurs well before or after the onset of observed runoff (typically a week or two) and none of the previously mention situations will explain the problem, it is very likely that the temperature values being used are too high or too low for the area they are representing. There can be two reasons for this situation. First, in some cases, especially in lower elevation zones of mountain watersheds, the elevation of the MAT time series is generally not the same as the mean elevation of the snow cover. The elevation of the MAT time series typically is selected as the mean elevation of the area being modeled, whereas in lower elevation zones, the snow may predominately be in the upper portion of the area. Thus, the mean elevation of the snow covered area is greater than the mean elevation of the entire zone. This situation can also occur during very low snow years in the upper elevation zone as described in Section 6-1. The solution to this problem is to use the lapse rates in the snow model to adjust the MAT time series values to the proper elevation. This is done by setting the mean elevation of the area to the mean elevation of the snow covered portion of the zone. Then the lapse rates will be used to adjust the MAT values by the elevation difference between that defined for the temperature data and that specified for the zone.

The second reason for the temperature values being off is that the MAT computations are producing biased values, typically due to improper monthly temperature-elevation relationships being used to extrapolate observed station data to the mean elevation of the area being modeled. Generally the problem involves extrapolating low elevation observations to higher elevations zones where most of the snow and runoff occur. In a few cases the problem is caused by an input error to the MAT program that causes the wrong stations to be weighted for one or more zones thus producing a biased temperature estimate. In order to see if adjustments to the temperature data will correct the problem, an elevation difference and lapse rate can be used to adjust the values or a non 0°C MBASE parameter value can be tried, however, once it is determined that the temperature data are biased, the MAT time series should be regenerated using the proper temperature-elevation relationships and station weights.