VI. Summary and Discussion

The interaction between topography and meteorology, as both vary over each of the major river basins of South Asia, and among sub-basins within these major rivers, produces a complex mosaic of "topohydrological" environments, analogous to "topoclimates", or climates determined by topographic characteristics (Thornthwaite 1953). The macro-scale hydrological environments of the three major river basins of South Asia - the Indus, Ganges, and Yalu Zangbu-Brahmaputra rivers - provide only limited insight into the great diversity of such environments present on the meso-scale, within individual mountain tributaries to these rivers. Much of the information on which discussions concerning the hydrological environment of the Himalayas, and the relationships between this environment and past or present land-use practices, has been drawn, or inferred, from analyses of data describing macro-scale phenomena, is based upon measurements from the lowlands to the south of the Himalayas.

It is clear from this study that global models, linking human activities to undesirable changes in the water or sediment output of the Himalayan mountains, overstate the role of these activities. Hydrologic and geomorphic processes operate throughout virtually the entire altitudinal range present in these mountains, while human activities are almost completely confined to the lower 3,000 m. Approximately 50 per cent of the water flowing from the Himalayas and an indeterminate, but presumably high, percentage of the total sediment in the rivers flowing from the Himalayas are produced from portions of the mountains outside the normal range of human habitation or activity - that portion above approximately 3,000-4,000 m. This percentage approaches 100 per cent in the upper Indus and Yalu Zangbu basins.

At the same time, the results of this study indicate that specific runoff in the Himalayas is at a maximum in an altitudinal belt of considerable human activity -- 1,500 to 3,500 m. While the hydrological consequences of environmental disturbances in this belt are unlikely to be detectable on the scale of the major river basins of the region, it is quite reasonable to assume that local problems of increased runoff or erosion could occur as a result of unwise land use.

On the scale of the major river basins of South Asia, the Indus, Ganges, and Brahmaputra rivers do not differ significantly from one another. The total annual discharge of the upper Indus River (including Karakoram and Trans-Himalayan tributaries) is 115,000 million cubic metres, of the Himalayan and Tibetan tributaries to the Ganges River 200,000 million cubic metres, and, of Himalayan and Tibetan tributaries to the Brahmaputra River, 200,000 million cubic metres, a total difference of less than a factor of two. Peak flows occur in all rivers during the summer monsoon, while the intermonsoon period is characterised by receding flows to a base flow reached just prior to the onset of the subsequent monsoon. Each river carries roughly comparable amounts of sediment. This apparent uniformity on the macro-scale masks a very great diversity among the three river systems on the scale of individual sub-basins within each river system.

On the meso-scale - the scale of individual sub-basins or topographic elements within a sub-basin, such as altitudinal belts - hydrological environments range from glaciers or cold-dry deserts to hot-wet, low-altitude subtropical forests. It is not uncommon for these contrasting environments to exist within a few tens of kilometres of one another, often within a single sub-basin. These contrasting environments produce a situation in which the hydrological diversity of a catchment basin cannot be inferred directly from measurements at individual hydrometric stations. Suggestions that additional hydrometric stations be added to the existing network, primarily for research purposes (Ives and Messerli 1987 and ICIMOD 1990), ignore the fact that, in all probability, "representative" basins do not exist.

The following specific points have emerged as a result of this study. On the macro-scale, both the upper Indus and Yalu Zangbu-Brahmaputra are largely snow-fed rivers, while probably not more than 30 per cent of the headwaters of the Ganges River are derived from this source. This fact alone is sufficient to cast doubt on the value of any regional approach to hydrological modelling, planning for water resource development planning/management or land-use evaluation.

An analysis of the hydrometric and climatological databases for the Nepalese portion of the Himalayas, in the mountain headwaters of the Ganges River, illustrates some of these differences in terms of single portions of this complex region.

1 Mean annual discharge, Q_v, m^3/s, ranges from less than ten cubic metres per second to over 400 cubic metres per second in the gauged sub-basins of the Nepalese Himalayas. This range of discharge volumes is a result of differences in both the regional climate and of sub-basin surface area. Based solely upon values of Q_v, no conclusions can be drawn concerning the nature or range of hydrometeorological environments above the gauging station. The highest value for mean annual discharge is from the Arun River, a sub-basin in the Sapta Kosi system, with approximately 80 per cent of its total surface area in the cold-dry desert of the Tibetan Plateau. This river has the lowest value of specific runoff. In contrast, the Balephi Khola, also a tributary to the Sapta Kosi, has a mean annual discharge, Q_v, almost one order of magnitude less than that of the Arun, but the specific runoff, Q_s, is over five times greater, indicating a much more humid environment and a much greater potential for land use-hydrological interactions.

2. Values of mean annual specific runoff, Q_s, mm, range from a low of less than 500 mm (for the Arun River) to nearly 2,800 mm for the Seti Khola, a small tributary to the Narayani River. In terms of specific runoff, the "wettest" major river in Nepal is not the Sapta Kosi, as might be assumed from the east to west climatic gradient often implicitly assumed in the literature, but, rather, the Narayani basin (1,893 mm) in central Nepal. The Sapta Kosi has intermediate values (1,609 mm), while the Karnali basin is considerably "drier" than either (1,203 mm). Differences within each of the major river basins are greater still than the differences among them, varying by a factor of from two to six among the sub-basins in each.

Specific runoff, plotted as a function of mean sub-basin altitude, shows a similar trend for the three major river basins, with maximum values in an altitudinal belt between approximately 2,000 and 3,000 metres and decreasing with altitude both above and below this belt. In contrast, specific runoff increases linearly with altitude in the upper Indus basin to the maximum altitude (approximately 5,000m) for which data are available. In the Yalu Zangbu basin, there is no comparable orographic trend.

3. Variations in the climatic factors influencing hydrological environments vary much more with altitude and with respect to the main crest of the Himalayan mountains than with the east-west position along the long axis of these mountains. Mean monthly air temperatures decline at approximately 0.5 degrees/100m from maximum values of approximately 30 degrees in June at the lowest altitudes to 15 degrees in January. The zero degree isotherm fluctuates seasonally between approximately 3,000 and 6,000 metres, promoting both freeze-thaw cycles in surficial materials, as well as snow accumulation and melt in this altitudinal range. Precipitation trends with altitude are not as well-defined as those of temperature. At any given altitude, within the range for which data are available, the scatter is great. Precipitation data are a poor index of streamflow.

4. For a period of between five and seven months, depending upon the individual sub-basin, rivers of the Nepalese Himalayas are in recession from the peak flows of the preceding monsoon and snowmelt season. Recession curve analysis suggests that relatively accurate short-term (30-90 days) forecasts may be prepared on the basis of the reliability of the recession curves for each sub-basin. Low flows are far less variable from year to year than peak flows; and that may vary by as much as a factor of two.

5. Based upon measurements at the headwaters of the Dudh Kosi River in the Sapta Kosi basin, it is tentatively suggested that snowmelt may contribute approximately 30 per cent of the total annual streamflow volume of this river system.

6. The rivers of Nepal do not respond uniformly to cycles of drought and flooding. During any given year, some rivers may be experiencing a major flood cycle, while others are near long-term minimum volumes of peak flow. This lack of uniformity in the annual peak flows casts doubt on the hypothesis that cycles of flood and drought in the Ganges or Brahmaputra basins are, in some way, a direct result of variations in the runoff from Himalayan tributaries.

A preliminary comparison of the sum of the annual peak flows from the three major Nepalese rivers with the annual peak flow at the Farraka Barrage indicates that the Himalayan tributaries can act as a modulating influence on the Ganges River. During drought years, the volume of the peak annual flow passing the Farraka Barrage is almost completely a result of runoff from the Himalayas. During years with high flow peaks, on the other hand, the Himalayan contribution shrinks to approximately 50 per cent.

A number of specific studies are of some immediate importance.

- A physical geography of Nepal should be produced, relating the factors of geology, geomorphology, climate, and vegetation to hydrologic regimes and land use practices within the Kingdom. This can best be done using the Geographical Information Systems' (GIS) technology.
- An intensive, quantitative analysis of all recession curves of Nepalese rivers should be undertaken to establish the reliability of recession analysis as a forecast methodology.
- A major effort should be directed towards development of a topographic data matrix, for use with the Geographic Information Systems' (GIS) technology. From this study, it is clear that the relationship between water and terrain is more complex than the simple altitude-runoff model developed from existing information. A topographic data matrix would aid considerably in resolving some of this complexity.
- Efforts should be made to maintain the accuracy of rating curves for each station, and funds should be sought to replace all staff gauges with recording hydrographs. Measurement of sediment transport in Nepal sub-basins may not be simply a matter of importing an existing methodology. The relative contributions of suspended and bed load are undefined for Himalayan rivers, but the ratio undoubtedly differs from that of better-studied river systems. Only intensive, scientific studies, rather than a simple monitoring programme, will resolve this question.