Chapter 11

Flood and Storm Control

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Main Messages

Floods and storms are an integral part of ecosystem dynamics and have both positive and negative effects on human well-being. Floods interact directly with the ecosystems of a floodplain while a storm interacts with coastal, estuarine, and desert ecosystems. Floods and storm waters bring nutrients, which are beneficial to the floodplain ecosystems (wetlands, agricultural lands, and crops, fishery, etc.) and coastal ecosystems (mangroves, mudflats, reefs, fishery, etc.). They eventually contribute to human well-being by delivering a range of ecosystem services. However, flood or flood risk management options can increase the discharge of pollutants and sediments to the coastal zones. Floods and storms also cause damage to the economic and social sectors such as infrastructure, agriculture, industry, and human settlements. Prudent management approaches can reduce the extent of damage to acceptable limits.

Historically, responses to reduce the negative impacts have emphasized physical structures/measures over natural environment and social institutions. Historical responses to floods and storms have emphasized the construction of physical structures (for example, dams/reservoirs, embankments, regulators, drainage channels, and flood bypasses) over the maintenance and enhancement of environmental features and over social institutions that inform and coordinate behavior changes to reduce losses. In many cases, such efforts have been implemented without assessing their possible long-term effects on ecosystems. Such measures often create a false sense of security and encourage people to accept high risks that result from living in the floodplains and on coasts.

The preponderance of evidence indicates that, in most situations, more emphasis needs to be given to the natural environment and nonstructural measures and less to structural measures. Although physical structures (if properly designed) protect communities and infrastructure in a floodplain from flood and storm surges, they often create irreparable damage to ecosystems. Ecosystems usually lose resiliency during the long inundation-free periods after the construction of physical structures. In many cases expensive restoration efforts have failed to fully regenerate ecosystems. Overall, physical responses (in the form of human interventions) may cause more damage than benefit to ecosystems over longer time-scales, in terms of restoration and resiliency. Therefore, the focus should be shifted to use of the natural environment and nonstructural measures in mitigating flood and storm hazards. For example, nonstructural measures such as flood and storm forecasting and warning, disaster preparedness, and acquisition of lands to accommodate flood waters can reduce economic damage and loss of human life. Coastal mangroves have been found to be very effective in providing protection against storms and surges.

Sustainable approaches of flood and storm control can ensure intergenerational equity. Sustainable flood and storm control schemes could include structural and nonstructural measures. Design modifications of physical structures that allow the maintenance of natural environment to a large extent could be sustainable. This, together with the nonstructural measures (for example, water retention areas, restoration of wetlands, land use, zoning, and risk assessment, and early warning systems), can deliver benefits to humans and ecosystems over a long period of time. However, uncertainty in flood and storm forecasting can influence the decision-making procedure for design and implementation of response measures.

Drivers of change, including climate change, indicate that the geographical distribution of floods and storms and perhaps their intensity will impose new stresses, which are probably best responded to through an adaptive approach to ecosystem management and social institutions. Floods and storms are the result of extreme rainfall/snowmelt and oceanic–atmospheric disturbances. In the future, climate change may have large-scale implications for these processes. Results from climate models suggest the possibility of increased intense rainfall in many parts of the world, which may lead to increased flooding. A rise in the sea levels may cause drainage problems in many river basins as well as aggravate coastal inundation. However, the net sea level rise is dependent on a number of factors that include sediment transport to the estuaries, land accretion subsidence, and coastal protection. Although the models indicate the likelihood of increased cyclones/storms, confidence is less than for floods. There is a need for designing a comprehensive adaptive approach integrating ecosystems and social institutions. The use of advanced flood forecasting and warning, strengthening of the institutions responsible for such actions and disaster management, quick relocation of people, emergency response, coastal mangroves, afforestation in the uplands and coastal areas, conservation, restoration, and creation of wetlands can markedly reduce the threats of increased flood and storm hazards.

A more integrated approach toward managing the consequences of floods and storms is needed. This requires a range of responses that includes land use planning, financial services, information and education, use of the natural environment, and physical structures. Such an approach is likely to balance and resolve multiple objectives and goals in a better way.

11.1 Introduction

Floods and storms are intrinsic components of the natural climate system and climate variability. These are a part of the natural disturbance regime, which is an important determinant of ecosystem structure and function, particularly in the long run. Public perception and response to floods and storms are largely driven by the short-term and negative impact of these disasters. Therefore, the responses have been historically focused on interventions to modify and control natural flood regimes through structural means (for example, flood mitigation program in Bangladesh).

Floods and storms are some of the most destructive hydrometeorological phenomena in terms of their impacts on human well-being and socioeconomic activities. While floods and storms have adverse impacts on humans, infrastructure, and economic sectors and ecosystems, they also generate beneficial effects that contribute to human well-being. The impacts of floods on human well-being and the role of ecosystems in flood control are extensively discussed in MA *Current State and Trends,* Chapter 16. Some of the main impacts of floods and storms are presented here.

11.1.1 Adverse Impacts

Floods and storms may have considerable adverse impacts depending on location, intensity and duration. In 2003, floods accounted for 3,723 fatalities around the world, exceeded only by heat waves (about 22,000 due to the very extreme summer heat wave in Southern Europe) and earthquakes (about 48,000, mostly due to the Bam Iran disaster) (Munich Re 2003). The International Federation of Red Cross and Red Crescent Societies reports that weather-related disasters from a global perspective have been on the rise since 1996 and increasing from an annual average of 200 (1993–97) to 331 (1998–2002) (International Federation 2001 and 2003).

The number of disasters attributed to floods is on the rise, while on average the number of people killed due to floods remains steady (Munich Re 2003). (See Figure 11.1.) The economic costs of flood disasters have been increasing globally. Pielke et al. (2002) found that flood losses were falling as a proportion of GDP although the gross loss is on the rise. The increase in flood

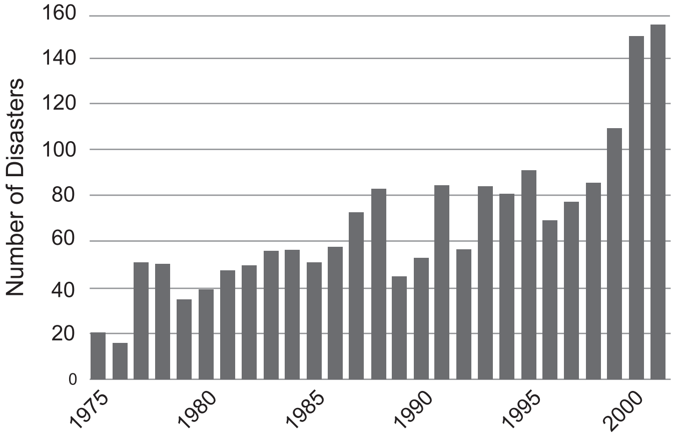

Figure 11.1. Number of Disasters Attributed to Floods, 1975–2001 (Munich Re 2003)

disasters is possibly due to more heavy rainfall events, increased economic activity, and efficiency of the use of a catchment (Green 1999; Mirza et al. 2001). Future climate change is expected to exacerbate the problem with possible increase in extreme precipitation events, perhaps in very serious ways (IPCC 2001). However, the Intergovernmental Panel on Climate Change projections put less confidence in the increase in frequency and magnitude of cyclones and storms.

Tropical cyclones are considered to be the most devastating of the natural disasters because of their capacity to cause loss of human lives and induce extensive economic losses (Gray and Landsea 1992; Diaz and Pulwarty 1997). Vulnerability to tropical cyclones is increasing due to fast population growth in the tropical coastal regions (Handerson-Sellers et al. 1998). McBride (1995) reported that each year around the globe, approximately 80–90 cyclones gain the intensity of tropical storm and about two thirds of them reach the intensity of a hurricane. Recent analysis of cyclone data for the North Atlantic and Northwest Pacific reveals an increase in windstorm activity from 1950 to 2003 (Munich Re 2003).

Floods can affect health directly, for example, by causing injuries and deaths due to drowning. These can occur during or in the aftermath of a flood disaster when the residents return to their dwellings to clean up the damage and debris. Floodwaters also can affect health indirectly, through changes in other systems (for example, waterborne infections, acute or chronic effects of exposure to chemical pollutants released into floodwaters, vector-borne diseases, food shortage, and others). Floods also can increase the risk of cholera, diarrhea, schistosomiasis, dengue, yellow fever, malaria, hantavirus, and other diseases.

After Hurricane Mitch devastated Central America, there was a widespread outbreak of communicable diseases; WHO reported 590 cases of cholera. Nicaragua had the highest number of cases, 335 (56%), followed by Guatemala, with 235 cases (40%). The remaining 4% of cases occurred in El Salvador, Honduras, and Belize (WHO 1999). Similarly, Barcellos and Sabroza (2000) identified floodwater as the cause of the outbreak of leptospirosis in 1996 in western Rio de Janeiro, Brazil. Floods in Bangladesh in the 1980s and 1990s caused an outbreak of diarrhea and other waterborne diseases that claimed the lives of thousands of people (Mirza et al. 2001). Bennet (1970) also synthesized in detail health effects of Bristol floods in the United Kingdom.

Ill health, particularly due to psychological distress, may persist for months or years following a flood. For example, the Saguenay flood in Quebec, Canada, in 1996 caused psychological distress (Auger et al. 2000). Floods and storms can also cause other kind of health problems such as carbon monoxide (CO) poisoning, as in Grand Forks, North Dakota in 1997 (Daley et al. 2001) and contamination of farmlands by pesticides as in Mississippi after the 1993 flood (Chong et al. 1998).

The actual impacts of floods and storms on human well-being are strongly dependent on the adaptive capacity of the affected groups and individuals, and their actual adaptation responses. For example, Ginexi et al. (2000) identified that the increases in symptoms as a function of flood impact were slightly greater among respondents with the lowest incomes and those living in small rural communities than among those on farms or in cities. Similarly, Kunii et al. (2002) reported widespread cases of diarrhea in Bangladesh during the 1998 floods. Some of the factors associated with developing or worsening diarrhea were: family size, poor economic condition, no distribution of water purification tablets, the type of water storage vessels, not putting a lid on vessels, no use of toilets, perceived change of drinking water, and food scarcity.

Development and urbanization patterns can exacerbate the impacts of floods. Floodplain development is increasing the number of people at risk, often because alternative (attractive) locations are not available. By contrast, in many industrial countries people put lives and property at risk by building houses and resorts on floodplains that are an attractive choice because of their aesthetic value. In many countries where land resources are scarce, expansion of human settlements and developments occur on the floodplains as there is no other choice. However, in such cases, planners should take into account the ''risk factor'' to reduce human and ecosystem vulnerability. For example, development and urbanization create conditions whereby runoff is greater in terms of both volume and rate of rise (speed of onset). However, efficient drainage provisions and conservation of urban wetlands can reduce vulnerability.

11.1.2 Beneficial Impacts and Well-being

Natural flooding has many beneficial effects. In Bangladesh, for example, a flood is categorized as *barsha* (beneficial flood) and *bonna* (disastrous flood). The annual flood *barsha* inundates up to 20.5% of the land area and the low-frequency, high-magnitude flood *bonna* inundates more than 35–70% of the country's area. A single flood can be both *barsha* and *bonna* (Paul 1984). Flooding has four important benefits.

First, it inundates floodplains, leaving the moisture content in the soil high at the end of the flooding season. This moisture is beneficial for agriculture depending on the crop cycle, for example, in Bangladesh. However, there are exceptions. For example, in the United Kingdom, winter flooding can make soil moisture content too high in the summer to support arable crops (Drijver and Marchand 1985). Soil moisture deficit is common in the soils of flood-free areas where irrigation is required to sustain agriculture. Second, floodwaters replenish groundwater aquifers. In many parts of the world, groundwater aquifers fully recover by natural recharge from rain or snowmelt. The replenished groundwater is used for irrigation.

Third, floodwaters contribute to increased soil fertility. However, deposition of sand carried by floodwaters on fertile agricultural land can cause serious harm (Brammer 1990). There is a notion among the farmers in Bangladesh that raw alluvium carried by floodwaters increases soil fertility. But raw alluvium is relatively infertile in the short term. It contains little organic matter and provides useable phosphorus or nitrogen. The minerals contained in river alluvium weather relatively slowly and consequently contribute to soil fertility on a long-term basis rather than in the year of their deposition (Chadwick et al. 2003). According to the World Bank (1990), the fertility associated with seasonal flooding comes mainly from the flooding itself, rather than the alluviums. Algae, including blue-green algae that are nitrogen fixing, potentially grow on the submerged soil and the stems of plants in the floodwater. The organic remnants of the algae fall on the soil surface and decompose, releasing nutrients to plants.

Fourth, natural flooding can benefit floodplain fisheries. In many countries in South and Southeast Asia, Africa, and Latin America, among others, fish is a source of animal protein. Edwards (2000) reported that fisheries supply at least 40% of all animal protein in the diet in 18 countries in Africa and Asia. Whereas the urban population has access to other sources of animal protein, many people in rural areas are highly dependent on floodplain fisheries.

Obstruction to natural flooding by the construction of high dams caused destruction of the Nile Delta (Stanley and Warne 1998). Decreased flooding also has implications for agriculture. The Aswan dam lowered the influx of nutrient rich silt to the floodplains of Egypt, where much of the food is grown.

Ecosystems play an important role in modifying and regulating hydrological and meteorological processes, and thereby affect the positive as well as negative consequences of floods and storms. The functions of ecosystems range from the regulation of surface and sub-surface flow to the modification of wave dynamics in coastal and near-shore areas. Costanza et al. (1997) listed a range of ecosystem services and functions related to floods and storms. (See Table 11.1.) Normal as well as flood flow regimes are affected by vegetation and its characteristics; hence, one important ecosystem service is to control floods and storms. This chapter aims to:

- assess the role of ecosystems in moderating or regulating storms and floods and their associated impacts, including estimates of the economic value associated with this service;
- examine the natural and anthropogenic drivers that influence this role;
- explore the range of management and policy options (for example, land use change) for ensuring the ability of ecosystems to provide these services, including the possibility of deliberate modification to enhance flood and storm protection; and
- explore the response options to reduce human vulnerability to storms and floods.

Table 11.1. Ecosystem Services and Functions (Constanza et al. 1997)

Ecosystem Service	Ecosystem Functions	Examples
Disturbance regulation	capacitance, damping, and integrity of ecosystem response to environmental fluctuations	storm protection, flood control, drought recovery and other aspects of habitat response to environmental variability mainly controlled by vegetation structure
Water regulation	regulation of hydrological flows	provision of water for agricultural (e.g., irrigation) or industrial (e.g., milling) processes or transportation
Water supply	storage or retention of water	provisioning of water by watersheds, reservoirs, and aquifers
Erosion control and sediment retention	retention of soil within an ecosystem	prevention of soil loss due to wind, runoff, or other removal processes; storage of silt in lakes and wetlands

11.1.3 Types of Events

In the context of this chapter, it is useful to distinguish between the four different types of flood events: flash, riverine, rain, and coastal floods and storms.

Flash floods occur in all climatic regions of the world. They can occur within a few minutes or hours of excessive rainfall, thunderstorms, and heavy rains from hurricanes and tropical storms; they can occur from a dam or levee failure, or from a sudden release of water held by an ice jam. Although flash flooding occurs often along mountain streams, it is also common in urban areas where much of the ground is covered by impervious surfaces and in arid areas such as North Africa.

Riverine flooding is an event of longer duration; it may last a week or more and in some cases months. (See Figure 11.2.) The riverine flooding in Bangladesh in 1998 lasted a record 68 days (Mirza 2003). In 1993, flood water stayed above the danger level for 45 days at Quad Cities, Illinois, along the Mississippi River (NOAA 1994).

Rainfall floods are a form of localized flooding due to intense rainfall occurring over a sustained period of time and the consequent drainage congestion. In 1998 (April 9–13), more 5,000 square kilometers in the regions of Midlands, Anglian, Wales, and Thames in the United Kingdom, for example, were inundated by flooding caused by heavy rainfall for three consecutive days (April 8–10) (Elahi 2000).

Coastal floods are caused by storm surge, coastal rainfall, and tidal action. Coastal flooding typically results from one or a combination of the following biophysical factors: storm surge, heavy surf, tidal piling, tidal cycles, persistence behavior of a storm that is generating flooding, topography, shoreline orientation, bathymetry, river stage or stream runoff and presence or absence of offshore reefs or other barriers. High winds can exacerbate damage.

The terms ''hurricane'' and ''typhoon'' are regionally specific names for a strong *tropical cyclone*. A tropical cyclone is the generic term for a nonfrontal synoptic scale low-pressure system over tropical or sub-tropical waters with organized convection (thunderstorm activity) and definite cyclonic surface wind circulation

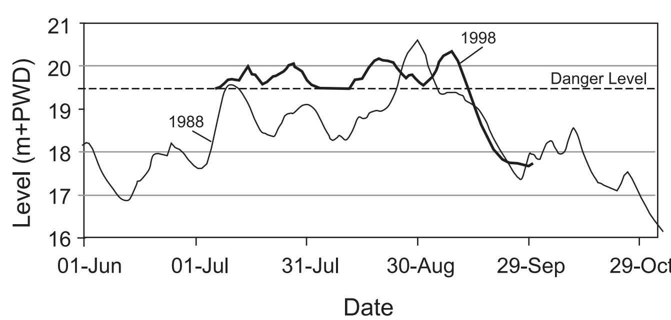

Figure 11.2. Water Levels of the Brahmaputra River at Bahadurabad in Bangladesh during the Floods of 1988 and 1998 (Mirza 2003)

(Holland 1993). Tropical cyclones with maximum sustained surface winds of less than 17 meters per second are "tropical depressions." Once the winds of the tropical cyclone reach at least 17 meters per second, they are typically called a "tropical storm" and assigned a name.

Another class of events that is particularly important in some regions is *sand and dust storms*. Dust storms are major, but understudied processes in dryland areas across the world (Goudie and Middleton 1992). They not only play an important role in desertification and land degradation, but also can cause substantial environmental impacts. Dust storms are common in the great plains of the United States, the former USSR, Morocco, the Arabian Gulf, Australia, the Sahel-Sudan Zone of Africa, China, Mongolia, and Mexico. Natural processes such as precipitation, snow cover, and wind speed are important determinants of frequency of dust events (Goudie and Middleton 1992; Qian and Zhu 2001).

Dust storms have important environmental consequences that include local climate change, nutrient additions to oceans and terrestrial ecosystems, ocean sedimentation, soil formation and loess deposition, possible rainfall suppression, health hazard, accidents, loss of agricultural outputs, and disturbance to satellite communications (Griffin et al. 2001; Goudie and Middleton 1992; USGS 2003).

11.1.4 Flood and Storm Protection Mechanisms by Ecosystems

In examining the mechanisms by which ecosystems provide flood and storm protection, it is useful to focus on two different settings: coastal regions and rivers/uplands.

11.1.4.1 Coastal Systems

In coastal regions, flood and storm protection is often provided by characteristic ecosystems that include coastal forests, mangroves, seagrass beds, coral reefs, dune systems, salt marshes, inter-tidal flats, and lagoons. Mechanisms for regulating storm and flood impacts in coastal areas include wave dissipation, absorption, reflection and resistance, barrier to flood surge, wind breaking, coastal accretion and stabilization (long-term), regulation of sediment transport, and linkage with coastal geomorphology.

11.1.4.2 Rivers and Uplands

Runoff in a catchment or flow at any given point in a channel depends on the interaction of a number of factors, the most important of which are: antecedent conditions; distribution; intensity and duration of precipitation; vegetative or other surface cover; soil type and depth; geologic structure; topography, including area, slope, and channel characteristics.

Singh (1987) assessed the role of forests in water conservation and in controlling rainfall-runoff processes. Leafy canopies intercept rain, reducing both the amount and the impact of that on the ground. Most of the interception loss develops during the initial storm period; thereafter, the rate of interception rapidly reaches zero (Singh 1987). Roots stabilize soils and form channels for rapid infiltration. Organic matter from roots and leaves improves soil structure and increases both infiltration rates and water-holding capacity, that is, the ability of the soil to retain water against gravity; water capacity can vary widely among various soils. Through transpiration, plants remove water from the soil profile, thus creating a greater storage capacity for future precipitation.

11.1.5 Drivers and Processes

Human activities and natural processes both affect ecosystem structure and function and impact services such as flood and storm protection. Following the terminology adopted in the MA, these drivers may be classified into direct and indirect drivers. The former refers to processes that directly interact with ecosystems, while the latter refers to the underlying causes. For example, habitat loss is a common direct driver, while indirect drivers might be population growth and consumption pressures.

The link between human activities and ecosystem degradation has been studied extensively and is now well established. Change in forest cover and, more generally, in land use/land cover is, perhaps, the dominant route by which human influence is expressed. In one study, Laurence and Bierregaard (1997) assessed the pattern and pace of tropical forest destruction in the Americas, Asia, and Africa and concluded that the four key drivers of forest destruction are human population pressure, weak government institutions and poor policies, increasing trade liberalization, and industrial logging. Secondary drivers include poverty and road construction. According to Tockner et al. (2002), by 2025, the increase in human population will lead to further degradation of riparian areas, intensification of the hydrological cycle, increase in the discharge of pollutants, and further proliferation of species invasions.

Urbanization has marked effects on basin runoff in terms of higher volume, higher peak discharge, and shorter time of concentration.[1] These changes are associated with the increased imperviousness and more efficient drainage that are characteristics of constructed drainage systems (Rustam et al. 2000; Singh 1987). UNESCO (1974) provides an excellent account of the hydrologic effects of urbanization. Some of the major effects are: (1) increased water demand, often exceeding the available natural resources; (2) increased wastewater, burdening rivers and lakes and endangering the ecology; (3) increased peak flow; (4) reduced infiltration; and (5) reduced groundwater recharge, increased use of groundwater, and diminishing baseflow of streams.

11.2 Response Categories and Management Approaches

Over the years, a number of management approaches and response options have been developed and followed for coping with the effects of floods and storms. These management approaches influence the extent and functioning of ecosystems, either directly through modification of ecosystems, or indirectly, by changing hydro-meteorological regimes. Five broad categories of response options may be identified, based on nature of response and familiarity of practicing managers:

- *physical structures*: river/estuary (multi-purpose storage dams/reservoirs, weirs, barriers), land protection (dikes/embankments);
- *use of natural environment*: vegetation (mangroves, wetlands, rice paddies, salt marshes, upland forests), geomorphology (natural river channels, dune systems, terrace farming);
- *information and education*: disaster preparedness, disaster management, flood and storm forecasting, early warning, evacuation;
- *financial services*: insurance, disaster relief, and aid; and
- *land use planning*: zoning, setbacks, flood-proofing (emphasis on regulation or modification of the built environment, often urban).

The actual operation and implementation of these responses and their effects on ecosystem structure and function are best examined in four distinct settings: upland/watersheds, floodplains, coastal regions, and islands. Each of these settings has distinct characteristics, biophysical as well as socioeconomic. In addition, the settings differ in terms of the institutional structures and management systems responsible for flood and storm protection as well as other services related to flood and storm protection, for example, irrigation or hydroelectricity generation.

11.3 Sustainable Flood and Storm Control: Analysis and Assessment of Responses

The concept of "sustainable development" is presently widely used and there is no common understanding of the term (Kundzewicz 1999). Table 11.2 presents alternative definitions of sustainable development, which shows the definitional diversity. Munasinghe (1993) argued that the concept of sustainable development evolved to encompass three major points of view: economic, social, and ecological. Takeuchi et al. (1998) mentioned that sustainable development entailed a blend of objectives in economic, social, and environmental areas and they had to be economically feasible, socially acceptable, and environmentally sound.

The definitions of sustainable development in Table 11.2 can be applied for floods and storms control. Although the definitions vary widely in terms of subjects, there is a general consensus on the intergenerational equity. Kundzewicz (1999) interpreted that sustainable development comprised three integral items—civilization, wealth, and environment (natural and human built) and they should be transferred to the future generations in a non-depleted condition. In terms of flood, he further argued that it was necessary for the present generation to attain freedom from the disastrous events but not at the cost of the future generations. The freedom (to a reasonable extent) can be achieved by implementing some defense schemes/response measures. The United Kingdom Environment Agency (1998, p. 9) defined a sustainable flood defense scheme as taking "account of natural processes (and the influence of human activity on them), and of other defenses and development within a river catchment . . . and which avoid as far as possible committing future generations to inappropriate options for defense." These schemes could comprise structural and nonstructural measures. (See Table 11.3.)

Table 11.2. Alternative Definitions of Sustainable Development

Definition	Focus
". . . development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (WCED 1987)	intergenerational equity
". . . development that secures increases in the welfare of the current generation provided that welfare in the future does not decrease." (Pearce and Warford 1993)	human welfare
". . . involves maximizing the net benefits of economic development, subject to maintaining the services and quality of natural resources over time." (Pearce and Turner 1990)	natural resource utilization
"Sustainable development [means] . . . improving the quality of human life while living within the carrying capacity of supporting ecosystems." (IUCN/UNEP/WWF 1991)	carrying capacity of ecosystems
"Sustainable development seeks to deliver the objective of achieving, now and in the future, economic development to secure higher living standards while protecting and enhancing the environment." (DOE 1997)	sustainable economic development

Takeuchi et al. (1998) criticized some flood protection infrastructure (levees, dams, etc.) in the context of sustainable development for closing options (measures that will last and generate benefits for successive generations) for future generations and introducing disturbance in the ecosystems. Kundzewicz (1999) argued that "soft" or nonstructural measures could be rated as more flexible, less committing, and more sustainable than "hard" or structural measures that might be indispensable in particular cases.

This section elaborates on the sustainable approach of flood and storm control with one or more specific examples of response and management options (structural and nonstructural). Internationally, sustainable flood and storm protection is being taken up on a priority basis. The United Nations and Economic Commission for Europe Sustainable Flood Prevention Guidelines (UN/ECE 2000) outline seven basic principles and approaches:

- Flood events are a part of nature.
- Human interference into the processes of nature has increased the threat of flooding.
- Flood prevention should cover the entire catchment area.
- Structural measures will remain important elements of flood prevention and protection, especially for protecting human health and safety, and valuable goods and property.
- Everyone who may suffer from the consequences of flood events should also take precautions on their own.
- Human uses of floodplain should be adapted to the existing hazards.
- In flood-prone areas, preventive measures should be taken to reduce the possible adverse effects on aquatic and terrestrial ecosystems.

The UN/ECE guidelines focus on recommendations for water retention areas, land use, zoning and risk assessment, structural measures and their impact, and early warning and forecast systems. Public awareness, education, and training comprise another important element of preventive strategies.

11.3.1 Physical Structures

Construction of embankments has been the most popular structural method of flood control/mitigation in many parts of the

Table 11.3. Compliance of Components of Pre-flood Preparedness Systems with the Spirit of Sustainability (Menzel and Kundzewicz 2003)

Flood Preparedness Measures	Compliance with Sustainability
Construction of large physical infrastructure	low to medium
Zoning; development control within the floodplain	medium to high
Source control, land use planning, watershed management	medium to high
Flood forecasting and warning system	high
Flood proofing	low to high
Disaster contingency planning and maintenance of preparedness of community self-protection activity	high
Installation of insurance plan	low to high
Capacity building; improving flood awareness, understanding, and preparedness	high

world (the Netherlands, Bangladesh, China, the United States, Canada, New Zealand, etc.). They are constructed to provide protection against flooding and aim to prevent the spill of river waters. The heights of these embankments are greater than those of the annual maximum water levels along the rivers in order to minimize internal flooding through the provision of appropriate drainage structures. Such measures are provided to protect agricultural lands, rural settlements, and urban areas. (See Box 11.1.)

Physical structures can meet some elements of sustainability, depending on their design criteria. In general, the flood control drainage/flood control drainage and irrigation projects in Bangladesh (Table 11.4) created the environment for crop agriculture that has been delivering benefits to generations. However, the benefits are not equitably distributed among various groups of landowners and farm laborers. On the other hand, they have deprived people of access to animal protein as the flood control projects proved to be detrimental to floodplain fisheries (Mirza and Ericksen 1996). They have also disrupted the livelihood of fishing communities (WCD 2002). They also demonstrated other side effects (ESCAP 1997), summarized in Table 11.5.

It is vital that the sustainable engineering works will ensure minimum disruption from flooding and enhance natural habitats while providing the levels of protection demanded by the public. In order to do so, the idea of ''controlled flooding'' is being promoted. The U.S. Fish and Wildlife Service proposed to release a volume of water from the Missouri River reservoirs (Gavin Point) within a specified period of time to help increase population of some threatened species. However, there are critiques of ''controlled flooding'' who argue that it will not result in any meaningful increase in species numbers because the hydrography on the lower river has been permanently altered due to years of reservoir management (UMIMRA 2004).

11.3.2 Use of Natural Environment

11.3.2.1 Wetlands and Flood Moderation

Wetlands hold the runoff generated from heavy rainfall or snowmelt events. They reduce the possibility of flooding in downstream or moderate flooding to some extent, depending on the magnitude of runoff. Wetland vegetation slows down the flow of flood water (Ramsar 2004). Flood mitigation capacity of a wetland system is limited by a number of factors, which include water level fluctuations, plant community, habitat elements, groundwater hydrology, and downstream conditions. According to Ramsar (2004), wetlands reduce the need for expensive engineering structures. However, this is highly dependent on the hydroclimatic conditions of the area in concern, types of settlements and infrastructure, etc. It should be noted that there are various categories of wetlands, each with distinct functions; the criteria for intervention and management of these wetlands also differ. In addition to the Ramsar definition, see also Cowardin et al. (1979) and National Research Council (1995).

In the past two centuries, a substantial area of wetlands was lost due mainly due to human interventions for settlement and agricultural expansion, infrastructure development, deforestation, excessive sedimentation, etc. Reduction of wetlands in the Red River basin in Manitoba, Canada, has been audited as worsening the water level of the 1997 floods. Wetlands have been recognized to reduce the peak flows of rivers or the total flood volume, in addition to storing water. A study by the Red River Basin Task Force estimated that the basin area, constituting 12% wetland in 1870, was reduced to 3% by 1995 due to the expansion of urban settlements and conversion to agricultural lands. In the Mississippi River basin, a large number of engineering projects (thousands of levees and creation of deep navigation channels) were implemented in the past 150 years to control floods and improve and restore navigation. In this process, 6.9 million hectares of wetlands were lost (Ramsar 2004; Hey and Philippi 1995).

Table 11.4. Various Types of Flood Control Projects in Bangladesh (ESCAP 1997)

Project Type	Number	Area Covered
		(million hectares)
Flood control	29	0.210
Flood control and drainage	173	2.019
Flood control, drainage, and irrigation	42	0.711
Drainage	128	0.759

BOX 11.1

Physical Structures for Flood Control: Examples from Various Countries

- The Dutch and their ancestors have 2000 years of experience in holding back and reclaiming lands from the North Sea by building dikes (embankments) (Driessen and De Gier 1999; van Steen and Pellenberg 2004).
- Between 1960 and 2000, the Bangladesh Water Development Board constructed a total of 5,695 kilometers of embankments, including 3,433 kilometers in the coastal areas; 1,695 flood control/regulating structures; and 4,310 kilometers of drainage canals over 3.77 million hectares (Khalequzzaman 2000).
- The Yangtze River basin in China has a long series of dikes to control floods. To improve flood control capacity, about 3,600 kilometers of dykes have been repaired, heightened, and strengthened. The flood diversion and detention basins constructed for flood control in the Yangtze Valley provide an effective storage capacity of over 50 billion cubic meters (Mingguang et al. 1998).
- As a response to the disastrous Mississippi River flooding in the United States in 1927, the U.S. Army Corps of Engineers built the longest system of levees in the world and minimized flooding and improved navigability. However, during the 1993 flood, 40 of the 229 Federal levees and 1,043 of 1,347 non-Federal levees were overtopped or damaged. Damage to locks and dams was also reported (NOAA 1994).
- In Canada, when the Red River flooded in 1997, the Winnipeg floodway prevented the inundation of the city of Winnipeg. However, communities to the south of Winnipeg such as Ste. Agathe sustained serious damage; the town did not have a permanent ringed dike surrounding it. Temporary dikes were built around properties to prevent damage. Dikes surrounding the city of Winnipeg were watched closely to ensure they were not breached. The Farlinger Commission estimated the cost of the flood at CAD $500 million, CAD $39 million claimed in the city of Winnipeg itself (Haque 2000).
- In the Waikato region in New Zealand, historically, mitigation of flooding has focused on structural measures, which include, particularly, stopbanking, drainage, and pumping facilities. However, there are also extensive schemes aimed to provide protection from coastal flooding (Environment Waikato 1997).

Table 11.5. Effects of Flood Control Embankment Projects in Bangladesh

Surface Water	Groundwater	Land and Soil Resources	Fisheries and Ecosystems
Reduction in river flood within the project	Reduced groundwater recharge	Scouring and rising bed levels	Markedly reduced floodplain fisheries
Increase in downstream flood risk	Increased chances of agro-pollution from fertilizer and pesticides	Changing bank erosion	Increase in cultured fisheries
Increase in risks from extreme flood event in schemes		Change in soil fertility status inside the project	Changes in wetland habitat
Reduction of dispersal contaminants inside the project		Increased occurrence of weeds	
Closed system needs flushing to control pollution			
Increased problem of agrochemical and sewage			

The economic value of wetlands in flood control and moderation is not often assessed; however, it could be significant (Ramsar 2004). Costanza et al. (1997) estimated the economic value of wetlands and coastal ecosystems for disturbance regulation and water regulation along with some other services; they generalized many assumptions to derive global values, but to have a comprehensive assessment of ecosystem services at a local scale, it is best to use the primary data. In the United States, the value of wetlands in preventing serious flooding has been put at $13,500 per hectare per annum (Hails 1996).

Wetlands also deliver more direct benefits or provisioning services for human well-being. The inner Niger Delta of Mali (30,000 square kilometers) supports more than half a million people and the post-flood grasslands provide food for two million heads of livestock. In 1985, $8 million worth of cattle, sheep, and goats were exported. Floods help migration of fish, their breeding and production in the floodplains. It was estimated that in 1986 the livelihood of some 80,000 fishermen depended on fishing in the delta and in that year more than 60,000 tons of fish were landed (Dugan 1990).

Efforts have been made and are underway to restore some destroyed wetlands in Europe and the United States for flood moderation and to obtain other ecosystem benefits (Galat et al. 1998; Simons et al. 2001; Schmidt 2001). A number of steps are involved in the restoration process:

- understand the causes of the wetland deterioration or destruction (increased stormwater flow due to urbanization and flood and storm control structures);
- develop a comprehensive wetland study to identify wetland elements (hydrology, soil, and plant) requiring amendment;
- conduct hydrological modeling to analyze water level fluctuations (frequency and duration) during various flood flows;
- select the level of flood protection that does not impact the desired plant community negatively;
- design the wetland system by integrating flow reduction, desired plant community, public safety, and recreational elements;
- determine whether regulatory reviews and permits are required to ensure no net loss of wetlands; and
- develop a plan for long-term monitoring and adaptive management, which are the key elements for a successful wetland restoration project.

In 2000, the World Wide Fund for Nature launched the "Green Corridor for the Danube" project in Europe. Under the project, the governments of Romania, Bulgaria, Moldova, and Ukraine have made a pledge to create a network of at least 600,000 hectares floodplain habitats along the lower Danube River and the Prut River, and in the Danube delta. This effort will require restoring an area of 200,000 hectares (Schmidt 2001).

In Louisiana, several sites drained out for crop agriculture, fish farms, and forestry projects are on the way to returning to their original natural state, as the result of a massive $14 billion wetland restoration program called "Coast 2050." The main objective of the plan is to protect more than 10,000 square kilometers of marsh, swamp, and barrier islands (Bourne 2000). One of the components of this project is to restore and maintain Louisiana's barrier islands, which are the state's first line of defense against storm surge generated by the hurricanes. The results of computer models show that certain configurations of islands and inlets along the coast could reduce surges in the inland areas by more than a meter (Bourne 2000).

11.3.2.2 Upland Reforestation/Afforestation

Changed vegetal cover affects the hydrological behavior of a catchment. The influence of deforestation and erosion on the deterioration of flood disasters is well documented (Gade 1996; Sandstrom 1995; and Sternberg 1987). When a forested area is deforested and the forest litter removed, the interception of precipitation is virtually eliminated. Litter removal changes the infiltration capacity of soil and has a pronounced effect on raindrop impact and the resulting soil erosion. With the loss of forest mulch, the infiltration capacity is reduced and rate of erosion increased. Vegetation loss leads to less evapotranspiration. These changes directly contribute to increased direct runoff, reduced surface roughness, and decreased recharge of groundwater aquifers (Singh 1987).

Reinhart et al. (1963) investigated the effect of vegetation on storm runoff in watersheds in the Allegheny mountains of West Virginia. Due to the vegetation cover, both peak flow and total storm flow were decreased substantially. However, storm flow also depends on other factors, including the maturity of the forest and regeneration after, for example, a forest fire. Forest cover may not always affect flow volume. For example, Hirji et al. (2002) reproduced a flow time series for the Iringa catchment in Tanzania, which showed equal runoff coefficient for the forested as well as cultivated land. Runoff from the forested catchment was markedly lower in the dry season. The performance of cultivated land in reducing runoff was not that insignificant (Shaxson and Barber 2003).

Lahmer et al. (2000) investigated the impacts of environmental changes on flood generation in the 575 square kilometer floods of the Stepenitz River basin (a sub-basin of the Elbe River basin) in Germany. They simulated floods in response to an extreme precipitation event that occurred on June 12, 1993, in the basin. A 255 millimeter rainfall (39% of the mean annual sum of 650 millimeters for the period 1981–1994) was recorded in 24 hours. Scenarios were developed to analyze the event's impact under alternative conditions:

- if all arable land (about 66.4% of the total basin area) were forests when the event occurred (forest scenario), and
- if all arable land were bare land (bare land scenario).

Figure 11.3 demonstrates that the forest scenario has a considerable impact on the flood wave at the basin outlet; compared to actual land use, peak flow and discharge volume are reduced by 42.3% and 39.3%, respectively. The reductions for the bare land scenario of about 13.6% (peak flow) and 13.5% (discharge volume) are considerably smaller, but still remarkable. Even for this extreme precipitation event, the water retention of the basin is high in both cases because of the long dry period before the event, which favored percolation due to low soil saturation.

Kramer et al. (1997) examined the effects of forest cover on flooding in the Mantadia National Park, Eastern Madagascar. For this purpose, hydrologic experiments were conducted in the Perinet Experimental Watersheds, which lies in the Vohitra River basin. Land uses studied included primary and secondary forests, traditional rice agriculture with burning (swidden), and agriculture with terraces and other conservation practices. The results of an eight-year experiment suggest that flooding differs quite considerably between primary and secondary forests. Storm flow from the 30-hectare secondary forest watershed was about threefold more in water volume than from a similar-sized primary forest catchment. Reduced infiltration capacity due to soil compaction, decreased evapotranspiration, and less extensive rooting in the secondary forest could have resulted in higher stream flow. Vegetation cover delivers other benefits as well. It is important for reducing soil erosion and sedimentation downstream (for example, Loess plateau of the Yellow River in China). In non-vegetated soils, extreme rainfall can cause earth movement endangering lives and property in the downstream. Settlements on steep and unstable slopes could be more dangerous than the floodplains, depending on its location.

Vegetation cover is also important in the context of sand and dust storms. Engelstaedter et al. (2003) studied dust storm frequency data from more than 2,400 meteorological stations worldwide. Comparisons with distributions of vegetation types suggest that DSF is highest in desert/bare ground (median: 60–80 DSF per year) and shrubland (median: 20–30 DSF per year) regions, and comparatively low in grassland regions (median: 2–4 days per year). Average DSF is inversely correlated with leaf area index and net primary productivity. In non-forested regions, DSF increases as the fraction of closed topographic depressions increases, possibly due to the accumulation of fine sediments in these areas.

11.3.2.3 Mangroves, Seagrasses, and Sand Dunes in Storm Protection

Mangrove forests are diverse communities growing in the intertidal zone (between the average sea level and the high tide mark)

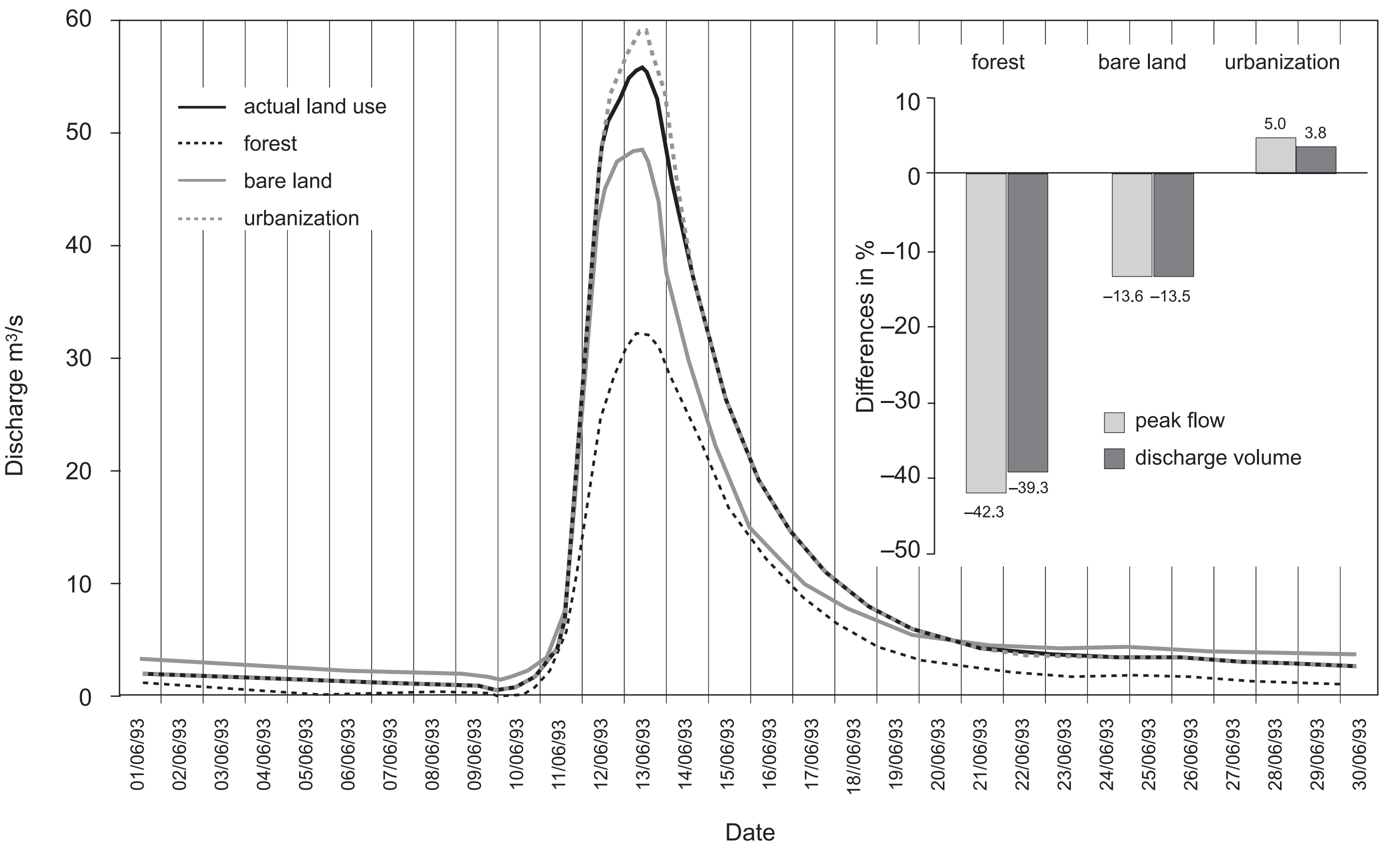

Figure 11.3. Impact of Land Use Change Measures on Stepenitz Basin Discharge following Extreme Precipitation Event on 12 June 1993. The differences for the peak flow and the discharge volume for the scenarios as compared to the actual land use are given on the right hand side of the figure. (Lahmer et al. 2000)

of tropical to sub-tropical coastal rivers, estuaries, and bays. The large amount of silt deposited by coastal rivers along the shoreline produces an environment suitable for the growth of extensive forests. Mangrove plants can also be found growing on the carbonate sediments deposited around reef-associated islands.

In 1997, the ''World Mangrove Atlas'' estimated approximately 18 million hectares of mangroves. South and Southeast Asia's coasts are enriched with mangroves. In 10 countries of South and Southeast Asia, the approximate area of mangroves is 4,913 thousand hectares. The highest coverage of mangroves is in Indonesia and the lowest in Sri Lanka.

Mangrove ecosystems play an important ecological role while providing a variety of services for human well-being. The benefits obtained from the mangrove ecosystems are quite broad and encompass a range of economic, environmental, and social aspects, including protection from erosion, flooding, cyclones, typhoons, and tidal waves (Primavera 2000).

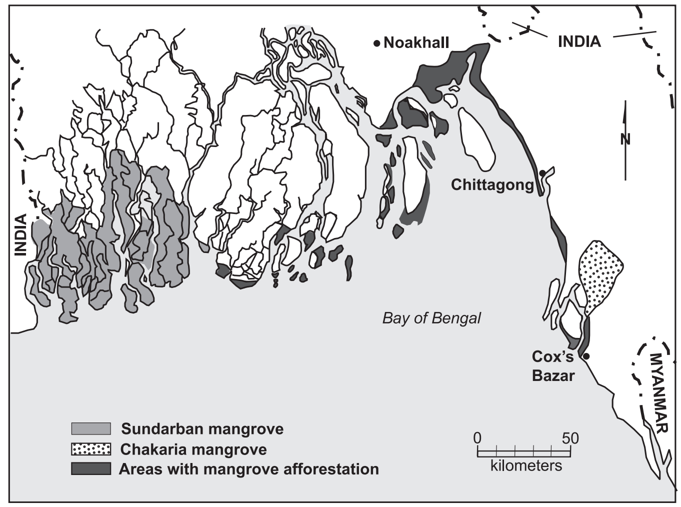

Figure 11.4. Mangroves in Bangladesh

11.3.2.3.1 Super cyclone, Orissa

On October, 29, 1999, the Indian ''super cyclone'' made landfall over the Indian State of Orissa (UK Met-office 1999). It was the strongest and deadliest cyclone in the region since the Bangladesh cyclone of 1991. The recorded wind speed was 356 kilometers per hour (Kriner 2000) and it generated 8–10 meter high surges. The cyclone and its aftermath led to 10,092 deaths; the demolition of millions of dwelling units; over 80% damage to standing crops, especially ready-to-harvest crops; and a loss of about 454,000 heads of cattle.

In the second half of the twentieth century, India lost more than half of its mangrove forests. In 1987, India had 674,000 hectares of mangroves. Within a period of 10 years, that amount decreased to 483,000 ha (Kumar 2000), leaving the country open to attack by the wind and waves of the cyclones that regularly hit the coast of eastern India and neighboring Bangladesh. The Orissa coastline was once covered by mangrove forests. In 1990, Orissa's coastline had a mangrove forest area of around 150 square kilometers, which had dwindled to 50 square kilometers by 1999 (Khan 1999). In the past, the mangroves would have dissipated the incoming wave energy. Mangroves trap sediment in their roots, which transforms the seabed to a shallow shape. This absorbs the energy of waves and tidal surges and thus protects the land under them. The destruction of coastal mangroves in Orissa has reduced the capacity of the coastal ecosystems to buffer storm surges and cyclonic winds (Shiva 2002). The lack of protective forest cover also made it possible for the floods to inundate large areas and cause much destruction. As forests have been lost, each consecutive cyclone has penetrated further inland (Tynkkynen 2000). However, an area near Paradeep in Orissa where forests were intact was largely saved from cyclonic damage (Tynkkynen 2000).

11.3.2.3.2 Bangladesh cyclone

Since 1822, a total of 69 extreme cyclones have landed on the Bangladesh coast, of which 10 hit the Sundarbans mangrove forest. (See Figure 11.4.) However, a cyclone that lands on the Sundarbans causes less damage than a cyclone of equal magnitude that lands on the central and eastern part of the coast. Most of the damage is caused by the surge. For example, a cyclone that landed on the Cox's Bazaar coast in 1985 generated a 4.3 meter surge and caused the deaths of 11,069 people. A similar cyclone that landed on the Sundarbans in 1988 caused half that number of fatalities.

11.3.2.3.3 Coastal flooding and Cyclone Drena, New Zealand

Coastal flooding around the Firth of Thames is reasonably frequent (annual probability of at least 3–5 %). The damage caused by flooding in July 1995 and Cyclone Drena in January 1997 was in the range of NZ$ 4–5 million or more (including damage to the settlements, agricultural lands, and roads). Dahm (1999) listed a range of natural buffer systems (beaches and wetlands, particularly mangroves) that provide effective protection from coastal flooding in the Waikato. For example, the mangroves in the southern Firth of Thames provide very effective wave and erosion protection for stop-banks protecting the Hauraki plains. It was reported that there was little or no wave action felt along the landward margins of the mangroves in Cyclone Drena despite the marked northerly waves impacting directly on the seaward margin of the mangroves (Dahm 1999).

Like mangroves, seagrasses are an important vegetation type that modifies the local hydro-meteorological regime in coastal regions. Seagrasses cover about 0.1–0.2 % of the global ocean, and contribute to developing highly productive coastal ecosystems (Duarte 2002). Seagrasses, an assemblage of marine flowering plant species, are valuable structural and functional components of coastal ecosystem and are currently experiencing worldwide decline. Widespread seagrass loss results from direct anthropogenic impacts, including dredging, fishing and anchorage, sedimentation, coastal constructions, as well as from natural causes such as cyclones (hurricanes) and floods. Over the period 1986–96, Short and Wyllie Echeverrira (1996) reported that 90,000 hectares of seagrass loss was documented; they estimate that the actual loss was greater.

Native vegetation, sand dunes, and wide beaches are the best coastal buffers for hurricanes (Theiler and Young 1991, cited in Coch 1994). The ebb surge of a storm (the flow of water returning to the sea) can be very destructive to the affected areas, causing localized flooding and damage. Ebb surge is exacerbated by coast parallel streets that trap the water, large areas without vegetation, and beach modifications such as dune overpasses and beach accesses (Coch 1994). Coastal structures can serve to worsen flooding as water gets trapped behind seawalls and is prevented from flowing back to the sea, although they can reduce the influx of the storm surge by preventing infiltration and absorbing energy from waves. Native species of vegetation are more resilient to hurricane winds and waves than the introduced species, and wide beaches help absorb the force of the storm. Sand dunes cushion wind and wave energy and prevent storm surge, or facilitate ebb surge if storm surge does occur. Natural sand dunes are more resilient than restored dunes, yet no dune is worse over all.

Management of the natural environment can reduce vulnerability to floods and storms. However, it alone may not be sufficient to reduce the losses, which can be achieved in combination with such other measures as information, institution strengthening, and education.

11.3.3 Information, Institution Strengthening, and Education

Institutions and public education programs are vital to reducing losses from floods and storms. Risk assessment is an essential component of any hazard or disaster management planning. Flood and storm forecasting and warning, and dissemination of this information play a pivotal role for saving lives, property, and crops. However, there are uncertainties in such forecasting activities. Accuracy is a vital element of forecasting to maintain public confidence. Inaccurate or partially accurate forecasting can cause more damage than reduction of losses. In many countries (especially in the developing world), flood loss occurs mainly due to the lack of institutional capability, trained manpower, and technological limitations.

In Bangladesh, flood forecasting and warning is conducted with the aid of a hydrological and hydrodynamic mathematical model (MIKE11-GIS) and the NOAA–AVHRR satellite imagery and processing system. The Flood Forecasting and Warning Cener in Dhaka is also equipped with experienced and trained personnel. FFWC is capable of issuing forecasts 30 and 72 hours in advance using real time data (Water Level and Reference Flood) from 74 stations and 44 rainfall stations. Hydrometeorological information from a limited number of Indian stations is also used. During the 1998 flood in Bangladesh, the model result was found to be very close to acceptable limits in the Brahmaputra and Ganges basin for both rising and receding time of water level. But forecasting in the flash flood areas, especially in the northeastern, southeastern, and extreme northern parts of the country suffered a setback due to the lack of hourly data.

Goswami (2000) discussed the flood forecasting and warning situation in the Brahmaputra river system in India. The Central Water Commission, the Indian Meteorological Department, and a few state government departments such as agriculture and irrigation and flood control maintain a network of hydrometeorological stations. However, the density of the network, especially in the case of automatic rain gauges, was found to be far short of the WMO suggested guideline (WAPCOS 1993).

Flood warnings are made mainly on the basis of travel time between the selected base station and the particular forecast station and the gauge-to-gauge correlations of water levels. The lead time for the forecasts varies depending on the travel time between the concerned gauges. For the main Brahmaputra river, the lead time is up to 112 hours. During the period of a high flood, flood-warning messages are broadcast through local radio and television centers and also through the printed media. Although the technology of satellite telemetry is available, it has yet to be used on an operational basis for flood forecasting purposes in the Brahmaputra basin. Mathematical models are in use for some rivers such as the Damodar, however, in the case of the Brahmaputra, there is no major effort to use mathematical modeling for the purpose of flood forecasting; disaster mitigation has been done (Goswami 2000).

Nepal established an early warning system to monitor glacier lake outburst floods. in the Tsho Rolpa glacier lake, located in the Rolwaling valley about 110 kilometers northeast from the capital Kathmandu. A GLOF is characterized by a sudden release of a huge amount of lake water, which eventually would rush down along the stream channel downstream in the form of devastating flood waves. The mitigation program designed to reduce GLOF vulnerability in Rolwaling valley includes: installation of test siphons, installation of the GLOF Early Warning System, nd construction of an open channel to lower the water level (Shrestha 2001). In 1996, the Meteor Burst type of early warning system was established for safe evacuation of people from the Rolwaling and Bhote/Tama Kosi valleys. The GLOF sensors are located downstream of the moraine senses and they relay a GLOF information to 19 stations distributed over 17 villages downstream of the lake.

The River Forecast Center of the Water Services Branch within the Manitoba government is responsible for preparing preliminary (outlook) and operational forecasts for all rivers in Manitoba, Canada. Preliminary forecasts are created in February and March based on model forecasts of expected flood peak data estimated using meteorological data. Operational forecasts are updated reports regarding the anticipated flood level, incorporating real time data collected from flood gauge stations, weather data, and river observers. Melt conditions, spring precipitation, air and dew point temperatures, wind data, and sunshine levels are incorporated into the operational forecasts.

Forecasts are communicated to the media through government information services, as well as to the Manitoba Emergency Measures Organization, Emergency Preparedness Canada, municipalities, aboriginal bands, and other interested stakeholders and government officials. The 47 pre-existing river monitoring sites were upgraded and supplemented with 37 more sites in response to deficiencies in forecasting the 1997 flood. Additionally, Environment Canada expanded its network of climate stations to 350, to improve the weather data collection for flood forecasting. A difficulty in the 1997 flood was the inability to accurately forecast overland flooding (Simonovic and Carson 2003). Several communities were flooded from overland flow rather than from the river.

In the United States, the National Hurricane Center in Florida is responsible for forecasting hurricane tracks and intensity in the North Atlantic and the eastern North Pacific, east of 140(W (DeMaria 1997). The NHC obtains data from satellites, buoys, reconnaissance flights to the storms, and radar (NHC 2004a). These data are put into models to determine the likely track and intensity of the storm. Most of the models also require data from global forecast models; after the storm the various models are evaluated against the best track positions as determined by data collected during the storm and re-analyzed (DeMaria 1997).

Error is unavoidable in hurricane forecasts and increases with the length of the forecast (NHC 2004b). Error is mitigated by the inclusion of a strike probability table that provides the statistical probability that a hurricane will strike a specific location in the following three days. Error is the reason why warnings cover a wider area than the most likely strike zone. Major cities that are vulnerable to the impacts of a hurricane (for example, New Orleans) require 48 hours to evacuate; however 48 hours prior to the anticipated arrival of hurricane force winds, the strike probability of any location is only 25% (NHC 2004b).

McAdie and Lawrence discovered that error in the NHC track forecasts since 1970 have decreased by one percent a year on average (cited in Nicholls 2001). This increase in accuracy was boosted further by another improvement in accuracy in the mid-1990s, during which predictions improved twice as fast (Kerr 1999, cited in Nicholls 2001). The addition of GPS dropwindsondes in 1997 notably improved the accuracy of hurricane models 48 hours prior to landfall, some as much as 32% for track forecasts and 20% for intensity forecasts (Aberson and Franklin

1999; Kerr 1999, cited in Nicholls 2001). Despite these improvements in forecast accuracy, the length of coastline-issued hurricane warnings did not decrease (Pielke 1999, cited in Nicholls 2001).

The NHC utilizes the Sea Lake Overland Surges from Hurricane (SLOSH) model to complement hurricane forecasts and alert locations to their storm surge risk (NHC 2004c). This model evaluates pressure, size of the storm, forward speed, track, and winds in its assessment of anticipated storm surge. This information is combined with local bathymetry and shoreline configuration to determine what the storm surge will be in a location. The SLOSH model is normally accurate within 20%; however, if the track and intensity data brought in from the hurricane forecast is inaccurate, the storm surge prediction will be as well.

It is evident that effective information generation and dissemination, public education, and strengthening of institutions can markedly reduce vulnerability to floods and storms. However, other means such as financial services are needed to recover from the losses caused by these events.

11.3.4 Financial Services

Different countries have taken various approaches to insuring flood. Under the *option system,* insurers agree to extend their policy to include flood on payment of an additional premium; examples include Belgium, Australia, Germany, Italy, Canada (commercial only). In the *bundle system,* flood cover is available only if it is bundled with other perils such as storm or theft (for example, Israel, Spain, the United Kingdom). In some countries, *disaster assistance* is available from different levels of government (for example, Canada), while others rely upon the private sector (for example, Germany, Portugal, the United Kingdom). This assistance can be automatic in the event of a disaster (for example, Canada and China), or it can rely upon a government decree (for example, France and the United States) (Crichton 2002). The U.S. system is unique in having a National Flood Insurance Program that is federally based; the NFIP has been criticized, however, for encouraging development within floodplains (Larsen and Plasencia 2001) even while it provides people with the means to recover from flood disasters.

It is difficult to insure for flood because of the problem of adverse selection. Because the spatial patterns of flood risk are fairly well known since floods tend to occur in floodplains, those at risk will buy insurance, while those not at risk will not. This contradicts one of the main principles by which insurance works, that is, where risk is spread among a large population due to uncertainty related to the hazard.

Both social programs and private insurance are important coping mechanisms for flood disaster recovery. They can, however, inadvertently contribute toward community vulnerability by encouraging development within floodplains or by creating cultures of entitlement. These issues are discussed in the next section.

11.3.5 Land Use Planning

Land use planning such as floodplain zoning is a process of determining the most desirable way land should be used so that it can help to mitigate disasters and reduce risks by directing development away from hazard-prone areas. Land use planning plays a major role in regulating development and the use of land. It is normally carried out in two ways (Gunne-Jones 2003). First, it works by controlling developments through a system of issuing permits or approvals. Second, it involves planning for the future needs of a state, region, or locality through the publication and adoption of development or zoning plans.

The first step in land use planning for flood management/damage reduction is to prepare flood risk maps in which flood magnitude, water depth, flow velocity, flood duration, etc., for a specific return period are incorporated. The main purpose is to inform the public about the flood risk derived from occupying a floodplain. Flood risk maps communicate the degree of flood risk to concerned agencies and the public, enabling a dialogue on the most appropriate flood prevention and protection measures (European Environment Agency 2001). Coastal land use planning for areas vulnerable to high storms and flooding from storms includes setbacks from the shore for new developments, etc. In the United Kingdom, the findings of the Environment, Transport, and Regional Affairs Committee (2000) recommended that flood risk maps should be included in development plans and information about flood risk should become a standard part of local authority searches that are carried out by prospective property purchasers. In France, zoning is tied to insurance; in theory, integrated catchment planning has been introduced in the forms of SDAGE (general water catchment basin plans-Schémas directeur d'aménagement et de gestion des eaux) and SAGE (sub-catchment management plans-Schémas d'aménagement et de gestion des eaux). Selected land use planning mechanisms from North America, Europe, Asia, and the Caribbean are described in Box 11.2.

Land use planning can be used to serve a broad range of purposes, some of which are co-beneficial, but others of which are in conflict with each other. For example, reducing storm and flood damage by mapping flood zones and restricting development can be compatible with environmental and recreational agendas by creating natural spaces and parkland. On the other hand, zoning for commercial or residential development can enhance a community's tax base, and diversify and increase its economic base, but may ultimately increase vulnerability to extreme events.

These different agendas or needs can all be valid to a community and require a zoning process that considers multiple stakeholders to trade-off costs and benefits. Of importance is the issue of who benefits and who pays the costs. If there is no connection between these two items, as is often the case, then the decision-making process can be distorted by imbalances in power or access to power and socioeconomic status among the various stakeholders. The nature of the political system becomes critical at this point. The degree to which it is egalitarian, corrupt, or transparent will have a large bearing on the outcome, as will cultural biases toward structural versus nonstructural solutions to hazards.

Urban settlements can be particularly vulnerable to floods and storms, and need careful spatial planning. Examples of Dhaka, Bangladesh, and Toronto, Canada, stress this need.

The location of the city of Dhaka—the capital of Bangladesh—has made it particularly vulnerable to floods. It is surrounded by the Buriganga to the south, the Turag to the west, the Tongi Khal to the north, and the Balu to the east. Dhaka and its adjoining areas are composed of alluvial terraces of the southern part of the Madhupur tract and low-lying areas of *doab* of the rivers Meghna and Lakhya. The city suffered from flooding mainly due to spillage from the surrounding rivers. Local rainfall often complicates the flooding situation. Although the city was periodically flooded, adaptation and coping mechanisms are not well documented. Some initiatives, however, were taken in the wake of disastrous flooding in 1988 and 1998 (Huq and Alam 2002; Jahan 2000). During the floods of 1988 and 1998, Dhaka was severely affected. In 1998, a catastrophic flood hit the greater Dhaka area during the months of August and September. About 56% of greater Dhaka was submerged, affecting about 1.9 million

BOX 11.2

Selected Land Use Planning Mechanisms from around the World

- Construction along or near the *Florida* coastline is governed by the Standard Building Code or the National Flood Insurance Program. Compliance with these codes makes individuals and businesses within the communities eligible to purchase flood insurance. In the 1980s, Florida reinforced the stipulations contained in the building code and insurance program by establishing the Coastal Construction Control Line, which defines specific areas along the coastline that are subject to flooding and erosion etc. The CCCL was adopted throughout Florida between 1982 and 1991 and reflects storm impact zones over a 100-year period. Distinctions were made between two categories of structures based on the CCCL regulations: (1) structures located seaward of the CCCL that were built prior to enactment of the CCCL regulation were categorized as nonpermitted structures at risk of sustaining hurricane damage; and (2) structures built after the adoption of the CCCL require a special building permit to certify that the builder will adhere to a more rigid set of building standards designed to reduce the risk of structural damages that can be sustained during a hurricane.
- *New Brunswick, Canada,* completed a re-mapping of the entire coast to delineate the landward limit of coastal features. The setback for new development is defined from this limit. Some other provinces have adopted a variety of setback policies, based on estimates of future coastal retreat.
- In *Barbados,* a national statute establishes a minimum building setback along sandy coasts of 30 meters from the mean high-water mark; along coastal cliffs the setback is 10 meters from the undercut portion of the cliff. In *Aruba and Antigua,* the setback is established at 50 meters inland from the high-water mark.
- A Coastal Zone Management Plan in *Sri Lanka* identifies setback areas and no-build zones. Minimum setbacks of 60 meters from mean sea level are regarded as good planning practice.
- In the *United Kingdom,* the House of Commons in 1998 endorsed the concept of managed realignment as the preferred long-term strategy for coastal defense in some areas.
- In the United States, the states of *Maine, Massachusetts, Rhode Island,* and *South Carolina* have implemented various forms of rolling easement policies to ensure that wetlands and beaches can migrate inland as sea level rises.
- Several states in *Australia* have coastal setback and minimum elevation policies, including those to accommodate potential sea-level rise and storm surge. In South Australia, setbacks take into account the 100-year erosional trend plus the effect of a 0.3 meter sea-level rise by 2050. Building sites should be above storm surge flood level for the 100-year return interval.

people. The economic damage caused by the flood was estimated to be $10–20 million (JICA 1990).

Important nonstructural measures include flood forecasting and warning, retention ponds, natural water bodies and a drainage network, land use planning, and relief and rehabilitation. Dhaka used to have many natural water bodies, which functioned as a buffer for floodwaters. Over the years, natural water bodies dwindled markedly due to public encroachments on land. Virtually no natural water bodies are left in the old part of the city. In addition, encroachments are going on even in the new upscale residential areas—Gulshan, Banani, and Baridhara. The minimum standard for retention pond is 12% of the urban areas, but at present, the amount retained is estimated to be less than 4% (RAJUK 1995). The government has recently issued a decree banning the filling in of any wetland for urban development (Huq and Alam 2002).

Hurricane Hazel struck the city of Toronto, Canada, on October 15, 1954, with 183 millimeters of rain swelling local rivers. In the ensuing flash flood, 81 people were killed and thousands were left homeless. A comprehensive mitigation plan would provide for the construction of dams and reservoirs, structural control of river channels, improved flood forecasting, land expropriation, and changes in land use zoning in the floodplains. The mitigation plan was to cost $35 million dollars, divided between the federal, provincial, and local governments. Four of the proposed 13 dams were constructed and 844 square kilometers of floodplain were zoned to prevent future development. Emphasis of mitigation was on expropriating floodplain land from residents, thus reducing the amount of money available to build dams. Opponents of the dams argued that if floodplain land was returned to the river, it would be unnecessary to build dams, whereas, proponents argued that the construction of dams would allow more development of the floodplain. Hurricane Hazel would become the foundation of the Toronto area's flood management plan, the structural controls used would create some new habitats and destroy others, but the removal of development on the floodplain would be the most beneficial and enduring flood control initiative.

11.4 Lessons Learned and Key Research and Policy Issues

Based on the assessment of responses in the previous section, the main lessons learned and the issues to be considered in development of future responses are summarized here.

11.4.1 Substitutability

The two issues related to protection and restoration of ecosystems are: (1) the degree to which the technologies can substitute for ecosystems services, and (2) whether ecosystem restoration can re-establish not only the functions of direct use of value to humans, but also the ability of the systems to cope with future disturbances.

Moberg et al. (2003) address these two issues in their study on a number of attempts at substitution and restoration of tropical coastal "seascape" ecosystem (which generally includes a patchwork of mangroves, seagrass beds, and coral reefs); these attempts include such things as artificial reefs, aquaculture in mangroves, and artificial seawalls. They write, "Substitutions often imply the replacement of a function provided free by a solar powered, self-repairing resilient ecosystem, with a fossil fuel-powered, expensive, artificial substitute that needs maintenance. Further, restoration usually does not focus on large-scale processes such as the physical, biological, and biogeochemical interactions between mangroves, seagrass beds, and coral reefs." (p. 27) They conclude that ecosystems services cannot be readily replaced, restored, or sustained without extensive knowledge of the dynamics, multifunctionality, and interconnectedness of ecosystems. Nonetheless, they do acknowledge that restoration might be the only viable management alternative when the system is essentially locked into an undesired community state (stability domain) after a phase-shift.

Post-flood evaluations recommend that risk management plans be made more effective in reducing adverse consequences for human health and well-being, and that they take into account the multiple ways by which floods and storms can affect populations. Yet recent flooding events demonstrate that better preparation is needed, that lessons learned are not consistently applied, and that long-term solutions need to be found for effective floodplain management in the context of a changing climate.

11.4.2 Linkages among Ecosystem Services

What are the conflicts and trade-offs that emerge when ecosystems provide multiple services? For example, the ecosystems that provide flood and storm protection are also important for other services including food and fiber, fresh water, and so on. What are the challenges for management in trying to accommodate conflicts between services? At the micro level, studies have explored the potential value of benefit-cost evaluation for stormwater quality management decisions at a local level in an urban setting such as Los Angeles; a study by Kalman et al. (2000) demonstrates the economic limits of uncoordinated institutional management at the local or individual level and attests to the value of coordinated basinwide management. Macro-level studies offer valuable lessons for flood and storm management for other regions of the world; for example, Gren et al. (1995) conducted a study on economic valuation of the Danube floodplains, which are shared by several countries and provide a complex ecosystem with various habitats or biotopes. Lessons of these assessments are valuable.

11.4.3 Conflict between Short- and Long-term Objectives

Conflicts between short- and long-term objectives involve reducing immediate impacts versus maintaining long-term stability and function. Since floods and storms are part of the natural disturbance regime, they may be considered to be important for long-term ecosystem function.

11.4.4 Institutional Issues

In practice, the actual provision of flood and storm protection is often the responsibility of a number of different actors working at different levels—local, regional, national, and transnational. These institutional settings not only affect the delivery of the services, but also the manner in which they are delivered as well as the direct and indirect effects on ecosystems.

11.4.5 Climate Change

Another issue to be considered is the potential implications of climate change for the underlying hydrometeorological processes responsible for floods and storms, and the consequent implications for response and management strategies. Using a full range of 35 SRES scenarios based on a number of climate models, the IPCC has projected an increase in global mean temperature between 1990 and 2100 of s 1.4 −5.8 Celsius. Over the same period, the global mean sea level has been projected to increase by 9–88 centimeters (IPCC 2001). Table 11.6 shows IPCC's assessment of flood and storm-related changes under three different variables: (1) climate and atmospheric systems; (2) terrestrial systems; (3) economic and social systems.

The IPCC reported a statistically significant 2% change in global land precipitation in the last century but it was not uniform in spatial and temporal scales. Schönwiese and Rapp (1997) reported a significant increase in precipitation over Central and Northern Europe and western Russia. These trends were reflected in the discharge of the Rhine river. Engel (1995) reported

Table 11.6. Flood-related Variables Listed in the Third Assessment Report of the Intergovernmental Panel on Climate Change (Kundzewicz and Schellhuber 2004)

Climate and Atmospheric Systems	Terrestrial Systems	Economic and Social Systems
Total precipitation	River discharge and stage	Anthropogenic pressure
Intense precipitation events	Water storage and capacity	Adaptive capacity
Wind intensity	Runoff coefficient and infiltration capacity, portion of impervious area	Vulnerability
Seasonal distribution and climate variability (e.g., ENSO)	Impacts on ecosystems	Measures of flood losses
Sea level		Risk perception

a rising tendency of the maximum annual discharge of the Rhine at Cologne over the last 100 years. Seasonal (autumn and winter) precipitation increases were observed in the mid- and high-latitudes of the Northern Hemisphere (Kundzewicz and Schellnhuber 2004). Increases in "heavy and extreme" precipitation events were also reported from some regions where total precipitation had either decreased or remained the same (Kundzewicz and Schellnhuber 2004).

Increased precipitation could mean increased flash floods and seasonal floods, but not necessarily uniform over all regions of the world (WMO and GWP 2003). A number of studies were carried out in various regions to examine the possible effects of climate change on flood magnitude, frequency, and extent. Reynard et al. (1998) estimated changes in the magnitude of floods of different return periods in the Thames and Severn catchments in the United Kingdom. They concluded that increases in flood magnitude were due to increases in winter precipitation. Total volume of rainfall (not the peak intensity of rainfall), over several days played a major role in the flood processes in these large catchments.

Schreider et al. (1996) also reported increases in flood risk in Australia under the wettest rainfall scenarios. Using scaled precipitation change scenarios for four climate models Mirza (2002), in a study on climate change and changes in the probability of occurrence of floods in Bangladesh, concludes that climate change caused by the enhanced greenhouse effect is likely to have considerable effects on the hydrology and water resources of the Ganga, Brahmaputra, and Meghna basins and might ultimately lead to more serious floods in Bangladesh. Nicholls (1999) estimated that sea-level rise could cause the loss of up to 22% of the world's coastal wetlands.

Different kinds of responses are expected to address increased precipitation and flooding. First, modifications of design standards for future flood control/mitigation structures are required. The U.K. government has initiated flood risk management schemes in the context of climate change, and has recommended examining the effect of a probable 20% increase in flood flows. For coastal schemes, the allowance required for anticipated increases in sea level is 5 millimeters per year, which is IPCC's business-as-usual projection for the current century (DEFRA 1999, 2003). However, in many developing countries, such kinds of actions may be constrained by economic principles and available resources (WMO and GWP 2003). Second, strengthening of flood forecasting and warning system based on present vulnerability is required. Third, mapping of the vulnerable areas and associated risks should be carried out. It is likely that vulnerability may expand to new areas/settlements. Fourth, land use planning based on vulnerability maps and future socioeconomic and demographic scenarios needs to be implemented.

11.4.6 Information Failure

Turner et al. (2000), in a study on wetlands management policy, illustrate that information failure is one of the chief reasons that wetlands over the world have been lost or are threatened. The other reasons for loss of wetlands are all related to information failure; they include the public goods nature of many wetlands products and services; user externalities imposed on other stakeholders; and policy intervention failures (because of a lack of consistency among government policies in different areas). They suggest a need for integrated research combining social and natural sciences to solve (in part at least) the information failure problem. An integrated research framework combining economic valuation, integrated modeling, stakeholder analysis, and multicriteria evaluation could provide complementary insights into sustainable and welfare-optimizing ecosystem management and policy.

11.5 Conclusion

Floods and storms can cause enormous economic, social, and human losses. However, they also generate beneficial effects. In the past, structural methods of flood and storm control received priority. At present, nonstructural measures including the use of the natural environment are being emphasized to reduce vulnerability as well as economic losses. The application of integrated flood and storm management approaches can maximize social, economic, and ecosystem benefits.

Note

1. The time of concentration is the time taken by a drop of water to travel from the furthest hydrologic point in a basin to the point of discharge. Determination of the time of concentration is the summation of the individual hydraulic travel times from each section of a subdivided basin. t_c = Tt. The travel time is a function of the flow conditions, surface roughness, and the topography.

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