GLOBAL CHANGE: CAN WE DETECT ITS EFFECT ON SUBALPINE HYDROGRAPHS?

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It has become a widely accepted theory that addition of greenhouse gases to the atmosphere will most likely increase temperatures and alter rainfall patterns. There is less agreement on the rate and magnitude of change, as well as on the secondary interactions. The World Meteorological Organization has reaffirmed earlier estimates that a doubling of CO_2 and increased temperatures of 1.5-4.5 °C are plausible in the next century (Smith 1989). Impacts on precipitation are less well defined, with predictions calling for increases or decreases depending on the region and the model being used for simulation. The purpose of this paper is not to defend the concept of global change or to predict how great the change will be if and when it occurs. Instead, the intent is to look at the potential impact of the most widely accepted global change scenarios on subalpine hydrologic response.

In a recent report, Smith and Tirpack (1989) divided the United States into 21 regions for comparative analysis using 3 different General Circulation Models (GCM's). The three models gave contrasting results as to both the magnitude and direction of response. Frederick and Gleick (1988) and others have done river basin (regional) analyses to evaluate the impact of predicted changes in the quantity and timing of runoff and the implications to or for water resource management.

When anticipating the impact of global change, scale becomes a key factor. At the global level, the direction and magnitude of a change in temperature is more predictable, defensible, and can be generalized; expected changes in precipitation also seem reasonable at the global scale, but there is no capability in the GCM's to deal with specifics. Regionally, the predictions are much less certain increases. Again, expectation of a change in temperature is defensible, but the predicted magnitude of change is less reliable. GCM predictions of precipitation change may be positive or negative, large or small. At site-specific levels (i.e., states, forests, or 4th-, 5th-, 6th-order drainages), there is no reliability in the predictions, yet these are the levels where water resources are managed, predictions of yield are made, and where diversions and storage occur.

The purpose of this paper is two-fold. First, I will present the results of simulating the impact of several global change scenarios on the amount and timing of flow from a subalpine hillslope, using the revised Subalpine Water Balance Model (WATBAL). Then, I will discuss the potential for detecting these site-specific changes in the subalpine hydrograph.

FLOW SIMULATIONS

In recent years, the Subalpine Water Balance Model (Leaf and Brink 1973) has been revised to incorporate current thinking on snowpack accumulation processes. Functions for simulating snow redistribution due to wind have been replaced by interception functions based on the relationship between basal area and snowpack accumulation (Troendle 1987). In addition, PROSPER (Goldstein and Mankin 1972), a plant water relations model, has been linked with WATBAL as a substitute module to simulate summer evapotranspiration. VSAS (Troendle 1985b, Bernier 1985) has also been incorporated as a surface/subsurface routing function.

When the subsurface routing module (VSAS) is run with the water balance model, the data requirements and iteration time increase significantly over just running the water balance model (VSAS runs at a 5-minute time step, PROSPER at a 15-minute time step, and WATBAL uses a daily time step). To date, VSAS has only been validated in the subalpine forest at the hillslope level using data from 2 study plots (Troendle 1985a, 1987). Plot 2 is forested, 210 m long, and has a 36-m-wide collection system across the base that intercepts lateral flow moving downslope at 3 levels: surface, surface to 1 m deep, and 1 to 4 m deep. The water intercepted at the base of the slope represents the contribution from the hillslope to the stream channel. This component could be considered a watershed segment. Plot 1 is similar to 2, but the collection system is only 15 m wide. The temporal and spacial integration of such "segment" flows generate the hydrograph from first-order basins (Hewlett and Troendle 1975), and these combine into 2nd, 3rd, etc., order watersheds.

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Figure 1 presents the observed flow for both plots and a common simulated outflow using the water balance model with VSAS for 1980. The snowpack model simulates accumulation of the winter snowpack and its subsequent melt. The melt water enters the soil environment and is routed vertically and horizontally on and in the soil mantle toward the channel using VSAS. When transpiration is occurring, tree roots extract water from various soil horizons via the PROSPER component.

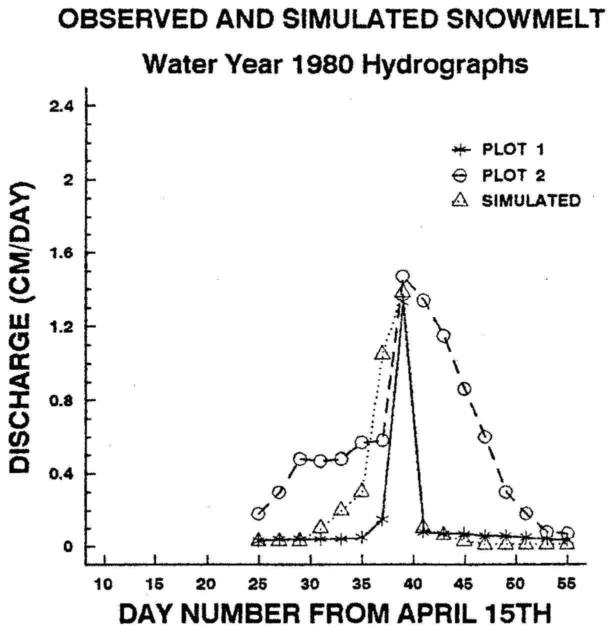

FIGURE 1. Comparison of simulated flow for generic hillslope with observed outflow from two hillslope plots, one larger (# 2) and one smaller (# 1) than the simulated plot.

Snow accumulation begins on the hillslope in October/November and continues until the pack melts in the spring, with the melt water then available to the hillslope. The collection systems are perpendicular to the base of the slopes and, as noted, are either 15 or 36 m wide. There are no lateral constraints on either of the plots. Both slopes are 210 m long, but we do not know the true "contributing" area to either interceptor system. We assume that plot 2 is a "converging" slope, implying the contributing area is larger than the rectangular "plot boundary" would indicate (Troendle 1985), while plot 1 appears to be a diverging slope and, therefore, smaller in size. Given these concerns, the "simulation," based on a rectangular shape, seems reasonable since the simulated flow, with no calibration, appears to fall between the observed flow for the two plots and the peak flow timing is almost exact.

CLIMATE CHANGE SCENARIOS

The model appears to be simulating both the timing and magnitude of the hillslope or "segment" flow that contributes to the hydrograph. Given this assumption, the simulations were re-run with modification in input data to reflect changes in precipitation and temperature.

The first simulation of "climate change" involved 5% and 15% increases in precipitation (Fig. 2). The melt (and flow) period was extended an additional 6 or 7 days with a peak that was 50% to 80% greater than for the baseline precipitation regime. A second "climate" scenario consisted of temperature increased 3 or 5 °C (Fig. 3). This had a much more dramatic impact on timing than on volume of flow. A 3 °C increase in average daily temperature advanced the peak 14 days, while the 5 °C increase advanced it 23 days. The tendency was also to cause a steeper or faster rise in the hydrograph with a relatively longer recession.

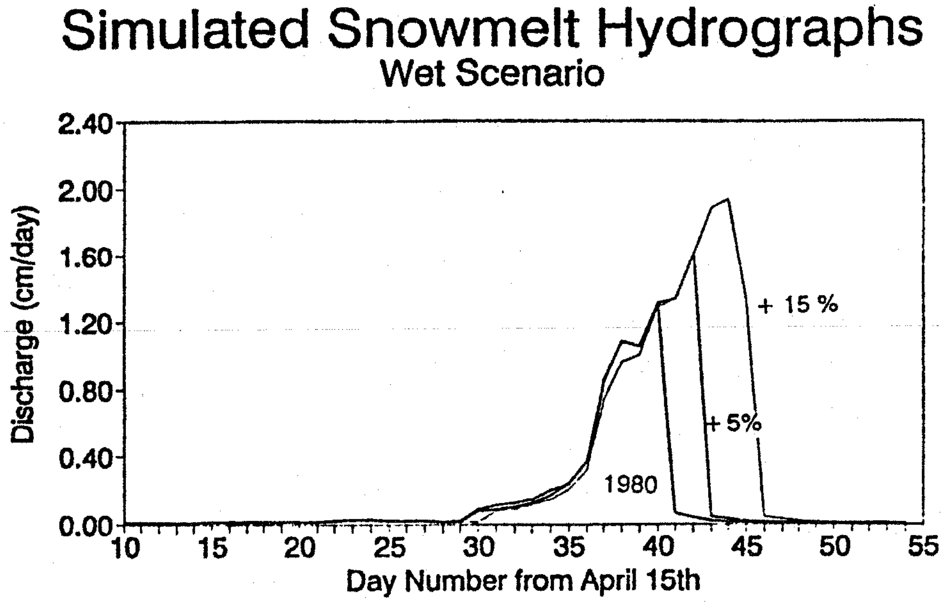

FIGURE 2. Comparison of base simulation for WY 1980 with those assuming a 5% and 15% increase in precipitation.

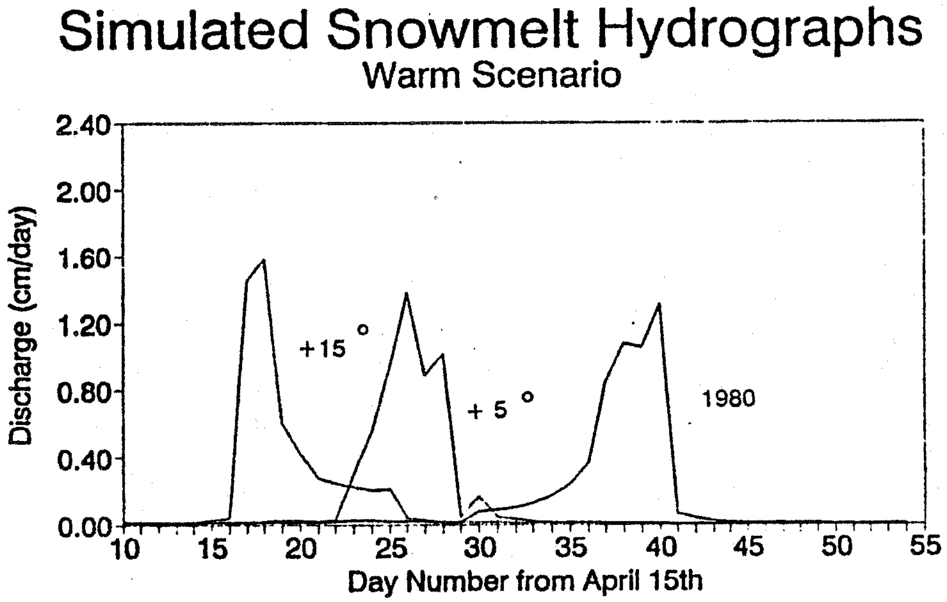

FIGURE 3. Comparison of base simulation for WY 1980 with those assuming a 3 and 5 °C increase in temperature.

A combination of warmer temperature and more precipitation caused both a much higher peak and one that occurred 3 weeks earlier (Fig. 4). As one might expect, warmer temperatures with less precipitation (+ 5 °C, - 15% precip.) caused a much smaller peak that occurred much earlier in the year (not shown). All temperature change scenarios caused lower summer flows (because recession begins earlier), which were further aggrevated by greater summer evapotranspiration (ET). The water balances are not presented in this paper, but they varied from an increase in evapotranspiration of 2 to 10 cm on an annual basis.

The plots described have been monitored for 10 years. The peak discharge rate has varied by an order of magnitude from year to year, but timing of the peak has varied by only a few days (less than 10). Therefore, the effect of precipitation change on the hydrograph is not outside the currently expected range, but the 3-week advance in the timing of the peak, due to temperature increase, is well outside the observed range of hillslope response during the 10 years of observation.

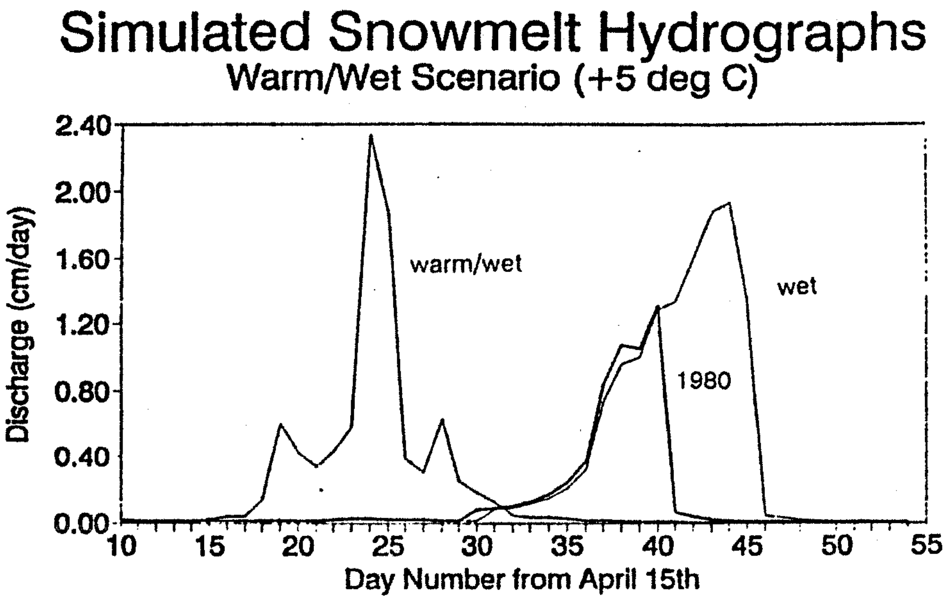

FIGURE 4. Comparison of base simulation for WY 1980 with those assuming a 15% increase in precipitation, and both a 5 °C increase in temperature and a 15% increase in precipitation.

STREAMFLOW DYNAMICS

The Fraser Experimental Forest (FEF) has 9 gaged watersheds ranging in size from 10 to 800 ha. East St. Louis Creek, the 800-ha control watershed, is fully forested and has been continuously monitored during the spring/summer period (4/15 to 10/15) since 1943. Stream gages are not operated during winter months (Nov.-Mar.). Eighty percent of the total annual yield occurs during April, May, and June, with 50% or more occurring during a 25- to 30-day period in late May to early June (Troendle and King 1987). The hydrograph from these environments is primarily driven by melting snowpack, with 72% or more of the annual variability in flow explained by the amount of water equivalent in the snowpack on April 1. Another 6% or 8% can be accounted for by melt season precipitation (April, May, June) and only 1% due to summer rainfall (Troendle and King 1985, Bevenger and Troendle 1987).

The streamflow record at FEF is collected using Fisher Porter data loggers as the primary recorder, and FW-1 drum recorders as both a back-up and for visual evaluation. The Fisher-Porters punch at 15-minute intervals. In the summary process, these 15-minute observations are integrated to get daily, weekly, and seasonal flow. Instantaneous (15 min.) flow data are available for the entire period of record.

Streamflow records are usually collected with the same degree of resolution as at other installations. However, long-term (48 years), clean (intensively monitored, maintained, and edited), high resolution (15-min. observations) record from an undistributed watershed, such as East St. Louis Creek, lends itself well to characterizing flow dynamics over time and detecting global change impacts.

Figure 5 presents the annual hydrographs for East St. Louis Creek for 1987 and 1988. On an annual cycle, the variability in daily flow is quite great, even though the hydrograph is snowmelt not rainfall driven. Diurnal fluctuation can be as much as 50% of the mean daily flow value. Taking this variability to the next level, Figure 6 presents a scattergram of all the maximum instantaneous daily values, by date, for the period of record for East St. Louis Creek, 1943-1988. As one can note, the variability in maximum flow, on any given day, can vary by an order of magnitude: from 22 to over 245 $L.s.^{-1}km^{-2}$. There is a clustering, with little variation or range, at the onset of the hydrograph and during the summer recession period. With only a few exceptions, the onset of melt is fairly consistent from year to year for this watershed. Recession and late summer flows reflect soil water drainage and are all relatively consistent. During this period, the watershed is not particularly responsive to precipitation. Most of the variation occurs at or about the time of peak, which averages June 17.

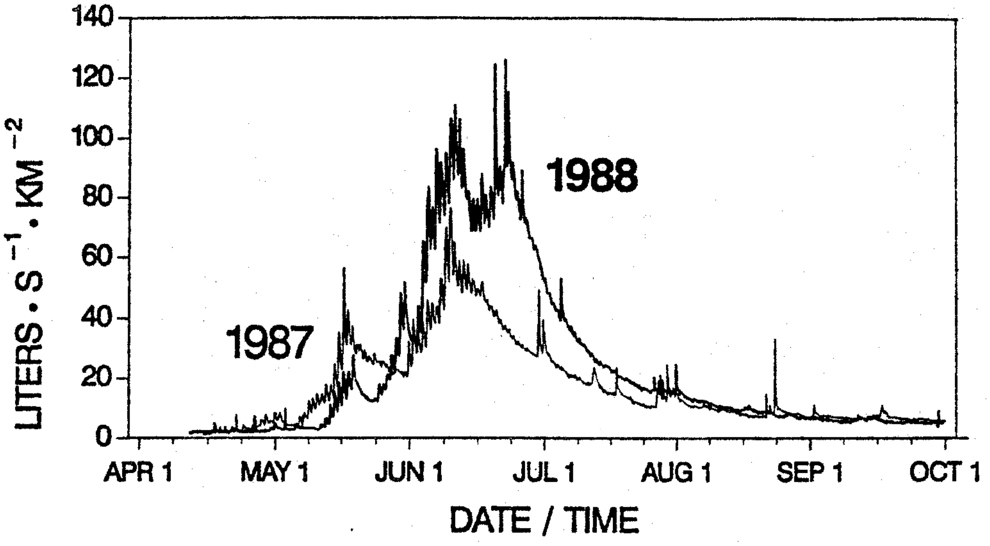

FIGURE 5. Annual hydrographs from East St. Louis Creek. Solid lines connect max and min daily flow.

Mean daily flow, with two standard error bars, for the 45-year record, is also plotted in Figure 6. The peak of mean daily flow from East St. Louis Creek is quite conservative at 73 L.s.$^{-1}$km^{-2} ± 3.3 L.s.$^{-1}$ km^{-2}. The average maximum daily flow peaks at a somewhat higher level than the mean daily flow (Fig. 6). The average instantaneous maximum daily flow is 88 L.s.$^{-1}$km^{-2} or 21% higher than the mean daily flow. Figure 6 represents a composite demonstrating the variability of in the range of individual instantaneous maximum flows relative to the long-term daily mean flow. Average annual flows are equally variable (Fig. 7). For the same 45-year period, mean annual flow varies by over 400% and appears (at least qualitatively) to be cyclical in nature, with a 10-year period.

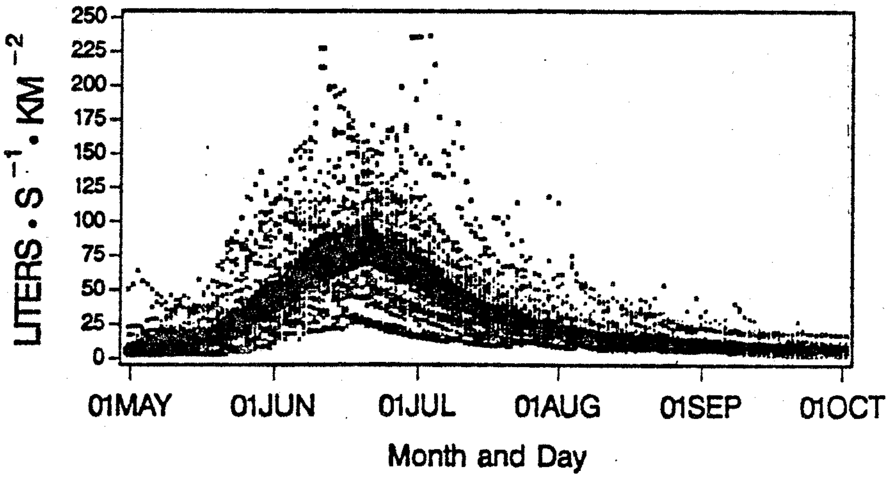

FIGURE 6. Composite graph showing maximum instantaneous flows, by date, and mean daily flow (with 2 S.E. bars) for East St. Louis Creek for period of record 1943-1988.

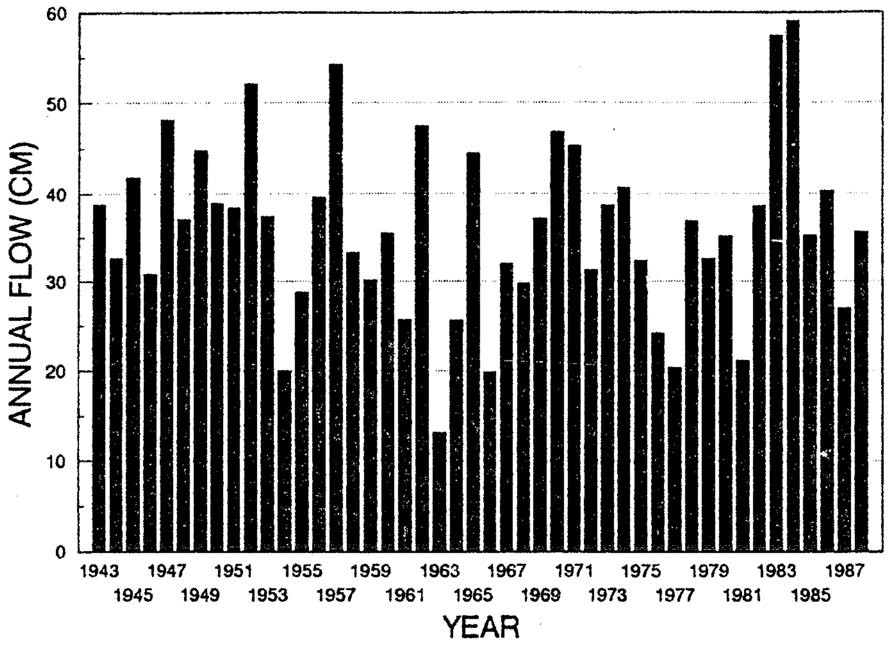

FIGURE 7. Mean annual flow for East St. Louis Creek for period of record, 1943-1988.

DISCUSSION

One of the purposes of this paper is to determine if the postulated changes in climate (temperature increase and precipitation increase/decrease) as simulated earlier can influence the hydrograph to a detectable level, given the variability associated with natural flow regimes.

Based on Figures 6 and 7, one can see that the simulated changes in climate are unlikely to cause shifts in the magnitude of the hydrograph that will rise above or fall below what is the normal variability. This does not mean that, given decades of record, such changes will not be detectable, assuming they occur. It does mean, however, they will not be readily apparent, and interpretations may actually be misleading based on where in the cycle the record is collected. Short-term hydrologic records will not be of much use in detecting these changes.

What appears to be more significant is the potential shift in the timing of the snowmelt response. Simulations indicate the hydrograph could be advanced 21 to 23 days with a 5 °C increase in temperature. If this shift were to occur, even with the variation in flow expressed in Figure 6, we would begin to see a "new" hydrograph with a significant advance in timing. If the peak of the hydrograph shown in Figure 6 were shifted from June 17 to a date 3 weeks earlier, the impact would be quite noticeable. Availability of water for diversion or storage would be significantly altered, and summer flow would be greatly reduced.

Although not presented, the simulated changes in evapotranspiration imply that changes in the water balance and in the volume of subsequent stream flow will be minimal (2-10 cm ± change) relative to actual variability in annual flow. The response that appears to have the greatest potential direct and indirect impact is the one dealing with timing of flow.

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