I. Introduction

Water is a factor in virtually all resource development undertakings in South Asia. Water resources' development or management represents an attempt to meet an existing or potential demand for water or a related resource, such as energy or food. Commonly, attempts to meet these demands are based upon engineering modifications of the existing water supplies. Engineering modifications, in turn, are dependent upon a quantitative understanding of the temporal and spatial variability of those supplies. It is apparent that a major component of attempts to develop or manage water resources in any environment must be scientific studies of the resource, in advance of need, if project planning is to be realistic. Within any river basin, attempts to meet demands that exceed the natural supply of water will be, at best, only partially successful. Also, attempts to ignore the annual excesses of water which move through the system will only contribute to further inundation of the natural flood plains.

There are two primary needs in understanding the water resources of South Asia:

- it is essential to assess accurately the existing demands for water, and
- the nature of the water supply must be understood if these demands are to be met.

Demographics determine the nature of demands upon water resources. Economics and engineering determine the extent of technologies available and the willingness of a society to apply those technologies. Hydrology determines the extent to which the supply will meet that demand. It is the purpose of this paper to consider some aspects of the hydrology of the headwaters of some of the major rivers of South Asia. A case study illustrating certain aspects of the nature of the water supply of the mountain watersheds of the region is also included. This case study is based upon a preliminary analysis of hydrometeorological data from Nepal.

Water Resources and Environmental Management

Whereas water resources may be defined with relative precision, the term "environmental management" is somewhat more ambiguous. In the context of factors affecting the flow of water through a watershed, the "environment" may be defined as:

- climate,
- geology,
- topography (or terrain), and
- vegetation.

"Environmental management", from a water resources' perspective, is a matter of determining the extent to which a change in any one, or some combination, of these factors will produce a corresponding change in the timing, volume, or quality of water flowing through the watershed. Alternatively, it is a matter of inducing a change in one or more of the factors so as to produce some desired change or correct a perceived imbalance. Environmental interactions are complex, and at least two of the factors -- climate and geology -- cannot be "managed" in any meaningful way. In the case of these two factors, it is essential to understand how each relates to the water and sediment balance of a watershed, but the only realistic management alternative is to make allowances for the prevailing conditions of climate and geology in the management planning. In every case, from a water resources' perspective, the primary goal of environmental management should be to understand the interactions within the environment well enough to predict, with reasonable accuracy, the probable outcome of any particular course of action.

Terrain and vegetation can be "managed", in the sense that the type and density of vegetation covers may be purposefully altered and terrain may be shaped, as in the case of terracing on the mountain slopes of Nepal, or altered by a variety of engineering structures, e.g., dams. The extent to which a change in vegetation or terrain will affect the water or sediment balance will be dependent upon the existing conditions of geology and climate, the nature of the changes in the vegetation or terrain, and the scale on which the change is effected. In all cases, however, **it must be recognised that those factors that can be managed may not be the critical factors in determining the water and sediment balance of the watershed.** Only a study of the interrelationships at a specific site can determine if, in fact, "environmental management" of any sort will have a positive or a negative effect on the water resources at, and downstream from, that site (Hamilton 1987).

Almost without exception, large water resources' development or management projects are based upon an understanding of the water regime derived from a limited database. It is critical to be able to extrapolate these data spatially in order to understand the significance of any form of environmental manipulation for water resources. Extrapolation techniques have been proposed for the mountain environment, but they have not been widely tested (Alford 1985). At the same time, individuals siting environmental monitoring instruments in mountain watersheds rarely are aware of the diversity of the environment that surrounds them.

Water is an integral aspect of all facets of the mountain environment and enters into virtually every resource development or management project in some way. All disciplines involved in resource planning or management have developed numerous technologies for modifying the natural characteristics of volume, rate, timing, or quality of water at a site. Basically, all technologies are variations of a few basic themes: storage of water during a period of surplus for use in a period of deficit, transfer of water from an area of surplus to one of deficit, or improving water quality. While there are only a handful of ways in which the hydrological regime of an area may be changed beneficially, in practice, there is a virtually endless number of variations, combinations, and permutations of these basic themes (Dunne and Leopold 1978).

For most environments, such as forests, or grasslands, or deserts, entire books have been filled with discussions of appropriate technologies to modify the timing and volume of water flows. As the list of environmental elements considered grows linearly, the list of possible technologies to modify the water associated with that element grows exponentially. This means that any discussion of water resources' technologies, within the context of environmental management, is essentially open-ended. For this reason, the discussion in this paper will deal with the basic concepts involved in individual environmental factors, rather than with specific technologies designed to deal with a specific problem in a particular place.

Approaches to water resources' engineering or management -- attempts to alter the volume, timing, location, or quality of the water supplies of a region -- have evolved largely in the "two-dimensional" environment of the lowlands. These operational models are often misleading when applied to the high-energy, three-dimensional environments of large mountain ranges. Only in very recent years have attempts been made to develop water resources within large mountain ranges such as the Hindu Kush-Himalayan Region.

A major difference between mountain and lowland environments is related to the extent of spatial environmental uniformity -- the degree to which the characteristics of one place in the watershed may be predicted by studies in a second place. In a lowland watershed there is commonly a great deal of uniformity among environmental associations from place to place within the watershed. Environmental management procedures which are successful in one part of the watershed may be transferred to another place with some degree of confidence. In a highland watershed, on the other hand, the distinguishing environmental characteristic is spatial heterogeneity. Two points within the watershed, separated only by a distance of a few kilometres, may differ from one another as much as the polar ice caps differ from an equatorial jungle. The central dogma of a successful manager of mountain environments will be that measurements are not necessarily valid for any point other than the one at which they were made. A project that succeeds completely at one point within a mountain watershed may be much less successful at another.

Uncertainty

For at least a portion of the Hindu Kush-Himalayan Region -- Nepal -- much has been made recently about the problems of uncertainty associated with the information upon which resource management or development decisions must be based (Thompson and Warburton 1985 and Kattelman 1987). It has been argued that this information is fundamentally unsound, incorrect, in some cases even manufactured, and, perhaps, given the political realities and poor institutional linkages that characterise environmental management and development in the region, irrelevant. This is not a matter that can be resolved absolutely, but there are aspects that are pertinent to the data on which this paper is based and which should be discussed.

In the case of the physical environment that determines the availability of water and the variations among elements of the hydrologic cycle over the region, reproducible information is provided by time-series' measurements made continuously by recording instruments, from periodic observations, or from geodetic surveys of watersheds. The instruments may be stream-gauges, precipitation gauges, or thermographs. The geodetic surveys result in the preparation of topographic maps. There are problems with the accuracy and representativeness of these types of data, but these problems are dealt with extensively in the literature on climatology, hydrology, and geodesy. Standard tests exist for determining, at least, the internal consistency of such data (Miller 1981 and Ward 1975).

There is no doubt that errors do exist in the hydro-meteorological database for the Hindu Kush-Himalayan Region, just as they exist in databases for all of the major mountain ranges on earth. The challenge to the scientist studying this environment, or to the environmental manager or planner, is to use these data in as effective a manner as possible. This effectiveness will stem more from the conceptual models that are used in the planning or management process than from the absolute accuracy of the data (Baker 1944). The problem is not with the "uncertainty" of the database but with the ways in which the data are organised, interpreted, and used to develop management policies (Dunne and Leopold 1978 and Alford 1987).

The information on which this paper is based has been taken from a variety of sources, including the hydrometeorological data collected by HMG, Nepal (Department of Irrigation, Hydrology, and Meteorology 1976 and 1977, unpublished), and it presumably has varying degrees of accuracy. It has not been possible in most cases to analyse the original data sources and so the absolute accuracy could not be determined. Every attempt has been made to ensure that the data used possessed internal consistency, that is, that the cumulative volumes of discharge, as measured in a series of nested basins, were consistent with the discharge reported for the major basin. Patterns of precipitation and runoff, as reported in the literature, were compared to ensure, at least, qualitative agreement. All values have been rounded off to one or two significant figures, introducing minor differences in values contained in various tables or illustrations. These differences are well within the limits of the normal errors of measurement to be expected in hydrometeorological data.