Chapter 4

Step 2 - Assess Spatial Variability

Introduction

After gathering all the information and data that may be needed for the calibration of a river basin, the next step is to carefully analyze the spatial variability of physiographic factors and hydrologic conditions over the basin. This analysis will be very beneficial in all of the succeeding steps. The spatial variability of conditions over the basin is very important in determining which streamflow points should be included in the calibration. Climatic variability will determine the methods used to analyze and process the historical data. It will also be used to determine if the watersheds need to be subdivided into elevation bands or split based on significant variability of soils and/or vegetation. This analysis of spatial variability will also be of great benefit in predicting how model parameter values might vary over the river basin. It will also form the basis for selecting initial parameter values and for assigning values to model parameters for portions of the basin that cannot be calibrated.

There are two general ways to assess the spatial variability over the basin. The first is to look at the variability of various physiographic factors such as topography, precipitation, temperature, evaporation, snow cover, soils, vegetation, and geology. The second is to look at variations in hydrograph response which is an integration of all the hydrologic factors.

Analysis of Physiographic Factors

Introduction

There are a number of physiographic factors, physical and climatic, that should be examined to understand how conditions vary over the river basin. Much of the physiographic data and certain analyses of these data are available in a digital, gridded form that can be processed using GIS applications. Some of these data may still only be in hard copy form. Most of these data should be able to be viewed and analyzed via CAP. Since the data available in the form needed for GIS applications are ever expanding and the features in CAP are periodically changing, this manual will not describe the details of how to obtain, view, and analyze these data.

Physical Factors

The physical factors that are important to examine include topography, soils information, vegetation cover and types, and geologic information. Displays of this information are based on information gathered and analyzed at some point in time. Generally the topography and geology of an area remain constant over the time frames involved in calibration. Soil characteristics also should remain basically constant over the period of record. Vegetation types and patterns can change in areas subject to land use changes, changes in agricultural practices, and forest variations

due to harvesting or large fires.

- Topography – The main question when viewing topographic information is how much does elevation vary over the river basin and within possible subbasins. Significant changes in elevation (more than about 1000 feet) generally indicate that there could be differences in precipitation, temperature, and evaporation that will need to be taken into account when analyzing and processing the data. The greater the range in elevation, the more chance that these variations will be important. One can also look at area-elevation curves for the basin and possible subbasins to determine if the vast majority of the area is at similar elevations and only a small fraction of the area is significantly different or whether there are major portions of the area at different elevations. If there is a significant difference in elevation affecting major portions of the area, it is very likely that mountainous area procedures need to be used when processing the data. As the elevation range increases there is also the likelihood that the individual drainages may need to be divided into multiple elevation zones for data processing and modeling purposes. Significant elevation differences also indicate that, if possible, it is important to include data that represent what is occurring at a variety of elevations.

  Topographic maps also generally show rivers and thus one can get a general idea of the shape of the individual watersheds with the basin. If there are watersheds that are long and narrow, this would indicate that these drainages may have a different shaped hydrograph depending on where the runoff occurs and may need to be subdivided if the necessary data are available. Also included on most topographic maps are lakes and reservoirs. It is important to note whether there are large lakes and/or reservoirs which may have a significant effect on hydrograph response and thus will need to be modeled separately. In extremely flat terrain, especially ones with many small lakes and ponds, it may be difficult to determine drainage boundaries and contributing areas. This will result in the drainage area, which is normally known, to be treated somewhat like a parameter in the calibration process. Topographic maps also typically show the location of large population centers and the general extent of forest cover. All of this information should be useful in the subsequent steps in the calibration process.

- Soils – The main thing to examine at this point regarding the soils data is whether there are significant differences in soil properties from one part of the river basin to another. In mountainous areas it could be helpful to see how the soil properties vary with elevation and whether a large change occurs within a particular elevation range. Differences in soil properties from one watershed to another within the river basin may indicate how certain model parameters should vary. Significant differences within watersheds may suggest that these watersheds possibly could be subdivided to improve simulation results. Since this author is not that knowledgeable regarding the details of the information contained in soils reports and gridded data sets of soil properties, only some general insights on what to look for will be offered. First, any information that indicates how the permeability of the soils may vary over the basin is important. This could be measured properties or general classification of the type of soils (e.g. clays versus silts versus sandy soils). This information will be helpful later in judging how the parameters involved in the percolation equation might vary from one watershed t

o another. Second, information on how the depth of the soil layers varies over the basin cou ld be helpful in determining variations in tension water capacities from one watershed to anot her.

• Vegetation – Several things are important to get an understanding regarding the variation in vegetation cover and types over the river basin. First is the general distribution of forest, o pen areas, and agricultural lands. Second is the variation in the types of forest cover, primar ily between conifers and deciduous trees, and the type of crops in agricultural lands. In mo untainous areas changes in vegetation cover and types with elevation, especially from semi-a rid types of cover to forest types that require a significant amount of water every year, can be helpful in determining if and at what elevation watersheds in these regions should be subdiv ided. The vegetation information should be helpful in determining variations in certain sno w model parameters from one watershed to another and how vegetation types and seasonal a ctivity patterns effect changes in evaporation demand rates over the basin. Variations in ve getation over the basin can also serve as an indicator of how the LZTWM parameter in the Sa cramento model may vary as this parameter is partly dependent on the depth of the root zone.

With vegetation it is also important to try to determine if significant changes have occurred i n the amount and type of cover over time. These changes could be due to factors such as ch anging agricultural practices, large scale harvesting of trees, forest fires, or rural areas being suburbanized. In these cases it will be important to use a period of record that reflects curre nt conditions to calibrate the models.

• Geology – Again this author is not that knowledgeable concerning the details of the inform ation contained in geologic reports. Some people within the NWS have indicated that there are relationships between certain model parameters, especially lower zone free water storage s in the Sacramento Model, and variations in the geology of the area. Since soil types are pr obably related in many cases to the underlying geology, soils data and geologic information may show similar general patterns. If geologic information is available, one mainly wants t o be aware of significant changes in properties across the river basin. The more knowledge of geology that one has, the better this information can be put to use during the calibration pr ocess.

Climatic Factors

Climatic factors to examine at this point in time are precipitation, temperature, evaporation, sno w cover, and frozen ground. One is primarily interested in analyses that show the average valu e of these quantities on a annual, seasonal, or in the case of snow cover and frozen ground, the av erage value at various times during the year. The values of these factors during extreme years a re also of interest. These climatic factors will have a significant influence on how the river basi n is subdivided and how the data are analyzed and processed.

• Precipitation – Isohyetal analyses are needed to assess the variability of precipitation over t he river basin. Ideally both annual, plus monthly or seasonal, analyses are available to exa

mine. The primary source of these analyses are the maps produced for the NRCS using the PRISM technique developed at Oregon State University. In some areas there may also be o ther isohyetal maps available, some which may even involve the use of other data, such as ru noff, to assist in the analysis. What is important at this stage is the variation of annual preci pitation over the area. This will determine if mountainous area procedures should be used when analyzing the data. If the variation in annual precipitation is small, in the order of ±5 % or less, or if the annual average changes very slowly across the basin, then non-mountaino us area data processing procedures should be adequate. If there are significant variations in mean annual precipitation over the basin, then mountainous area procedures should be used when generating areal precipitation time series. Variations may be significant even if the te rrain is relatively flat due to variations in precipitation amounts based on, for example, distan ce from a large water body. If mountainous area procedures are indicated, they should typic ally be used over the entire river basin even though the variation in precipitation may be slig ht in some subbasins. This is because the ratio of monthly averages between stations is use d to estimate missing data in the mountainous area procedure. In order to ensure one station is not estimated from another with a significantly different average value, generally monthly average values need to be defined for all stations. Operationally, over an RFC area a transi tion can be made from defining monthly averages for each station to not providing these valu es, as long as monthly averages are defined for all stations that could possibly ever be used to estimate a mountainous station.

• Temperature – The variation in average temperature over the basin determines whether mo untainous area procedures should be used when generating Mean Areal Temperature (MAT) time series. Variations in average temperatures can generally be determined using either an nual or monthly analyses. These analyses normally use temperature and elevation data. S uch analyses are available from NRCS as part of the PRISM project. Significant variations in temperature over portions of the basin indicate that the mountainous area procedure using a synthetic station for each subarea should be used for these regions. The use of the mounta inous area procedure for temperature can vary from one watershed or subbasin to the next, de pending on the variation of temperature over the area. In general a significant range in elev ation indicates that there will be a significant range in temperature. In some cases the variat ion in temperature could be significant even with flat terrain (e.g. based on the distance from the ocean).

• Evaporation – NOAA Technical Report NWS-33 contains maps showing the variation in L ake or Potential Evaporation (PE) over the 48 contiguous states. In regions of the country where PE varies slowly, the non-mountainous area procedure can be used to determine Evap otranspiration (ET) Demand for use with the Sacramento Model. In regions of the country where there is a considerable variation in PE over a river basin, these maps typically don’t de fine the variation in evaporation in sufficient detail for modeling. In these areas, the mount ainous area procedure involving the development of a ET Demand versus elevation relations hip is recommended (see Section 6-5). This also true for Alaska.

• Snow Cover – Snow cover data are used first to determine if the snow model should be incl

uded when simulating the hydrograph. In areas where snow occurs infrequently or only in small amounts, snow depth data from climatic stations can be used to determine when the most significant snow events occurred. By examining the hydrograph response to snowmelt after such events, one can judge whether snow computations need to be included when simulating the hydrograph. If the response is small compared to even moderate rain events, then the snow model is probably not needed.

Snow Cover data are also used, along with precipitation and temperature data, to help determine if headwater and local drainages will need to be divided into multiple zones. When significantly different amounts of snow typically accumulate in different parts of a drainage, then the area probably needs to be divided into zones in order to get reasonable simulation results. Averages from snow course sites during the time of maximum accumulation can be used to make this judgment. Also, variations in snow depth from climatic sites during large accumulation periods could be used. Satellite snow cover data may also be helpful. In locations where multiple zones are needed, these comparisons will typically not only show different amounts of snow in different parts of the area, but also depletion of the snow cover will occur at different times.

• Frozen Ground -- In regions where data on frozen ground are available, these data can be used to determine if frozen ground needs to be considered when simulating the hydrograph. These data could consist of soil temperatures at individual sites or frost depth analyses. What is most important from a streamflow modeling point of view is whether significant frozen ground can occur and whether there is significant variation in the amount of frozen ground from one year to another. In region, where soils are frozen every year, e.g. permafrost areas, the soil moisture model parameters can probably absorb the effect the frozen soil has on runoff. In such regions frozen ground doesn't need to be included in model computations. Also in regions with significant amounts of snow every year, very little frost will develop in the soil, thus there is no need to model the effect of frozen ground. The primary areas where frozen ground needs to be explicitly accounted for is where cold temperatures occur frequently in the winter and the amount of snow cover varies considerably during these cold periods. It is also more likely that frozen ground is important in non-forested areas since a dense forest acts like a snow cover to insulate the ground. In addition, frozen ground will have a greater effect in regions where the soils are reasonably permeable than in areas with low soil permeability. This is because the existence of frost will have a greater effect on the percolation rates.

Integrated Analysis of Hydrologic Conditions

Introduction

The hydrograph at a point on a river integrates all of the factors affecting runoff generation above that point. By comparing hydrographs at different points within a river basin it is possible to determine if the factors controlling runoff are similar from one area to the next or whether differences exist.

These differences may be partly the result of differences in climatic input, i.e. precipitation amounts, temperature, etc. and will hopefully be accounted for by the input time series used for modeling. Other differences may be the result of differences in soil properties, vegetation cover, etc., and thus indicate variations in model parameters from one part of the basin to another. Still other differences can be caused by the effects of lakes, reservoirs, channels, diversions, etc., and thus indicate the need for additional models or runoff adjustments. Generally two types of hydrograph comparisons are useful to examine. The first involves comparing watersheds with few man-made controls in order to get an indication of how parameter values might vary across the river basin. This includes headwater areas and those local areas where a good definition of the hydrograph can be generated by merely subtracting upstream flows from downstream flows. The second involves comparing hydrographs at locations with man-made controls and downstream river locations to determine the effects of such items as reservoirs, irrigation, and channel routing.

Headwater Comparisons

These comparisons involve headwater areas with few complications (i.e. no significant reservoirs, diversions, or regulation of flow). In some cases local areas without complications can be included if a good definition of the local hydrograph can be obtained by merely subtracting upstream from downstream daily flows or by using a simple routing of the upstream flows before computing the local contribution. Also headwater inflows to reservoirs can be included if a good definition of the inflow hydrograph can be computed from pool elevation or storage and outflows from the reservoir. The purpose of the comparisons at these sites is to determine if model parameters should be similar over the river basin or whether they are likely to vary. Variations in the hydrograph response from different parts of the basin can be used to predict which parameters are likely to change and the pattern of these changes. This information may be able to be associated with physical attributes such as soils and vegetation to help in determining which headwater area's parameters are best to use as the starting point when calibrating other headwaters, including those with complications, and local areas.

The comparisons are done by plotting the results using the WY-PLOT operation graphical display in ICP. Typically in order to not have too many lines on the screen so that one can properly visualize the differences between individual locations, no more than about 7 hydrographs should be included on a single WY-PLOT. In river basins with more than 7 gages to plot, several plots can be created by grouping the streamgage locations in various ways (e.g. by general location within the river basin or by separating those with no complications from those with minor disturbances). Before plotting the hydrographs, some scaling needs to be done so that a proper assessment can be made of the displays. First, the hydrographs should all be scaled to a common drainage area. The drainage area of one of the locations is typically selected as the base and then the other hydrographs adjusted to that drainage area by using a WEIGH-TS operation for each. The WEIGH-TS operation multiples all the daily flows by the ratio of the base area to the area of the drainage being adjusted. Second, in river basins where there is a significant difference in runoff from one part of the basin to another, it may be helpful, in addition, to scale the flows to a common mean annual runoff amount. This again can be done by using WEIGH-TS operations and the ratio of a selected base annual runoff to the annual runoff at each location. A common period of record should be used to compute these ratios. Once the hydrographs are scaled, then the

responses can be evaluated.

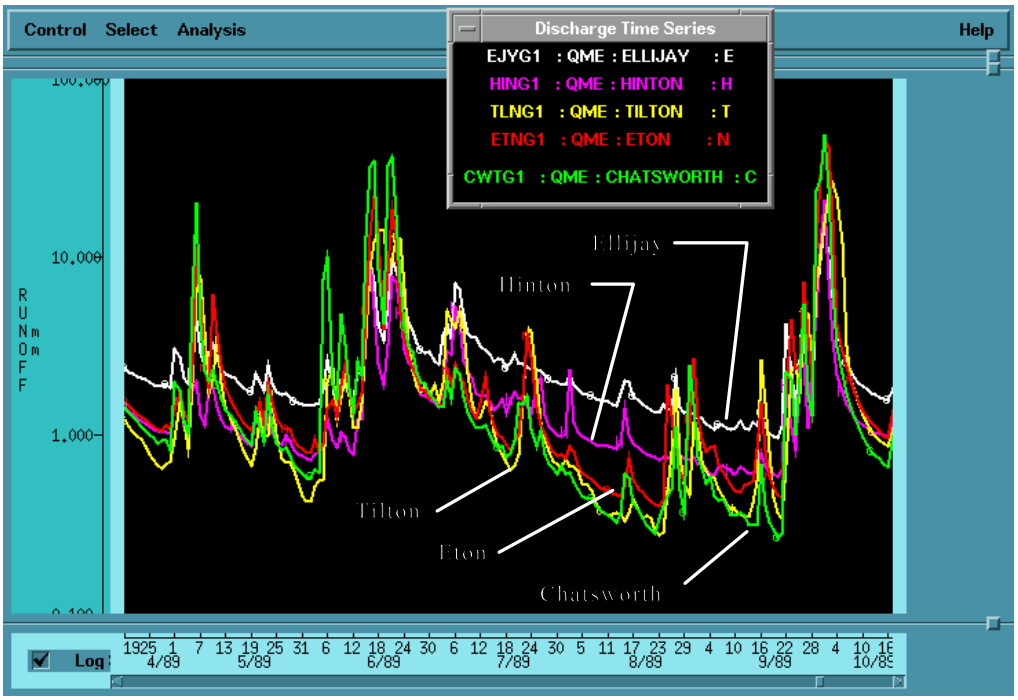
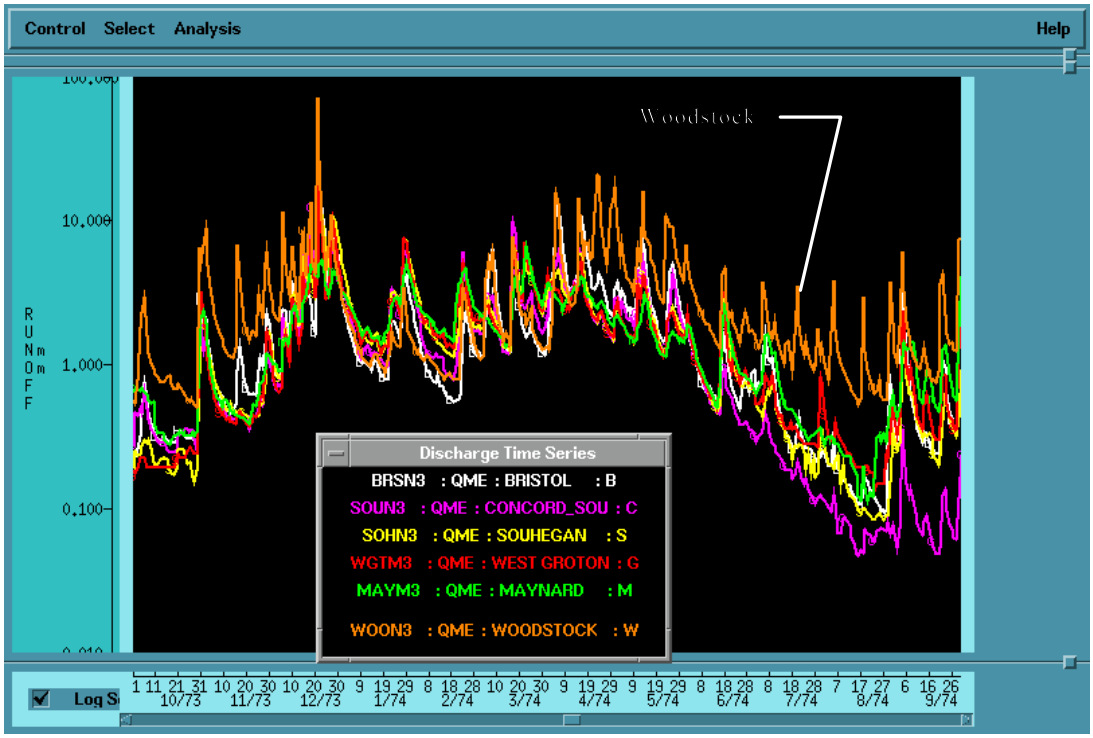


Figure 4-1 - Hydrograph comparisons for Oostanaula River basin.

Figure 4-1 shows a semi-log comparison of 5 locations within the Oostanaula River basin above Rome, Georgia. Eton and Chatsworth are small headwater areas above the Tilton streamgage.

The Tilton plot is for the entire drainage above that location. First, it can be seen that the response for the Eton and Chatsworth drainages are very similar to the response for the entire area above Tilton. Since Eton and Chatsworth are not points that require a forecast, they were not modeled separately based on this comparison. If the response for Eton or Chatsworth were different from the entire area above Tilton, then improved simulation results would be likely by modeling the small headwaters separately from the rest of the area above Tilton. Second, it can be seen that there are significant differences between the responses from the Tilton, Ellijay, and Hinton drainages. The amount of baseflow is greatest above Ellijay and least above Tilton. The amount of storm runoff is greatest for Tilton and least for Ellijay. This pattern clearly indicates that the percola



tion rates for these areas are quite different, since percolation separates fast response storm runoff from slow response baseflow. Most of this difference should be able to be modeled by altering the lower zone free water capacities (LZFSM and LZFPM) from one area to the next though there is also some evidence that the slope of the supplemental baseflow (model parameter LZSK) probably also varies between the drainages (greatest for Tilton, least for Ellijay). Since there are apparent differences in the immediate storm runoff, the UZFWM parameter may also vary between the drainages in addition to the percolation rates. All of this information will be very helpful in deciding how to divide the river basin to get the best simulation results, in making parameter adjustments, and in assigning parameters to other portions of the river basin.

Figure 4-2 - Hydrograph comparison for the Merrimack River basin.

Figure 4-2 shows a comparison of a number of headwater drainages scattered across the Merrimack River basin in New Hampshire and Massachusetts. Even though there is some difference in annual runoff amounts (especially more runoff above Woodstock), the plots are scaled only by drainage area. In this case the shape of the hydrograph response is, in general, very similar from one headwater to the next. This would indicate that there should only be small variations in model parameters from one area to the next. The area above Woodstock (in the White Mountains at the northern end of the river basin) shows some differences in response from the other areas. There is more and later snowmelt runoff in the spring which is expected because of the mountain location. Low flow levels in the summer are higher than for the other areas suggesting that the lower zone primary storage (LZFPM) may be greater for the White Mountain drainages. There is also more quick storm response which is partly due to more rain in the mountains, but may also indicate more frequent surface runoff in this region and thus a lower value of UZFWM.

Figure 4-3 is from a number of headwater areas draining from the east into Puget Sound in Washington. Since there is a very large difference in annual runoff from one drainage to another in this region, the hydrographs are scaled by annual runoff amounts in addition to drainage area. During the fall and winter period the hydrograph response is very similar for all the drainages. During the spring and summer, there are differences in the magnitude and timing of the response. In the spring most of the variation is due to differences in the amount and timing of snowmelt. Some of the areas, such as Arlington, get very little snow accumulation, while others, such as Goldbar, get a lot of snow. During the summer most of the variation is due to differences in glacial contributions, with National, which drains off Mount Ranier, having the greatest glacial effect. Thus, in order to determine whether the variations in hydrograph response between areas can likely be accounted for by varying model parameters or whether there are other causes, one needs to have a reasonable understanding of how factors such as topography, snow cover, and glaciers vary over the region. In this case, it appears that the model parameters should be very similar from one drainage to another and that the differences in the response will be accounted for by the magnitude and

timing of snowmelt and the size of the glaciated area.

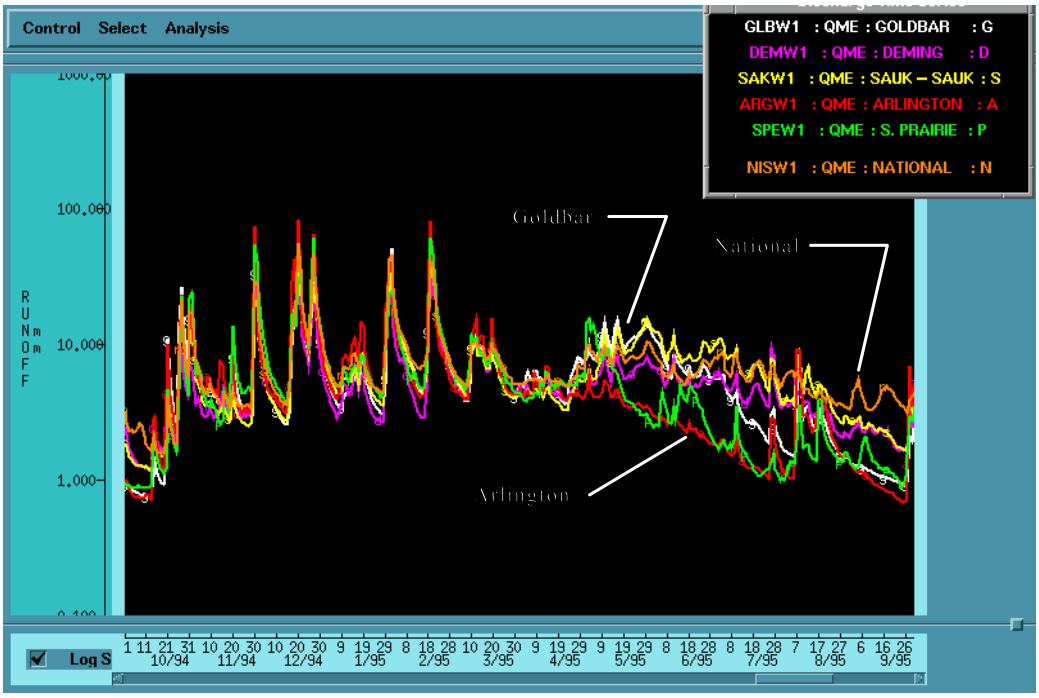


Figure 4-3 - Hydrograph comparison for eastern Puget Sound drainages.

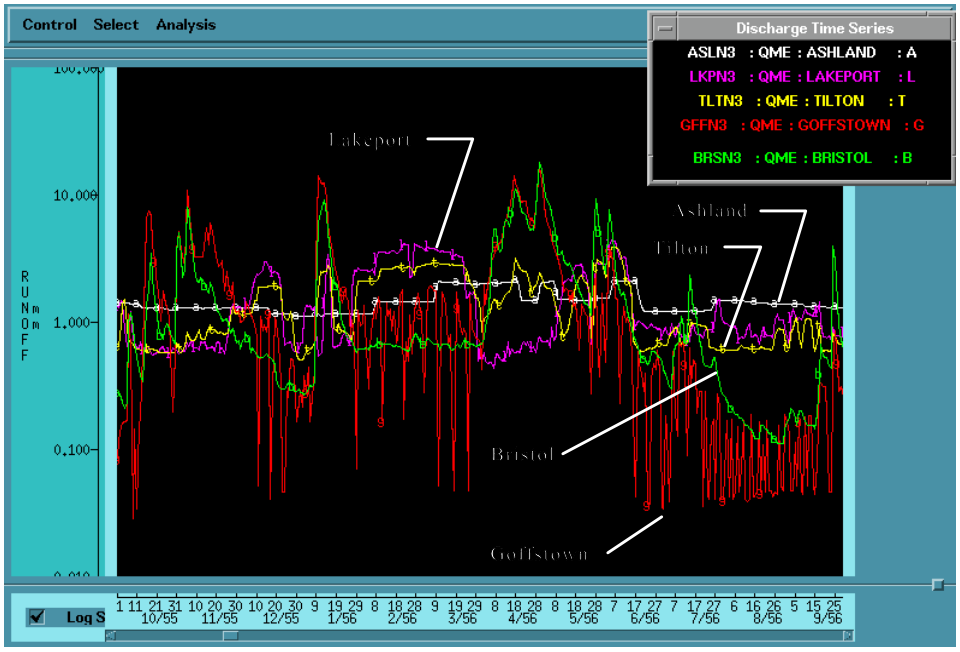
<u>Hydrograph Comparisons at Other Locations</u>

Hydrograph comparisons can be made at other streamgage locations to assist in understanding the effect of features such as reservoirs, lakes, diversions, power plants, etc. and to get a general idea of the lag and attenuation of the flow as it passes downstream through the river channels. In general, these plots will not help with determining possible variations in model parameters, but will assist in determining what modeling procedures and adjustments will be needed to generate reasonable flow simulations and how to divide the river basin for modeling purposes. For these comparison plots, it may or may not be appropriate to scale the hydrographs before plotting the values. If a semi-log plot is going to be used to view the streamflow traces, then the discharge time series should be scaled to a common area since the WY-PLOT operation uses a single area to convert daily flow into depth of runoff. This may be the case when one is comparing the response from headwater areas, affected by such features as lakes or reservoirs, diversions, or power plants. If an arithmetic plot is going to be used, which is normally the case with many of these comparisons, then no scaling is needed. An arithmetic plot is generally used when comparing the flows at a series of downstream river locations to assess the effects of the channel, reservoirs, or other features that affect the magnitude and timing of the flow.

Figure 4-4 shows a semi-log comparison of upstream locations in the Merrimack River basin that exhibit man-made effects. The hydrograph for Bristol is included to show the response for a location with minimal complications. The flows at Ashland, Lakeport, and Tilton are significantly affected by large lakes. Ashland is downstream from Squam Lake. Lakeport is at the outlet from Lake Winnipesaukee and Tilton is further downstream below the outlet from Lake Winnisquam. The effect of the lakes definitely needs to be explicitly modeled in order to produce reasonable simulations at these locations. The low flows at Goffstown during this period are affected by a power plant, which appears to release only a minimal flow on weekends. At this location it will be difficult to adjust the model parameters that control low flow with any degree of confidence. These parameters will most likely be obtained from a similar nearby watershed.

Figure 4-4 - Merrimack River basin locations with man-made effects.

Figure 4-5 shows an arithmetic plot of the hydrographs at several downstream locations on the M errimack River. This figure indicates that the amount of lag and attenuation is not large as the w ater moves through the channel system or does it vary significantly with the flow magnitude. It



also shows that there are some minor low flow controls, at times, above the further downstream lo cations. This comparison indicates that channel routing should be fairly straight forward in this

basin and that local area hydrographs, determined by subtracting upstream flows from downstrea m, will exhibit a lot of noise at lower discharges, though a reasonable definition of the local area c ontribution might be possible at high flows. The computation of the local area flow will also req uire subtracting gaged tributaries between these river locations and this will affect whether a reas onable local hydrograph can be obtained. Whenever the local area is small compared to the upst ream areas, it is difficult to obtain a good definition of the local hydrograph.

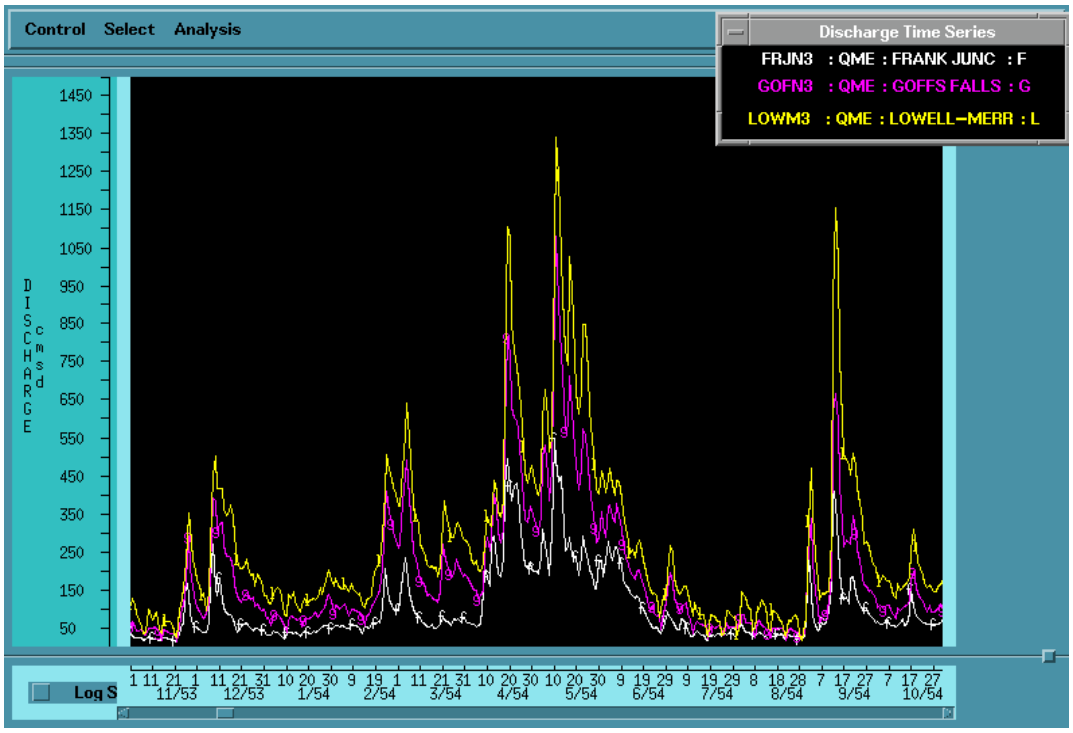


Figure 4-5 - Comparison of Merrimack River basin downstream locations