Chapter 3
Hydro-Meteorology of the Country

3.1 River Basins

For hydrological studies, Nepal is divided into seven drainage basins: the Kankai Mai River Basin, the Koshi River Basin, the Bagmati River Basin, the Narayani River Basin, the West Rapti River Basin, the Karnali River Basin, and the Mahakali River Basin. Among them only the four basins described below contain glaciers and glacial lakes.

The Koshi River basin

The river system of eastern Nepal is occupied by the Koshi River Basin, which is also known as the Sapta Koshi River, i.e., a network of seven major rivers flowing through the Koshi River Basin. All these seven rivers, namely, the Tamor River, the Arun River, the Dudh Koshi River, the Likhu River, the Tama Koshi River, the Sun Koshi River, and the Indrawati River, from east to west, originate from the High Himalaya. Among the tributaries, the Sun Koshi-Bhote Koshi, the Tama Koshi, and the Arun River originate in Tibet.

The Gandaki River basin

The river network of central Nepal is occupied by the Gandaki River system, which is popularly known as Narayani. The river network forming Narayani comprises the Trishuli River, the Budhi Gandaki River, the Marsyangdi River, the Seti Gandaki River, and the Kali Gandaki River. Among these rivers, some parts of the Kali Gandaki River and the Budhi Gandaki River and major parts of the Trishuli River lie in Tibetan territory and flow down through the Himalayan range to Nepal.

The Karnali River basin

The Karnali River is about 507 km in length and is formed by the joining of Mugu Karnali and Humla Karnali at Galwa. The West Seti River and the Bheri River are the main tributaries of the Karnali River. The Kawari River and the Tila River are other minor tributaries of the Karnali River, which originate from the glaciated region of Nepal, whereas the Humla Karnali River originates in Tibet.

The Mahakali River basin

The Mahakali River is about 223 km long and originates from Api Himal. This western border river has two main tributaries on the Nepalese side. They are the Chamelia River and the Surnagad River. The Mahakali River has a total catchment area of 15,260 sq.km at Banbasa barrage, of which 35.4% lies within Nepal.

3.2 Hydro-meteorological Observation

Precipitation observation

Prior to 1964, the Indian Meteorological Department operated a network of four climatological and about a hundred precipitation stations in Nepal. The Nepal Meteorological Service (NMS) was established in 1965, with technical assistance from The United Nations Development Programme (UNDP) and The World Meteorological Organization (WMO). Since then, a number of WMO projects have assisted NMS in establishing its own network of meteorological stations, which consist of precipitation, climatological, agrometeorological, synoptic, and aeronautical stations. These networks came under the Department of Irrigation, Hydrology, and Meteorology (DIHM) in 1971. In 1988, the Department of Hydrology and Meteorology (DHM) was separated from DIHM and currently operates 267 stations which measure precipitation (DHM 1999a). The existing network of stations is based towards the central part of the country, mainly the Kathmandu Valley and extends towards the eastern part. Stations are sparse in the mountainous regions and the western part of the country. With the exception of 14 stations, precipitation measurements are made using ordinary rain gauges. Rain gauges with an 8 inch orifice, 1m above ground, consisting of an overflow can, measuring rod or tube, mounted on three-legged stands are standard equipment used to measure precipitation. Precipitation data were traditionally published in a monthly format. Monthly precipitation data are available up to 1996 (DHM 1968–1999). Recently, DHM published daily precipitation values for selected administrative zones of Nepal and intends to extend this to other parts of the country in the future (DHM 1999b).

Hydrological observation

The systematic collection of hydrological data was started in the Karnali Basin in 1961 by the of the United Nations (UN) special fund for the feasibility study of hydropower projects (DHM 1998a). A project of the United States Agency for International Development (USAID) established a priority network of river gauging stations between 1962 and 1968. The 120 stations in this network typically consisted of substantial structures such as cableways, stilling wells, and sediment sampling facilities. After 1968 the station numbers increased to more than 300, and these included regular stations and partial recording stations. In 1988 all partial recording stations were closed due to operational difficulties. At present a total of 120 water-level gauging stations are in operation under the management of DHM (DHM 1998a). The network of stations is relatively dense in the middle hills, and is sparser near the northern and southern borders. The number of gauging stations is far from adequate for the drainage density of Nepal. Hydrological data publication has not been regular in the past. Monthly discharge data have been published up to the year 1995 (DHM 1998a).

High altitude hydrometeorological observation

Although some hydrometeorological observations at high altitudes were carried out in the past and are continued by various national and international institutions in the form of short-term studies, organised observations began in Nepal in 1987 with the establishment of the Snow and Glacier Hydrology Unit (SGHU) within DHM. The unit began its work with the collection of meteorological (surface air temperature, relative humidity, solar radiation, precipitation, and wind speed/direction) and hydrological (stage and stream discharge) data in three Himalayan catchments: Imja Khola (Dingboche, Khumbu), Langtang Khola (Kyangjing, Langtang), and Modi Khola (Machhapuchhre Base Camp, Annapurna). Later the network was extended to six stations under the Snow and Glacier Hydrology Project (SGHP 1989–1994) assisted by the Gesellschaft für Technische Zusammenarbeit (GTZ) by adding Makalu (Tashigaon/Phematan Kharka/Sipton La), Kanjiroba (Hurikot/Kaigaon/Singha Chaur), and Humla (Takche/Halji) stations (Grabs and Pokhrel 1992). Several problems, mainly of a logistical nature, prevented regular collection and publication of data. More or less regular data have been collected from

Khumbu, Langtang, Annapurna, and Kanjiroba stations. Daily meteorological and hydrological data have been published up to 1995 (DHM 1997a). A snow and glacier melt runoff model using data from this network was developed and tested for the Langtang Basin.

3.3 Climatological Characteristics

The climate of Nepal is characterised by monsoon circulation, principally easterly winds during the summer, and westerlies from October to May. The summer monsoon, which lasts from June to September, involves a large amount of precipitation. However, the monsoon does not begin abruptly. There is a gradual transition from the dry winter season to the summer monsoon as a result of the pre-monsoon convective rains, which are frequently accompanied by thunderstorms (Kraus 1988). Nepal can be divided into five characteristic climate zones roughly parallel to each other and showing a trend from east to west.

- Hot monsoon climate in the Terai, Inner Terai, and Siwilak regions with a hot and wet summer, and mild and dry winter
- Warm temperate monsoon climate in the Middle Mountains up to a height of about 2,100 masl
- Cool temperate monsoon climate in the Middle Mountains and the High Mountains between 2,100 and 3,300 masl
- Alpine climate in the High Mountain region up to a height of about 4,800 masl
- Tundra type of climate above the snow line where there is perpetual frost and cold desert conditions (Shankar and Shrestha 1985a)

Precipitation, air temperature, evaporation, and relative humidity play an important role in building the climate of a particular place. Characteristics of these parameters in the context of Nepal are discussed in the following paragraphs.

Precipitation

Being located in the northern limit of the tropics, Nepal gets both summer precipitation and winter precipitation (Singh 1985). The thermal regime in the vast Eurasian region, the location of the Inter-Tropical Convergence Zone (ITCZ), and the resulting general atmospheric circulation dominates the precipitation regime of Nepal. The onset and retreat of the southeasterly summer monsoon is associated with the movement northwards and southwards of the ITCZ (Nayava 1980). During the monsoon, depressions form in the Bay of Bengal and move northwest causing heavy rain in their path. Nepal receives the first monsoon showers in the southeastern part of the country and they spread slowly towards the northwestern part of the country with diminishing intensity. The retreat of the summer monsoon begins from the northwestern part of the country. The amount of summer monsoon precipitation, therefore, shows marked variation from south to north and east to west. Further the contribution of the summer monsoon precipitation to the annual total is substantially greater in the southeastern part of the country compared to the northwestern end (Figure 3.1). In addition, there is also the altitudinal dependence of monsoon precipitation. Maximum precipitation occurs around 1,000 masl in the Narayani Basin and around 1,500 masl in the Sapta Koshi Basin, whereas for the Karnali Basin, the maximum precipitation altitude is not unambiguous (Alford 1992).

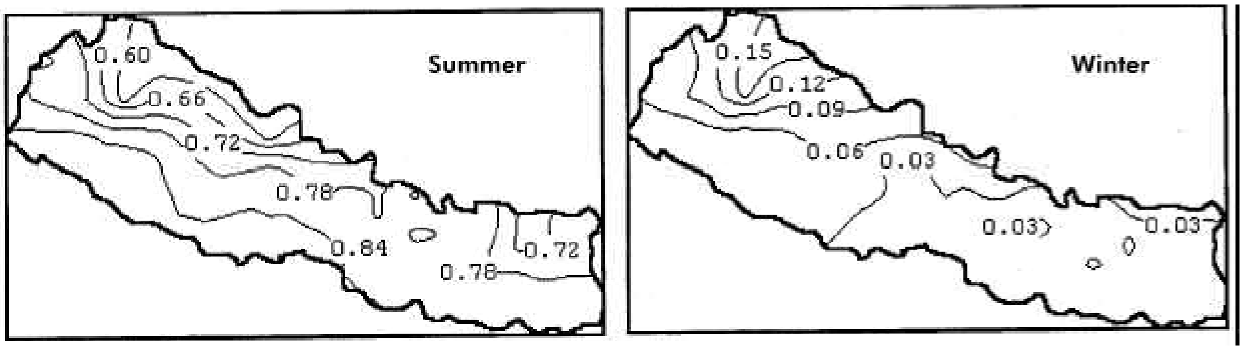

Figure 3.1: Fraction of total annual precipitation accounted for by summer monsoon and winter precipitation (Shrestha et al. 2000)

Summer monsoon precipitation occurs in solid form at high altitude and plays an important role in the nourishment of numerous glaciers of the Himalayas as most of the glaciers in the central and eastern parts of the country are of the summer accumulation type. While general circulation models predict a significant increase in monsoon precipitation with the increase of atmospheric greenhouse gases, amounting to a 15% increase with double carbon dioxide concentration, no long-term trend in precipitation is yet apparent in Nepal. On the other hand, monsoon precipitation in Nepal is found to be related to El Niño and other large-scale climatological parameters (Shrestha et al. 2000).

Winter precipitation is caused by westerly disturbances having their origin in the Mediterranean. The lows formed here are steered and swept eastwards by the westerly aloft. Westerly disturbances affect northern and western parts of Nepal (Singh 1985). Winter precipitation contributes significantly to the annual total precipitation in the northwestern part of the country (Figure 3.1). It plays a major role in the mass balance of glaciers in western Nepal, while it plays a secondary role in glaciers of eastern and central Nepal (Seko and Takahashi 1991).

Air temperature

Air temperature is a parameter with both temporal and spatial dependence. Annual temperatures in 1995 at some selected stations representing a wide range of elevation of the country from south to north are illustrated in Figure 3.2. Spatial distribution of air temperature over Nepal is displayed in Figure 3.3. As can be seen in Figure 3.2, the air temperatures at high altitude are relatively lower than those at low altitude. The environmental lapse rate is around $-0.005^{o}C\ m^{-1}$ (Alford 1992).

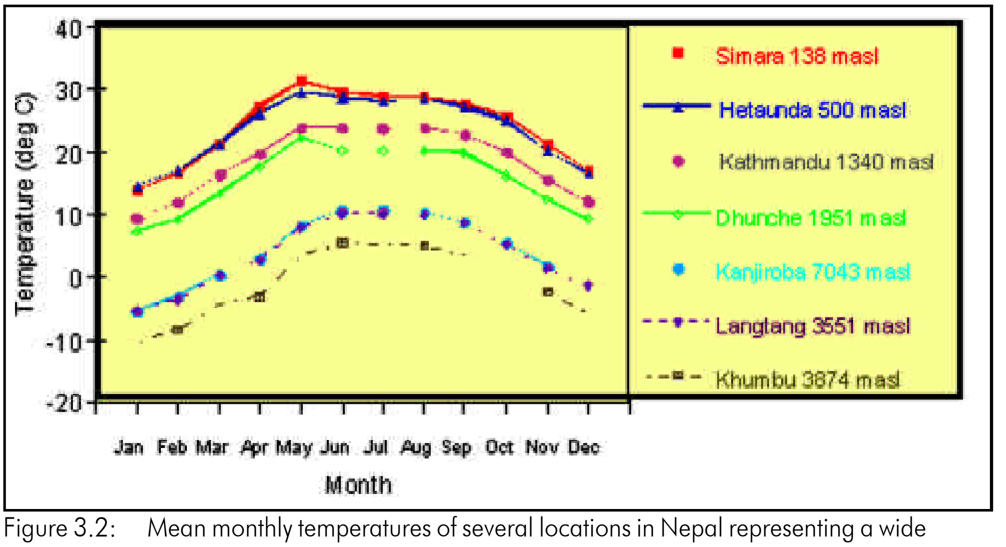

Figure 3.2: Mean monthly temperatures of several locations in Nepal representing a wide range of elevation (DHM 1997a and 1999a)

Air temperature is perhaps the most important single parameter when evaluating the climatic fluctuation of a location. An analysis of records from 49 stations distributed throughout Nepal reveals a clear increase in temperature after the mid-1970s (Figure 3.4, Shrestha et al. 1999). The trends are high in higher altitude regions of the country (Figure 3.4). This result is in agreement with global temperature trends (Hansen et al. 1996; Shrestha et al. 1999). The increase in temperature can have a two-fold impact on the condition of glaciers. Higher temperatures can cause rapid melting of glacier ice on the one hand, on the other hand precipitation will take liquid form rather than solid even at higher altitude. Without a layer of blanketing snow on the surface, the ice with lower surface albedo will be more prone to radiative melting. While many studies report a rapid decrease in the size of glaciers (Ageta and Kadota 1992; Kadota and Ageta 1992; Yamada et al. 1992; Shiraiwa 1993; Pender 1995; Nakawo et al. 1997), linking temperature increase and glacier fluctuation in the Nepal Himalayas is still premature and requires detailed investigations.

Evaporation

Evaporation is a variable that accounts for temperature, humidity, solar radiation, and windspeed. It is the balance between precipitation and evaporation that eventually determines the streamflow. There are

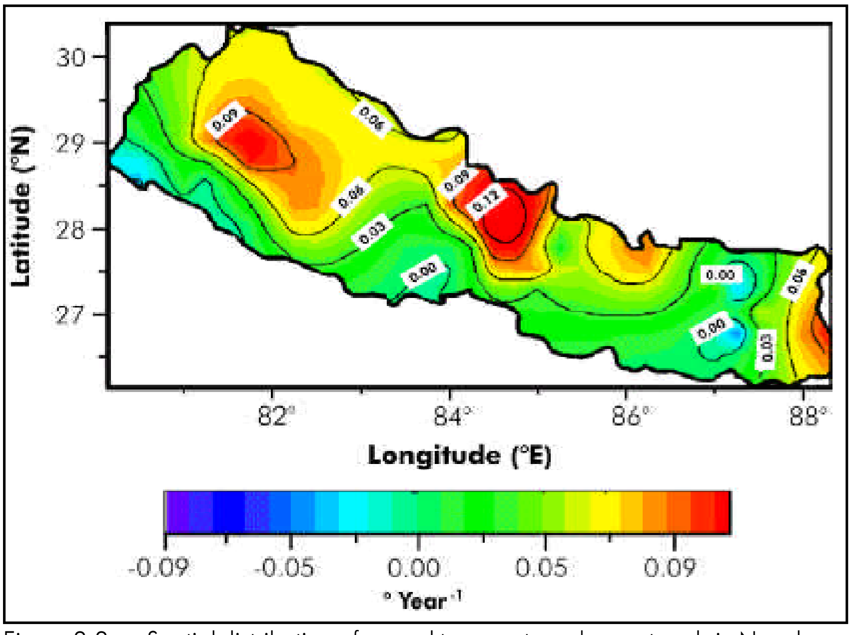

Figure 3.3: Spatial distribution of annual temperature change trends in Nepal from 1977 to 1994 (Shrestha et al. 1999)

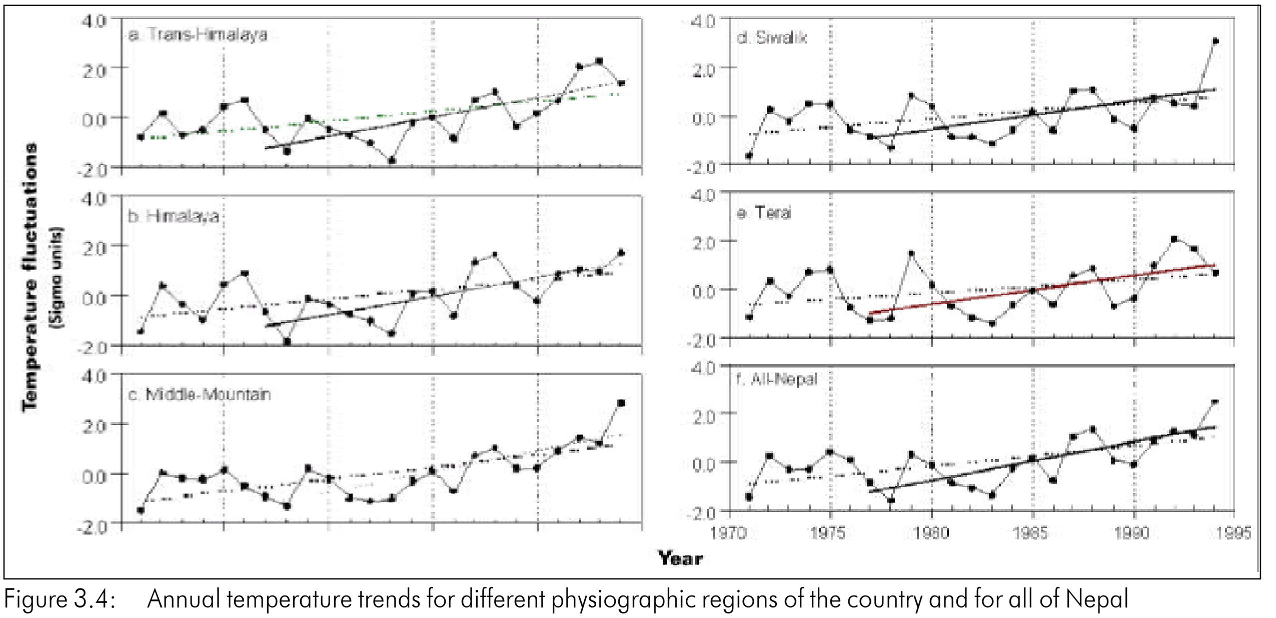

Figure 3.4: Annual temperature trends for different physiographic regions of the country and for all of Nepal (Shrestha et al. 1999)

a limited number of stations measuring evaporation in Nepal, they are mainly located below 2,000 masl. Measured values range from 800 mm to slightly more than 1,300 mm. Evaporation in Nepal has been derived using the methods of Penman (1956), Thornthwaite (1948) and Morton (1983). Both measured and derived values are far from adequate to characterise the spatial variation of evaporation in Nepal.

3.4 Runoff Characteristics

River discharge

Discharge data of major rivers of Nepal are given in Table 3.1. The timing of discharge coincides closely with seasonal maxima and minima of precipitation at basin scales (Figure 3.5). Discharge maxima generally occur in August coinciding with the peak of the monsoon. About 75% of the annual volume of water leaves the respective watershed during the monsoon season (June–September). Minimum values occur during the months of January–May (Alford 1992).

Table 3.1: Discharge data of the major rivers of Nepal#															
Rivers and location	Drainage area (km^2 in '000)	Average discharge ($m^3 s^{-1}$ in thousands)													Period of observation
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual mean	
Mahakali** at Pancheswor	12.60	0.165	0.148	0.156	0.203	0.335	0.634	1.338	1.798	1.198	0.534	0.277	0.195	0.582	1984–92
Karnali at Chisapani	42.89	0.373	0.337	0.354	0.455	0.734	1.490	3.270	4.330	2.980	1.270	0.628	0.447	1.400	1962–93
Narayani at Narayangh	31.10	0.369	0.304	0.285	0.360	0.595	1.650	4.230	5.020	3.410	1.530	0.779	0.495	1.600	1963–95
Sapta Koshi at Chatara	54.10	0.383	0.338	0.340	0.416	0.684	1.590	3.490	4.020	2.980	1.330	0.743	0.501	1.400	1979–95
Babai at Bargadh	3.000	0.019	0.016	0.013	0.011	0.016	0.059	0.243	0.259	0.251	0.098	0.036	0.235	0.087	1967–86
W. Rapti at Jalkundi	5.150	0.029	0.024	0.019	0.015	0.016	0.095	0.296	0.396	0.334	0.135	0.055	0.035	0.123	1964–95
Bagmati at Karmaiya	2.700	0.033	0.029	0.028	0.023	0.044	0.107	0.413	0.420	0.365	0.118	0.043	0.028	0.137	1979–90
Kamala*	1.450	0.007	0.005	0.003	0.003	0.009	0.044	0.130	0.157	0.109	0.045	0.017	0.011	0.045	1957–70
Kankai at Mainachuli	1.148	0.129	0.010	0.009	0.012	0.023	0.067	0.182	0.180	0.123	0.057	0.027	0.018	0.060	1972–90

Source: DHM (1998a).
* Source: Koshi Basin Master Plan (Japenese International Co-operation Agency [JICA] 1985).
** Source: Pancheswor Multipurpose Project (1994).

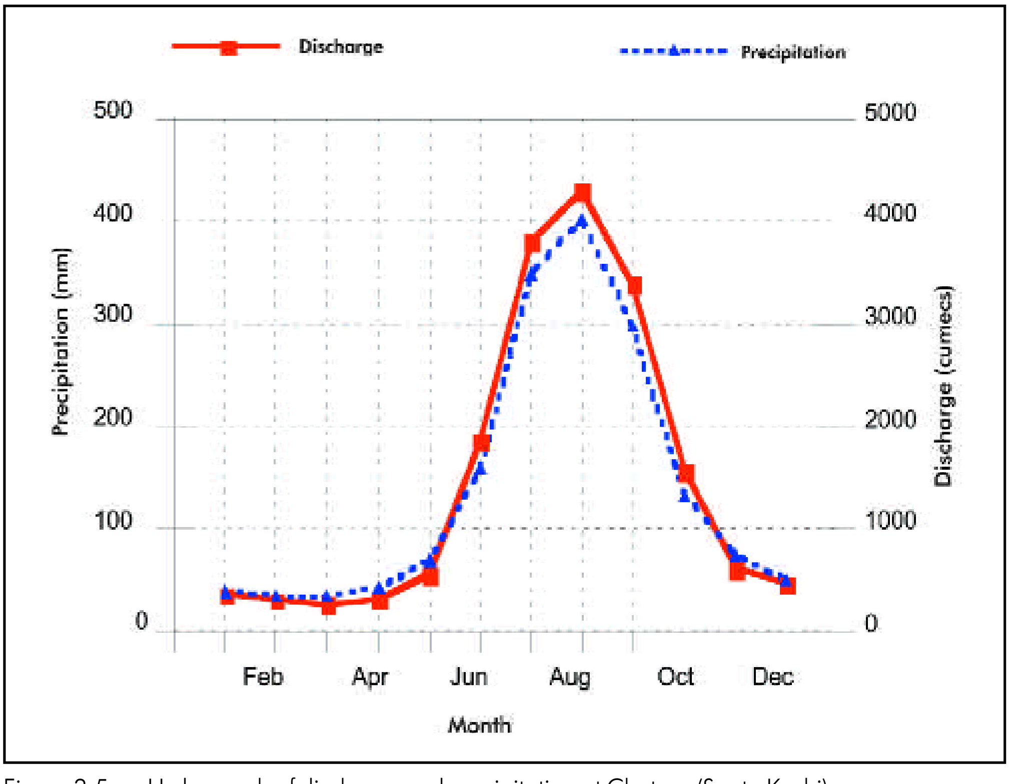

Figure 3.5: Hydrograph of discharge and precipitation at Chatara (Sapta Koshi) (Bhusal 1999; Alford 1992)

Despite general coincidence in the maxima and the minima in precipitation and streamflow hydrograph, owing to great environmental diversity within the basin, correlation between point-measured precipitation and discharge values is not found. Similarly, the general rule of linear relationship between discharge and basin area is not followed in Nepal.

In addition to intra-annual variations in discharge, rivers in the Himalayan headwaters show diurnal variation. The increase in discharge in the afternoon is due to daytime melting of snow and glacier ice in the catchment. There is an increasing interest in understanding the role played by snow and ice melt in the flow of Himalayan rivers. Particularly, it is important to know the effect of global warming on the regional hydrology. While the country is just beginning to harness the vast hydropower potential estimated at 83 x 10^6 kW (Shrestha 1985, 1996), changes in the streamflow regimes could negatively impact planning and implementation of hydropower and other water-related structures.

It is expected that the streamflow will increase initially due to rapid melting of snow and glaciers but will drastically decline as the glacier volumes decrease. Nevertheless, any trend in annual volume of water is not yet detected in the rivers of Nepal (Alford 1992). This could be mainly because of large inter-annual variations owing to similar variations in precipitation.

The Himalayan headwaters contain a plethora of glacial lakes, several of them vulnerable to outbursts. The normal flow pattern of these rivers can be significantly altered by a glacial lake outburst flood (GLOF) event. Depending on the nature of the breach and the volume of water released the stream discharge can experience a manifold increase during a GLOF surge.

The nature of the basin, geology, and stream topography plays an important role in the surge propagation, which might extend several tens of kilometres downstream. A detailed discussion on hydrological aspects of GLOFs is given in Chapter 9.

Sediment transport

The topography and geology of Nepal is favourable to soil erosion and mass wasting. Erosion rates vary largely and range between 800 and 57,000 t km^{-2} (Bhusal 1998). Sediment transport measurement in Nepal is limited to daily sampling for suspended sediment at 20 stations. Samples are collected by an integration method using 500 ml bottles and the sediment concentration is determined in the laboratory by an evaporation method (Bhusal 1998). Average monthly sediment yields of selected rivers of Nepal are given in Table 3.2. The monsoon is mainly responsible for surface erosion, hence sediment yield closely follows river discharge, peaking in August (Figure 3.6).

The sediment delivered by rivers of Nepal is expected to increase due to land use and climatic changes. However, there is no clear indication on the contribution of land use and climatic changes on the sediment load. Sediment yield from Nepal is still considered to be due to geomorphic and climatic characteristics of the country. Massive amounts of sediment can be delivered occasionally to downstream regions due to GLOF (Water and Energy Commission Secretariat [WECS] 1987a). The one sample a day routine of sediment sampling in the far downstream areas is not capable of measuring sediment load due to GLOF and, therefore, there is not much quantitative knowledge about sediment load caused by GLOF. Electrowatt Engineering Service Ltd. (1982) took regular sediment samples between June 1978 and January 1981. Extremely high concentrations of sediment were measured in the summer of 1980 (Figure 3.7). Various indirect evidence suggests that this was caused by a GLOF at Nagma. Sediment concentration during the GLOF was around 100,000 mg l^{-1}.

Table 3.2: Sediment transport in Nepalese rivers					
Rivers and location	**Area (km^2)**	**Annual sediment transport (suspended only, tonnes)**	**Specific sediment yield ($t\ km^{-2}\ year^{-1}$)**	**Data period**	**Sources**
Sapta Koshi Barahshetra	54,100	133.56	2417	1948–77	Feasibility Report of Koshi High Dam Project (GOI 1981)
Tamor Mulghat	5640	39.9	7074	June 1978–January 1981	Feasibility Report of Mulghat Hydro-electric Project (Electrowatt Engineering Service Ltd 1982)
Arun Arun-3 dam site	29 310	6.72	229	Computed based on 10 samples measured March–July 1986 and the developed sediment and discharge relationship	Feasibility Report of Arun-3 (JICA 1987)
Sapa Gandaki Naranghat	31,100	106.9	3437	Computed for 1964–80 based on DHM sediment data of 1975–78 and 16 sample measurements taken between 5 March and 20 October 1981	Feasibility Report of Sapta Gandaki Hydro-electric Project (JICA 1983)
Karnali Chisapani	43,000	91.98	2139	May 1963–October 1964	Feasibility Report of Karnali Chisapani Hydro electric Project (Nippon Koei 1966)
Karnali Chisapani	43,000	105	2442		Feasibility Report of Karnali Hydro-electric Project (Electrowatt-Norconsult 1976)
Karnali Chisapani	42,890	92.84	2165	403 samples in the wet season of 1987 with 10% addition for the unmeasured dry season (9 months). It is stated that 1987 was a low flow year	Feasibility Report of Karnali Multipurpose Project (HPC 1989)
Mahakali Pancheswor	12,600	55	4365	June to November 1990. Samples were taken and 10% added for non-monsoon	Feasibility Report (EDC 1994)

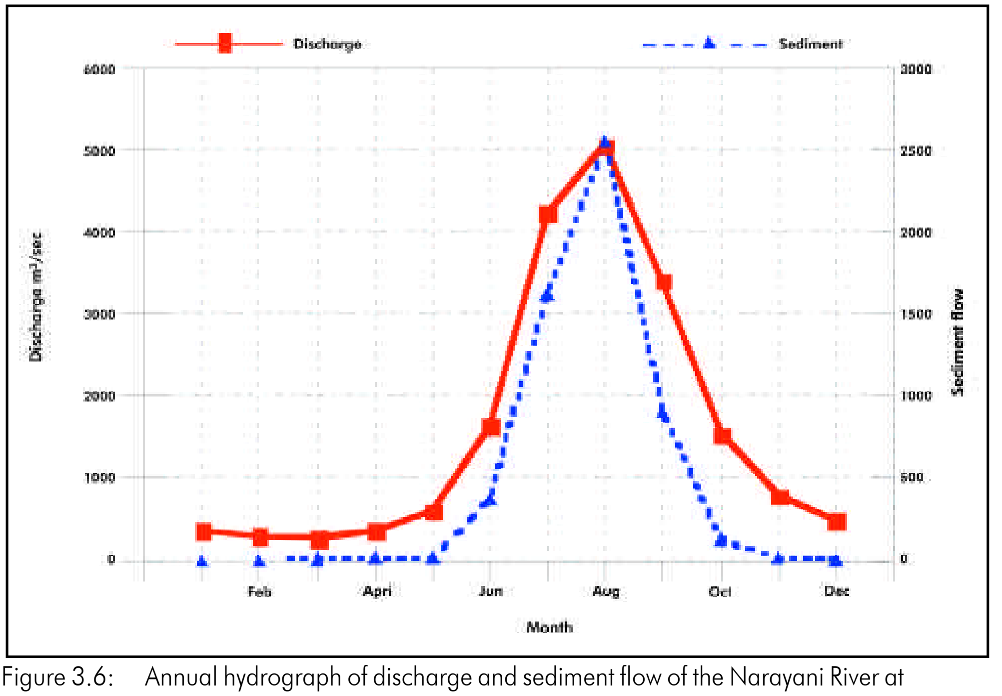

Figure 3.6: Annual hydrograph of discharge and sediment flow of the Narayani River at Narayanghat (Bhusal 1998)

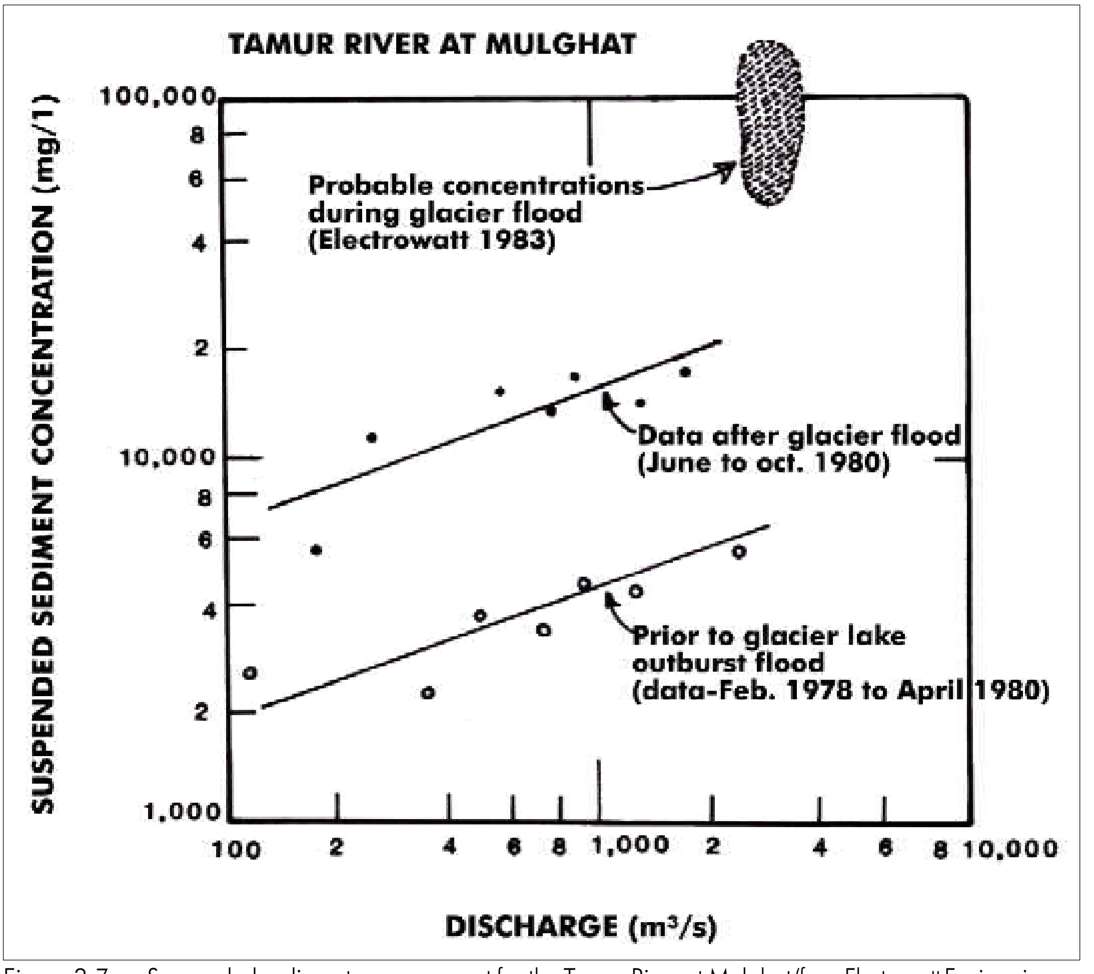

Figure 3.7: Suspended sediment measurement for the Tamor River at Mulghat (from Electrowatt Engineering Service Ltd 1982, in WECS 1987a)