Chapter 1: Introduction

Flash floods are sudden and intense surges of water that rise and fall very rapidly along a river course (see Box 1). They differ from riverine floods in terms of their rapid onset and decline, high intensity, and unpredictability as well as their usually more localized impact in hill and mountain areas rather than the plains. The flood wave moves at high velocity, often with a high load of debris, and can thus be extremely destructive, damaging buildings and other infrastructure; washing away fields, crops, and animals; and causing loss of life. Flash floods often occur in remote mountain catchments far from rescue services. They are among the most common natural hazards in the Hindu Kush Himalayan (HKH) region, but they are highly unpredictable and leave little time for warning and evacuation, making it difficult to mitigate their effects.

Box 1: **What makes a flood a flash flood?**

Intense short-lived precipitation or sudden release of a mass of water compounded by:

- increased impervious cover
- increased stream density
- increased slope

and

- decreased channel length
- decreased surface roughness
- decreased vegetation

Major Factors Contributing to Flash Floods

Flash floods in the Hindu Kush Himalayan region have a variety of causes, the main ones being localized intense rainfall, rapid melting of snow, and failure of natural or artificial dams or breakout of ice jams on watercourses. A number of meteorological, geological, and hydrological or hydraulic factors contribute to the development of such floods. The first is the seasonal (monsoon) rainfall and cloudbursts that occur in the mountain region, compounded by the high and rapid runoff from areas with steep slopes, an impermeable surface, saturated and/or compacted top soil, and lack of vegetative cover. Second, landslides and debris flows, which are also common in mountain areas, can form unstable dams across rivers, leading to the formation of temporary lakes and the development of a flash flood when the dam collapses. Bridges can also trap debris and obstruct flow, leading to inundation upstream followed by collapse of the debris accumulation and a flash flood as a result. Similarly, the development of glacial lakes behind unstable moraine dams poses a threat of a specific type of flash flood – a glacial lake outburst flood (GLOF) – when the moraine dam collapses (Ives et al. 2010). All of these can be compounded by factors related to people's use of the landscape – anthropogenic factors – which increase the intensity and impact of the flood. These different factors are discussed in more detail in the following paragraphs.

Intense rainfall

Intense rainfall resulting from cloudbursts, monsoon depressions, or stationary monsoon troughs is a common cause of flash floods in the Himalayan region. During the summer, humid winds flow from the Indian Ocean to the region, which results in intensive orographic rainfall on the southern aspect of the mountains. Intense rainfall in a small catchment can lead to a rapid rise in the water level in streams, especially where watercourses are narrow. Impervious soil surfaces increase the rate of runoff, and steep slopes result in acceleration of water velocity and a high rate of discharge downstream in the form of a flash flood. The flash flood event in the Kulekhani catchment of central Nepal in July 1993 is an example of the type of damage that can be caused by flash floods resulting from intense rainfall (see Box 2).

Box 2: **Flash flood in central Nepal, 19–20 July 1993**

In July 1993, the Kulekhani catchment in central Nepal experienced intense rain, which caused several devastating flash floods that transported high loads of debris and sediment into the reservoir of Nepal's only storage-type hydropower station, thereby reducing its life by several decades. Other installations of the power plant were severely damaged. The highway joining the capital city to the rest of the country was seriously damaged, with several bridges and kilometres of paving washed away. Fourteen hundred lives were lost. The total impact was so enormous that it pushed the country back in its development efforts by several years.

Source: Dhital et al. 1993

Rapid snowmelt

Especially in the western Himalayas and Karakoram mountains, rapid melting of snow can have a similar impact to intense precipitation. These areas experience considerably more winter precipitation than in the east of the region. Temperatures can rise very rapidly in the early summer leading to rapid melt of snow and high runoff from the bare rocky slopes. This type of flash flood is well-known in areas like Chitral, where communities may have memories and knowledge of potential flood paths reaching back through generations (Dekens 2007).

Landslide dam outburst

Landslides and debris flows are very common in the Hindu Kush Himalayan region. Weak geological structures, active tectonic forces, steep and fragile topography, heavy seasonal rainfall, and river bank erosion are the major factors responsible. Deposits from landslides and debris flows can block a narrow river course to create a natural dam resulting in the formation of a temporary reservoir upstream. The water level in the reservoir will rise due to the continuous inflow from the river. When the water overtops the dam, or its weight exceeds the holding capacity of the dam, the dam can burst resulting in a sudden torrent of water downstream – a landslide dam outburst flood (LDOF). Landslide dam outbursts are generally random and cannot be predicted with precision. The Yigong LDOF in 2000 in Tibet Autonomous Region, China (see Box 3), the Tsatichhu LDOF in 2004 in Bhutan, and the Pareechu LDOF in 2005 in Tibet Autonomous Region are notable examples of large LDOF events in the region (Shrestha 2008).

Glacial lake outburst

As in many parts of the world, glaciers in much of the HKH region are retreating and thinning, a phenomenon now accelerated by climate change (Mool et al. 2001; Xu et al. 2007; Eriksson 2009). This has led to the formation of glacial lakes behind the end moraines that formed when the glaciers were at their maximum. The moraine dams are composed of unconsolidated boulders, gravel, sands, and silt and are thus structurally fragile and potentially subject to catastrophic failure. The collapse of a moraine dam can result in the sudden release of a large amount of water and debris – a glacial lake outburst flood (GLOF). The distribution of glacial lakes in the Hindu Kush Himalayan region and the potential for outburst is described in some detail in Ives et al. (2010) and ICIMOD (2011). Though these types of flash floods are not very frequent in the region, they threaten populated areas downstream with potentially serious consequences. The Zhangazanbo GLOF in China in 1981 is a notable example of a GLOF that caused significant damage. The flood damaged the highway and bridges below the lake up to the Sunkoshi power station, including the Friendship Bridge between Nepal and China and the diversion weir of the Sunkoshi hydropower station, and the erosion and sedimentation led to a marked change in the landform downstream (Shrestha 2008). The Dig Tsho GLOF in Bhutan is a further example (see Box 4).

Box 3: **Yigong landslide dam outburst flood, Tibet Autonomous Region, China, 10 June 2000**

One of the most striking examples of a LDOF took place on the Yigong River in eastern Tibet in 2000. As a result of a sudden increase in temperature, a huge amount of snow and ice melted in the region, which led to a massive, complex landslide on 9 April in the upper part of the Zhamulongba watershed on the Yigong River, a tributary of the Yarlung Zangbo River. Within eight minutes, about 300 million cubic metres of debris, soil, and ice was dumped across the river bed, forming a landslide dam 100 m high, 1.5 km wide (along the river), and 2.6 km long (across the river) (Shang et al. 2003). The blocked river formed a lake behind the dam; the inflow from the river was about 100 m^3 per second and the lake level rose by about a metre per day. An attempt was made to dig a large trench to release the water but this failed. On 10 June 2000, the dam broke leading to a huge flash flood downstream. The flood was 1.26×10^5 m^3/s, with a maximum depth of 57 m and maximum velocity of 11.0 m/s. The peak flood was 36 times greater than the normal flood. Tongmai Bridge, the highway between Yigong Tea Farming Base and Pailong County, and two suspension bridges in Medong County were destroyed. There were no injuries or deaths on Chinese territory, but on the Indian side of the border, the damage was on a scale seldom seen and resulted in the deaths of 30 people, with more than 100 missing. The flood in the Brahmaputra River as it entered India was 1.35×10^5 m^3/s (Zhu and Li 2000; Zhu et al. 2003). More than 50,000 people in five districts in Arunachal Pradesh were rendered homeless, and more than 20 large bridges, lifelines for the people, were washed away. The total economic loss was estimated at more than USD 22.9 million.

Source: Shrestha 2008

Anthropogenic factors

In addition to natural factors, there are a number of anthropogenic factors that either contribute to creating the conditions that favour the development of flash floods or increase the associated risk, in particular settlements on flood plains, urbanization, deforestation, and failure to maintain or manage drainage systems (Shrestha 2008). Many of these are the direct result of population growth and the associated pressure on natural resources and land for food production and development. For example, deforestation and soil erosion in mountain and hill regions as a result of increased farming on marginal lands, demand for fuel, and poor construction of roads and trails, means an increase in landslides and slips and the associated potential for the creation of landslide dams. Similarly, poor management of watersheds, introduction of intensive agricultural practices, and poor land use practices leading to deforestation, degradation, and soil compaction or loss (see, for example, Mehta 2007; Dixit 2003), as well as building footprints that reduce infiltration and failure to maintain drainage systems, can all lead to decreased retention of precipitation and higher runoff, directly contributing to flash floods. Poorly planned infrastructure construction, such as the construction of bridges (especially low truss or box bridges) across narrow river channels and altering of water channels, can also contribute to the development of flash floods by hindering the free flow of water and debris and causing blockages which can burst out. The failure of man-made structures such as dams, embankments, and water reservoirs can also be a direct cause of flash floods (see Box 5).

Box 4: **Dig Tsho glacial lake outburst flood, Nepal, 4 August 1985**

The Dig Tsho GLOF of 4 August 1985 was triggered by an ice avalanche from the Langmoche Glacier which induced a dynamic wave on the lake. Vuichard and Zimmerman (1987) reported that an ice mass of 100,000 to 200,000 m^3 dislodged itself from the overhanging glacier tongue and plunged into the lake causing the moraine dam to breach. According to the report, the flood began in the early afternoon and lasted for 4–6 hours. By reconstructing the hydrograph, Vuichard and Zimmerman estimated that the peak flood had been 1,600 m^3/s; Cenderelli and Wohl (2001) estimated a higher peak discharge of 2,350 m^3/s. Local witnesses reported that the flood surge moved rather slowly down the valley as a huge black mass of water and debris. The mean velocity of the surge front was between 4 and 5 m^3/s. The most significant impact of the GLOF was the complete destruction of the newly-built hydropower station in Thame, which had cost an estimated USD 1.5 million.

Source: Bajracharya et al. 2007

Box 5: **Collapse of Gouhou Reservoir, China, 27 August 1993**

At 23:40 on 27 August 1993, the Gouhou Reservoir dam in Qinghai Province (total capacity 3.3×10^6 m^3) collapsed and the water in the reservoir flooded out. The maximum flow rate at the dam was 3,000 m^3/s. Some 2.68×10^6 m^3 of water was released. The flood rushed into Qiabuqia Town, 13 km downstream, with a population of about 30,000. More than 1,000 houses were destroyed instantly, 288 people died, and more than 1,000 were injured. The direct economic loss was around USD 27.7 million (RMB 160 million). The collapse was not due to any extraordinary storm or flood but took place in fair weather.

Source: Zhou and Wan 2005

In addition to factors that increase the likelihood of flash floods occurring, the associated risk is also increasing as a result of, for example, increased urbanization in mountain areas; location of settlements, roads, and infrastructure close to narrow water courses and on floodplains; and lack of awareness of migrant populations of local risk factors.

Flood Risk Management

Flood risk is a combination of the probability of a flood occurring (the hazard) and of the potential adverse consequences of the flood for human health, the environment, cultural heritage, and economic activity (the vulnerability) (FRM 2009). The combination of these factors gives a measure of the risk, the likelihood and likely cost of damage occurring to people and property. Thus flood risk management has two major aspects: changing the conditions so that a flood is less likely to occur, and reducing the vulnerability of people and property if a flood does occur. When considering measures to reduce risk, it is necessary to achieve a balance between the economic, social, and environmental dimensions (Klijn et al. 2009).

Measures to reduce flood risk can be divided into two categories: non-structural and structural. A complete plan for flood risk management usually contains elements of both approaches.

Non-structural measures

Non-structural measures refer to any measure that does not involve physical construction but instead uses knowledge, practices, and/or agreements to reduce the potential impacts of a flood. Non-structural approaches can be a cost-effective alternative to traditional engineering solutions. Typical approaches include policies and laws, raising public awareness, and training and education. Such measures offer a variety of possibilities including the installation of early warning systems, soil management and acquisition policies, insurance, perception, awareness, and public information actions, emergency systems, and post-catastrophe recovery, all of which can help mitigate flood-related problems. Non-structural measures are generally more sustainable and less expensive than structural measures. They can be the most effective way of managing flash floods, which are often localized and difficult to predict, in contrast to riverine floods. However, non-structural measures are only efficient with the participation of a responsive population and an organized institutional network. Non-structural measures for management of flash flood risk are discussed in detail in Module 2 of this Resource Manual (Shrestha 2008).

Structural measures

Structural measures refer to any physical construction designed to intervene, control, or mitigate the potential impacts of floods. In other words, they refer to the use of engineering techniques to achieve hazard resistant and resilient structures or systems. They include measures to increase infiltration and reduce rates of runoff in upper catchment areas, measures to stabilize slopes and reduce the likelihood of landslides and mudflows, and structures designed to keep floodwaters away from people and property, such as dams, levees, diversions, and check dams.

Structural measures for flash flood management can be separated into four broad groups in terms of the overall focus (APFM 2007): activities in the whole of a catchment area, activities to shape retention, regulating rivers and streams, and river conservation. Activities in the whole of a catchment area focus on measures to limit the speed of surface runoff and limit flood erosion, including the promotion of good farming practices, terracing, and stabilizing slopes and drainage ditches. Water retention activities can help reduce the flood wave by reducing the amount of water that runs off a catchment surface. Activities to promote retention include constructing small reservoirs, dry reservoirs, and polders and building small dikes and dams. Rivers and streams can be regulated by measures to slow the speed of water flow, including reducing the slope of the riverbed to check erosion, constructing barriers and thresholds, and building different types of anti-debris dams, dikes, and embankments. Finally, in the river valley, the river corridor can be shaped by controlling the depth and slope of the river bed so that flood water is directed away from high impact areas.

Bioengineering is a way of using living plant material to provide reinforcement and create guiding structures. Bioengineering methods are not structural methods in the strict sense of the term as structural methods are usually considered to refer to physical or artificial construction. However, bioengineering techniques are closely related to the physical structural approach, and are often used in combination with and complementary to structural measures. Thus bioengineering methods have also been included in this volume on structural measures.

The Resource Manual

The present volume focuses specifically on the structural measures that can be used to manage risk from flash floods. In order to design appropriate structural measures, it is first necessary to understand the mechanisms of the major contributing factors so that these can be addressed. Thus the next two chapters are devoted to an understanding of the development and characteristics of landslides and debris flows (Chapter 2) and of landslide dam lakes and glacial lakes (Chapter 3). These, together with intense runoff, are the major causes of flash floods in the Hindu Kush Himalayan mountains. The following three chapters describe various techniques for structural measures that can be used to reduce flash flood risk. These have been divided into three major groups: bioengineering or vegetative measures (Chapter 4); physical measures for slope stabilization and erosion control (Chapter 5); and river training structures (Chapter 6). The final chapter (Chapter 7) looks at the whole approach of integrated water resource (and flood) management in terms of implementing structural measures.