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Indus Basin Floods

Mechanisms, Impacts, and Management

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Asian Development Bank

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Foreword

More than 138 million people in the Indus River Basin in Pakistan depend on irrigated agriculture for their livelihoods, with the cultivated areas encompassing about 14 million hectares in the floodplains of the Indus River and its five main tributaries. But problems such as rising population pressures, climate change, and a continuous degradation of ecosystem services have resulted in increased flood risks, which are further exacerbated by inadequate flood planning and management. Pakistan suffered from 21 major floods between 1950 and 2011—almost 1 flood every 3 years. These floods have killed a total of 8,887 people, damaged or destroyed 109,822 villages, and caused economic losses amounting to $19 billion. On average, the annual flood damage from 1960 to 2011 was about 1% of the mean annual GDP. The devastating 2010 flood caused the highest damage of all in terms of economic costs: about $10 billion.

The Government of Pakistan has been relying on a traditional flood control approach based on structural measures, but the 2010 flood exposed the inherent weaknesses of this approach. A shift from traditional flood management to a contemporary holistic approach could more effectively mitigate the flood risks, and provide an additional source of freshwater for productive use. This report proposes such an approach, which would operate within an integrated water-resources-management framework.

Evolved from 6 decades of flood management experience in the basin, this approach applies scientific assessments that take people, land, and water into account. It also includes planning and implementation realized through appropriate policies, enforceable laws, and effective institutions. I am confident that, with proper adaptation to the Indus Basin realities, this report will serve as an important guide for flood management in the Indus Basin.

Klaus Gerhaeusser
Director General
Central and West Asia Department
Asian Development Bank

Currency Equivalent

(as of 31 August 2013)

Currency Unit	=	Pakistani rupee (PRs)
PRs1.00	=	$0.0096
$1.00	=	PRs104.16

Weights and Measures

ha	–	hectare
km	–	kilometer
km^2	–	square kilometer
m	–	meter
mm	–	millimeter
m^3s^{-1}	–	cubic meters per second

Abbreviations

asl	–	above sea level
ADB	–	Asian Development Bank
CFMA	–	contemporary flood management approach
CRED	–	Centre for Research on the Epidemiology of Disasters
DNWP	–	draft national water policy
FFC	–	Federal Flood Commission
FFD	–	Flood Forecasting Division
FPL	–	flood protection levee
IWRM	–	integrated water resources management
NDMA	–	National Disaster Management Authority
PDMA	–	provincial disaster management authority
PID	–	provincial irrigation department
PMD	–	Pakistan Meteorological Department
PRC	–	People's Republic of China
WAPDA	–	Water and Power Development Authority

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Glossary

afflux	The rise in water level (above normal) on the upstream side of a bridge or obstruction caused when the effective flow area at the bridge or obstruction is narrower than the natural width of the stream immediately upstream of the bridge or obstruction
barrage	A gated hydraulic structure built across a river or other water course to control, regulate, and divert flows to canals or to facilitate navigation
bund	An embankment constructed along a water course to protect an area, town, or structure from flooding
breaching section	A designated erodible earthen section upstream of a barrage that channels away floodwaters in excess of the barrage's design capacity. In an emergency situation, a breaching section, sometimes called a fuse plug, is operated through controlled blasting.
defense bund	See loop bund
exposure	The total of human life, assets, and/or physical infrastructure threatened or potentially threatened with loss in the case of a particular hazard or peril
flash flood	A sudden, localized flood of great volume and short duration, typically caused by unusually heavy rain, dam break, or cloud burst. Flash floods can reach their peak volume in a matter of a few minutes to a few hours and often carry large loads of mud and rock fragments.
flood hazard	A significant rise of water level in a stream, lake, reservoir, or coastal area. A potentially damaging physical event, phenomenon, or human activity that may cause injury or loss of life, property damage, social and economic disruption, or environmental degradation.
fuse plug	See breaching section
headworks	A hydraulic structure on a waterway, smaller and more limited than a barrage, which diverts the river flow into canals
isohyetal map	A map showing rainfall contours
loop bund	A second line of bunds that safeguards property in case the frontline bunds fail or suffer flood damage. Sometimes referred to as a defense bund.
risk	The probability of harmful consequences, such as personal injury, loss of life, damage to or loss of property, loss of livelihood, disruptions in economic activity, or environmental damage. These consequences can result from an interaction between natural or human-induced hazards and vulnerable conditions. [Risk = function (Exposure + Hazard + Vulnerability)]
spur	A levee or stone wall constructed transversely or obliquely to the flow direction to divert flooding at critical locations
vulnerability	Conditions determined by physical, social, economic, and environmental factors that increase community susceptibility to hazard impact

Introduction

Context

Floods are created by unusual water-level rises in rivers or lakes, or by sea-level rises along coasts, that overflow their natural or artificial confinements. A natural and random phenomenon, floods are sparked by high rainfall, storm surges, typhoons, dam failures, glacial lake outbursts, or tsunamis. In developing countries, floods are also linked to ever-increasing demographic pressures and economic development, which have often resulted in catchment degradation and waterway encroachment. Further, poorly planned river basin development, flawed land-use planning and practices, inadequate legal and policy instruments, and poor governance facilitate the inappropriate exploitation of resources near rivers, lakes, and seacoasts by populations and governments, often resulting in devastating damage during floods.

Worldwide, floods were responsible for 84% of all disaster-related deaths between 2000 and 2005, and for 65% of disaster-related economic losses between 1992 and 2001 (ADB 2009). Globally, floods accounted for 31% of the 9,632 natural disasters that occurred in the 20th century (Guha-Sapir et al. 2012). The 4,035 major floods during 1900-2012 killed 6.9 million people, affected another 3.6 billion people, and caused economic losses totaling $550 billion (Appendix 1). In Asia, 1,625 flood disasters (40% of total disasters worldwide) resulted in 6.8 million deaths (98% of deaths worldwide), displaced 3.4 billion persons (95% of affected persons worldwide), and caused $330 billion in economic losses. Other flood-related losses include damage to ecosystems, land, and water quality degradation, and an increased incidence of waterborne diseases.

Flood damage in Asia in the 20th century was estimated at 60% of global economic losses due to floods (Figure 1). The People's Republic of China (PRC) suffered the highest economic losses, followed by India, Pakistan, and Bangladesh (Figure 2). From 1965 to 2011, total economic losses due to floods in Asia showed an upward trend (Figure 3),[1] which may be attributed to the greater frequency of floods, the acceleration of the economic development in flood-prone areas, or both.

1 It is difficult to quantify the rate of increase over time due to the absence of common reference values for converting flood damage costs into comparable figures for different years. Because the last period measured (2005–2012) was not a full decade, the average economic losses per year were compared with those of the previous periods, showing $15 million per year during 1995–2004 and $20 million per year during 2005–2012.

Figure 1 Worldwide Flood Damage Distribution, 1900–2012 ($ million)

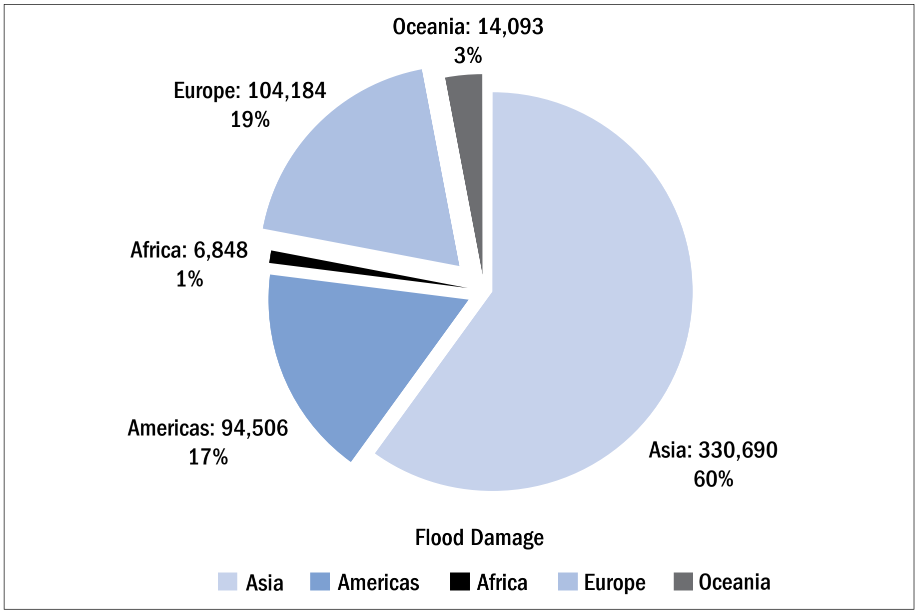
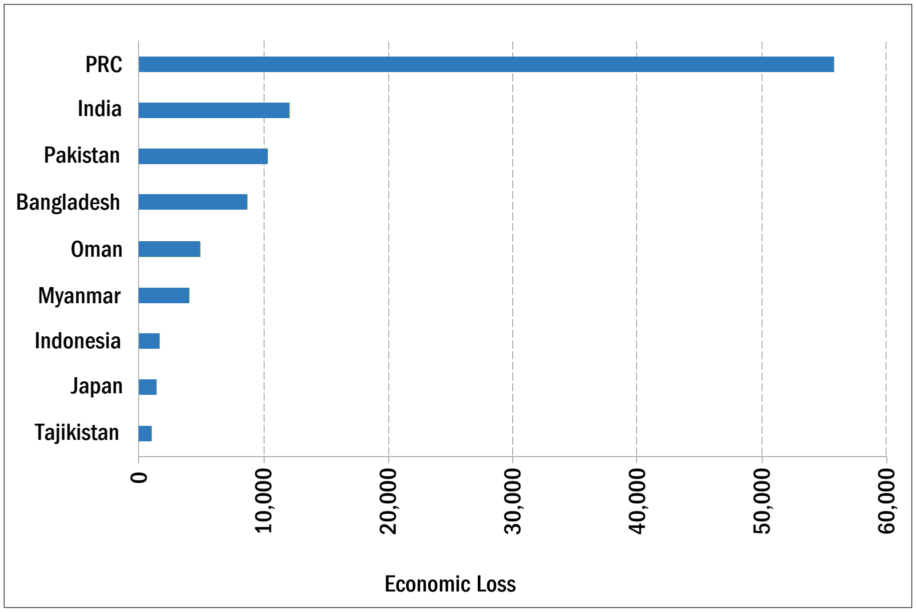


Figure developed by the author using data from EM-DAT: The International Disaster Database.

See Centre for Research on the Epidemiology of Disasters (CRED). EM-DAT: The International Disaster Database.

http://cred01.epid.ucl.ac.be:5317/?after=2007&before=2012&continent%5B%5D=Asia&dis_group%5B%5D=Natural&dis_subgroup%5B%5D=Hydrological&dis_type%5B%5D=Flood&agg1=dis_type&agg2=dis_type (accessed 8 June 2013).

Figure 2 Asian Countries with High Flood Damage, 2000–2011 ($ million)



PRC = People's Republic of China.

Figure developed by the author using data from the *Annual Disaster Statistical Review 2011*.

See D. Guha-Sapir et al. 2012. *Annual Disaster Statistical Review 2011: The Numbers and Trends.* Brussels: Centre for Research on the Epidemiology of Disasters (CRED), Université catholique de Louvain. http://cred.be/sites/default/files/2012.07.05.ADSR_2011.pdf (accessed 15 September 2012).

Figure 3: Flood-Induced Economic Losses in Asia ($ million)

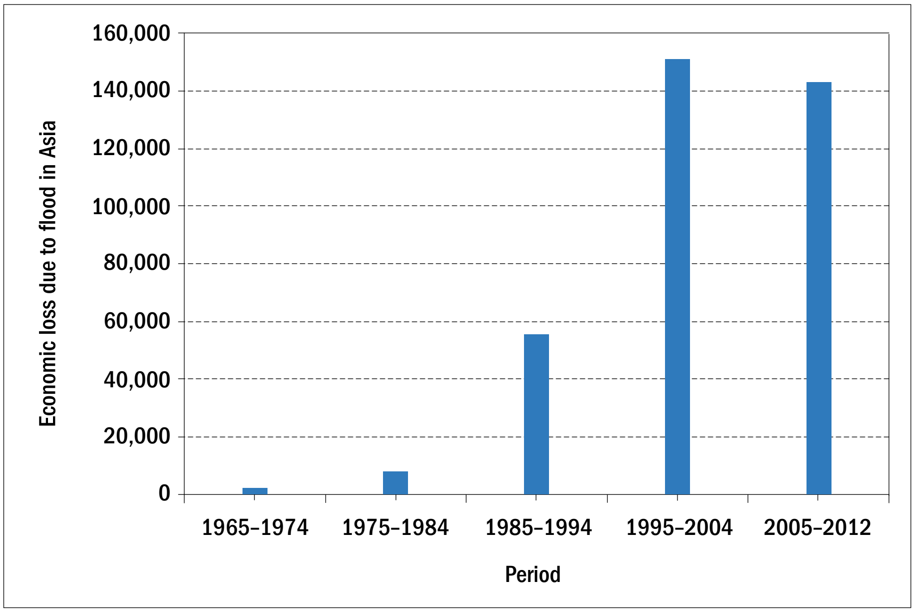


Figure developed by the author using data from the *Annual Disaster Statistical Review 2011*.

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From 1950 to 2010, 21 major floods in Pakistan's Indus River Basin killed a total of 8,887 people, affected 109,822 villages, and caused a cumulative direct economic loss of about $19 billion. Indirect losses that were not quantified included health hazards, land and water quality degradation, temporary disruption of transport, and the slowing down of economic growth.

Drawing on lessons from several decades of flood mitigation experience in the Indus Basin, this report aims to provide managers and policy makers in Pakistan with guidance on flood management. Its key objectives are to (i) present a structured overview of the flawed traditional flood management procedures in Pakistan; (ii) identify various constraints, gaps, and opportunities associated with these procedures; and (iii) suggest new, practical flood management solutions adapted to the prevailing conditions of the Indus Basin.

The Indus Basin

The Indus River is a major transboundary river in Asia[2] with nine tributaries. Its five tributaries on the left bank are the Beas, Chenab, Jhelum, Ravi, and Sutlej rivers. The Beas, Ravi, and Sutlej are also transboundary rivers, with upper catchments in India. The main right bank tributaries are the Gomal, Kabul, Swat and Kurram rivers. The Kabul River is a transboundary river that flows through Afghanistan

2 Others include the Amu Darya (Afghanistan, Turkmenistan, and Uzbekistan), Amur (People's Republic of China [PRC] and Russian Federation), Brahmaputra (Bangladesh, PRC, and India), Euphrates (Iraq, Syria, and Turkey), Ganges (Bangladesh and India), Mekong (Cambodia, PRC, Lao People's Democratic Republic, Myanmar, Thailand, and Viet Nam), and the Tigris (Iraq, Syria, and Turkey).

and Pakistan. The Swat River joins the Kabul River near Charsadda town, about 50 km upstream of their common outfall into the Indus River, near the town of Nowshera, in Pakistan's Khyber Pakhtunkhwa Province. A few hill torrents join the Indus River between the Jinnah and Guddu barrages. The Indus Water Treaty (1960) between India and Pakistan allocates the water from three eastern rivers (Beas, Ravi, and Sutlej) to India and from the three western rivers (Chenab, Indus, and Jhelum) to Pakistan. Figure 4 is a map of the Indus Basin while Figure 5 is a line diagram depiction.

The Indus River is about 2,800 kilometers (km) long, with 2,682 km in Pakistan. Its alluvial plain area is about 207,200 km^2, while its deltaic area is about 20,000 km^2. It originates in the Tibetan tableland at Singi Kahad spring, on Kailas Parbat (mountain) near Mansarwar Lake. It then passes through the Himalayan range, and collects runoff from the Hindu Kush and Sulaiman ranges. Its annual water runoff is about 200 cubic kilometers, and sediment discharge is approximately 200 billion kilograms yearly (Pakistan Water Gateway; accessed 29 November 2011).

The Indus drainage basin covers an area of about 1,140,000 square kilometers (km^2) stretching from Afghanistan through the PRC, India, and Pakistan. One of its tributaries, the Jhelum River, originates in the Nanga Parbat range and drains an area of 3,680 km^2. One of its other tributaries, the Chenab River, originates in the Indian state of Himachal Pardesh, at an elevation of 4,900 meters (m) above sea level (asl), and drains an area of 3,437 km^2.

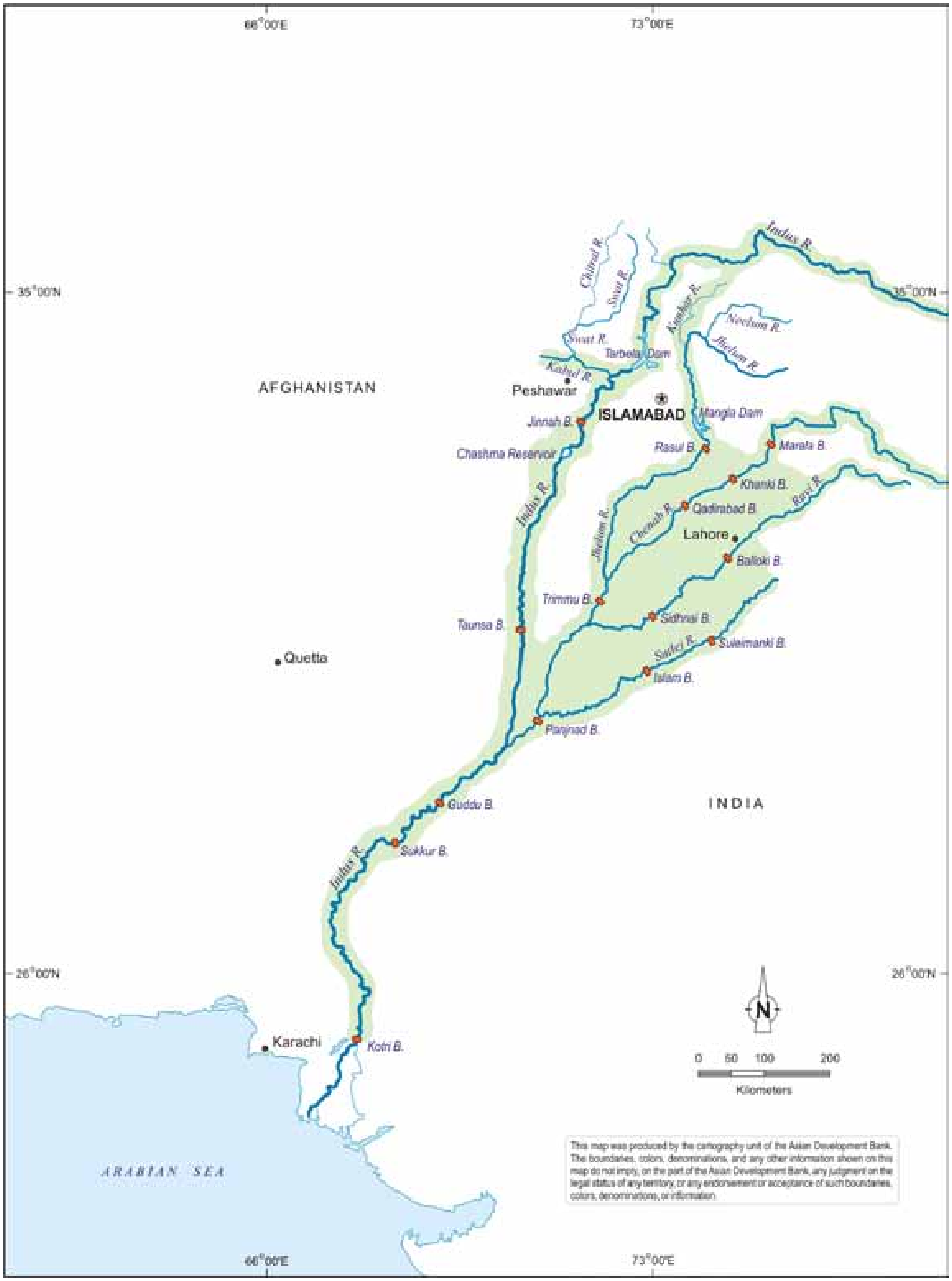
Based on the stream hydrology and morphology, the Indus River can be broadly divided into three segments: (i) the upstream segment, from the Singi Khahad spring down to Jinnah Barrage; (ii) the midstream segment, between Jinnah and Guddu barrages; (iii) and the downstream segment, from Guddu Barrage to the Arabian Sea. The upstream segment is largely a hilly catchment area; the midstream segment is an upper floodplains area dominated by a braided pattern of channels and tributary inflows; and the downstream segment is a lower floodplains area and has a flat topography, a meandering channel pattern and deltas. Taking into account the basin's geophysical and hydroclimatic characteristics, Hewitt (1989) further divides the upper Indus Basin catchment into four zones: zone one - more than 5,500 m asl; zone two - 4,500–5,500 m asl; zone three, 3,000–4,000 m asl; and zone four, 1,000–3,000 m asl.

The climate of the Indus Basin plains is semi-arid to arid, with average temperatures ranging between 2º and 49º Celsius. Mean annual rainfall varies between 90 millimeters (mm) in the downstream segment to 500 mm in the midstream segment. In contrast, it is more than 1,000 mm in the catchments in the upstream segment. Mean evaporation ranges between 1,650 mm and 2,040 mm in the midstream and downstream segments.

The Indus Basin in Pakistan has three main reservoirs (Mangla, Tarbela and Chashma),[3] 19 barrages, 12 inter-river link canals, about 56,000 km of canals, and 110,000 km of water courses. The inter-river link canals transfer water from the Indus and Jhelum rivers to the Chenab, Ravi, and Sutlej rivers. The Upper Chenab Canal and Marala-Ravi Link Canal transfer flows from the Chenab River to the Ravi River to feed areas previously irrigated by Ravi and Sutlej rivers. Overall, the Indus Basin irrigates about 14 million hectares (ha) of land in Pakistan. Appendix 2 provides key data regarding the irrigation, drainage, and flood-protection infrastructure in the Indus Basin in Pakistan.

3 The Chashma Reservoir plays an insignificant role in flood management due to its limited storage capacity and its importance for irrigation.

Figure 4 Map of the Indus Basin



Source: Author, modified from an existing map of Pakistan.

Figure 5 Line Diagram of the Indus Basin in Pakistan

Source: Developed by the author with the assistance of ADB's cartography unit.

Indus Basin Flood Mechanics

In the Indus Basin, monsoonal rains are the most important flood-causing factor, followed by the size, shape, and land-use of the catchments, and by the conveyance capacity of the corresponding streams. The monsoon weather system originates in the Bay of Bengal, and the resultant depressions often give rise to heavy rains in the Himalayan foothills. The monsoon rains fall from June to September, and are generally intense and widespread. The weather systems from the Arabian Sea (seasonal lows) and the Mediterranean (westerly waves) also occasionally produce destructive floods in the basin.

The Indus River at Jinnah Barrage, in the upper reach, drains an area of 286,000 km^2 with an average annual rainfall of 760–1,270 mm. The topography is steep, the hill slopes are degraded, and there is only one major reservoir on this section of the river, at Tarbela Dam. Intense rains and steep topography quickly generate high flows and high sediment yields in streams. Late-season rains, exacerbated by high soil moisture from earlier rains and by the large size of the drainage area, generate high runoff volumes. The Tarbela Reservoir cannot handle late-season runoffs because of earlier-season filling of reservoir for irrigation and energy generation. The same priorities are true for the Mangla Reservoir, on the Jhelum River, and so during a flood, the reservoir can only absorb water to the extent of the storage space available at the time.[4]

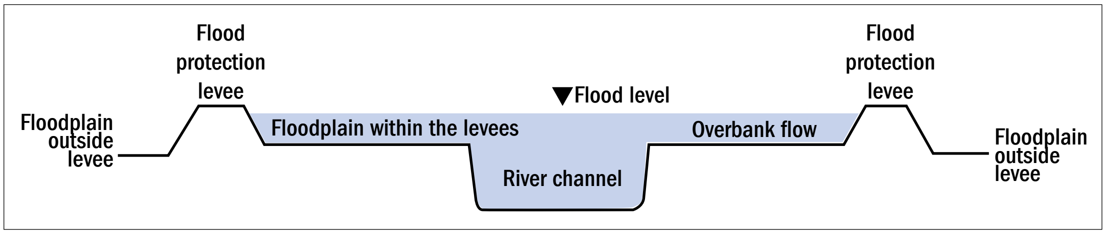
In the catchment, apart from the loss of floodwater due to evaporation and seepage, the overflow from the streams ebbs as the flood wave recedes. However, as in the case of the Swat River in 2010, high velocities and flow energy cause erosion and damage infrastructure such as bridges, roads, and houses. In addition, the catchments lack surface storage capacity, so they cannot absorb the runoff, and, therefore, pass on sharp flow peaks and high sediment yields to the downstream channels.

In the plains areas of the middle river reach, direct water flows from the catchments become insignificant; instead, it is the tributaries' flows into the Indus River that dominate. The flash flows from the right-bank tributaries and stream flows from the left-bank tributaries further elevate the flood peaks of the Indus. In the plains of the middle and lower river reaches, floods engender changes in the river channels and the floodplain; and, in turn, the changes in the river channels and the floodplain affect the flood frequency. Floods are also affected by exogenous processes such as climate change; endogenous processes such natural changes in river morphology; and anthropogenic processes such as channelization, regulation, and water diversions. Not all changes are undesirable, but the development of agricultural irrigation facilities and other infrastructure has altered the river morphology and significantly reduced the floodplain area available for accommodating high floods.

In the 19th century, the floodplain comprised almost the entire area between the Indus River and its left-bank tributaries. Economic development in the floodplain, however, has since necessitated the construction of levees along the rivers to protect the infrastructure there. The levees' construction divided the floodplain into two parts: an active floodplain within the levees and an inactive floodplain outside of the levees (Figure 6). Today, the active floodplain contains the main river channels and accommodates the bulk of the floodwaters. The distances between the left- and right-bank levees vary from 1 to 5 km, depending on the locations of the levees; and the heights of the levees vary from 2 to 5 m. The inactive floodplain, which is an area of major settlements and high economic development, including major irrigation infrastructure that supplies water to over 14 million ha., is only flooded when the levees are breached.

4 For example, Tarbela Reservoir attenuated the flood discharge peaks of the July 1988 flood by 21%, the peaks of the July 1989 flood by 26%, and those of the August 1997 flood by 43%. However, it diminished the flood peak in the September 1992 flood by only 2%, as the flood occurred late in the season, when the reservoir was already full (Asianics Agro-Dev. International, 2000). In the 2010 flood, the Mangla Reservoir reduced the flood peaks by 35%, while Tarbela reduced it by 28%.

Figure 6 Typical Cross Section of a River Channel Protected by Levees



Source: Author.

In the midstream segment, the likelihood that tributary peaks will coincide with flooding in the Indus River is high because of the longer flood-peak periods. The construction of bridges, levees, and barrages for flow diversion has constricted the waterways and caused channel aggradations. The encroachment on waterways near towns has further constricted river sections, and the flood situation is worsened when flood peaks in the tributaries coincide with flood peaks in the Indus River.

In the downstream segment, several sections of the Indus River now flow at a higher elevation than that of the adjoining lands. By virtue of this topography, the overflow along the left bank of the Indus River in Sindh Province never returns to the main river channels. Instead, most of it passes through hundreds of kilometers of developed irrigated and populated areas on the way to the sea, with the exception of the portion of the flow that evaporates into the air or seeps into the groundwater. Moreover, the flat topography and slow drainage in this segment result in long periods of flood inundation.

Major Floods in the Indus Basin

General

As mentioned, 21 floods occurred between 1950 and 2010 in the Indus Basin, causing cumulative direct economic losses of about $19 billion (in 2010 dollars), killing 8,887 people, and damaging or destroying a total of 109,822 villages (within an area of around 446,000 km^2). Table 1 provides a breakdown of the damage per year during that period. The data indicate that the 2010 flood caused the greatest damage, although the flooded area was smaller than those in 1956, 1973, 1976, and 1992. This may have been due to the timing of the flood, locations of the embankment breaches, and the significant increase in economic development that had occurred in the floodplains by 2010.

Table 1 Flood Damage in the Indus Basin, 1950–2011

Year	Direct losses ($ million)[a]	Lost Lives	Affected Villages	Flooded Area (km^2)
1950	227	2,910	10,000	17,920
1955	176	679	6,945	20,480
1956	148	160	11,609	74,406
1957	140	83	4,498	16,003
1959	109	88	3,902	10,424
1973	2,388	474	9,719	41,472
1975	318	126	8,628	34,931
1976	1,621	425	18,390	81,920
1977	157	848	2,185	4,657
1978	1,036	393	9,199	30,597
1981	139	82	2,071	4,191
1983	63	39	643	1,882
1984	35	42	251	1,093
1988	399	508	100	6,144
1992	1,400	1,008	13,208	38,758
1994	392	431	1,622	5,568
1995	175	591	6,852	16,686
1998	na	47	161	na
2001	na	201	na	na
2003	na	230	na	na
2010	10,056	1,600	na	38,600
2011	66	516	38,700	9,098

km^2 = square kilometer; na = not available.

[a] In 1995 US dollars, except for the figure for 2010, which is given in October 2010 dollars.

Sources: Government of Pakistan, Ministry of Water and Power, Federal Flood Commission. 2006. *Flood Protection Plan, 2006.* Islamabad; M.S. Sardar, M. A. Tahir, and M. I. Zafar. 2008. Poverty in Riverine Areas: Vulnerabilities, Social Gaps and Flood Damages. *Pakistan Journal of Life and Social Sciences.* 6 (1). pp. 25–31.

Historically, flood damage in the active floodplain (i.e., within the levees) occurred in all medium-to-high floods (see Appendix 3 for the flood limits). Levee breaches occurred only in exceptionally high floods, but they caused especially heavy casualties and economic losses. Although constrictions at bridges and barrages, with the resultant fluxes, were the primary reasons for these breaches, the damage was aggravated by the flat topography, slow drainage, and the long periods of inundation.

1955 flood. From 4 to 6 October 1955, 200 mm of rain fell in the town of Dalhousie, 200 mm in the city of Sialkot, and 500 mm in the catchments of the Ujh and Basantar rivers, covering almost the entire catchment area of the Ravi River. Further, a weather depression in the Bay of Bengal, combined with moist air from the Arabian Sea, resulted in an estimated 500 mm of rain in the Ravi catchment during the following 2 days. As the earlier rains had already saturated the catchment, the additional 500 mm generated a huge flood.

The 1955 flood was the highest on record for the Ravi River, with peak discharges of 17,840 cubic meters per second (m^3s^{-1}) at Madhopur Headworks,[5] 18,661 m^3s^{-1} at Ravi Siphon, and 15,341 m^3s^{-1} at Balloki Headworks. It breached the flood embankments of the Bambanwala–Ravi–Bedian–Dipalpur Link Canal, upstream from Ravi Siphon, and at Shahdara Bridge, a suburb of Lahore. The Punjab Irrigation Department estimated that flood discharges of 7,334 m^3s^{-1} passed through the breaches at Ravi Siphon and 8,495 m^3s^{-1} through the breaches at Shahdara Bridge.

1973 flood. Intense rainfall of 324 mm generated flood peaks up to 28,331 m^3s^{-1} at Khanki Headworks and 22,725 m^3s^{-1} at Panjnad Barrage, both on the Chenab River, inundating 3.6 million ha in several districts with waters up to a height of about 6 m. Wheat and cotton crops were devastated. Punjab lost 70,000 cattle and 255,000 houses, and 474 people perished. The total flood damage was estimated at $2.39 billion.

1976 flood. Monsoon rainfall of 579 mm during July and September 1976 on the Indus catchments resulted in flooding of up to 24,410 m^3s^{-1} at the Jinnah Barrage and 33,972 m^3s^{-1} at the Guddu Barrage, both on the Indus River. The flood killed 425 people and affected another 1.7 million people, inundated 8 million ha of land, and affected 18,390 villages, damaging 11,000 houses. Total economic losses were estimated as $1.62 billion.

1988 flood. An average of 400 mm of rainfall occurred on the catchments of the Ravi, Sutlej, and Chenab rivers on the 23–26 September. Along the Ravi River, the rainfall generated a flood of 13,480 m^3s^{-1} in the town of Madhopur; 16,481 m^3s^{-1} at Jassar Bridge (estimated); 16,566 m^3s^{-1} at Ravi Siphon; 13,479 m^3s^{-1} in Shahdara Bridge; and 9,855 m^3s^{-1} at Balloki Headworks. A flood flow of about 4,248 m^3s^{-1} passed through a breached section at Shahdara Bridge. The flood deluged 1 million ha of agricultural land and irrigated crops, killing 500 people and causing economic damage totaling about $400 million.

1992 flood. The 1992 monsoon caused widespread rain on the catchments of the Indus, Jhelum, and Chenab rivers. The continuous 5-day rainfall during 7–11 September 1992 was the highest in the history during the same period. The rainfall led to flooding in the Chenab, Jhelum, and Indus rivers. An extreme flood flow of 27,960 m^3s^{-1} was recorded on the Jhelum River at Rasul Barrage. With the Mangla and Tarbela reservoirs already filled to capacity, the excess water at these spots also resulted in widespread flooding. The breaching of flood protection levees (FPLs) exposed large areas to the

5 One cubic meter per second (m^3s^{-1}) is equivalent to 35.3146667 cubic feet per second (ft^3s^{-1}).

ravages of the flood, which inundated 13,000 villages, damaged 960,000 houses, affected 4.8 million people, and killed more than 1,000 (World Bank 1996). The Government of Pakistan estimated the damage at about $1.4 billion, including $0.5 billion worth of damage to public infrastructure. The hardest hit were the agriculture and communications sectors, for which the cost of flood damage repair was estimated at a total of $396 million.

1994 flood. Widespread rains from July to September 1994 caused flooding in the Indus and Sutlej rivers. The rainfall on 3 July, at the start of the monsoon (62 mm in the town of Murree, 29 mm in Risalpur town, and 31 mm in Karachi) saturated the soil and reduced its water absorption capacity. High floods occurred as a result of subsequent rains, including 133 mm in Jhelum town on 5, 7, and 8 July, and 47 mm in Sialkot on 8 July. The government's damage assessment showed that, as of 21 September, the floods had killed 386 people, damaged 557,000 houses, and resulted in the loss of 14,000 cattle and of about 700,000 ha of crops.

Floods in 2005 and 2006. The Kabul and Chenab rivers experienced high flooding in 2005 and 2006. In July 2005, the flood peaks in the Chenab were 10,987 m^3s^{-1} at Jammu, in India; 9,770 m^3s^{-1} at the Marala Barrage; and 10,420 m^3s^{-1} at Khanki Headworks. A flood peak of 4,785 m^3s^{-1} in the Kabul River combined with water released from the Tarbela Dam into the Indus River to generate a flood peak of 14,866 m^3s^{-1} at Jinnah Barrage. These two floods resulted in the death of 591 people and affected about 1 million ha of land in 117 districts.

Post-2010 floods. Since the major flood in 2010, two more floods have occurred in Pakistan, though they caused less damage. In August and September 2011, the rainfall in Sindh Province and a part of Balochistan Province was 2.5 times higher than during the same months in the past. This high rainfall, combined with poor drainage and a prolonged period of flooding, affected 9.6 million people in an area of more than 27,000 km^2. A total of 200,000 people lost their homes in 17 districts in Sindh and 5 districts in Balochistan (ADB, Government of Pakistan and World Bank 2011). The heavy monsoon rains also caused a widespread loss of life, livelihoods, and infrastructure across southern Punjab, northern Sindh, and northeastern Balochistan during August, September, and October 2012. The rains and the resultant flood affected 4.9 million people (with 571 reported dead) and damaged more than 600,000 houses; they also ruined crops within an area of 500,000 ha (National Disaster Management Authority 2012; United Nations Office for the Coordination of Humanitarian Affairs 2012).

The 2010 Super Flood

The Damage

The 2010 flood—which affected all the provinces and regions of Pakistan[6]—killed 1,600 people, caused damage totaling over $10 billion, and inundated an area of about 38,600 km^2. This flood was Pakistan's most damaging on record. Sindh Province, the most downstream section of the Indus Basin, suffered the highest damage (43% of the total), followed by Punjab (26%) and Khyber Pakhtunkhwa (12%). The damage to infrastructure in the province of Balochistan was estimated at 6% of total national losses. Damage to national infrastructure accounted for 11% of the total. In the country as a whole, the floods damaged nearly 2 million houses and displaced a population of over 20 million.

6 This includes four provinces (Punjab, Sindh, Khyber Pakhtunkhwa, and Balochistan) and four federally administrated territories.

Flood damage occurred mainly in the agriculture and livestock sector (50%), followed by housing (16%) and transport and communications (13%). The damage done to agriculture rises to 53% of the total if irrigation infrastructure is included. The prolonged inundation of large areas of cultivated land resulted in massive losses in the agriculture sector. Table 2 shows the 2010 flood damage breakdown by sector and region.

Table 2 Flood Damage by Sector and Region, 2010 ($ million)

Flood Damage by Sector			Flood Damage by Region		
Sector	**Damage**	**%**	**Region**	**Damage**	**%**
Agriculture and livestock	5,045	50.2	Balochistan	620	6.2
Education	311	3.1	FATA	74	0.7
Energy	309	3.1	Gilgit- Baltistan	49	0.5
Environment	12	0.1	Khyber Pakhtunkhwa	1,172	11.7
Finance sector	674	6.7	National	1,095	10.9
Governance	70	0.7	Northeast Pakistan	86	0.9
Health	50	0.5	Punjab	2,580	25.7
Housing	1,588	15.8	Sindh	4,380	43.6
Irrigation and flood protection	278	2.8			
Private sector and industries	282	2.8			
Transport and communications	1,328	13.2			
Water supply and sanitation	109	1.1			
Total	**10,056**				

FATA = Federally Administered Tribal Areas.

Note: Percentages may not total 100% because of rounding.

Source: ADB, Government of Pakistan, and the World Bank. 2010. Pakistan Flood 2010. *Preliminary Damage and Needs Assessment Report*. Islamabad, Pakistan.

Extreme Rainfall

High evaporation over the Indian Ocean (Pakistan Meteorological Department 2010) and the oceanic phenomenon La Niña caused severe monsoon weather in 2010 (National Oceanic and Atmospheric Administration [NOAA] 2010b; Riebeek 2010). Wildfires in the Russian Federation and precipitation in Pakistan also coincided with an unusually strong polar jet stream that generated unprecedented levels of moisture over the Himalayas (Marshall 2010; NOAA 2010a, as cited in Mustafa and Wrathall 2011). This resulted in widespread high rainfall in the Indus Basin in July and August 2010, with rainfall recorded in all four provinces.

A 24-hour rainfall on 29 July 2010, for instance, ranged from 21 mm to 280 mm at 18 stations in the Indus Basin, with an average of 128 mm. Rainfall was recorded at 143 mm in the city of Mirpur Khas, in Sindh Province, and at 73 mm in Zhob, Balochistan. The next day, a 24-hour rainfall of 240 mm was recorded in the city of Kamra, Punjab, and 189 mm in Ghari Dopatta, Northeast Pakistan. The average rainfall for the 18 Indus Basin stations on 30 July was estimated at 290 mm in July and 189 mm in August (Table 3). The July and August rainfall was almost double the historical levels for the same months.

Table 3 Comparison of the 2010 Monsoon Rainfall with Historical Means (mm)

Station	Mean July Rainfall (1962–2010) (1)	July 2010 Rainfall (2)	Mean July–August Rainfall (1962–2010) (3)	July–August 2010 Rainfall (4)
Gilgit (KP)	16.2	53.0	31.1	112.0
Muzaffarabad	359.0	359.4	576.0	758.0
Peshawar Airport (KP)	46.0	402.0	na	535.0
Saidu Sharif (KP)	152.0	471.0	189.0	757.0
Risalpur (Punjab)	na	433.0	na	795.0
Kakul (KP)	263.0	389.0	519.0	524.0
Cherat (KP)	93.0	388.0	187.0	618.0
Ballakot (KP)	372.0	327.0	650.0	528.0
Dir (KP)	154.0	317.0	301.0	609.0
Lower Dir (KP)	56.0	295.0	na	448.0
Dera Ismail Khan (KP)	80.0	147.0	110.0	282.0
Muree (Punjab)	364.0	579.0	665.0	848.0
Faisalabad (Punjab)	117.0	244.0	204.0	468.0
Multan (Punjab)	60.0	55.0	93.0	222.0
Mianwali (Punjab)	na	528.0	na	703.0
Sibi (Balochistan)	37.0	56.0	65.0	149.0
Jacobabad (Sindh)	42.0	132.0	154.0	182.0
Sukkur (Sindh)		42.0	45.0	81.0
Average	**147.0**	**290.0**	**271.0**	**479.0**
Ratio to mean		**2.0**		**1.8**

KP= Khyber Pakhtunkhwa; mm = millimeter; na = not available; ratio to mean = ratio of [column 2 to column 1 and column 4 to column 3].

Source: Government of Pakistan, Ministry of Defense, Pakistan Meteorological Department. 2010. *Rainfall Statement July 2010*. www.pakmet.com.pk/FFD/index_files/rainfalljuly10.htm

High Flood Flows

The widespread rain generated high runoff in the Chenab, Indus, Jhelum, Kabul, and Swat rivers. Further, flash floods[7] from the Kurram River and hill torrents from the Sulaiman Mountains contributed to the Indus flood peak. On the Swat River, a flood peak of 7,646 m^3s^{-1} was observed at the Amandara Headworks, about 60% higher than its design discharge capacity of 4,813 m^3s^{-1}. Downstream, at the Munda Headworks, the flood peak was 8,495 m^3s^{-1} almost 71% higher than its design capacity of 4,955 m^3s^{-1}. This flooding at the Amandara and Munda headworks was unprecedented: it severely damaged the Amandara Headworks and washed away the Munda Headworks altogether. Downstream from the Munda Headworks, a flood peak of 4,248 m^3s^{-1} from the Kabul River, combined with the flood peak from the Swat River, increased the total peak flow of the Kabul River at Warsak Dam to 13,592 m^3s^{-1}. This exceptionally high flow in the Kabul severely damaged the town of Nowshera and further contributed to the flooding of the Indus River downstream from there.

7 Flash floods differ from normal floods in that a flash flood will have (i) a sharp hydrograph, with steep rising and falling limbs; and (ii) a shorter time of concentration. It is also difficult to predict their occurrence. Flash floods may result from intense rainfall on degraded catchments or dam breaks, or from a glacial outburst. They can have serious socioeconomic and environmental consequences.

On the Indus River, the water flow into the Tarbela Reservoir (23,645 m^3s^{-1}) was equivalent to a flood event with a return period estimated at more than 3,000 years. However, the flood inflow was within the design capacity of the dam, which was constructed to handle the probable maximum flood levels (Table 4). The observed peak of the outflow hydrograph (17,104 m^3s^{-1}) at Tarbela indicates that the reservoir-routing effect had reduced the flood peaks by 28% (6,541 m^3s^{-1}). At Jinnah Barrage, a flood peak of 26,546 m^3s^{-1} was observed, and an estimated 4,287 m^3s^{-1} of discharge passed through the designed breach section upstream from the barrage. These figures indicate a total flood peak of 30,833 m^3s^{-1} at Jinnah Barrage, which was almost equal to a 100-year return period (30,894 m^3s^{-1}), and about 15% higher than the barrage's design capacity (26,902 m^3s^{-1}).

Table 4 Flood Peaks along the Indus and Kabul Rivers, 1929–2010 (in m^3s^{-1})

			2010 Flood		Historical Flood Events	
Location	Design Discharge	100-Year Floods	Peak	Return Period (year)	Year	Peak
Tarbela inflows	42,476	18,491	23,645	3,461	1929	19,317
Tarbela outflow	na	na	17,104	na	na	na
Kabul at Nowshera	na	6,173	13,592	>10,000	1965	6,173
Jinnah	26,902	30,894	30,833 (4,287)[a]	100	1942	25,967
Chashma	26,902	26,448	29,356	250	1942	22,988
Taunsa	31,149	25,797	30,724 (3,539)[a]	211	1958	22,333
Guddu	33,981	37,719	32,529	40	1976	33,305
Sukkur[b]	25,486	36,529	32,060	46	1976	32,890
Kotri	24,778	27,241	27,323	101	1956	27,779

m^3s^{-1} = cubic meters per second; na = not available.

[a] The values within the parentheses indicate an estimated discharge that passed through the breach sections at upstream of the Barrage structure. The tribunal report includes estimated discharges through breaches. See M. A. Shah, A. S. Shakir, and S. Masood. 2011. *A Rude Awakening.* Report of the Judicial Flood Enquiry Tribunal, 2010. Lahore: Judicial Enquiry Commission.

[b] The original design capacity of Sukkur Barrage was 42,476 m^3s^{-1}.

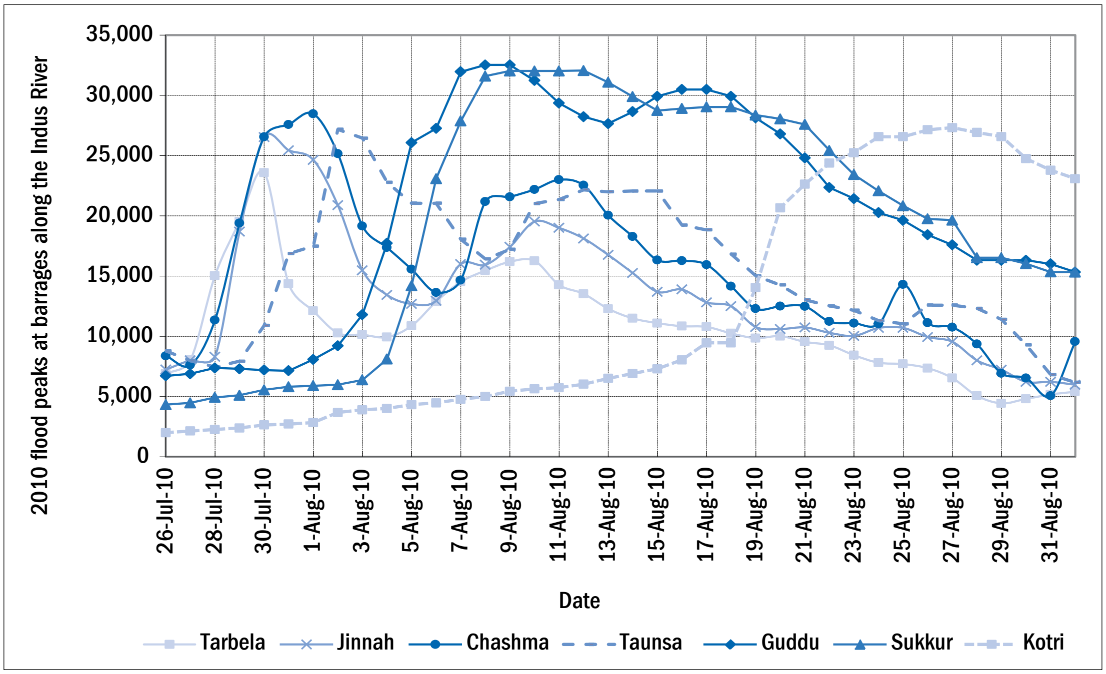
Sources: Government of Pakistan, Ministry of Water and Power, Federal Flood Commission. 2011. *Annual Report 2010.* Islamabad. www.ffc.gov.pk/download/flood/archieve/Annual.report2010.pdf?bcsi_scan_97e98328e2b67804=0&bcsi_scan_filename=Annual.report2010.pdf (accessed 22 March 2013); 2011; Government of Pakistan, Supreme Court of Pakistan. 2011. *Enquiry Report of Flood Commission Appointed by the Supreme Court of Pakistan.* Islamabad; Government of Pakistan, Ministry of Defense, Pakistan Meteorological Department, Flood Forecasting Division. Flood Peak Data, 2010. www.pmd.gov.pk/FFD/cp/floodpage.asp (accessed 9 September 2010).

At Chashma Barrage, the 2010 flood peak of 29,356 m^3s^{-1} (a return period of 250 years) topped the barrage's design capacity of 26,902 m^3s^{-1}. This flood peak at the barrage was the highest since its construction in 1971, and nearly 10% higher than its design capacity. However, the 2010 flood passed through the structure without significant damage. Farther downstream, Taunsa Barrage sustained the worst flood damage in Punjab province. With a total flood peak of 30,724 m^3s^{-1}, the flood peak was 27,185 m^3s^{-1} through the barrage structure. An estimated additional discharge of 3,539 m^3s^{-1} passed through the breach section. This was higher than a 100-year return period flood by about 20%; however, it was lower than the barrage's design capacity of 31,149 m^3s^{-1}. The flood peak at Guddu Barrage remained within that barrage's design capacity as well, but the design capacity of Sukkur Barrage was exceeded by about 25% and of Kotri Barrage by 10%.

During the 2010 flood, the Tarbela Reservoir attenuated its peak inflow discharge of 23,362 m^3s^{-1} to 17,104 m^3s^{-1} at outflow. Similarly, Mangla Reservoir, on the Jhelum River, attenuated its peak inflow of 8,665 m^3s^{-1} to 6,428 m^3s^{-1} at the outlet. Tarbela Reservoir reduced its flood peak by 28% and Mangla by 35%, thereby playing a major role in lowering the downstream flood peaks at the Jinnah and Panjnad barrages. The Mangla Reservoir also significantly reduced the contribution of the Jhelum River to the flood flow at Guddu Barrage.

The Indus River experienced two distinct back-to-back flood peaks in the reach between Jinnah and Taunsa barrages, with an average lag time of about 5–6 days (Figure 7). The lag time between the peaks varied from 10 days in the upper river reaches to 3 days in the lower river reaches. The two peaks merged at Kotri Barrage, the most downstream structure on the Indus River. From upstream to downstream, the lag time of the first flood wave was 2 days between Tarbela Reservoir and Chashma Barrage, 1 day between Chashma and Taunsa barrages, 7 days between Taunsa and Guddu, 4 days between Guddu and Sukkur, and 17 days between Sukkur and Kotri.

Figure 7 Flood Wave Propagation in the Indus River, 2010 (in m^3s^{-1})



m^3s^{-1} = cubic meter per second.

Source: Author, using data from Government of Pakistan, Ministry of Defense, Pakistan Meteorological Department, Flood Forecasting Division. Flood Peak Data, 2010. http://www.pmd.gov.pk/FFD/cp/floodpage.asp (accessed 9 September 2010).

Flood Policy, Planning, and Practices

Policy

National Water Policy

Pakistan does not have an approved water policy but there is a draft national water policy that recognizes the need for appropriate flood management, including (i) the continued construction of flood-protection facilities and the maintenance of existing infrastructure, (ii) a review of the design and maintenance standards of existing flood protection structures, (iii) the establishment and promotion of flood zoning, and enforcement of appropriate land use, (iii) optimized reservoir operating rules, (iv) improved and updated flood manuals, (v) effective use of nonstructural measures, and (vi) the creation of flood response plans (Government of Pakistan, Ministry of Water and Power 2006). The national water policy should also include flood risk planning, regulatory zones, and watershed management in the uplands—all of which could have positive impacts on flood management.

Legal Aspects

Although Pakistan does not have a comprehensive flood management law, or river-plains regulatory laws, existing water and land-use laws do address some flood-related legal issues. For example, the Indus River System Authority Act (1992) defines the institutional setup for the distribution of surface waters among the provinces, while the Provincial Water Accord (1991) deals with the apportionment of Indus River waters among the provinces. The Punjab Irrigation and Drainage Authority Act (1997) allows the participation of water users in the operation, maintenance, and management of minor canals and distributaries. In 1991, the Council of Common Interest, which decides on resource allocation among the provinces, concluded the first formal agreement for the apportionment of river water, known as the Water Apportionment Accord 1991. Then the Indus River System Authority Act (1992) was enacted; this law guides the year-round distribution of river and reservoir waters among the provinces (see Box 1).

Institutions

Twelve organizations participate in flood mitigation and management work at the national and provincial levels in various capacities (Table 5). These organizations can be broadly divided into the following areas: (i) flood-related planning; operation, maintenance, and management of major infrastructure; (ii) flood forecasting and early warnings; and (iii) rescue and relief operations. However, most of these organizations have other core responsibilities and play only a subsidiary role in flood management.

Box 1 Major Water-Related Legislation in Pakistan

- Water and Power Development Authority Act, 1958
- Territorial Waters and Maritime Zones Act, 1976
- Indus River System Authority Act, 1992
- Environmental Protection Act, 1997
- Provincial Water Accord, 1991
- Balochistan Ordinance 1980
- Balochistan Water Supply Regulation 1941
- Balochistan Pat Feeder Canal Regulation ,1972
- Balochistan Canal and Drainage Ordinance, 1980
- Balochistan Coastal Development Authority Act, 1998
- Balochistan Irrigation and Drainage Authority Act, 1997
- Balochistan Groundwater Rights Administration Ordinance, 1978
- North-West Frontier Province (NWFP) Canal and Drainage Act, 1873
- NWFP Irrigation and Drainage Authority Act, 1997
- Punjab Minor Canals Act, 1905
- Punjab Minor Canal (North-West Frontier Province Amendment) Act, 1948
- Punjab Soil Reclamation Act, 1952
- Punjab Canal and Drainage Act, 1873
- Punjab Water Users Association Ordinance, 1981
- Punjab Irrigation and Drainage Authority Act, 1997
- Sindh Water Users Association Ordinance, 1982
- Sindh Irrigation and Drainage Authority Act, 1997
- Sindh Irrigation Act, 1879

Table 5 Flood Management Institutions and their Responsibilities

Organization	Responsibility	Status
Pakistan Commissioner for Indus Waters	Coordinates with India on floods in the transboundary rivers	National
Water and Power Development Authority (WAPDA), Ministry of Water and Power	Operates and manages the Mangla and Tarbela reservoirs and manages hydrometeorological data	National
Federal Flood Commission (FFC), Ministry of Water and Power	Prepares and coordinates implementation of national flood protection plans, and conducts oversight of flood forecasting, warning, and management	National
Pakistan Meteorological Department (PMD)	Forecasts rainfall and flood, and issues warnings	National
Flood Forecasting Division, PMD	Conducts model simulations, forecasts flood, and issues warnings	National
Emergency Relief Cell, Cabinet Division	Coordinates relief operations at the national level	National
National Disaster Management Authority (NDMA)	Conducts oversight and coordination of disaster management, including rescue and relief operations, at the national level	National
Provincial irrigation departments	Constructs, manages, operates, and maintains barrages and flood protection works, and implements protective measures	Provincial
Provincial disaster management authorities	Coordinates with other provincial departments, including for rescue and relief operations	Provincial
District administrations	Conducts relief and rescue operations at the district level	Provincial
Other relief organizations	Manages post-flood relief operations at the provincial level	Provincial
Pakistan Army	Assists the civil authorities in real-time flood fighting and rescue and relief operations	National

Source: Government of Pakistan, Ministry of Water and Power, Federal Flood Commission. 2011. *Annual Report 2010*. Islamabad.

The Water and Power Development Authority (WAPDA) was established in 1959 under the Ministry of Water and Power to implement and manage major water-resource and energy projects around the country and is responsible for the operation of the Mangla and Tarbela reservoirs during floods.

Created in 1977 under the Ministry of Water and Power, the Federal Flood Commission (FFC) is responsible for flood management planning, coordination, overseeing implementation, and allocating funds.

The Pakistan Meteorological Department (PMD) operates under the Ministry of Defense, and is responsible for weather and flood forecasting. The Flood Forecasting Division, within the PMD, concentrates exclusively on forecasting floods.

The National Disaster Management Authority (NMDA) was created in 2007, and the provincial and national disaster authorities in 2008. These agencies are responsible for the implementation of national-disaster management policies. However, in the case of flooding, they also coordinate post-flood activities, including rescue-and-relief operations and the activities of donors, government agencies, and nongovernment organizations.

The provincial irrigation departments (PIDs) manage irrigation infrastructure, oversee the operation of barrages, and maintain the flood protection levees (FPLs).

Table 5 provides a summary of the roles and responsibilities of the various flood management agencies, while a more detailed description can be found in Appendix 4.

Planning

Medium- and Long-Term Planning

Medium- and long-term flood management planning occurs at the national and provincial levels, and includes developing and implementing flood protection plans. The FFC developed and implemented three 10-year national flood protection plans between 1977 and 2007 (Table 6). The three plans implemented a total of more than 1,200 flood protection schemes, and disbursed about PRs18 billion. The three plans included flood management actions such as (i) the execution of flood-protection schemes, mainly the construction of spurs and levees to train streams and to protect adjoining land from erosion; and (ii) the procurement and installation of a flood-forecasting system and floodplain mapping. A fourth 10-year national flood protection plan is being prepared by the national government.[8]

8 A draft version of the fourth national flood protection plan (2007–2016), largely an extension of three earlier plans, was not approved by the national government. The author has been tasked with preparing a revised version of the fourth national flood protection plan.

Table 6 National Flood Protection Plans

Description	Main Activities	Total Cost (PRs billion)
NFPP-I (1977–1987)	A total of 311 flood-protection schemes completed, mainly river-training works.	1.6
NFPP-II (1988–1998)	A total of 438 flood-protection and river-training schemes completed. Procured and installed a 10-cm weather radar and a meteor burst telecommunication system (69 high-frequency radio sets), and carried out prefeasibility studies, as well as floodplain mapping of some areas.	8.6
NFPP-III (1998–2008)	A total of 463 flood-protection schemes completed. Procured and installed 24 high frequency radio sets, 20 remote stations, and a 10-cm weather radar. Upgraded existing 10-cm weather radar in Lahore, and developed an early warning system.	7.6
Draft NFPP-IV	The NFP-IV is being prepared. The proposal tentatively includes finishing the work left over from earlier plans; improving the operation of major reservoirs; updating the flood operation manual; determining the extent of the floodplain; and improving flood forecasting, flash flood monitoring, and capacity building.	≥ 30.0

cm = centimeter; NFPP = national flood protection plan.

Source: Government of Pakistan, Ministry of Water and Power, Federal Flood Commission. 2006. *Flood Protection Plan, 2006.* Islamabad.

Emergency Response Planning

Every year, before the onset of the monsoon, all provinces, in relation to their river jurisdictions, as well as the federal government in its field of operations, conduct a pre-flood planning exercise to review the conditions of major river infrastructure such as reservoirs, barrages, and levees, and decide on advance actions to prepare for an effective response to probable floods. Most of the organizations listed in Table 5 participate in such emergency-response planning. Flood preparedness planning ensures that (i) the flood forecasting and early warning system is functional; (ii) community-based early warning systems are in place for the issuance of timely and effective flood warnings; (iii) strict vigilance is exercised and sufficient resources are deployed to strengthen critical levees and barrages; (iv) safe havens are identified in case evacuation is required; (v) emergency relief supplies (food, fodder, and medicine) and temporary shelters are arranged; (vi) transport for evacuation is made available; and (vii) rehearsals and drills are conducted.

The other key aspects of flood preparedness include an agreement on the roles and responsibilities of various government and nongovernment organizations involved in flood management, as well as measures to ensure that standard operating procedures are known at the management and field levels of each participating organization. Other important aspects include the (i) deployment of resources, (ii) provision of basic needs, (iii) minimization of disruptions during floods, (iv) effective flow of information, (v) coordination, and (vi) the fast restoration of essential facilities in case of flood damage.

Based on their experience with earlier flood disasters, provincial and district governments also prepare inventories of available resources to identify gaps to be filled before flooding occurs. Finally, search and rescue teams are recruited and trained, and their rapid mobilization and deployment ensured.

Flood Mitigation Measures

Structural Measures

The major flood-protection infrastructure comprises 6,800 FPLs and 1,410 spurs that have been built since 1960 to protect the main towns and important infrastructure (Table 7). These FPLs now cover most of the critical points along the river reaches. River-training works have been installed at key locations to control actively meandering channels and to save erodible beds and banks from erosion.

Table 7 Levees and Spurs on Major Rivers

Province	Levees (km)	Spurs (no.)
Punjab	3,332	496
Sindh	2,422	46
Khyber Pakhtunkhwa	352	186
Balochistan	697	682
Total	**6,803**	**1,410**

km = kilometer.

Source: Government of Pakistan, Ministry of Water and Power, Federal Flood Commission. 2011. *Annual Report 2010.* Islamabad.

The Mangla and Tarbela reservoirs are used to regulate flood flows, to the extent of their available capacities at the time of a flood. However, because the operational priorities of these reservoirs are for irrigation supplies and energy production, their full potential for flood management cannot be realized. The reservoirs' operating rules also place structural safety first, with little room for flexibility.

The existing 18 barrages and a number of bridges on the rivers affect flood transmission through the downstream channel systems. The deliberate operation of breaching sections of barrages to protect the structures also impacts flood flows at downstream.

Nonstructural Measures

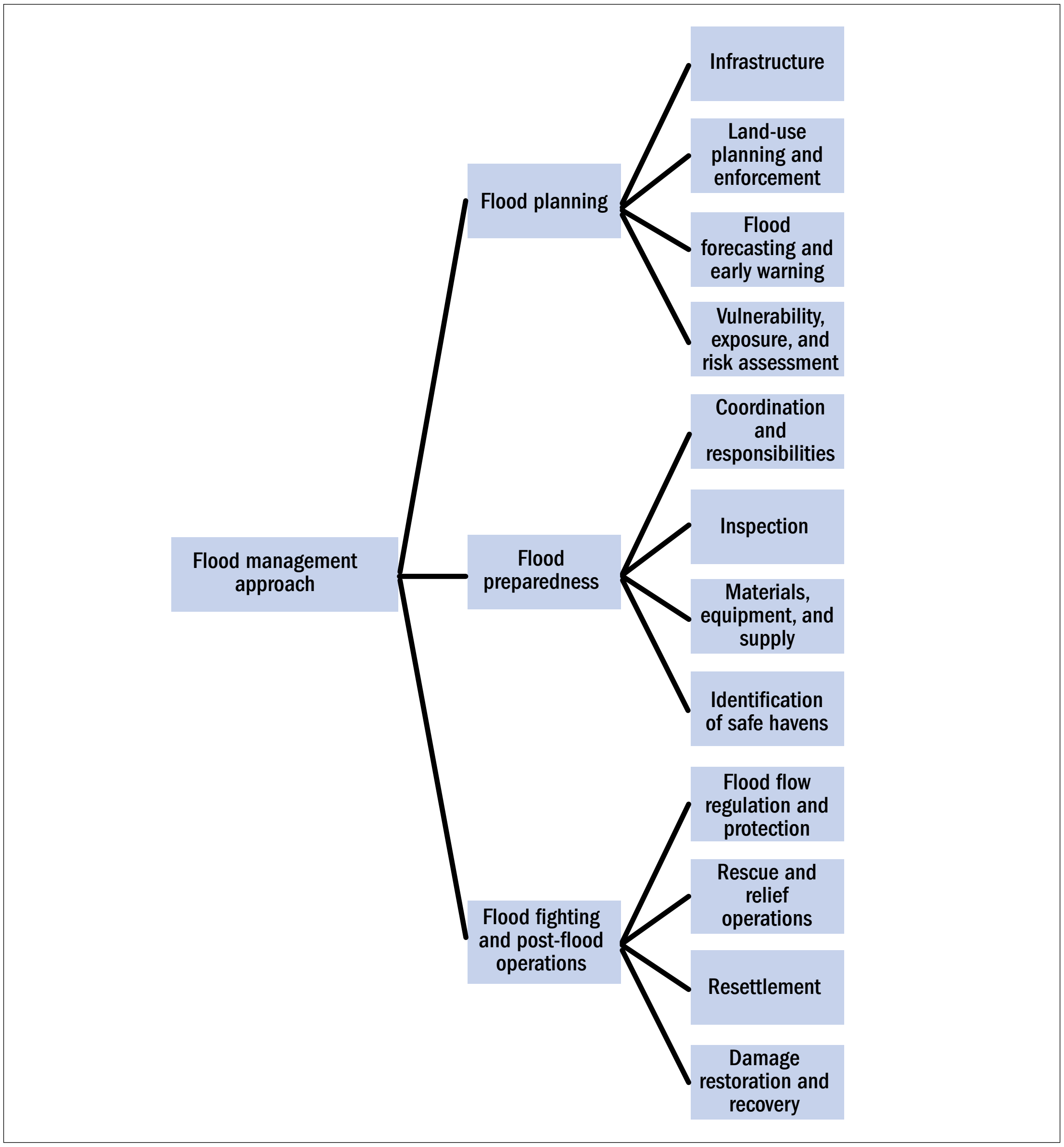
Flood forecasting and early warning system. The PMD's Flood Forecasting Division plays a key role in flood forecasting and early warnings. Its flood forecasting and early warning system comprises (i) 10-centimeter, S-band, quantitative precipitation-measuring Doppler radar facilities in Lahore and at Mangla Dam that remotely sense rainfall over the catchments of the Beas, Chenab, Ravi, and Sutlej rivers; (ii) meteor burst communications for the transmission of the hydrometric data; (iii) 5-centimeter weather surveillance radar facilities in the cities of Dera Ismail Khan, Islamabad, Karachi, Rahim Yar Khan, and Sialkot; and (iv) the Indus River system mathematical model, which computes stream hydraulics, including stage and discharge hydrographs along the rivers, to estimate the areas vulnerable to inundation as a basis for the issuance of flood warnings.

Flood fighting and post-flood operations. The movement of the flood wave is closely monitored along the rivers, and appropriate actions to regulate the flow are taken at critical locations as needed. Government agencies such as the PIDs, WAPDA, and the Pakistan Army Corps of Engineers participate in real-time flood fighting. The PIDs and WAPDA regulate their respective structures, barrages, and reservoirs following standard operating procedures. The Pakistan Army assists the PIDs and WAPDA in operating the breaching sections, and the district governments in rescue and relief operations.

Rescue and relief operations are field actions organized at the district level. They include rescuing people from flooded areas and providing temporary shelter, food, and health care with a view to preventing epidemics.

The post-flood restoration and recovery phase starts as soon as the flood recedes from the affected areas. Completing recovery takes a longer time: 2–3 years, depending on the nature and extent of the damage. Figure 8 shows the Indus Basin flood management approach currently in practice.

Figure 8 The Indus Basin Flood Management Approach



Source: Author.

Investment in Flood Management

Pakistan suffered cumulative flood damage of $20.0 billion from 1950 to 2010, and spent over $1.2 billion to mitigate the effect of the floods during this period (Table 8). A large amount of this spending was borrowed from the Asian Development Bank and the World Bank.[9] There was also bilateral financial and in-kind support, which is not detailed here. The FFC (2010) reports that the government spent PRs12.6 billion[10] ($163 million at the September 2010 rate) of its own resources. This investment helped to support the construction of flood levees of about 400 km in length and 13 new flood-diversion structures; capacity building for the FFC, WAPDA, and the PMD; and the development of flood forecasting and telemetry systems. However, a major proportion of the spending was used for emergency relief and the repair of flood damage.[11] No comprehensive basin-scale flood management plan was ever prepared.

Table 8 Spending for Flood Management in Pakistan ($ million)

Description	Funding Source	Amount
1986 Flood Protection Sector Project	ADB	124.0
	Government	24.4
	Beneficiaries	3.9
1988 Flood Protection Sector Project	World Bank	44.0
	ADB	39.0
1992 Flood Protection Sector Project	World Bank	139.0
	ADB	78.0
	Provinces	41.6
1998 Flood Protection Sector Project	ADB	100.0
2010 Flood Emergency Reconstruction	ADB	649.0
Total		**1,242.9**

ADB = Asian Development Bank.

Sources: Government of Pakistan, Federal Flood Commission. 2011. *Annual Report 2010.* Islamabad; Asian Development Bank. 1992. *Completion Report: Flood Damage Restoration Project in Pakistan.* Manila; 1998. *Completion Report: Flood Protection Sector Project in Pakistan.* Manila; 1999. *Completion Report: Flood Damage Restoration Project in Pakistan.* Manila.

9 Asian Development Bank's total financing was around $990 million: $124 million for the Flood Protection Sector Project in 1987; $39 million in 1989 for the implementation of a government flood protection plan; $78 million for flood damage repair in 1992; $100 million for the Flood Protection Sector Project II in 1998; and $649 million for emergency reconstruction in 2011, in the aftermath of the 2010 flood. The World Bank provided assistance for recovery from damage by the 1988 and 1992 floods.

10 Estimated from data provided by FFC (2010).

11 More than 1,000 irrigation and drainage channels, over 500 km of roads, 300 km of flood levees, and about 3,000 schools were restored between 1989 and 1992.

Gaps in the Existing Flood Management Approach

Policy

Pakistan's draft national water policy includes six pillars of flood management (see earlier section on national water policy), but these seem to comprise a plan rather than a policy. There is a gap between the issues as described in the issues section and recommended actions to address the issues. The draft policy focuses on a few traditional actions, and provides no guiding principles. For example, the issues section defines proper planning as that which not only minimizes flood loss but also conserves surplus water for productive use. Yet these important aspects are missing from the policy principles.

The draft policy recognizes the ineffectiveness of FPLs, and the heavy loss of life and property as a result of their frequent breaching, but recommends the same structural approach to flood management that has long been used. It proposes optimizing the operation of the two existing reservoirs, but does not provide any guidance on the priority to be assigned to irrigation, flood control, and energy generation, or on the need for new reservoirs.

The country's water-related acts (Box 1) evolved from the need for drainage, groundwater, and water supply for irrigation and other uses. They do not provide sufficient guidance on flood-related issues. These acts were drafted for specific needs at particular times. As a result, various provisions overlap and, in some cases, override each other. A more robust water law should be created through an appropriate amalgamation and modification of the provincial acts, and possibly embodied in one water law at the national level. This, however, would have some legal implications that would need to be addressed under the constitutional provisions.

Water governance,[12] as defined by the Global Water Partnership (2002) and the United Nations Development Program (2004), is either weak or works on an ad-hoc basis in Pakistan. Integrated water resources management (IWRM) is largely missing, and so is integrated flood management. The involvement of more than a dozen organizations during and after floods has so far been advantageous. But proactive and integrated flood management requires a full-time, basin-scale, and effective organization that could prepare and implement flood policy, lay down a plan for the Indus Basin, implement effective interventions, and coordinate efforts to minimize flood risks with the provincial governments and other stakeholders.

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12 Water governance refers to the political, social, economic, and administrative systems in place for developing and managing water resources and for delivering water services. (Global Water Partnership 2002).

Finally, although the national as well as provincial governments oversee flood management, disaster response is constitutionally a provincial area of responsibility, and the national government has no constitutional basis for intervening in disaster response unless requested to by a provincial government (Haider 2010). Nevertheless, the national government did receive considerable criticism for its slow response to the 2010 flood.

Planning

In the Indus Basin, planning for the medium and long term has resulted in three flood protection plans created by the FFC (Table 6). These plans largely focus on building new FPLs and strengthening the existing ones, restoring damage from previous floods, and establishing a flood forecasting and early warning system. The plans lacked IWRM and basin-scale approaches, so they could not serve as foundations for comprehensive Indus Basin flood management. These plans did not fulfill the requirements of broader planning, such as indicating ways to use natural resources in a sustainable manner, protecting the environment, and effectively reducing flood risks. They also lacked sufficient scope for strategic planning, which should have included guidance on the allocation of resources needed for the realization of the plans' objectives (Armstrong 1986).

The government's flood management planning was rarely mainstreamed into its development policy, and too little attention was paid to linkages among floodplain resources; livelihood generation; and the risks affecting floodplain populations, particularly their vulnerability due to widespread poverty. Nevertheless, the planners may have understood that absolute safety from floods is a myth, and that flood-risk mitigation could be the better approach for many locales. Even with its operational difficulties and financial constraints, the government's emergency planning has been more responsive to the needs of the floodplain populations.

Flood Mitigation Measures

Structural Measures

Flood design limits. Structures such as levees, barrages, and bridges can only provide protection and safe disposal for floods that are limited to the sizes for which these structures are designed. Therefore, it should be recognized that floods over and above the design capacity of structures would cause damage. During the 2010 flood, the peaks in the Swat River at Munda Headworks, in the Kabul River in Nowshera, and in the Indus River at Taunsa Barrage were much higher than the historical peaks, with 100-year return periods.[13] Yet the flood management approach currently in use has no provisions for floods exceeding design limits. Due to changes in the patterns of flooding and in the behavior of streams, the design limits and criteria for major river structures, as well as structures in rural and urban areas, should be reviewed.

Flood protection levees. FPLs provide the bulk of the flood protection infrastructure in the Indus Basin. So far, the height of these levees remains arbitrarily fixed at an embankment height of 1.8 meters (6 feet), which is higher than the previously observed high flood mark in the basin. However, due to morphological changes in the rivers, flood stages do not necessarily have a linear relationship with the quantity of floodwater. Thus, scientific data are needed to accurately determine the optimal levee height.

13 The existing barrages that were designed for 100-year return period performed better in flood protection.

Additionally, these levees have been constructed gradually over 5–6 decades under various programs, and thus differ in design and construction quality. At some locations, construction has caused sedimentation and aggradations of the riverbed, which may require a continuous increase in the heights of the levees (Box 2). Further, wetting channels, which were built along the FPLs to test the levees against water leaks through the embankment, are now largely nonoperational. Consequently, the structural weaknesses in the FPLs cannot be determined before a flood. Other challenges include the FPLs' remote locations, inadequate maintenance, and continuous degradation due to natural and human factors.

Box 2 Flood Protection Levees

The experiences of Viet Nam and the People's Republic of China (PRC) demonstrate that, because of riverbed sedimentation, there is a continuous need to increase the heights of flood protection levees. The Lower Yellow River, in the PRC, with levees 1,000 kilometers in length, has risen to levels that are on average about 5 meters higher than the levels of the land outside its dikes. This phenomenon is often referred to as a "hanging river." The riverbed is 13 meters higher than street level in Kaifeng and 20 meters higher in Xinxiang. The river experienced 50 major floods, 1,500 dike breaks, and 20 changes of course in roughly 2,500 years. Ian B. Fox notes that flood protection levees are a long-practiced technology, but he considers them an ineffective protection against bigger floods.

Sources: A. Borthwick. 2005. *Is the Lower Yellow River Sustainable?* Oxford, UK: Society of Oxford University Engineers; I. B. Fox. 2003. *Floods and the Poor: Reducing the Vulnerability of the Poor to the Negative Impacts of Floods*. Manila: Asian Development Bank.

Flood damage costs might have been much higher, though, without the earlier investments in the levees. Given that more than 6,000 km of levees provide the bulk of flood protection; their importance should not be underestimated. In addition, the Bund Manual, a 1978 document that describes the planning, design, construction, operations, and maintenance of flood protection levees, should be thoroughly reviewed, with a view to incorporating the latest knowledge concerning levee safety.[14]

Barrages. Some barrages and bridges have low flood capacities. For this reason, these structures create constrictions, which cause affluxes upstream that damage FPLs and river-training works. The high seasonal variability of river flows due to upstream development, most notably on transboundary rivers, causes disproportionate sedimentation upstream from the barrages, obstructing smooth flows and thus reducing discharge capacity. Most of the purposely built breaching sections, which were identified and constructed 50–100 years ago, can no longer operate because of morphological changes in the river channel and economic activities around the flood-disposal channels downstream. Given that a barrage can only be designed for floods of a certain return period, the importance of breaching sections must be emphasized, and alternative solutions must be found for these locations. The Punjab government has already initiated an upgrade and modernization of the province's barrages and appurtenant structures. It may be appropriate to reexamine the Punjab government's solutions, and to explore alternative ways to repair ineffective breaching sections.

14 Government of Sindh, Irrigation and Power Department Irrigation Secretariat. 1978. *Bund Manual*. Karachi, Pakistan.

Reservoirs. The 2010 flood demonstrated the effectiveness of the country's two main reservoirs: Mangla and Tarbela. However, sedimentation in both has significantly reduced their storage capacities. Because of structural constraints, the reservoir at Tarbela Dam must be filled cautiously.[15] A recent increase in the height of Mangla Dam has created additional storage, but this is not a substitute for a new reservoir.

Pakistan currently has a water storage capacity equal to about 30 days of mean annual discharge, and this water would be mostly used for irrigation and energy generation. Moreover, the government places limits on the reservoirs' flood management operations. New reservoirs are thus crucial, especially given the looming water and energy crises, as well as such change drivers as urbanization; population growth; the doubling of the food requirement by 2050; increasing water demand for environmental, industrial, and economic development; and variability due to climate change and flood management requirements. The increased reservoir storage capacity from building new reservoirs could store a part of floodwater for productive use and lessen flood peaks downstream.[16]

Nonstructural Measures

A mono-disciplinary approach based on engineering solutions—as in the case of the Indus Basin—cannot fully handle hydrological cycles, ecosystems, and the security of people prone to flood risks. Nonstructural measures such as vulnerability and risk assessments, floodplain zoning, and land-use planning and enforcement, are generally not featured in Pakistan's flood management practices. In addition, early flood warnings to communities at risk, and greater flood preparedness on the part of these communities, have not been fully incorporated into the country's flood management planning.[17] Appropriate nonstructural measures to reduce flood vulnerability should be introduced. These could also include the establishment of earth mounds or elevated platforms to serve as temporary refuges during floods.

While Pakistan's flood forecasting and early warning system has demonstrated its usefulness, it does not currently cover the entire basin. As a result, the system's predictive capacity is limited. There is an urgent need to extend the system's coverage to the upper Indus reach, to the Swat and Kabul rivers, and to the major hill torrents. The required organizational setup is already in place, so procurement and implementation could be immediately carried out.

Real-time flood fighting has been increasingly criticized for the (i) absence of appropriate plans to guide the overflow in the floodplain, (ii) the role of political influence in the designation of sites for breaches, and (iii) a tendency to divert flood flow from areas of high economic importance to those of low importance. A 2010 flood inquiry (Shah et al. 2011) concludes that a lack of flood preparedness, inadequate real-time flood-fighting arrangements, and negligence in observing the standard operating procedures caused the breaching of the flood levees at the Jinnah and Taunsa barrages, and the resultant serious damage in Punjab.[18] This weakness could be overcome by preparing a flood-fighting

15 The main structural constraints include sinkholes in the marginal bunds of the main embankments and in the auxiliary dam, the grout curtain at the auxiliary dam, and problems with the auxiliary spillway foundation.

16 Worldwide investments in dam construction reached $2 trillion by the end of the 20th century (World Commission on Dams. 2000. *Dams and Development: A New Framework for Decision-Making*. London and Sterling, VA: Earthscan Publications Ltd.). Asia accounted for about 65% of all dams in the world. The PRC had 45%; India, 9%; and Japan, 6% of the world's total dams.

17 The Pakistan Meteorological Department operates the country's flood early warning system, under which the dissemination of information to at-risk communities is the responsibility of the provincial governments, involving several departments.

18 In addition, several press reports indicated that the purposeful breaching of some of the flood protection levees during the 2010 flood, particularly the Tori Bund levee, was a politically motivated decision. However, these reports have not been substantiated.

plan for critical locations with several options, and by discussing the plan with the communities and other stakeholders before the monsoon season.

In the lower Indus Basin, flat topography and slow drainage have caused flooding to spread over a large area for prolonged periods, thus causing further damage. Another aspect that complicates flood management is the transboundary nature of the rivers. Historical floods in the Indus Basin have revealed such problems as (i) delayed or insufficient rain-and-flood information regarding the catchments of the upper riparian zones, which does not allow adequate reaction time; and (ii) deforestation in the upper catchments of the Indus Basin, contributing to sharp peaks and heavy sediment loads in some of the tributaries. These challenges have not been appropriately factored into flood management.

Most of the irrigation engineers—who are responsible for barrage operation, FPLs, and flood management—lack the appropriate skills for river engineering and mechanics. It is therefore difficult for them to assess structural weaknesses and make critical decisions concerning barrage operation and embankment breaching during high flows. The provincial irrigation departments (PIDs) should develop the necessary engineering skills among the relevant staff members.

Finally, the current approach considers flooding solely as a burden, so the goal of protection has dominated flood management operations. This approach needs to be reassessed, with a view to transforming the "burden" into a water asset. A comparison of Pakistan's 2010 flood with the Thailand's 2011 flood shows many similarities and lessons to be learned (Box 3).

Box 3 Similarities between Pakistan's 2010 Flood and Thailand's 2011 Flood[a]

	Pakistan's 2010 Flood	Thailand's 2011 Flood
Economic loss	$10.0 billion	$45.7 billion
Cause of flooding	Abnormal monsoon rains amounting to double the rainfall amount as compared with the 50-year average annual rainfall (natural factor)	Abnormal monsoon rains amounting to five rainstorms as compared to an annual average of three (natural factor)
Operational priority of reservoirs	Irrigation was the operational priority of the Tarbela and Mangla reservoirs, with flood protection a lower priority (policy issue)	Irrigation or flood protection was the operational priority of the multipurpose reservoirs (policy issue)
Level of preparedness	Poor anticipation of the flood disaster scale (operational level issue)	Poor anticipation of the flood disaster scale (operational level issue)
Drainage time	Estimated at 7–10 days (Taunsa Barrage) for midstream segment and 14–20 days for downstream segment (Sukkur Barrage) It was known in advance by a couple of days that around 4–10 km^3 of water would pass through the Taunsa, Guddu and Sukkur barrages and of course the water would not queue up for several days and wait.	Drainage capacity of the East and West Corridor is 500 million cubic meters a day against an expected inflow of 10 km. It required at least 20 days for drainage (Simple mathematics) It is unrealistic to assume that 10 billion cubic meters of water could be released at a rate of 500 million m^3 a day while the rest of the water would queue up.
Effect on the dikes	Dikes could not bear sustained flood pressure for several days, resulting in terrible damage (technical and operational issue)	Pressure started to build behind the dikes, resulting in terrible damage after overtopping (technical and operational issue)

continued on next page

table continued

Box 3 Similarities between Pakistan's 2010 Flood and Thailand's 2011 Flood[a]		
	Pakistan's 2010 Flood	**Thailand's 2011 Flood**
Other factors	Planning, policy and management played a role (see Shah, Shakir and Masood, 2011)	Planning, policy and management have all played a role in this disaster. However, land use and deforestation also played a fundamental role.
Public response	Policy, institutional role and coordination were largely criticized.	The whole system, including policy, institutions and coordination, need to be reconsidered.
Integrated Water Resource Management (IWRM)	Not yet initiated	Government agencies reluctant to adopt IWRM
Knowledge of flood management techniques	Pakistan has reasonable knowledge of modeling and experience in flood management	Thailand has adequate knowledge of modeling, experience and common sense but has to use them wisely
Flood planning	No flood planning existed except for protection of main reservoirs and barrages. There needs to be a mindset based on scientific knowledge and acceptance of risks.	The mindset that everything can be protected needs to change. Each sector's priorities need to be identified, and some sectors have to sacrifice.
Water expressway	The Indus Basin has a water highway in the form of the Indus River. This highway must be upgraded to a water expressway.	A water expressway must be built to allow water to flow out.
Other recommendations	A comprehensive policy and planning and implementation of IWRM at the basin scale is needed	The mindset of politicians, engineers and developers regarding appropriate water management in the context of upstream and downstream linkages need to change.

[a] Source for information on Thailand's 2011 flood: A. Anukularmphai. Interview by M. Wojciechowska-Shibuya. Maxims News Network. www.maximsnews.com/news20120714FloodsThailandCRBOM11207140801.htm (accessed 1 April 2013).
Reference: A. Anukularmphai and M. Wojciechowska-Shibuya. 2012. The 2011 Floods in Thailand and the Role of IWRM. *CRBOM Small Publications Series No. 46.* Central Java, Indonesia: Center for River Basin Organizations and Management (CRBOM). July.

Investment in Flood Management

A large part of the total investment of $1.2 billion in flood management between 1950 and 2010 was spent on repairing flood damage, developing a flood-forecasting system, and building new levees at various locations. This reactive approach to flood management has led to high recovery costs, and to ad hoc measures that are not sustainable. The emergency nature of recovery operations sometimes may be associated with inappropriate use of funds. The government must therefore choose a proactive approach to flood management over the traditional method of paying the high cost for flood disasters.

Emerging Trends and Flood Management Options

Traditional Flood Management Approach

In the Indus Basin, the traditional flood management approach is centered on flood protection levees (FPLs), which have inherent limitations in their design and maintenance. They cannot ensure the protection of the basin against exceptionally high floods. Barrages have been provided with purposely built fuse plugs (i.e., breaching sections) to bring the water level down to their design limits for safety. Due to the development along the downstream floodways, however, the operation of the breaching sections causes severe flood damage, and is no longer feasible in many places.

The traditional approach also fails to address the sharp flood peaks in the upper reach catchments, as well as the ineffective drainage of floodwater in the lower floodplains. Due to the steep topography of the Swat and Kabul catchments and deforestation, runoff generates and dissipates quickly, producing high flood peaks during the monsoon. Further, there are no reservoirs on these rivers or on the Indus downstream of the Kabul-Indus confluence. Therefore, flood peaks from these two tributaries are not attenuated, and they directly add to flood peaks of the Indus River. Inefficient drainage in the lower floodplains causes widespread destruction due to prolonged inundation periods, as happened in 2010, 2011, and 2012.

The large area and scale of flooding also add to operational difficulties, including the inefficiency of information dissemination and rescue and relief operations. In the absence of effective flood management institutions, sociopolitical pressures may also limit competent decision making during a flood.

The traditional flood management approach lacks preemptive solutions, operating only when danger becomes real and imminent. It is ad hoc in nature, and does not comprehensively consider the basin's hydro-climatic realities, physical settings, and development needs. Moreover, it lacks effective policies, planning, and institutional backing.

Climate Change Is Impacting the Himalayan Region and the Indus Basin

The Intergovernmental Panel on Climate Change (IPCC) predicts that the average global surface temperatures will increase by 1.4°C–5.8°C between 1990 and 2100 (Solomon et al. 2007). Vellinga and Van Verseveld (2000) show that climate change anywhere in the world will be accompanied by changes in the nature and frequency of extreme weather events. Min et al. (2011) refer to a number of recent studies that link a substantial increase in atmospheric water-holding capacity to atmospheric water content. Thus, climate change is predicted to aggravate floods and droughts, and to affect the water availability in arid Pakistan.

The increase in rainfall intensity and changes in rainfall patterns (Turner and Slingo 2009a), as well as a greater frequency of extreme events (Christensen et al. 2007), may further increase the frequency and/or intensity of floods in the Himalayan–Hindu Kush region, of which the Indus Basin is a part. The predicted changes in the patterns and frequency of extreme events are likely to affect Pakistan's water resources (Turner and Slingo 2009b). Landslide and debris flow have already caused eight floods in the Indus Basin (Pakistan Agricultural Research Council 2005), and more downstream flooding is predicted due to the increasingly variable rainfall and runoff (Eriksson et al. 2009). The Himalayan and downstream river basins are likely to face more riverine and flash floods.

Solomon et al. (2007) predicts an increase in summer precipitation, which will be distributed unevenly across the Indian subcontinent, with an increased frequency of intense precipitation in some parts. That study also maintains, as do Mani et al. (2009), that quantitative estimates of predicted precipitation changes are uncertain, and that "it is likely that some local climate changes will vary significantly from regional trends due to the region's very complex topography and marine influences" (Solomon et al. 2007). The study indicates that the melting of glaciers will initially increase the flow by 14% to 90% of mean flows over the first few decades of this century, to be followed by mean flows decreasing by 30% to 90% of the baseline by the end of the century (Rees and Collins 2004).

Need to Adopt a Contemporary Flood Management Approach

The world is in transition, undergoing demographic changes, rapid urbanization, accelerated economic development, changes in lifestyle, quests for renewable energy, and climate change. For instance, Pakistan's population is projected to double by 2050. Correspondingly, the economy is expected to expand, and climate change is likely to increase the frequency of extreme events. High rainfall variability and flooding will make the population and infrastructure more vulnerable. Overall, these changes will aggravate the looming water, food, and energy crises, as well as water-related disasters. Table 9 shows the main change drivers and their flood risks.

Table 9 The Main Change Drivers and Associated Flood Risks

Change Drivers	Main Elements of Change Drivers	Likely Effects	Flood Risk Low	Flood Risk Moderate	Flood Risk High
Social change	Population growth	• Increased number of people exposed to flood risks			√
		• Competition for resources and related natural-resource degradation		√	
	Urbanization	• Increased flood peaks		√	
		• Increased drainage problems			√
		• Increased damage potential		√	
	Changes in lifestyle	• High vulnerability and low resilience		√	
		• Increased damage potential	√		
Physical processes	Land use changes	• Catchments: deforestation, increase in built-up areas			√
		• River channels: encroachments, over-exploitation			√
		• Floodplain: encroachments, over-exploitation, risk-prone development			√
	Fluvial processes	• Channel conveyance		√	
		• River morphology and sediment accumulation		√	
		• Increased uncertainties in flood wave predictions			√
		• Increased erosion of adjacent lands			√
		• High damage potential to the flood-protection infrastructure			√
Economic development	Infrastructure	• High vulnerability and damage risks		√	
		• Constriction and increasing flooding depth and duration	√		
		• Increased periods of interruption of energy and communications		√	
	Urban vulnerability	• High damage potential to commercial and noncommercial assets, such as buildings		√	
	Intensive agriculture	• Increased crop damage			√
		• Increased agricultural infrastructure damage		√	
Climate change	Temperature, rainfall, and runoff	• High rainfall variability		√	
		• Increased flood frequency			√
		• Increased uncertainty, difficulty of prediction		√	

Source: Author.

Contemporary Flood Management Approach Outline

The failure of the traditional flood management approach and the overwhelming effects of the change drivers (including likely climate change impacts) necessitate the adoption of a contemporary flood management approach (CFMA). However, in order to work, the CFMA must be incorporated into government policy and strategy, and embedded in appropriate legislation and institutional arrangements.

Framework and Scale

Recent floods—for example, in the PRC (Yangtze River in 1998), continental Europe (Danube River in 2006), the United Kingdom (2007 and 2009), Pakistan (2010 and 2011), Australia (2011), and Thailand (2011 and 2012)—have increased general awareness of the limitations of traditional flood management approaches. Flood management should not rely only on engineered flood-defense structures, but should also consider technological, policy, planning, and operational measures. It should include responses to flood loading,[19] techniques for handling expected changes, and risk-based flood management decision making. A CFMA could be centered on (i) avoiding and/or minimizing the destructive effects of floods, (ii) enhancing the beneficial effects of floodwater, and (iii) making people and livelihoods central to the decision-making process. Finally, a CFMA could follow a three-step strategy of retaining, storing, and draining the floodwater.

Indus Basin floods contain large volumes of freshwater that, if properly managed, could be used beneficially. Pakistan is a water-scarce country in the midst of an energy crisis, and is potentially facing a food crisis as well. It should therefore not allow such a precious resource to be wasted. For this reason, the CFMA recommended here would require that flood management be integrated into the management of water resources in general, following a framework based on integrated water resources management (IWRM) at the basin scale, and linking it with economic development and social and environmental welfare. The CFMA would aim to transform the flood burden into a water asset through basin-scale planning and effective implementation. Figure 9 shows the main elements of the CFMA.

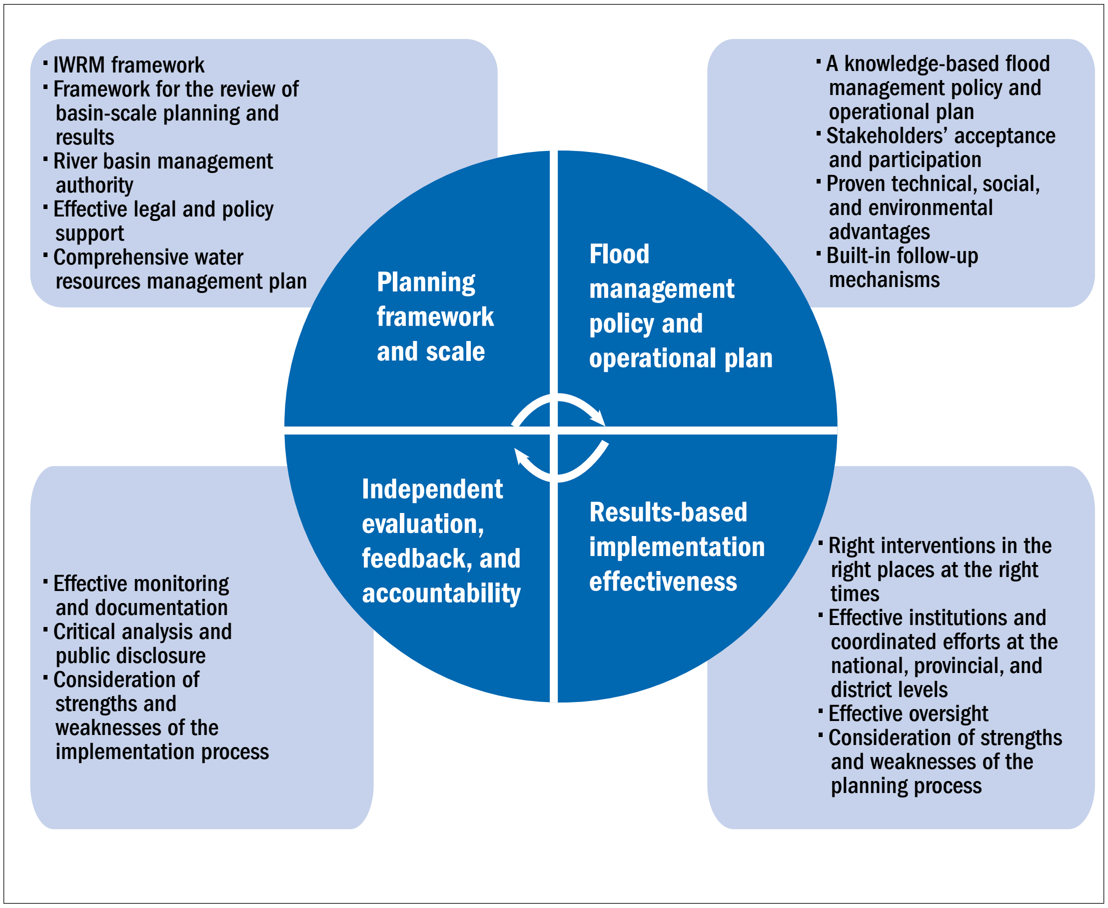
Policy and Planning

Pakistan urgently needs a robust water and flood management policy supported by appropriate laws and effective institutions. Given that flood management will be a subset of IWRM, an IWRM framework should provide guidance on technological, institutional, and policy issues regarding the changing Indus Basin environment. The flood management policy should address the specific issues and challenges of flood-related risks, with its vision centered on preventing the loss of lives and livelihoods, preserving natural resources, and furthering economic development. The policy objectives should be clearly defined so as to avoid mixing the policy and planning aspects. Policy may be based on the principles of (i) managing the water cycle as a whole; (ii) integrating water and land-use management; (iii) managing risks and uncertainties; (iv) protecting catchments, water courses, and floodplains from encroachment and degradation; (v) allowing the equitable and reasonable exploitation of catchments and floodplains; (vi) making beneficial use of floodwater; (vii) protecting the ecosystem; and (viii) ensuring institutional integrity and financial sustainability.

Following the principles laid out in the government's policy statement, a comprehensive Indus Basin flood management plan should shift the focus from controlling floods in the conventional manner to achieving sustainable basin development that maximizes the net benefits from floodplains through more appropriate flood management. This would require integrating land and water resources within the context of IWRM, as well as maximizing net benefits from (and minimizing losses in) the floodplains. The CFMA should therefore include the development of a basin-scale flood management plan incorporating well-designed flood-protection safeguards into all development activities within the floodplain.

19 Flood loading is the pressure applied by a flood on structures. It can be a static load due to floodwater height, a dynamic load due to flood wave momentum, an impact load due to debris flow, or a combination of these.

Figure 9 Framework for a Contemporary Flood Management Approach



IWRM = integrated water resources management.

Source: Author.

The plan should consider the management of all kinds of floods (from low to exceptionally high), foresee how flooding beyond design capacity could be managed, and identify areas to be sacrificed for the sake of channeling the floodwater. It should also consider the following specific factors:

(i) Land use in the floodplain should depend on the trade-off between flood risks (e.g., danger to lives, health, and safety; damage to property; and degradation of water quality and the environment) and development benefits. However, land development should follow a certain set of criteria that minimize flood risks.

(ii) The high flows in the rivers occur during the monsoon season, about 3 months a year, while the low flows, largely due to melting snow, prevail during the other 9 months. Maximum effort must be made to store excess water from the high flows in order to improve water availability during the drier periods.

(iii) For food, the country depends on its 14 million hectares (ha) of irrigated land, which are located in the floodplain immediately outside the FPLs, and which are prone to flooding.

(iv) The lower Indus plain is prone to more frequent flood damage than other areas because of its ineffective drainage.
(v) Irrigation and hydropower will continue to be priority water-sector issues in the near future due to their importance to the country's economy.
(vi) Water scarcity will continue to create political tension among the provinces, regardless of the Water Apportionment Accord.[20]

Preparing the plan may require (i) reassessing the basin hydrology in the context of upstream transboundary development and change drivers; (ii) adapting existing management plans to potential changes; (iii) addressing rapid urbanization; (iv) recognizing the need for the revitalization of agriculture; (v) gauging water, food, and energy needs in the context of demographic and development pressures; and (vi) considering environmental requirements. The following questions may be relevant in developing the plan.

- What are the flood-related issues in relation to national development plans and objectives?
- What measures were effective or ineffective in the past, and why?
- How can local actions best fit into the plan?
- What role does the Indus floodplain play in the economy, and how can it be sustained?
- How will improved flood management contribute to national development?
- How can flood risks be appropriately factored into national development planning?
- Why have the existing policies achieved, or not achieved, their desired objectives?
- How should the national development vision and/or policy be aligned with existing and future flood risks?
- How can flood-risk mitigation costs be shared among local and national governments and individuals?
- When can specific flood management goals be achieved?

Choice of Interventions

The CFMA must explore appropriate, knowledge-based technological options in the light of past experience and emerging trends. A range of technical options should be put forward for discussion among the stakeholders. A consensus may be developed in support of the principles of maximizing protection and minimizing harm.

Structural interventions. By storing floodwater during high flows and releasing it during periods of lower flows, the major reservoirs could lessen the flood peaks, reduce flood risks, and conserve freshwater for productive use. In the Indus Basin, the existing water-storage reservoirs are inadequate for meeting water, energy, and flood management requirements. The Kabul River flood peaks cannot be reduced, as storage is not available. Sedimentation in the Tarbela Reservoir is a sign that the reservoir must be replaced. Appropriate storage is also required to effectively attenuate the flood peaks in the Indus and Jhelum rivers. The development of new water reservoirs will therefore be critical for effective flood management, and for an increase in per capita water storage capacity. As reservoirs require heavy investment, however, and as only a few locations are available, the preference is to build multipurpose reservoirs for water, hydropower, and flood management.

20 The Pakistan Water Apportionment Accord for Resolving Inter-Provincial Water Conflicts was signed in 1991 by the chief ministers of four provinces: Punjab, Sindh, Balochistan, and the North-West Frontier Province (now called Khyber Pakhtunkhwa).

In areas where the construction of reservoirs is not possible, artificial wetlands and detention basins could help reduce the flood risk in downstream areas. Wetlands and detention basins could also improve water quality, create an environment-friendly aquatic ecosystem, and help recharge groundwater.

In addition, the improvement of river channels to increase their conveyance capacity at critical locations may help reduce flood risks. Interventions such as removing constrictions, reducing channel roughness, and increasing slopes by removing sharp bends may individually or collectively contribute to an increase in channel-conveyance capacity. However, modifications may result in increased flow velocity and discharge intensity downstream, so they should be done cautiously.

Diverting a part of the floodwater or creating additional floodways could help reduce flood risks downstream. Diversion could also provide the added benefit of aquifer recharge. In the Indus Basin, this possibility could be explored at many locations. For instance, one option might be to divert floodwater to the Cholistan and Thar deserts, thereby creating intermediate temporary water storage and inter-river transfer of part of the floodwater.

The FPLs and floodwalls cut out a part of the floodplain, reducing the temporary flood storage capacity and increasing the flow velocity downstream. In addition, because levees are soil structures, they have a high risk of failure. Thus, well-designed FPLs, with stone protections and aprons, should be used to protect critical areas such as urban centers, industrial zones, and important sites.

Nonstructural interventions. In the Indus Basin, nonstructural measures, such as the enforcement of a land-use policy, introduction of a flood insurance policy, capacity building for vulnerable communities in the floodplain, and dissemination of information related to flood risks, have not been fully applied. Two other measures that have not been applied are flood-proofing (e.g., building elevated platforms, protecting property in existing structures, or using flood shields and rubber gaskets for temporary or permanent closure) and floodplain control (involving public parks, golf courses, and other facilities that would not be harmed by floods).

Catchments determine how rainfall is transformed into flood flows. Therefore, sustainable catchment management is also important for effective flood management. There will be a need for catchment management approaches that integrate water and land resources, ecosystems, and livelihoods, and that provide a key role for communities in natural resource management. Accordingly, Gregersen et al. (2007) raise two fundamental questions: (i) what mechanisms exist to ensure that the people within a catchment area have common and positive goals regarding land and water use, and that their actions do not adversely affect land and water resources for future generations; and (ii) how can one enable the stakeholders to act in a cooperative and coordinated fashion to achieve their goals? They propose approaches that would be broad-based, incremental, and a combination of top-down and bottom-up, along with appropriate technology and adequate assistance that would emphasize short-term gains. The Food and Agriculture Organization of the United Nations (1977) suggests that water could be the integrator in integrated catchment management.

Alluvial fans, gully heads and slopes, and badland systems are critical areas that challenge catchment management in the Indus Basin (Figure 10). Alluvial fans function as major sedimentation zones within mountainous river systems by storing sediment, changing flow regimes, and reducing the kinetic energy of flows (Harvey 1978). They also offer opportunities to divert stream flows for various uses. In the Indus Basin, many irrigation and water-supply channels draw from the alluvial fan areas, so the management of these areas is an important part of overall catchment management. Gully erosion protection, including the management of head-cuts and headlands, is also crucial.

Figure 10 Views of a Degraded Catchment in the Indus Basin in Pakistan

Source: Author.

Soil erosion and sediment redistribution affect river flow regimes, stream hydraulics, and the performance of water storage areas. By reducing water absorption capacity, they can significantly affect flood generation and propagation. Owens and Collins (2006) suggest a two-tier management approach: at the local and basin levels. In the localities, land-use changes may drive erosion, but site-specific actions such as the management of agricultural land, forests, grazing lands, and gullies may offer solutions. Communities could also play a key role in local actions. However, any measures must also work within a river basin framework, and this is the responsibility of the basin authority and/or province.

About a dozen main hill torrents contribute to the Indus flow. These hill torrents produce flash floods, cause damage, and raise river flood peaks. Flash flood management strategies may include engineering measures (e.g., building reservoirs, FPLs, flood detention areas, diversions, and the clearing of floodwater ways) and nonengineering measures (e.g., establishing a unified command and disaster management system, monitoring, and enforcing flood insurance). Shrestha et al. (2008) say that community-based approaches, including empowerment, have improved governance, and they suggest that harnessing women's potential to combat disasters would better address flash flood risk management challenges in the Himalayan-Hindu Kush region.

The CFMA should also include a robust flood forecasting and early warning system, floodplain mapping and zoning along the main rivers, and the implementation of land-use regulations in the floodplains. The advent of satellite remote-sensing methods and hydrological modeling could provide inexpensive, timely spatial data and flow-related information on complex responses. There are dozens of hydrological models that can be used for predictions regarding different catchment settings, including hill torrents. Hydrological rainfall–runoff models (using aerial rainfall estimates, runoff generation, and time of concentration at the outlet) and runoff-formation forecasting models (based on initial and later loss models), infiltration curves, and instantaneous unit hydrograph models can also be used in flash flood forecasting and early-warning systems. There is a need for real-time data exchange on transboundary rivers, particularly during floods. Reasonably accurate information, effective organization, efficient communications, and rapid mobilization are critical for a good warning system.

Design Options and Criteria

When it comes to protecting urban and rural areas, as well as activities related to economic development, flood-frequency and design criteria should be in place, especially given the expected flood damage and the investment required to protect against it. Hydro-economic analysis could be used to determine protection needs based on flood frequencies. As a rule of thumb, protection measures designed for 100-year/24-hour storms are generally considered adequate for preserving major infrastructures such as populated areas, barrages, and bridges; and measures designed for 10–25-year/24-hour storms could be considered for the protection of less critical areas such as agricultural land.

Identifying the rainfall events, interventions, and specific characteristics of areas that cause or contribute to low-runoff volumes—but that also have high recharging potential—may help reduce runoff volume downstream. However, this option should take into account the groundwater table and recharging requirements. The intent of the recharge and/or volume-reduction criteria is to maintain groundwater recharge rates that will preserve the existing water table and support natural flows in streams and wetlands. Under natural conditions, the amount of recharge that occurs at a site is a function of the slope, soil type, vegetative cover, precipitation, and evapotranspiration. Sites with natural ground cover, such as forests and meadows, typically exhibit higher recharge rates, lower runoff volumes, and greater transpiration losses than sites dominated by impervious cover.

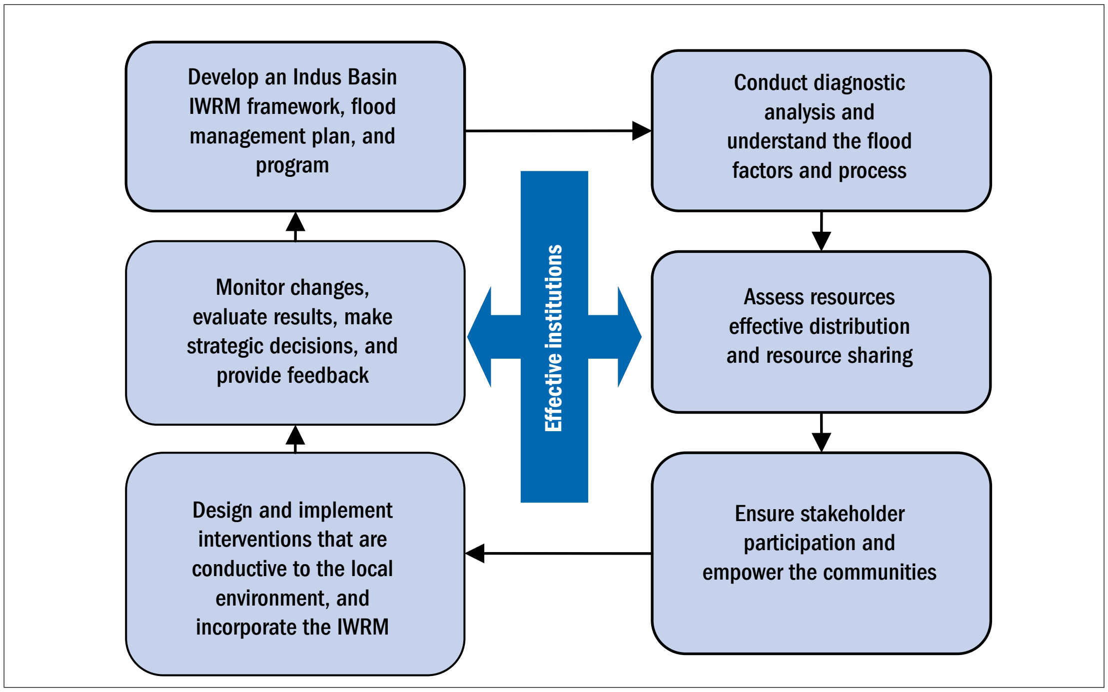
Floods can carry high pollutant loads and cause the degradation of water quality in affected wetlands. Introducing water quality protection criteria into the design of technical interventions may help conserve freshwater resources.

Flood Governance, Institutions, and Legislation

In the Indus Basin, many challenges exist at the operational level that can only be overcome through better governance, effective institutions, and conducive legislation. Good governance should effectively implement socially acceptable regulations, ensure that there are no conflicts of interest, and assign responsibility. Legislation on flood management should thus define institutional roles and responsibilities, determine and protect rights and obligations, and provide a mechanism for dispute management. It may be guided by well-acknowledged principles such as the equitable and reasonable use of watercourses, avoidance of significant harm, and the protection of the ecosystem. The institutions responsible for flood management should also provide dispute-settlement mechanisms.

The CFMA should consider integrating the roles of several organizations, as well as creating viable, effective institutions to handle coordination and implementation. Figure 11 indicates the responsibilities of the relevant institutions. An organization such as the Indus Basin Commission, for example, may be required for planning, coordination, and monitoring at the basin scale. Other organizations, such as the Pakistan Meteorological Department (PMD), Water and Power Development Authority (WAPDA), and the Federal Flood Commission (FFC), may redefine their roles in flood management. The provincial irrigation departments (PIDs) may be restructured as provincial water resource management departments, with flood management among their responsibilities. This may also require strengthening the capacity of the flood forecasting and early warning system and the PIDs for effective monitoring, maintenance, and barrage operations. Beneficiaries' participation should also be a part of effective flood management. Moreover, identifying the right stakeholders, engaging them in the flood management process, and creating a sense of ownership are all important for the success of a contemporary approach.

Figure 11 A Standard Institutional Role in Effective Flood Management



IWRM = integrated water resources management.

Source: Author.

Research, Training, and Information Dissemination

Research, training, and information dissemination should be an essential part of the CFMA. Action, research, and learning-by-doing could all be applied to many aspects of flood management, including sustainable catchment management. One goal of research should be to determine the best flood management practices. Also important for reducing flood-related damage would be the training of officers involved in flood management, and flood-prone communities, in addition to the dissemination of information on flood risks and management.

Action Plan

An action plan suggests short-, medium- and long-term measures. The priority actions may include the following:

Short term (1–5 years)

(i) Develop a framework and flood management policy for integrated water resources management (IWRM) in the Indus Basin centered on a water–food–energy nexus.
(ii) Develop a land-use plan and legislative requirements, and incorporate them into a land-related legal framework.
(iii) Carry out a vulnerability and flood-risk hazard study focusing on critical areas.
(iv) Develop a flood-related fiscal policy and incorporating it into the overall fiscal policy.
(v) Develop an effective institutional and legal framework and a national basin-scale organization for flood management.
(vi) Develop an Indus Basin master plan within the IWRM framework involving basin-level organizations, and prepare flood management plans in consultation with stakeholders.
(vii) Improve databases and information-sharing mechanisms.
(viii) Expand the coverage of the flood forecasting and early warning system to major streams and hill torrents (Box 4).
(ix) Invest in modeling and floodplain mapping and zoning, and implement land-use regulations.
(x) Identify stakeholders and prioritize appropriate interventions, and promote community participation in flood risk management.
(xi) Review design criteria and inspection protocols for all major structures and flood-protection works along the rivers.
(xii) Assess the requirements of a flood insurance policy.
(xiii) Strengthen and upgrade the existing flood protection works.

Medium term (5–10 years)

(i) Develop small and medium-sized reservoirs.
(ii) Develop retention basins and wetlands, as well as flood-diversion and flood-bypassing arrangements.
(iii) Repair the critical hot spots of catchments, as part of an overall effort to support communities' livelihoods and environmental protection.
(iv) Develop disaster management plans, including dam-break and dam-burst scenarios.
(v) Pilot flood proofing.

Long term (10 years and beyond)

(i) Incorporate infrastructure planning for catchments and floodplains into the overall flood management framework.
(ii) Implement the integrated Indus Basin master plan.
(iii) Develop strategic storage reservoirs.
(iv) Implement floodplain and catchment ecosystem plans.
(v) Conserve soil and reduce sediment inflows into the system.
(vi) Implement a flood-adaptation plan based on climate change projections.
(vii) Implement effective capacity building for the communities and related institutions.

Box 4 The Mekong River Commission Flash Flood Guidance System

The Mekong River Commission Flash Flood Guidance System, developed by the Hydrologic Research Center, located in the United States, provides flash flood information on a small-basin scale across the four riparian countries. The system has the capacity to observe intense rainfall through the use of satellite- and gauge-based rainfall estimates, and to address the risk of injuries and deaths from the devastation caused by flash floods.

The system is responsible for real-time data acquisition, data ingestion, model processing, product export, and the uploading of products to the dissemination server. It can integrate real-time data from various hydrometeorological sources and evaluate a number of diagnostic indexes related to the occurrence and development of natural flash floods. Satellite precipitation estimates are used, along with available precipitation gauge data. It can also use the Global Telecommunication System for precipitation data, which are applied by the soil moisture model to update soil moisture estimates.

A user-friendly dissemination interface provides quantitative real-time diagnostic information on rainfall and hydrologic responses—the two important factors in determining the potential for a flash flood—and disseminates the information with remote real-time access for online reviewers, who can download the information onto their computers. This information may be used by the forecaster in conjunction with other local forecast data to produce reliable flash flood forecasts and warnings.

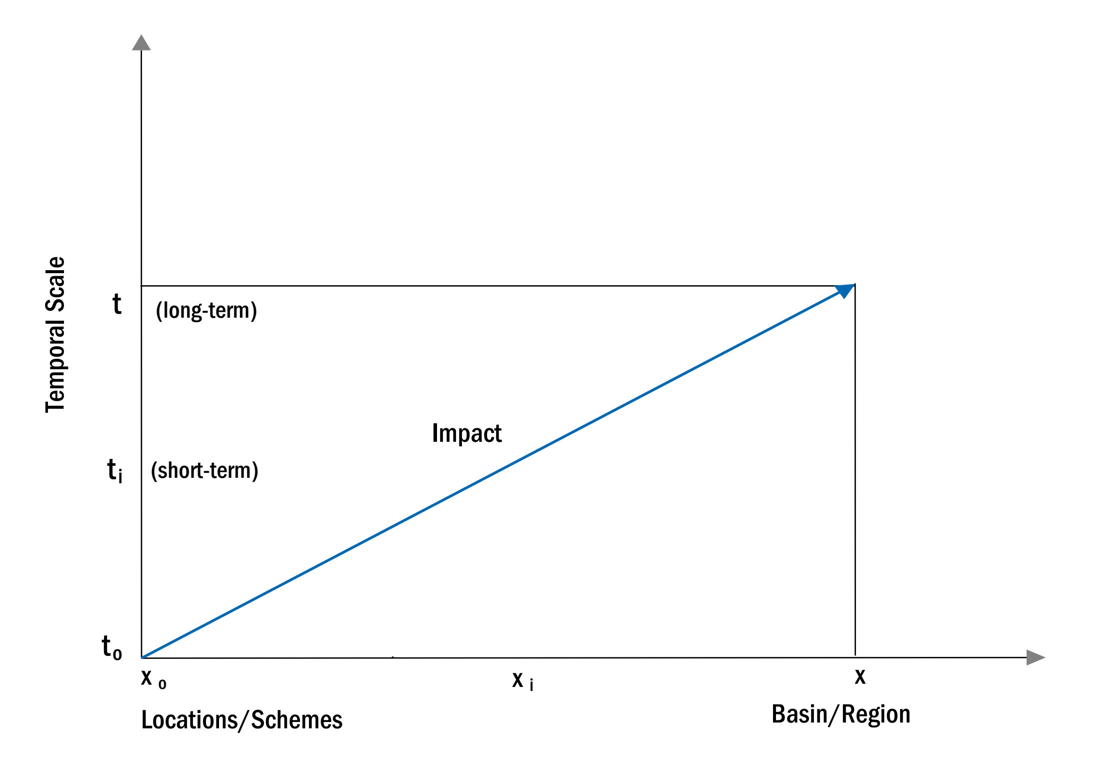
The system's outputs are made available to users as diagnostic information for analyzing weather-related events that can initiate flash floods, and then for rapidly evaluating the potential for a flash flood at a specific location. The system allows the use of the forecaster's experience with local conditions, along with other data and information (e.g., numerical weather prediction output) and any last-minute local observations (e.g., nontraditional gauge data), to assess the threat of a local flash flood. Evaluations of the threat of flash flooding are done at intervals of one to six hours for basins with a mean area of approximately 150–200 square kilometers.

Important technical elements of the system are the development and use of a bias-corrected satellite precipitation estimate field, in situ synoptic observation gauge data, and hydrologic modeling. The system's results have been better than those of streamflow synthesis and the reservoir regulation-based system in terms of greater accuracy, longer lead time, and lower dependency on missing data.

Source: Mekong River Commission. Some Products of the MRC Flash Flood Guidance System. http://ffw.mrcmekong.org/mrcffgs.htm (accessed 8 August 2012).

The effectiveness of comprehensive flood management measures will depend on their continuity in the spatial and temporal dimensions. Experience at short-term pilot sites has demonstrated that measures characterized by small coverage and short duration can only serve as entry points. The upscaling and outscaling of successful interventions must be continued so that larger areas are covered by flood protection measures. A conceptual x-t plan for flood mitigation measures explains the impact pathway (Figure 12). Results may take many years to become apparent, but any discontinuity of action at intermediate stages would be detrimental to the entire process. The continuity of action will hinge on whether (i) the necessary resources are available, (ii) the steps are clear, and (iii) the benefits are visible.

Figure 12 A Typical x-t Plane for a Flood-Protection Impact Pathway



Source: Author.

Lessons Learned and the Way Forward

Monsoonal rains, steep topography, and degraded catchments contribute to high flood peaks in the Indus Basin. A large drainage area and inadequate surface-storage capacity result in high stream flows. Coinciding peaks from the tributaries further add to the flood peaks in the river downstream.

Encroachments and poorly planned developments along the streams and in the floodplains cause serious flood damage. Flow constrictions caused by bridges and barrages, combined with poorly maintained flood protection levees (FPLs), have been the main reasons for heavy damage and many deaths.

The Indus Basin lacks an appropriate flood policy, comprehensive laws, and adequate flood-control infrastructure. To date, no approved national water and flood policy exists, and too many institutions are involved when disasters occur. Considering the large basin area and scale of flooding, rescue and relief operations have been inadequate. During the 2010 flood, there were also problems in operational decision-making at the field level.

Indus Basin flood management emerged from risk acceptance (1947–1973) and risk management (1973 to the present) approaches. A coherent system for integrated water resources management (IWRM) planning is lacking, and the required levels of investment are not available. Consequently, the implementation of interventions is not effective. Change drivers are a reality, yet their probable impacts have not been incorporated into the flood planning and management processes. The traditional flood management approach does not work, comprehensive flood management has yet to evolve, and so a contemporary flood management approach (CFMA) is needed.

There is an immediate need to (i) assess technological, institutional, and policy options; (ii) develop a flood policy, IWRM framework, and Indus Basin flood plan following integrated river-basin approaches; (iii) rationalize organizational roles and institutional reform; (iv) develop and enforce a land-use policy; (v) set short-, medium-, and long-term goals, with identified means to achieve those goals; (vi) identify and involve all the stakeholders in the process; and (vii) increase revenue for the maintenance and management of flood protection infrastructure. In addition, the Indus Basin flood forecasting and early warning system does not cover the entire basin, so its prediction capacity is limited. It needs to be strengthened and expanded.

Pakistan did not include large dams in its priority agenda in the past. However, recent water and energy crises have demonstrated the need for large reservoirs, and the government is considering large reservoirs as one solution. It is highly desirable that any effort to build large reservoirs be linked to flood management.

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APPENDIX 1

Worldwide Flood Events and Related Damage, 1900–2012

Region	Number of Events	Deaths	Average Deaths per Event	Total Affected Persons	Affected Persons per Event	Damage ($ million)	Damage per Event ($ million)
Asia	1,625	6,790,101	5,567	3,401,945,078	3,805,054	330,690	204
Americas	955	105,624	159	86,906,580	234,326	94,506	99
Africa	806	24,475	53	62,319,466	156,054	6,848	8
Europe	520	9,830	28	15,655,549	45,311	104,184	200
Oceania	129	493	8	1,133,796	24,475	14,093	109
Total	**4,035**	**6,930,523**	**1,718**	**3,567,960,469**	**884,253**	**550,321**	**136**

Source: Centre for Research on the Epidemiology of Disasters (CRED). EM-DAT: The International Disaster Database.

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APPENDIX 2
Salient Features of the Indus Basin in Pakistan

Description	Quantity
Punjab Province	
Headworks and barrages	14
Inter-river link canals	8, with 850 km in total length and a total carrying capacity equal to 3,115 m^3s^{-1}
Main canal commands	19, with a total length of 6,429 km
Distributary and minor canals	2,794, with a total length of 31,214 km
Field outlets and total capacity	58,000 units, with a total intake capacity of 3,399 m^3s^{-1}
Gross command area	9.45 million ha
Cultivable command area	8.41 million ha
Public sector tube wells	3,544
Surface drains (total length)	9,856 km
Flood embankments (total length)	3,228 km
Small dams	50
Sindh Province	
Headworks and barrages	3
Years of construction of barrages on Indus in Sindh Province	Guddu Barrage (1963), Sukkur Barrage (1932), Kotri Barrage (1956)
Flood protection embankments (total length)	2,120 km
Main canals	15, with a total length of 8,298 km
Distributary and minor canals (total length)	12,748 km
Command area	2.5 million ha
Tube wells	Total = 5,835 (freshwater = 3,697, saline water = 1,777, scavenger = 361)
Lakes	7
Main drainage systems managed by Sindh Irrigation and the power departmenta (total length)	2,240 km

ha = hectare; km = kilometer; m^3s^{-1} = cubic meter per second.

[a] The Water and Power Development Authority (WAPDA) also manages some of the drains in Sindh Province.

Source: Pakistan Water Gateway. Key Water Information. waterinfo.net.pk/cms/?q=kwi (accessed 29 November 2011).

APPENDIX 3

Flood Limits of the Indus Basin Rivers

The flood limits of the rivers in the Indus Basin at different locations were arbitrarily fixed for the purpose of flood control, taking into account the design capacity of the major cross-river structures and the history of flooding at each location. The limits were defined as follows:

(i) **Low flood**. This corresponds to the bank-full stage of the river at any particular location.
(ii) **Medium flood**. This represents a flood stage and discharge between low flood and high flood.
(iii) **High flood**. This corresponds to a flood stage 1.2 meters (4 feet) higher than the bank-full stage, or a discharge double that at the low flood stage.
(iv) **Exceptionally high flood**. A flood is considered exceptionally high if its level approaches 1.5–3.0 times that at the high flood stage.

Table A3.1 Flood Limits at Critical Structure Sites in the Indus Basin (m^3s^{-1})

River	Location	Design Capacity	Flood Limits				
			Low	Medium	High	Very High	Exceptionally High
Indus	Attock Bridge		7,079	10,619	14,159	18,406	22,654
	Jinnah Barrage	26,902	7,079	10,619	14,159	18,406	22,654
	Chashma Barrage	26,902	7,079	10,619	14,159	18,406	22,654
	Taunsa Barrage	31,149	7,079	10,619	14,159	18,406	22,654
	Guddu Barrage	33,981	5,663	9,911	14,159	19,822	25,486
	Sukkur Barrage	25,486	5,663	12,743	15,575	19,822	25,486
	Kotri Barrage	24,778	7,079	11,327	15,575	18,406	22,654
Jhelum	Kohala Bridge	na	2,832	4,248	5,663	8,495	11,327
	Mangla Dam	25,486	2,124	3,115	4,248	6,371	8,495
	Rasul Barrage	24,070	2,124	3,115	4,248	6,371	8,495
Chenab	Marala Barrage	31,149	2,832	4,248	5,663	11,327	16,990
	Khanki Headworks	24,070	2,832	4,248	5,663	11,327	16,990
	Qadirabad Barrage	25,486	2,832	4,248	5,663	11,327	16,990
	Trimmu Barrage	18,406	4,248	5,663	8,495	12,743	16,990
	Panjnad Barrage	19,822	4,248	5,663	8,495	12,743	16,990
Ravi	Jassar Bridge	7,787	1,416	2,124	2,832	4,248	5,663
	Shahdara Bridge	7,079	1,133	1,841	2,549	3,823	5,097
	Balloki Headworks	6,371	1,133	1,841	2,549	3,823	5,097
	Sidhnai Headworks	4,956	850	1,274	1,699	2,549	3,398

continued on next page

table continued

River	Location	Design Capacity	Flood Limits				
			Low	Medium	High	Very High	Exceptionally High
Sutlej	Sulemanki Headworks	9,203	1,416	2,265	3,398	4,956	6,371
	Islam Headworks	8,495	1,416	2,265	3,398	4,956	6,371
	Mailsi Syphon	11,327	2,124	3,115	4,248	6,371	na

m^3s^{-1} = cubic meters per second; na = not available.

Notes:

1. The figures given for Mangla (outflow) and Rasul, both on the Jhelum River, apply only for the period after the Mangla Dam had been built, in 1967.

2. The original design capacity of Sukkur Barrage was 42,476 cubic meters per second (1,500,000 cubic feet per second), but after the formation of an island and the closure of six bays, it is considered to be 25,485–28,317 cubic meters per second (900,000–1,000,000 cubic feet per second).

Source: Ul Haq, R. 1994. Floods in Indus Basin: Their Control and Management. *Punjab Engineering Congress Paper Series.* No. 181, Vol. XXIII. Paper presented at the Symposium on Flood Management in Pakistan organized by Pakistan Engineering Congress. Lahore. 4 July. http://pecongress.org.pk/images/upload/books/P181.pdf.

APPENDIX 4

Flood-Related Institutions and their Functions

Council of Common Interest

The Council of Common Interest (CCI) comprises the prime minister of Pakistan (chairperson), the chief ministers of the provinces, and three members from the national government who are nominated by the prime minister. The CCI ensures the equitable distribution of water among the provinces. It formulates and regulates policies and reports to the Parliament. The role of the CCI in flood management, however, is limited.

National Disaster Management Authority, Ministry of Climate Change

The National Disaster Management Authority (NDMA) was established in 2007 to plan and coordinate responses to all sorts of disasters, including floods. The NDMA operates under the Government of Pakistan's Ministry of Climate Change. The provincial disaster management authorities (PDMAs) function under the provincial governments, and are responsible for coordinating disaster management at the provincial level. The PDMAs have also taken over the responsibility (previously held by the Provincial Relief Commission) for the relief, compensation, and rehabilitation of people affected by natural disasters. Although the structures of the NDMA and PDMAs appear to be harmonized, their operation under different governments can cause inefficiency. The National Disaster Management Act 2010 defines the functions of each disaster management authority as follows:

(i) act as an implementing, coordinating, and monitoring body for disaster management,
(ii) prepare plans for the approval of the National Disaster Management Commission (NDMC),
(iii) implement, coordinate, and monitor the national policy,
(iv) establish guidelines for the preparation of disaster management plans by other government organizations,
(v) assist the provincial governments in preparing disaster management plans in line with NDMC guidelines,
(vi) coordinate responses in the event of a disaster or danger of disaster,
(vii) provide guidance to the communities on risks and general population regarding responses to dangerous situations or disasters,
(viii) create awareness of disaster management, and
(ix) perform other functions at times, as directed by the NDMC.

Pakistan Meteorological Department, Ministry of Defense

The Pakistan Meteorological Department (PMD) operates under the Ministry of Defense. The PMD is responsible for weather data and forecasts, participates in fighting floods, and provides services in the fields of meteorology, hydrology, and in associated seismic sciences. Its Flood Forecasting Division (FFD), in Lahore, is responsible for the operation and management of Pakistan's flood forecasting and early warning system. The flood forecasting model comprises a network of dedicated weather radars, a hydrometeorological telemetry system in the upper catchments of the Indus Basin, and rainfall-runoff and river-flow simulation models. The FFD receives hydrometeorological data from various national and international sources, processes it, and uses it to run the models. The FFD also produces (i) surface and upper air meteorological charts; (ii) isohyetal maps, and (iii) tabulated data sheets.

Federal Flood Commission, Ministry of Water and Power

The Federal Flood Commission (FFC) was created in 1977 under the Ministry of Water and Power. The main functions of the FFC are to

(i) prepare national flood protection plans,
(ii) approve the flood-control schemes of the provincial governments,
(iii) assess flood damage in collaboration with other departments,
(iv) update and standardize designs and specifications for flood protection works,
(v) monitor implementation progress,
(vi) prepare research programs for flood control and protection, and
(vii) oversee flood forecasting, warning, and management.

Water and Power Development Authority, Ministry of Water and Power

The Water and Power Development Authority (WAPDA) was established in 1959 under the Ministry of Water and Power to implement and manage major water and energy projects throughout the country. It is also responsible for the operation of the country's two reservoirs during floods (Mangla and Tarbela). However, due to the priority given to irrigation and energy, the two reservoirs are used only in a limited fashion for flood management. WAPDA maintains a telemetry and meteor-burst communication system; collects hydrometric flood data, as well as data from Chashma Barrage and the two reservoirs; supports flood forecasting processes; and participates in real-time flood fighting. WAPDA's telemetric network is directly linked to the FFD, and both organizations coordinate their data acquisition.

National Emergency Relief Cell, Cabinet Division, Islamabad

The National Emergency Relief Cell (NERC) was created in the government's Cabinet Division. NERC acts as a focal point during emergencies, its main responsibilities including (i) coordination with national and provincial governments, nongovernment organizations, and international aid organizations; (ii) administration of relief funds; (iii) stockpiling of relief-related items; and (iv) cash and in-kind support for provincial governments. NERC operates an emergency control room, from which it coordinates responses to calamities by liaising with the relevant agencies. It also maintains an aviation squadron with a fleet of four helicopters, whose task is to assist rescue operations and enable officials to visit the affected areas.

Pakistan Commissioner for Indus Waters

The Indus Waters Treaty (1960), following the provisions of Article VII(1), created the Permanent Indus Commission. Two commissioners, one appointed by Pakistan and the other by India, comprise the full membership of the commission. The commission's main functions are to (i) establish and maintain cooperative arrangements for the implementation of the treaty; (ii) promote cooperation between the two countries in developing the waters of the rivers; (iii) settle disputes between the two countries over water; and (iv) inspect the rivers, with a view to coordinating flow data regarding the transboundary rivers.

The Pakistan commissioner receives flood data on almost a daily basis, and passes the data on to the FFD, where they are used in flood forecasting for the Chenab, Jhelum, Ravi, and Sutlej rivers. The data are then passed on to the FFD's chief meteorologist. During severe flood situations, the frequency of data reception is increased to every six hours, or even to every hour. The Pakistan commissioner is the country's only official who can obtain clarifications or other information from India with regard to flood data and the flood-control structures in India.

Provincial Irrigation Departments

By virtue of their custodianship of irrigation and flood facilities, provincial irrigation departments (PIDs) play a key role in effecting flood mitigation measures at the provincial level. The PIDs operate barrages and breaching sections. They also maintain flood protection levees totaling 5,585 kilometers (km) in length, as well as over 800 main spurs along the rivers. The flood protection levees are divided among the provinces as follows: Punjab: 2,687 km; Sindh: 2,376 km; Khyber Pakhtunkhwa: 249 km; and Balochistan: 273 km. The major flood-related functions of the PIDs are

(i) operation of barrages and measurement of discharges at selected barrages;
(ii) planning, design, construction, and maintenance of flood-protection and river-training works;
(iii) collection of relevant data for the FFD and tracking of flood propagation;
(iv) supervision of operations of the flood warning center, if requested by a PDMA;
(v) collaboration with the FFD in generating flood forecasts and early warnings; and
(vi) preparation and implementation of real-time flood-fighting plans for monsoon periods.

Pakistan Army

The Pakistan Army Corps of Engineers (i) carries out pre-flood inspections of the flood protection levees and other major structures, along with the PIDs; (ii) assists the PIDs in operating embankment breach sections; (iii) helps the civil administration to carry out rescue and relief operations during and after floods; and (iv) participates in the issuance of flood warnings.

Other Organizations and Government Entities

Agencies such as relief organizations and provincial and district administrations provide assistance to the main flood-related government agencies in the form of various administrative and relief operations. For example, district administrations assist in rescue and relief operations, and provincial health departments provide post-flood health-related assistance.

Indus Basin Floods: Mechanisms, Impacts, and Management

More than 138 million people in the Indus River Basin in Pakistan depend on irrigated agriculture. But rising population pressures, climate change, and the continuous degradation of ecosystem services have resulted in increased flood risks, worsened by inadequate flood planning and management. The devastating 2010 flood alone caused damage of about $10 billion.

This report proposes a contemporary holistic approach, applying scientific assessments that take people, land, and water into account. It also includes planning and implementation realized through appropriate policies, enforceable laws, and effective institutions.

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