The impacts of the four scenarios on the quantitative indicators of watershed functions appear to be largely captured by the impact on total water yield relative to rainfall.The scenarios predict an increase of this discharge fraction from the current 19% (and 13% under 'all forest' scenario) to 25 % for the Parks scenario and even 38% fore the Food Bowl scenario. Most of the other indicators change in proportion to this increase in water yield: the buffering indicator will decrease, the 'soil quick flow' fraction of rainfall will cause nearly all increase in river discharge with the slow flow reduced below the level for the current LU mix.

3.8. The Dynamics of Water Movement across the Mekong Basin (VIC)

The record of river flow at multiple stations throughout a large basin provides an integrated signal of how landscape processes and climatology intersect with human use to produce the amount of water in channels. Being able to understand that record provides insight into how the water cycle might change under changing conditions. In the context of the Functional Value of Biodiversity program, we are particularly interested in the following questions for the Mekong basin:

- How does land use intensification affect watershed functions in large-scale drainage basins? Would switching landcover back to fre, leading to land covers that represent low values for both functions
- How does total water yield depend on the distribution of rainfall and portioning between hydrologic processes, under historical and current conditions?
- How are the temporal dynamics of high and low flows of rivers influenced by spatial scale?
- How are "Far field effects" on people living downstream linked to changes in total and seasonal water yield?

The Mekong represents a transition from individual smaller basins up to the Pan Tropics scale.

The analysis is done in the overall data/model framework described in Section 2.7. The organization of data and computer models is focused on providing a common information scheme, in which a series of analyses can be done. It is further worth noting that ht computer model used (VIC) is a spatially-explicit, process based model. It explicitly does not utilize detailed calibration to produce observed hydrographs. Rather it does it on "first principles." As a result, it is a more robust method for analyzing scenarios than more traditional, calibrated, lumped models. Our first step is to assemble the sequence of information required to describe the flow regime. The second step is to interpret that information, though a combination of observation, statistical, and simulation techniques. The third step is to analyze scenarios of potential changes in system state.

3.8.1. Surface Water Regime of the Mekong Basin

Understanding the flow regime of a major river system, especially possible changes in that regime, requires data records covering decades. Hence we analyzed the (recently acquired) discharge and stage data, obtained from the Mekong River Commission (Figure 3.51). These data represent a significant upgrade on the publicly-available data, in terms of length and completeness of record, and re-analysis of rating curves. In the following it should be noted that the last station with a data record is Stung Treng, which is above the

Cambodia part of the basin, including the Tonle Sap. The following values are thus less than the discharge to the ocean.

a) Basic Patterns: 1910 – 2002.

Visual inspection of the hydrograph reveals patterns of interannual variability – some years are drier and some years are wetter. The wet years are associated with the normal flooding regime of the river. Super-imposed on the high-frequency variation are several lower frequency patterns. The most characteristic pattern is a harmonic with a period of 20 years (plus/minus 5 years). Cumulative flow builds towards a peak, then declines. This pattern has been observed on other large rivers, most notably the Amazon (Richey et al. 1989), where it was attributed to variations in the El Nino-Southern Oscillation. Higher peak flows were present earlier in the century than in more recent times, and tended to be associated with the higher flow cycles. The last several decades appear to be slightly "noisier" than early periods, possibly on the upward side of the long-term cycles. Greater variability occurs further upstream, and is greatest in the tributaries.

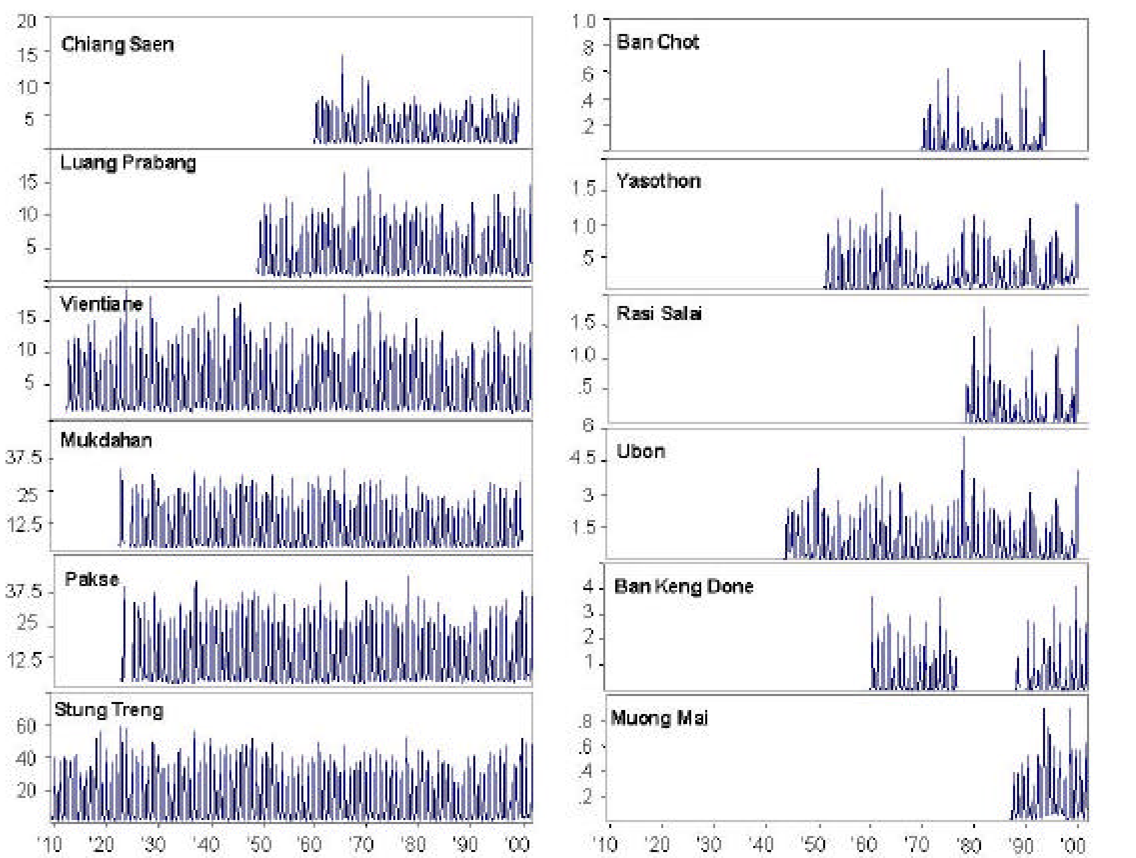

Figure. 3.51. Hydrographs of the Mekong River (left panel) from upstream to downstream along the Mekong (right panel) Mekong tributaries. Flows are in $m^3 s^{-1}$. Data are from the MRC (Sok, pers. comm.)

b) Annual Discharge Trends: Mean, Maximum, and Minimum Flows

Individual river station records can be summarized in the terms of annual flow trends for mean, maximum, and minimum flow conditions (Figure 3.52). The mean trends maintain the long term 20-year cycle. The downstream minimum and maximum patterns may be showing trends towards an increase in minimum flow and possibly an increase in the "noise" of the maximum signal. These hypotheses will be tested below.

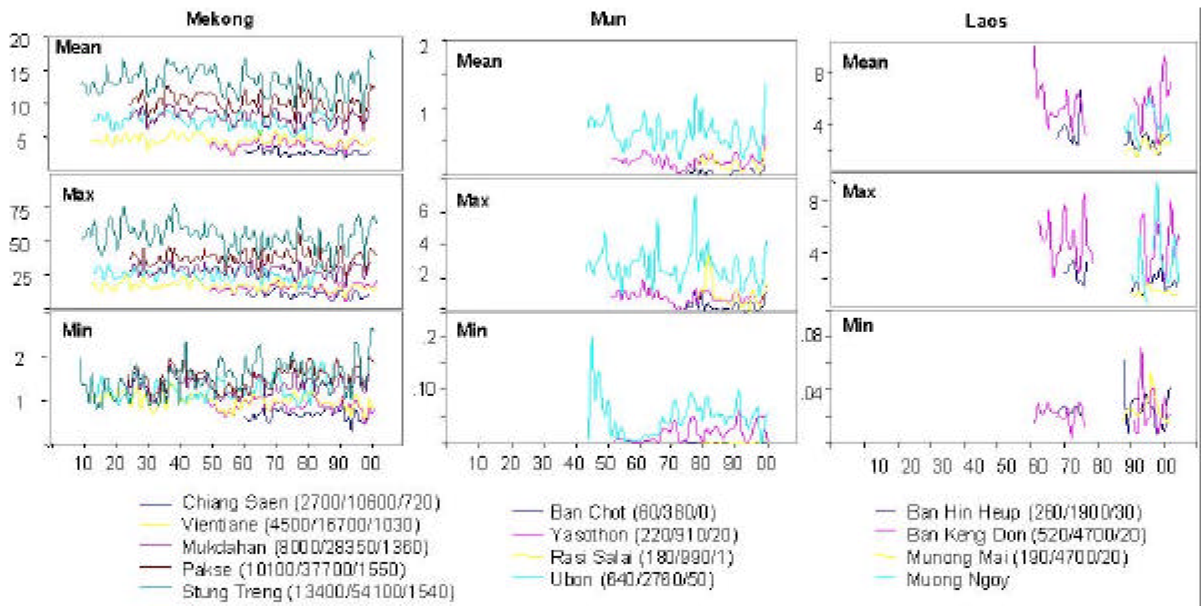

Figure 3.52. Annual yields for respective stations (1000 x m^3/s); Mean (annual average), Maximum (max, highest per year), Minimum (lowest per year). Values in (m^3/s) after station names are summary statistics.

c) Interannual Variability

To examine more closely possible systematic changes in the Mekong hydrograph, we looked at annual trends in the stage records (stage provides a more stable signal than discharge for a long time series, as discharge requires a rating curve that can change over time). Our primary reference station is Stung Treng, as the most downstream station, with the longest record (Figure 3.53). The possible changes seen in the earlier figures are being clearer. There are suggestions of a lowering of mean stage, possibly due to a reduction in peak flows, but with an increase in minimum flows. Overall variability (excursions from the mean) seems to be increasing in recent times.

Finally, to test the statistical validity of these observations, we used the non-parametric Mann-Kendall method for testing the presence of a monotonic increasing or decreasing trend (Figure 3.54).

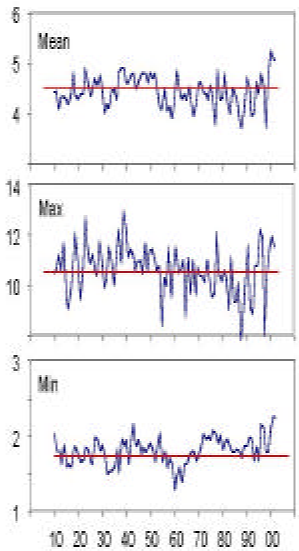

Figure 3.53. Annual mean, maximum, and minimum stage trends at Stung Treng (red line is long term mean).

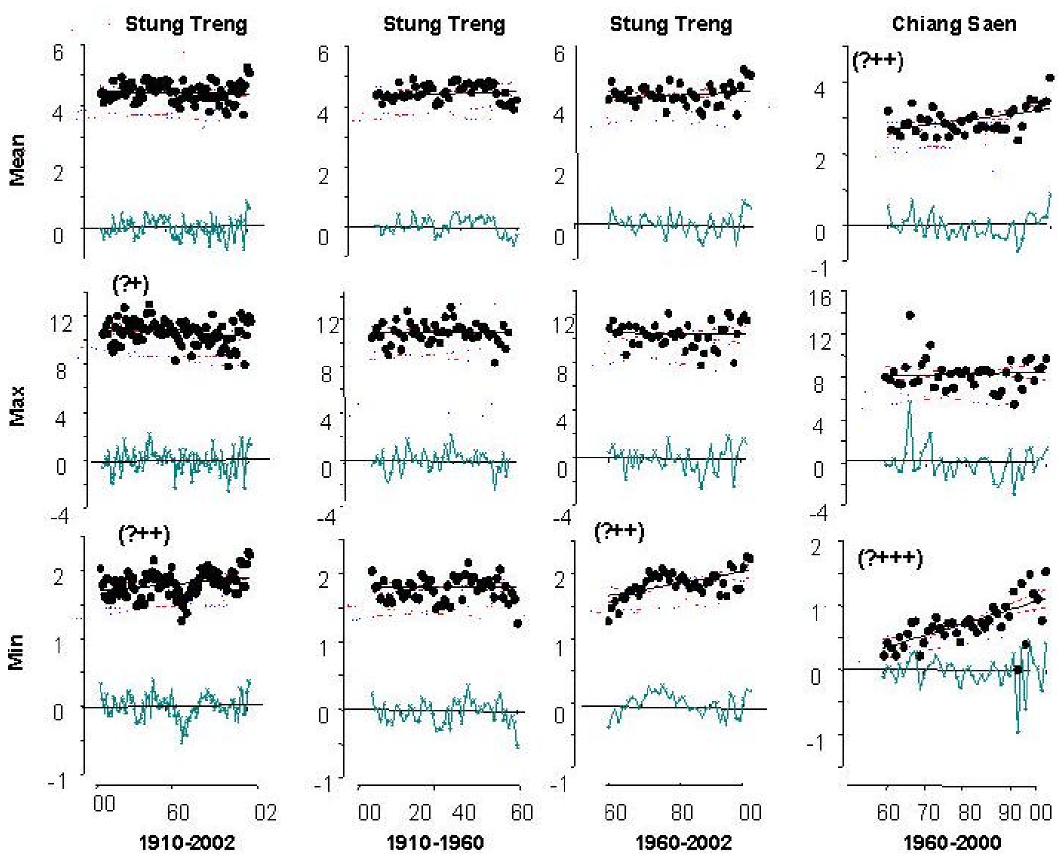

Figure 3.54. Results of the Mann Kendall test for linear trends over time for Stung Treng stage records, over the entire period of record (1910-2002), The first half of record (1910-1960, at which time data becomes more common for other stations), and the latter part of the record (1960-2002). The records of Chiang Saen (at the top of the lower Mekong, exiting Yunna province). Dots are data points, the blue line is the residual in the analysis, Fine blue and red dotted lines are confidence interval. +++ indicates significant at .001 level, ++ at the .05 level, for increasing? Or decreasing trends.

The results show that the overall mean stage at Stung Treng has not increased has not increased significantly over the period of record. However, the results strongly imply a greater variance towards the latter part of the century (by the increases in the residual and spread in the observations). Low flows shows a significant increase over the latter half of the century. Chiang Saen shows a pronounced increase, especially recently. Clearly there are multiple factors at play, from climate shifts, to landuse shift, to increase in water management through dams and irrigation. These results are consistent with the Mae Chaem results, showing increase discharge with increasing conversion from forest to crops. We will now focus on the recent period, through decomposition of the hydrographs and analysis of the scenarios, using VIC.

3.8.2. De-Convolution of Hydrographs

We now move to using the VIC model to dissect the observed hydrographs, and in the process get insight into the constituent dynamics.

a) VIC Model Calibration and Validation

Ideally a process-based model should not "have" to have any calibration. The reality is that the full set of data required to drive a model are virtually never sufficient. Inadequacies frequently occur in how well known the soil is, and in the climate forcings. Hence some calibration is required. Runoff is parameterized in the VIC model due to the large spatial extent of each model grid cell. Calibration of some model parameters is necessary to give a good agreement between simulated and observed runoff. There are five main soil calibration parameters. These parameters and their typical ranges are briefly described below:

D_{smax}: Ranges from 0 to about 30 mm/day. This variable is the maximum baseflow that can occur from the deepest soil layer. (The actual flow will depend on D_s and on hydraulic conductivity of the soil layer.)

D_s: A fraction of unity. This parameter represents the fraction of D_{smax} where non-linear (rapidly increasing) baseflow begins. With a higher value of D_s, the baseflow will be higher at lower water content in the lowest soil layer.

W_s: A fraction of unity. This parameter represents the fraction of the maximum soil moisture of the deepest soil layer where non-linear baseflow occurs. W_s is analogous to D_s but is a threshold of moisture rather than a baseflow rate threshold.

b_{inf}: Ranges from 0 to about 0.4. This parameter defines the shape of the Variable Infiltration Capacity curve. It describes the amount of available infiltration capacity as a function of relative saturated area of the grid cell. A higher value of b_{inf} results in lower infiltration and yields higher surface runoff.

D_i: Typically ranges from 0.1 to 1.5 meters. This parameter is the depth of soil layer i. Soil depth affects many model state variables. In general, deeper soils result in a reduction of seasonal peak flows and in an increase of losses by evapotranspiration.

Additional parameters which also may be used in more difficult calibrations, or for fine tuning, include the saturated conductivity of each soil layer i, k_{si}; the exponent of the dependency of unsaturated conductivity in layer i, n_i; and even the wilting point and field capacity (w_{pi} and f_{ci}) of a soil layer i.

Calibration was performed separately for each sub-basin, defined by each stream gauge station, starting with the most upstream sub-basins and moving downstream to larger sub-basins. All calibration parameters were used, but rather than fixed values for each sub-basin, calibration was performed based on the initial parameter values which depended on soil type.

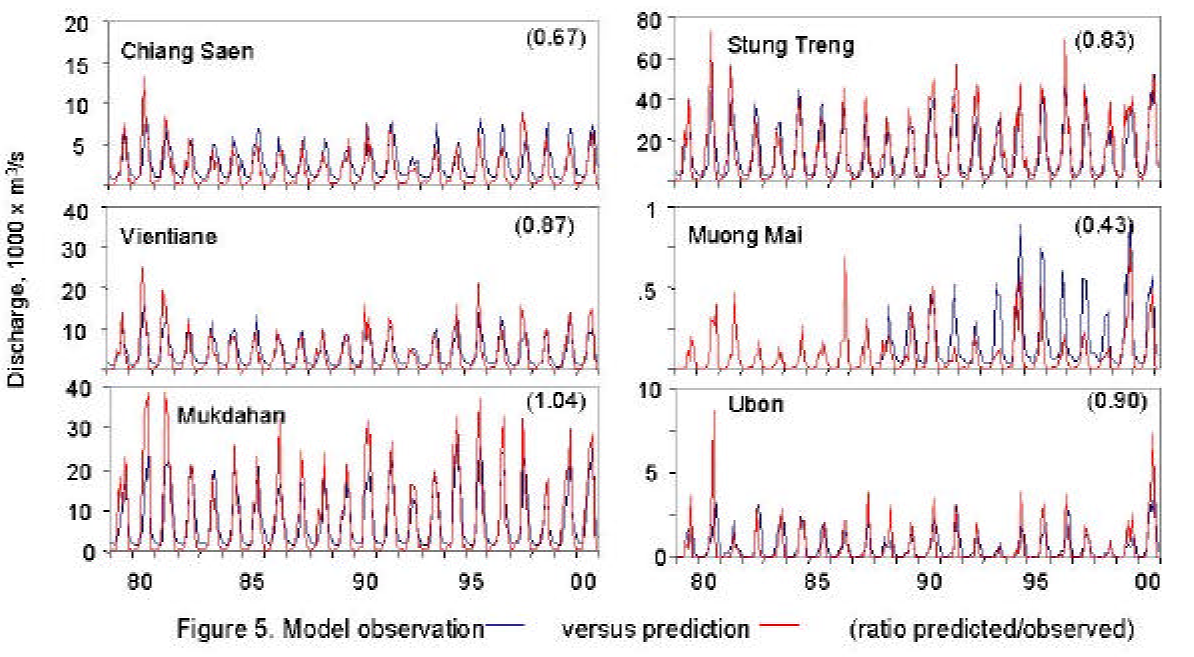

Figure 3.55. Model observation ——— versus prediction ——— (ration predicted/observed)

The calibration period was 1979-1988, and the verification period was 1989-2000. The model was run for the entire simulation period, Jan.1979-Dec.2000, in water balance mode at a daily time step. The initial soil moisture condition of every model grid cell was set to 80% of field capacity, following Nissen et al. (2001a). However, no model spin-up period was used, and there is some effect of the arbitrary moisture initialization over the first months of 1979.

Model runs were made with the dams and irrigation schemes in place. Overall model behavior captures the basin dynamics of the Mekong flow regime (Figure 3.55), with several exceptions. Overall minimum base flow is under predicted (further calibration in progress is expected to address that problem). Rainfall over Laos is known to be underestimated (reported rainfall is generally lower than riverflow). Lower estimates of rainfall are also likely above Chiang Saen.

b) De-Convolution of Components of Water Cycle

We will now use the hydrology model to “de-convolve,” or explain, the factors producing the discharge hydrograph. We will focus on our benchmark mainstem station, Stung Treng, and on Ubon, the downstream reference station on the heavily impacted Mun River. The period of analysis will be 1979-2000, covering the period of the overall dataframe of VIC (requiring not only discharge, but climatology and landcover). We will focus on the peak discharge years of 1984, 1991, 1996, 1997, and 2000 (Figure 3.56).

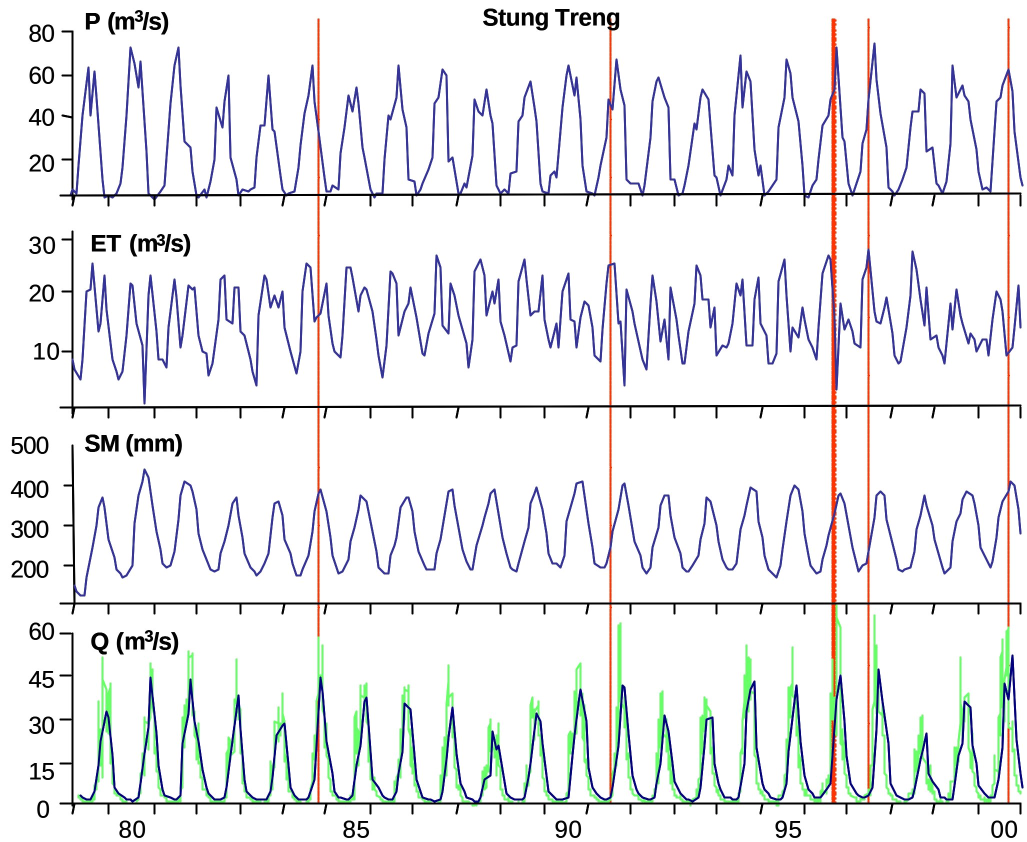

Figure 3.56. Deconvolution of discharge hydrograph (Q). Monthly composites from VIC model runs (green linesuperimposed on Q is the daily observed discharge (for perpective on monthly aggregation). Red dashed line to track peak flows.

The hydrograph at Sung Treng represents the damped signal of the cumulative "history" of the basin upstream. Discharge lags precipitation by about a month (within the time step of the model), on both ascending and descending limbs. Discharge lags soil moisture on the rising limb, and follows on he descending. ET rises simultaneously with increasing rainfall, but the descending limb of ET is delayed relative to rainfall, but is synchronous with falling soil moisture.

Years of greatest discharge and flooding do not necessarily correspond to unusually high precipitation, particularly the flood of 2000. The peak rainfall in 2000, while above average, was less than non-flood years. ET was uncharacteristically low, compared to other years of higher rainfall, while soil moisture was higher.

Clearly immediate strong storms can produce localized flooding. At a more basin scale, antecedent effects may be influential. Figure 3.55 looked at aggregation from daily to monthly. We now turn to aggregating from monthly to (3-month) seasonal aggregation of flow. The relative balance of flow magnitudes changes (Figure 3.57). The cumulative rainfall of 2000 is greater in the second quarter (AMJ) than in most years. When coupled with a lower than normal ET, soil moisture is highest in that period over the entire 1979-2000 period. This suggests that more rain earlier lead to soils being more saturated earlier, allowing modest increments in rainfall to promote the flooding. Variants of this pattern account for other high flow periods. That is, peak downstream flow is the "far-field" affect of multiple up-stream events.

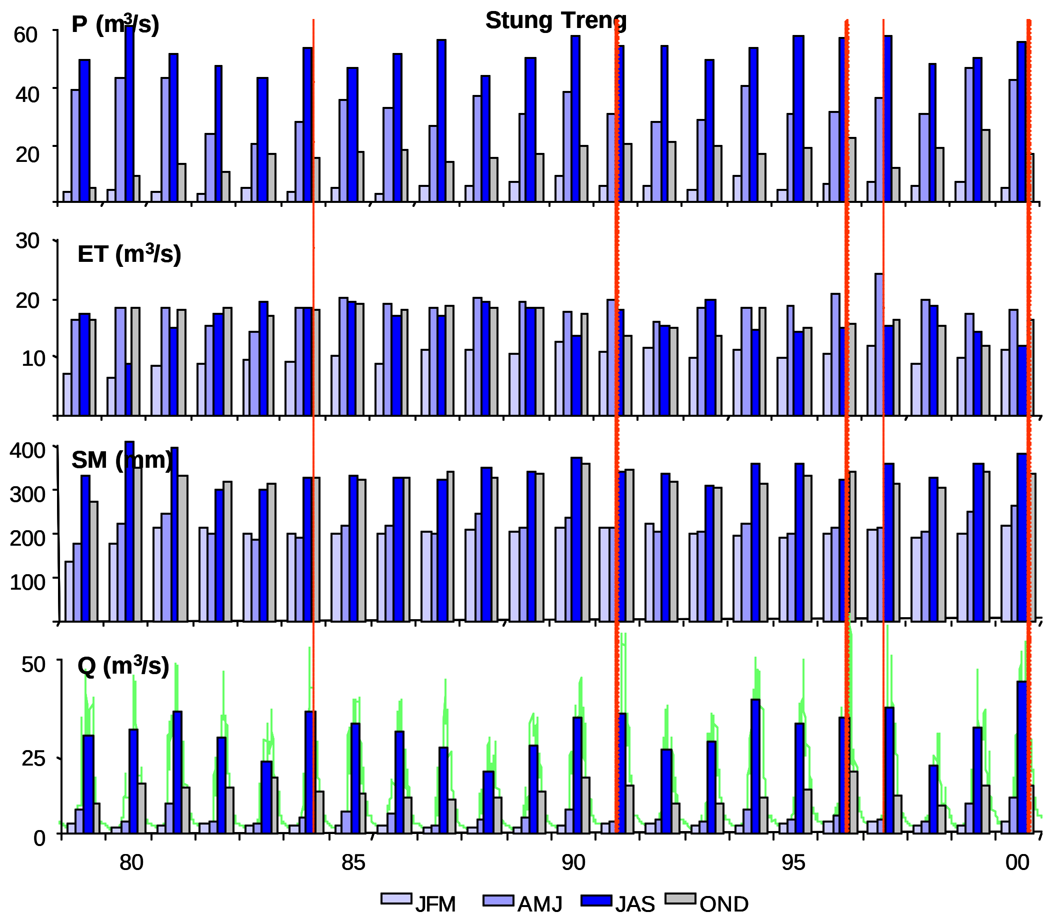

Figure 3.57. Deconvolution of discharge hydrograph (Q) at Stung Treng, Mekong mainstream Seasonal composites from VIC model runs (green line superimposed on Q is the daily observed discharge (for perspective on seasonal aggregation). Red dashed line to track peak flows.

We will now look in more detail at a sub-basin, the Mun River, represented by Ubon, at monthly (Figure 3.58) and seasonal aggregations (Figure 3.59). Discharge is more lagged from rainfall than for the basin as a whole, with the exception of 2000, when it was nearly synchronous. ET is a much higher percentage of rainfall than is the mainstem. ET rises with precipitation, but lags more slowly on the descending limb. Soil moisture tracks ET quite closely. The flood of 2000 is even more pronounced, with the highest monthly composite discharge of the period. Discharge in 1980 and 1983 were proportionately greater than at Stung Treng.

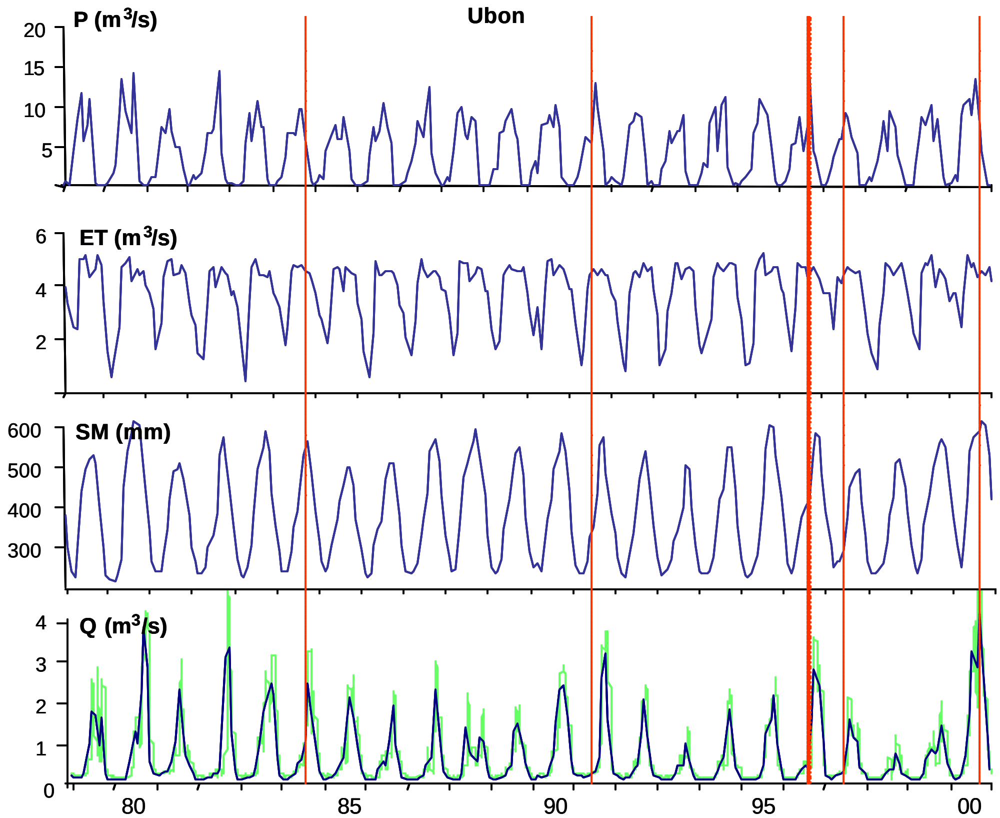

Figure 3.58. Deconvolution of discharge hydrograph (Q) at the Mun River, at Ubon. Monthly composites from VIC model runs (green line superimposed on Q is the daily observed discharge (for perspective on monthly aggregation). Red dashed line to track peak flows.

The seasonal patterns seen at Stung Treng are more pronounced (Figure 3.59). The second quarter of 2000 had the highest rainfall over the period, which was reflected in the very high soil moisture and discharge of the third quarter.

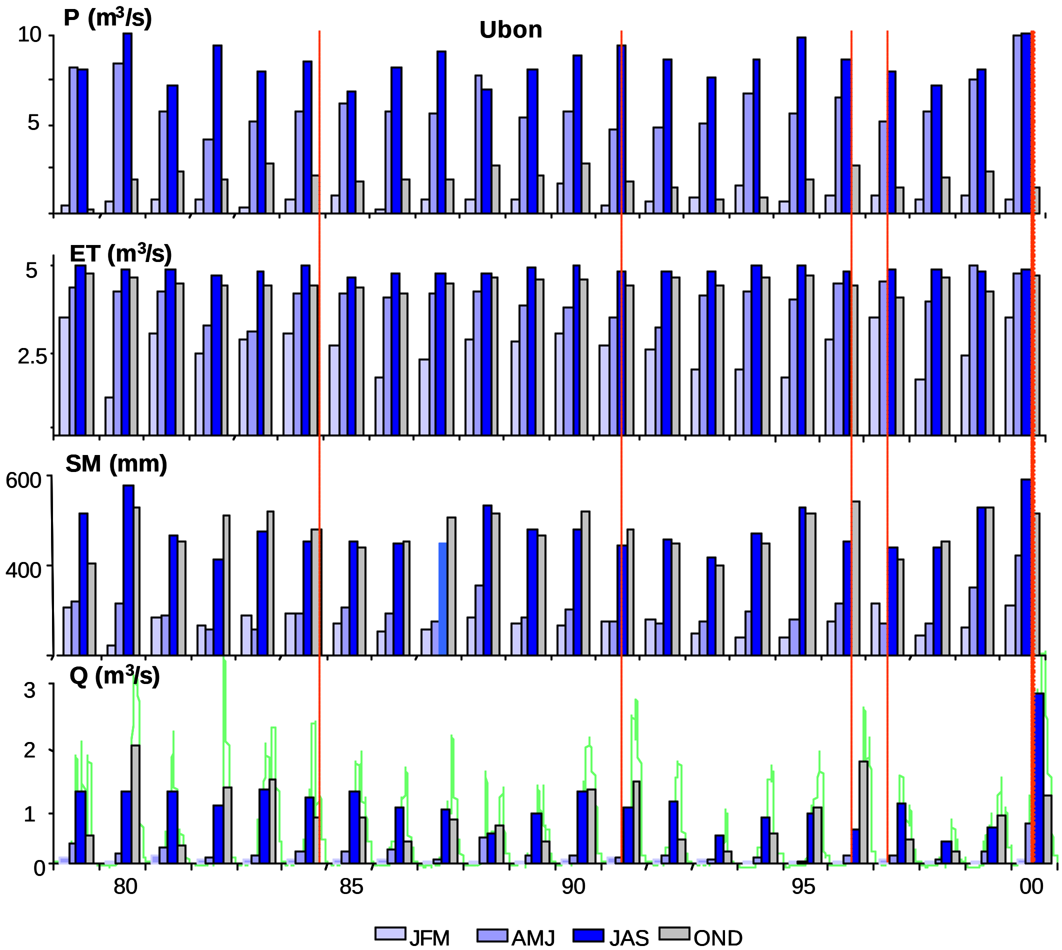

Figure 3.59. Deconvolution of discharge hydrograph (Q) at Ubon, Mun River. Seasonal composites from VIC model runs (green line superimposed on Q is the daily observed discharge (for perspective on seasonal aggregation). Red dashed line to track peak flows.

3.8.3. Scenarios

In the modeling/data environment, many analyses of are possible. In the interest of time, we will review one case – that of the Mun River basin. The basic properties of the Mun River at Ubon, and its tributaries Chi (Ban Chot and Yasothon) and the upstream Mun (Rasi Salasi) were given in previous graphs. The Mun basin is characterized as being the most developed, and is already converted primarily to crops. The scenario of removing the remaining trees from the Mun produces little change, as few trees are left to remove. So we performed the opposite experiment, of replacing crops with forests. The result is that discharge is reduced by nearly 40%, through an increase in ET and reduction in soil moisture. These results confirm the Mae Chaem results – that a conversion from forests to crops increases discharge.

In the next several weeks, we will be analyzing and compiling the results of a series of scenario experiments. These will include irrigation and dams (water management schemes), different levels of vegetation cover, and a detailed analysis of high flow events promoting flooding. This work is in progress, but too preliminary to report here).

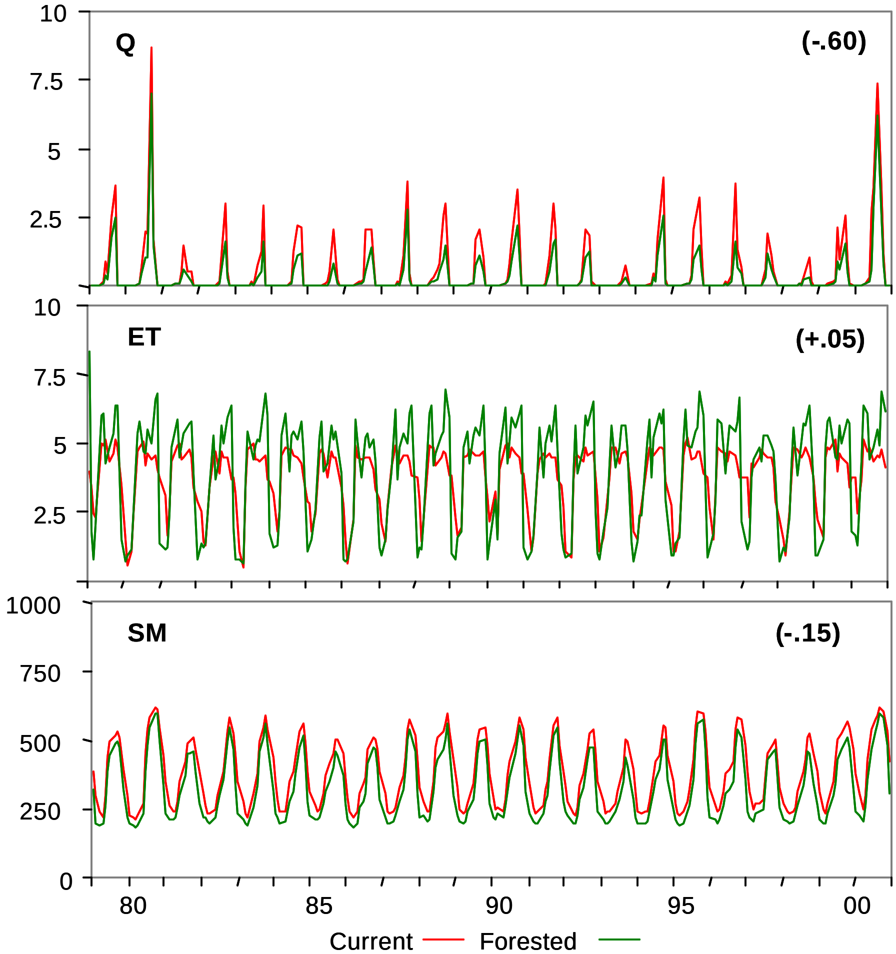

Figure 3.60. Model of current versus "if forested" conditions in the Mung River basin, at Ubon, for discharge (Q, 1000 x m^3/s), evapotranspiration (ET, 1000 x m^3/s), and soil moisture (SM, mm)

3.8.4. Preliminary Conclusions

While consider work remains in interpreting these results, there are several important "take home" messages. (An initial caveat is that these results do not yet include the Tonle Sap and environs). The Mekong basin is indeed subject to a modification in flow regime, due to both climate variability and anthropogenic actions. There is significant evidence that "far-field" effects are indeed taking place, resulting in a greater variability of the flow regime, with an increase in at least base flow. The ability of the VIC modeling environment to reproduce hydrographs, as a function of the constituent processes, speaks to the applicability as a potential decision support system, particularly if coupled to a climate model. This would apply both for peak flow/flood prediction several weeks in advance to low flow/drought predictions, also several weeks to months in advance.

3.9. Application of the DHSVM model to the Mae Chaem basin

The primary question we are addressing here is, does vegetation “make a difference” in water flow patterns? I.e., do trees “matter?”

3.9.1. Historic Trend of Hydrograph and Water Yield

The Mae Chaem hydrologic regime consists of high flow from May to October, contributing 73% of the total flow, and an average annual water yield (1996-2000) of 240 mm (we consider the water year to begin in November, of the year previous to the year cited). The rainfall variation within the basin is large due to high fluctuation in altitude (Figure 3.61).

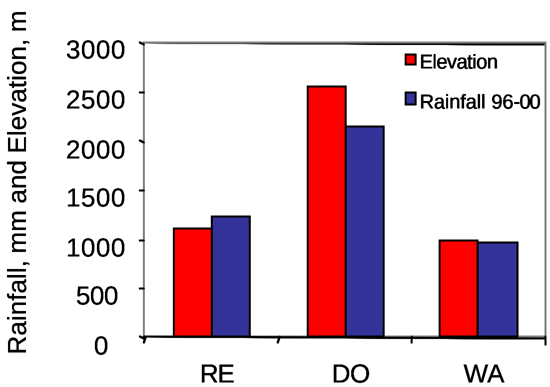

Figure 3.61. Average rainfall distribution in Mae Chaem and the relationship with elevation

Therefore, the surface runoff ratio is between 12 – 23%, depending on which climate station was referenced. This number is consistent with the 15-25% ratio published in Alford’s study of annual runoff in the mountainous regions of northern Thailand (1992). The Mae Chaem basin is an example of a small catchment where the discharge varies considerably from year to year, and is sensitive to rainfall intensity and duration due to short travel times caused by steep topography (Figure 3.62).