Annual Runoff from Glaciers of the Nepal Himalaya

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Abstract

Recent concerns related to the potential impacts of the retreat of Himalayan glaciers on the hydrology of rivers originating in the catchment basins of the Himalaya have not been accompanied by any analysis describing the role of glaciers in the hydrologic regime of these mountains. This note presents an estimate of glacier runoff from the altitudinal belt above 5000 meters above sea level for the Karnali, Narayani and Sapta Kosi basins of the Nepal Himalaya, based on a comparison of specific runoff (depth/unit area) and the distribution of surface area with altitude in those catchments. Specific runoff for the altitudinal belt occupied by the glaciers of these catchments was estimated to be between approximately 500 - 1000 mm, based on analysis of published data from the Nepal Department of Irrigation, Hydrology and Meteorology. The surface area of this altitudinal belt was determined by planimetry of 1:500,000 maps. Glacier areas were taken from the literature.

It was assumed that runoff for altitudes above approximately 5000 m is produced by the melting of glaciers, perennial snow fields or transient snow deposits, Based on a value of 1000 mm for the mean annual specific runoff for the 5000-7000 m altitudinal belt, the total estimated runoff from the belt within the catchment basins was slightly more than 27,000 million cubic meters annually, or slightly less than 20% of the total annual discharge of the rivers of Nepal. Runoff from the glacierized portion of the three catchments was calculated to be slightly less than 5200 million cubic meters annually, representing approximately 4% of the estimated 145,000 million cubic meters flowing on average into the Ganges River from Nepal each year.

I. Introduction

The Himalaya are a formidable mountain range, and it will undoubtedly be many years before data bases exist that will permit the use of many of the analytical tools that have been developed for the mountains of North America or Europe. In the meantime, techniques providing results with an accuracy comparable that available for the complex Himalayan topography should be developed. This note has been written to describe one such procedure, and the results obtained from it.

The potential impacts of climate change and “global warming” on the timing and volume of streamflow from Himalayan catchment basins have been discussed recently in the literature. (e.g., Iyngararasan, et.al., 2002; IPCC, 2007; ICIMOD, 2006; WWF, 2005). Arguments offered in support of the concerns expressed are generally associated either directly or by inference with the observed retreat of Himalayan glaciers and the assumption that a significant amount of the annual runoff in the rivers of the region is produced by these glaciers.

There are several difficulties involved in an assessment of these concerns, and the assumption on which they are based.

- Few studies of mass and energy balances of Himalayan glaciers have been reported in the literature
- Few general studies of the hydrologic regime of the rivers of the Himalayan region were found in the literature. In particular, there appear to have been no studies of the hydrology of the altitudinal belt – 5000 to 7000 meters above sea level – in which a majority of Himalayan glaciers are found.

What is required is the development of a methodology that will permit assessments of the hydrologic characteristics of the mountains of the Himalaya-Hindu Kush region from existing data bases. Very generally, these data consist of hydrometric and climatologic measurements, and topography, either as maps or satellite imagery. As a first step toward realistic studies if the hydrology of the Himalaya-Hindu Kush mountains, it is the responsibility of the countries of the region to make the necessary data available.

The hydrology of the Nepal Himalaya is dominated by the interaction between the summer monsoon and the extreme relief of the mountains (e.g., Rao, 1981, Sharma, 1983). This altitudinal relief produces a range of hydrologic environments, ranging from humid tropical forests to arctic deserts. Primary water input is monsoonal precipitation. Disribution and form (rain or snow) of this precipitation within the mountain catchment basins is determined by orographic controls on water and energy exchange. The ultimate volume of runoff produced by the interaction of these controls is determined by variation in the relative importance of the processes of energy and water exchange with altitude, and the surface area of altitudinal interval over which they are acting. The primary challenge is to develop a realistic estimate of the runoff from the range of hydrologic environments represented by the altitudinal zonation of the mountains. Glacier runoff must be considered as only one of a number of factors determining the streamflow volume and timing of Himalayan rivers.
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It is the purpose of this note to present the results of a preliminary analysis of the hydrologic contribution of the 5000 -7000+ m altitudinal belt of the Nepal Himalaya to the annual streamflow volume of the major rivers of Nepal, and to assess the hydrologic role of the glaciers within this belt. This analysis is based on a comparison of orographic runoff gradients for the Nepal Himalaya from published data (DIHM, 1976, 1977 , 1986, Grabs, personal communication, 1989, Alford, 1992) with the area of the 5000+ m altitudinal belt within the three major basins, and the glacierized area of each basin (WWF, 2005).The surface area of the 5000+ m altitudinal belt was determined by planimetry of 1:500,000 TPC (Tactical Pilotage Charts) of Nepal.

II. Assumptions and Procedures

1. It is first necessary to develop a model, or models, to assess the general hydrologic regime(s) of the Himalaya before the glacier contribution to the regime(s) can be evaluated;
2. It is most efficient to base development of this model on existing data,
3. These data are streamflow measurements, low altitude precipitation and air temperature, topography,
4. Streamflow volume integrates the interrelationships among the processes associated with topography, geology and climate and is therefore a useful indicator of net mass (input – output) exchange in mountain hydrologic systems (Rasmussen and Tangborn, 1976; Alford, 1985; Tangborn, 1999)
5. The general hydrology of the Nepal Himalaya may be approximated empirically from an analysis of the relationship between the orographic gradient of specific runoff and the area-altitude distribution within catchment basins (Alford, 1992).
6. At altitudes above approximately 5000 meters, runoff is produced primarily by the melting of glaciers, perennial snow fields, or transient snow deposits.

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Streamflow volumes, in m^3/s, are converted to mean annual specific runoff, Qs, mm:

$$Q_s = \frac{(Q_v * t)}{A} \qquad (1)$$

Where:

Qs = Specific Runoff, mm
Qv = Streamflow volume, m3/s
A = area of gauged catchment basin above hydrometric station in km^2.
t = time in seconds.

Total volume of runoff, Qvt, from 1) the gauged catchment basin, A1, 2) the basin above 5000 m, A2, and 3) the glaciers reported as being in the three major basin, A3

$$Qs * A1, A2, A3, \ldots An = Qvt \qquad (2)$$

Where:

Qvt = Total Runoff, milliom cubic meters
A1, A2, A3, …An = Area of gauged catchment basin

Runoff from the glacierized portions of any altitudinal belt containing glaciers or permanent snowfields will be:

$$Qvg = Ag * Qs \qquad (3)$$

Where:

Qvg = Volume og glacier runoff
Ag = Glacierized ares of altitudinal belt

III. Results

Figure 1 illustrates the successive altitudinal belts (A1….An) in two representative gauged (1, 2) catchment basins.

Figure 2 is a composite of mean annual specific runoff (Eq. 1) vs. mean basin altitude values for the three major river basins of Nepal. It can be seen that the composite orographic gradient of mean specific runoff for the major river basins of the Nepal Himalaya is generally negative above altitudes of 3000 m, reaching minimum specific runoff values of approximately 1000 mm at 5000m, 500 mm at an altitude of 6000 m and 0 mm at 7000m. These values are comparable to the few values for glacier melt of less than 1000 mm for Himalayan glaciers (e.g.,Bertier, et.al., 2006; Kulkani, et.al., 2004).

Table 1 is a listing of the three major catchment basins of the Nepal Himalaya, showing the total catchment area (At), area of each catchment above 5000 m , and glacierized area, (Ag), together with the mean specific runoff, Qs) and total annual streamflow volume for the total basin (Qvt), the 5000+ m altitudinal belt (Qv), . Estimates of mean annual streamflow volumes for the 5000+ m altitudinal belt and glacierized portions of each catchment are also included, based on a specific runoff value of 1000 mm taken from Figure 1. The glacierized areas are from WWF, 2005.

A comparison of streamflow volume from the 5000+ m altitudinal belt with total streamflow volume for each basin (Table 1, columns 6 and 8,) indicates that the percentage contribution from this belt ranges from 7-35 per cent of total basin volume, with an average of 19 per cent for Nepal as a whole. The glacierized areas in each of the major basins averages approximately 4% of the total area involved (Table 1, Column 5) and are estimated to contribute an average of 4% to the total annual streamflow of the rivers of Nepal (Table 1, Column 10).

IV, Discussion

Many factors determine the runoff characteristics of mountain catchment basins (e.g., Alford, 1985). With increasing altitude, atmospheric moisture decreases, increasing amounts of precipitation fall as snow, and short wave radiation becomes the dominant source of the energy controlling snow and ice melt. All of the data available for the high altitude portions of the catchment basins of the Nepal Himalaya indicates that this belt is characterized by low values of mass and energy exchange.

The most salient finding of this study is that the glaciers of the Nepal Himalaya do not appear to make a significant contribution to the total streamflow of the rivers of Nepal. The results of this study are considered preliminary. The values used here are consistent with measured orographic trends of air temperature and water runoff.and what would be considered reasonable from a purely theoretical perspective. The results could be improved by using the most recent data, and with a more precise method of measuring area-altitude units, such as a digital elevation model (DEM) as well as in the determination of glacier area.

Future trends in runoff from these glaciers will depend upon the surface area of the glaciers over which melt is occurring, the seasonal duration of melt versus accumulation, and the intensity of the energy exchange processes responsible for glacier melt. Much of this trend will be dependent upon factors for which little, or no, data are available. Ultimately, they will reach a new equilibrium state, or disappear completely, as some have suggested. It is probably unreasonable to assume, as some have, that the present retreat of Himalayan glaciers is somehow a result of rising air temperatures. These are relatively low-latitude glaciers, at altitudes between 4000 meters and 7000 meters above sea level. Under these circumstances, it is most probable that the dominant energy source driving ice melt is radiation, not air temperature. Glacier retreat is clearly on ongoing phenomenon, but the cause(s) are most probably more complex than a simple relationship between this retreat and an increasing air temperature associated with "global warming".

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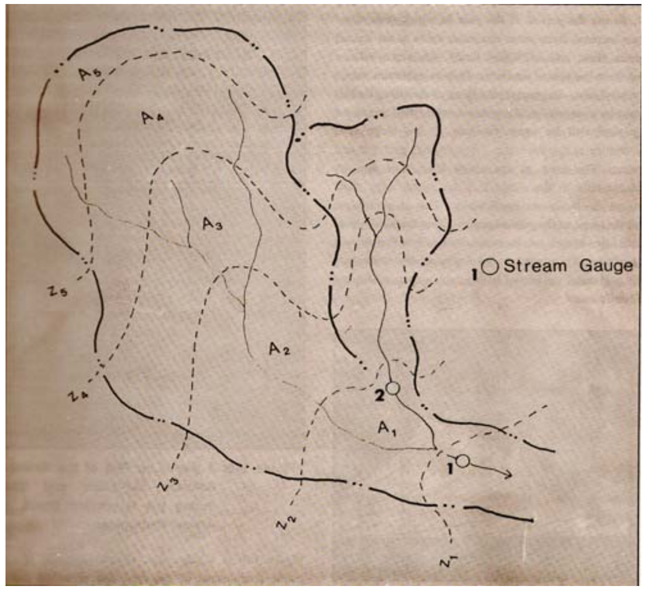

Figure 1. Area-Altitude relationships. The product of the area of altitudinal belts, A1….A5 and the specific runoff, Qs, from each belt equals the volume of streamflow measured at gauging stations 1,2 for time period t.

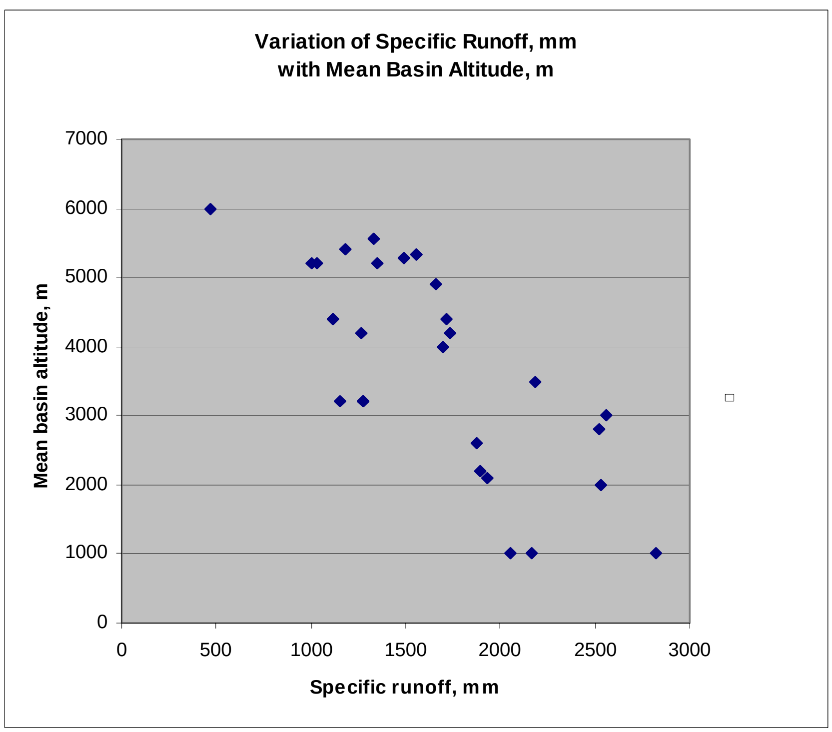

Figure 2. The relationship between mean annual specific runoff depths, mm, and mean catchment basin altitudes for gauged basins in the Nepal Himalaya. Although there is considerable scatter at lower altitudes, there is a definite negative gradient of runoff, above altitudes of approximately 2000 – 3000 m. Data from DIHM, 1976, 1977, 1989, Grabs, 1989; Alford, 1992.

Table 1

Basin	Area, At	Area	Area, Ag	Ag/At	Qvt	Qs	Qv	Qs	Qvg	Qvg/Qvt
1	2	3	4	5	6	7	8	9	9	10
		5000+ m	Glaciers		Total		5000+ m	Glaciers	Glaciers	
	km2	km2	km2	%	mcm	mm	mcm	mm	mcm	%
Karnali	42890	15020	1740	4.1	47241	1101	7510	1000	1740	4
Narayani	31753	6785	2030	6.4	49385	1555	3393	1000	2030	4
Sapta Kosi	51440	33220	1409	2.7	48155	936	16610	1000	1409	3
Totals	126083	55025	5179	4.1	144781	1143	27513	1000	5179	4

Calculated Specific runoff (Qs) and Streamflow (Qv) from 5000 – 7000 Altitudinal Belt and from the Glacierized Area of this Belt (Qvg).. Glacierized area from WWF, 2005. Streamflow Data from: DIHM, 1976, 1977; 1986, Alford, 1992. (mcm = million cubic meters).