On May 22, 1960, an earthquake off the coast of Chile triggered a tsunami that travelled across the Pacific Ocean, causing damage in many places. This may have been the most destructive tsunami in recent history; it killed more than 2,000 people in Chile, Hawaii, the Philippines, and Japan. The destruction was greatest along the Chilean coast, with coastal deformation extending from 38°–43° south latitude. In some places, the ground was lifted up by 1 to 2 meters; in other places it sank about 2 meters. With three large waves, the tsunami struck the coast about 15 minutes after the earthquake. Inundation caused a great deal of damage. More than 900 people were killed, and more than 800 were reported missing. The tsunami reached the coast of Japan some 22 hours later, killing more than 100 people, washing away or flooding thousands of homes, and sinking or damaging hundreds of ships.

Tsunami Protection

Some measure of protection against tsunamis is afforded by the construction of sea walls and by land use practices that keep valuable property and residential housing out of susceptible coastal areas. However, the most effective approach toward saving lives is the issuance of tsunami warnings as a basis for evacuation of threatened areas. Such a warning system for the entire Pacific basin is operated by the U.S. National Weather Service. Warnings are based on seismometers that detect earthquakes and tide gauges that detect tsunami waves. Tsunamis originate near the epicenters of the earthquakes that cause them, and travel outward in all directions at speeds that depend on the depth of the water. The seismic data indicate the time and location of earthquakes; the tide data indicate where tsunamis are actually occurring. This system has made it possible for most of the Pacific countries to receive warnings of tsunamis several hours in advance.

TROPICAL CYCLONES

Tropical cyclones are large, rotating, migratory storms that form over the tropical oceans. Tropical cyclones are called hurricanes in the Atlantic, Caribbean, and eastern Pacific; typhoons in the western Pacific; cyclones in the Indian Ocean; baguios in the Philippines; cordonazos in Mexico; and tainos in Haiti. Their characteristics are lifetimes of 1–2 weeks, winds in excess of 75 miles per hour, heavy rain, and a storm tide or surge that floods coastal areas and causes more death and destruction than either the wind or the rain. Although tropical cyclones have certain common characteristics, there are many variations, and the tracks of some individual storms have taken twists and turns that bedevil weather forecasters, sometimes even travelling in a loop and returning to a location previously struck.

Tropical cyclones occur in certain parts of the world at certain times of the year. They usually occur between 5° and 30° latitude in both the northern and southern hemispheres, in the western Pacific and Indian Oceans, and north of the equator in the eastern Pacific Ocean, the Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico. They do not occur in the south Atlantic. They occur primarily during the late summer months, although they may occur in the western north Pacific at any time of year.

Tropical cyclones may be the most destructive of all natural disasters. They kill large numbers of people, primarily by drowning, destroy houses and other structures, disrupt agriculture and destroy crops, and in many small, poor countries significantly disrupt the national economy.

About 15% of the world's population is exposed to tropical cyclones, including persons residing in the southeastern United States, the Caribbean, Japan, Southeast Asia, the Philippines, South China, India, and Bangladesh.

Examples of Tropical Cyclones

On at least eight occasions during the past 25 years, tropical cyclones in the Indian Ocean and Bay of Bengal have killed more than 10,000 people. The most catastrophic of these events was the tropical cyclone that struck Bangladesh in 1970, killing between 250,000 and 500,000 people. Tropical cyclones in the Atlantic and Caribbean are not as big killers; among the most destructive of these were the hurricane that hit Galveston, Texas, in 1900, killing more than 5,000 people, and the hurricanes that struck Dominica and the Dominican Republic in 1979, killing more than 1,000 people.

On November 12, 1977, a tropical cyclone that originated in the Bay of Bengal struck the central coast of Tamil Nadu in southern India with winds of 60–70 miles/hour. The number of casualties was limited, apparently because people had heeded warnings and fled to high ground, but much of the region's irrigation system was destroyed. Seven days later, on November 19, a second tropical cyclone, which had been expected to hit Tamil Nadu, struck the central coast of Andhra Pradesh some 500 miles distant. Here many people perished, apparently because the warnings were too slowly or narrowly disseminated. On November 22–23, the storm that had hit Tamil Nadu 10 days earlier crossed the Indian peninsula into the Arabian Sea, became stronger, and turned landward again. On November 23, it moved northward along the western coast of India, causing damage in northern Kerala and the Lakshadweep Islands, although the damage and loss of life were less than in Tamil Nadu and Andhra Pradesh. The official combined toll for these storms was nearly 10,000 dead and more than 4,000 missing; unofficial reports claimed that there were more than 25,000 dead and more than 5 million homeless. More than 3.5 million acres of crops, 23,000 cattle and sheep, and 5,000 poultry birds were lost, and damage was done to irrigation works, roads, railroads, power and communication networks, and more than 1.4 million houses.

The damage in Andhra Pradesh was caused primarily by a storm surge 19 feet high, moving at 120 miles/hour as it hit the coast, that devastated 65 villages. The factors that combined to form this dangerous tidal wave were the low-lying flatness of the land, the gentle slope of the sea floor, the concavity of the coastline, and the fact that the storm struck when the tide was already high. Normally in this area, the heavy rains of tropical cyclones cause flooding upstream, which brings topsoil to the river deltas, making them fertile and inducing people to move into those areas for agriculture. That is what happened in Tamil Nadu. In Andhra Pradesh, however, the coastal and delta areas were flooded by sea water, which left saline silt on fields and in wells. This not only made agricultural reclamation necessary, but rendered housing reconstruction difficult because salinized mud would not hold together.

Characteristics of Tropical Cyclones

Tropical cyclones are cyclonic spirals, anywhere from 100–300 miles in diameter. The winds form a vortex which spirals inward toward a calm area near the center, called the eye, where the atmospheric pressure is extremely low. Because of the earth's rotation, in southern hemisphere storms, the winds blow clockwise around the center, while in northern hemisphere storms they blow counter-clockwise around the center. The storms typically move westward during the early portions of their lives and then curve toward temperate latitudes, although there is considerable variation. Although the peak winds in these storms may exceed 120 miles/hour, the storms themselves move slowly, generally in the range of 5–15 miles/hour. The cloud systems associated with tropical cyclones may extend as high as seven miles or more, and the rainfall rates may be as great as 1–2 inches/hour. The strongest winds and heaviest rains usually occur 10–30 miles from the storm center, but clouds, wind, and rain associated with the storm may be detected as far as 300 miles from the center.

Tropical cyclones draw their energy from the warm, tropical oceans. They tend to occur in the late summer, when evaporation and conduction transfer heat from the hot ocean to the air so effectively that air and water temperatures seldom differ by more than 1° Fahrenheit. Hurricanes in the Atlantic and Caribbean typically begin as low pressure centers off the coast of Africa, westward migrating storms that may have originated as African thunderstorms. Some Atlantic hurricanes, and many Pacific typhoons and Indian Ocean cyclones, develop from low pressure centers in the equatorial trough, the calm, cloudy doldrums that separate the tradewinds of the northern and southern hemispheres. As the storm develops, when winds begin to form a vortex, it is first called a tropical depression. When the maximum sustained winds reach gale force (40 miles/hour), it becomes a tropical storm; finally, when the winds reach 75 miles/hour, it is a tropical cyclone. Not all of these disturbances develop into full-fledged storms. In fact, fewer than 10 of the more than 1,000 incipient waves tracked each year in the Atlantic evolve into tropical storms or tropical cyclones. Even among the storms that are classified as tropical cyclones, there is considerable variation, from relatively small, weak storms with winds around 75 miles/hour to more severe storms with peak winds approaching 150 miles/hour. The intensity of the storm is often characterized by the Saffir-Simpson scale (Table 14-3), which includes five categories of tropical cyclones ranging from those that do relatively little damage to those that cause widespread destruction. While the storms are far out at sea, their primary hazard is to shipping. When they approach land, the real disaster potential emerges.

When a tropical cyclone strikes the coast, it causes death and damage in three ways. High winds can tear roofs from buildings and smash vulnerable structures (Figure 14-4). Heavy rains can produce devastating floods, particularly if the rain reaches into hilly terrain where flash floods may result. Runoff from the intense rainfall can accumulate quickly in narrow valleys and flow rapidly downstream, causing local flooding and carrying high concentrations of sediment and debris. Tidal flooding can also occur along the coast when floodwaters are joined by wind-driven ocean waves, especially when the tide is already high.

Frequently, the major destructive agent in a tropical cyclone is the storm surge, the abnormally high tide generated by the storm independent of the rain. As a tropical cyclone approaches land, low atmospheric pressure at its center causes sea level to rise, perhaps by as much as 3 feet in a severe storm. The storm's strong winds, together with waves and swells, transport water toward the coast and pile it along the shore, contributing another few feet of elevated sea level. Friction along the sea bottom, the shape of the coastline, the angle and speed with which the storm crosses the coast, and the normal tide on which all this is superimposed contribute to determining the ultimate height of the surge, which in extreme cases may be several tens of feet above normal sea level.

If the storm is strengthening, its winds will have an increasingly greater effect on the water, causing larger waves and swells. While the storm is some distance from the coast, countercurrents beneath the ocean sur-

Table 14-3. The Saffir/Simpson Hurricane Scale*

Scale No. 1: Winds of 74 to 95 miles per hour. Damage primarily to shrubbery, trees, foliage, and unanchored mobile homes. No real damage to other structures. Some damage to poorly constructed signs. And/or: storm surge 4 to 5 feet above normal. Low-lying coastal roads inundated, minor pier damage, some small craft in exposed anchorage torn from moorings.

Scale No. 2: Winds of 96 to 100 miles per hour. Considerable damage to shrubbery and tree foliage; some trees blown down. Major damage to exposed mobile homes. Extensive damage to poorly constructed signs. Some damage to roofing materials of buildings; some window and door damage. No major damage to buildings. And/or: storm surge 6 to 8 feet above normal. Coastal roads and low-lying escape routes inland cut by rising water 2 to 4 hours before arrival of hurricane center. Considerable damage to piers. Marinas flooded. Small craft in unprotected anchorages torn from moorngs. Evacuation of some shoreline residences and low-lying island areas required.

Scale No. 3: Winds of 111 to 130 miles per hour. Foliage torn from trees; large trees blown down. Practically all poorly constructed signs blown down. Some damage to roofing materials of buildings; some window and door damage. Some structural damage to small buildings. Mobile homes destroyed. And/or: storm surge of 9 to 12 feet above normal. Serious flooding at coast and many smaller structures near coast destroyed; larger structures near coast damaged by battering waves and floating debris. Low-lying escape routes inland cut by rising water 3 to 5 hours before hurricane center arrives. Flat terrain 5 feet or less above sea level flooded inland 8 miles or more. Evacuation of low-lying residences within several blocks of shoreline possibly required.

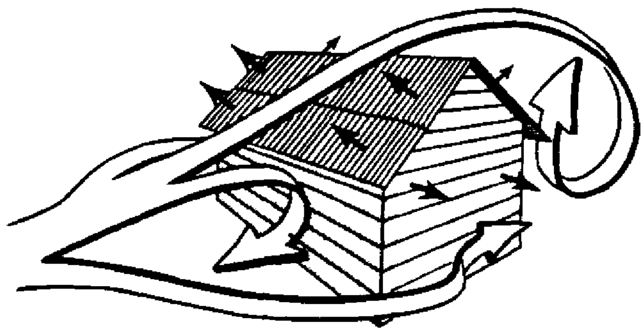
Scale No. 4: Winds of 131 to 155 miles per hour. Shrubs and trees blown down; all signs down. Extensive damage to roofing materials, windows, and doors. Complete failure of roofs on many small residences. Complete destruction of mobile homes. And/or: storm surge 13 to 18 feet above normal. Flat terrain 10 feet or less above sea level flooded inland as far as 6 miles. Major damage to lower floors of structures near shore due to flooding and battering by waves and floating debns. Low-lying escape routes inland cut by rising water 3 to 5 hours before hurricane center arrives. Major erosion of beaches. Massive evacuation of all residences within 500 yards of shore possibly required, and of single-story residences on low ground within 2 miles of shore.

Scale No. 5: Winds greater than 155 miles per hour. Shrubs and trees blown down; considerable damage to roofs of buildings; all signs down. Very severe and extensive damage to windows and doors. Complete failure of roofs on many residences and industrial buildings. Extensive shattering of glass in windows and doors. Some complete building failures. Small buildings overturned or blown away. Complete destruction of mobile homes. And/or storm surge greater than 18 feet above normal. Major damage to lower floors of all structures less than 15 feet above sea level within 500 yards of shore. Low-lying escape routes inland cut by rising water 3 to 5 hours before hurricane center arrives. Massive evacuation of all residential areas on low ground within 5 to 10 miles of shore possibly required.

* Source: National Oceanic and Atmospheric Administration, *Tropical Cyclones of the North Atlantic Ocean, 1871–1977*, National Climatic Center, Asheville, North Carolina, 1978, page 25.

face may offset any tendency for winds and waves to cause an elevation in sea level. Where the coastline is straight or convex, the storm surge may be distributed over a large area. Where the coastline is concave, as in a semi-enclosed bay, water forced into the shore may be trapped and the sea level elevation be much greater than along the open coast. A storm approaching the coast on a perpendicular path can produce a much higher surge than a storm moving parallel to the coast, but the surge will affect a smaller stretch of coastline. Moreover, since the winds are spiraling around the storm center, the winds on one side of the storm will be blowing water toward the shore while on the other side they will be blowing water away from the shore; as a consequence, the height of the surge can vary considerably within the region where the storm strikes. Finally, a storm that strikes when the normal tide is high will have a more severe impact than one that strikes when the tide is low. In some locations, the variation between high tide and low tide is not great. In other places, the difference may be many feet, and may also vary in the course of the year. If landfall of a tropical cyclone coincides with a very high tide, the result can be devastating, particularly if the normal tide alone would be enough to flood portions of the coast.

A



B

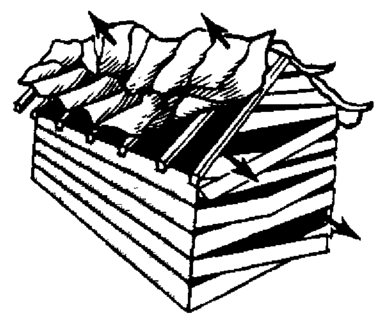


Figure 14-4. How high winds damage buildings. (A) Wind blowing into a building is slowed at the windward face, creating high pressure. The air flow separates as it spills around the building, creating low pressure or suction at end walls, roof and leeward walls. (B) The roof may lift off and the walls blow out without special reinforcement to the structure. (U. WI. DMC)

The impact of the storm surge depends heavily on the topography of the land. If the coastal strip is narrow and changes quickly to foothills, flooding may be extreme within the narrow coastal strip, but the population will not have to travel far to reach high ground. If, however, the land is flat for a considerable distance inland, much of it is likely to be flooded and many people are likely to be trapped and drowned.

Once the storm crosses the coast and is no longer over the warm waters from which it draws energy, it frequently weakens rapidly. For this reason, most severe damage caused by tropical cyclones is usually confined to the coastal regions. There are exceptions; the heaviest loss of life associated with Hurricane Camille in the United States in 1969 was caused by flash floods and debris flows caused by the storm's heavy precipitation in hilly portions of Virginia, well inland from the coast.

The places that are most vulnerable to tropical cyclones are located where tropical cyclones tend to be most severe and where large amounts of low-lying land are found on islands and adjacent to closed and semi-enclosed bays facing the ocean. These include portions of Japan, China, India, Bangladesh, Mexico, the West Indies, and the southeastern United States. Vulnerability is increased when there are insufficient transportation facilities to permit evacuation of threatened populations, when highways that would be used for evacuation are too close to the sea surface, or when communication systems are inadequate for quick dissemination of warnings. There is concern for the loss of life that would be sustained if a major storm were to strike any of the resort beach areas located on barrier islands off the coast of the United States, where there are far too few bridges to the mainland to permit complete evacuation of the threatened population.

Predicting and Forecasting Tropical Cyclones

Attempts to forecast tropical cyclones date to the nineteenth century. Indications that a storm is approaching have been taken from such signs as falling atmospheric pressure, changeable winds, erratic tides, unusual sea swells, and microseismic tremors.

There is an international weather observing system known as the World Weather Watch, operated under the leadership of the World Meteorological Organization. The system draws on stations all over the world, including 8,500 land stations, 5,500 merchant ships, several special ocean weather ships, and automatic weather stations in remote locations, as well as on aircraft and weather satellites. Incipient tropical cyclones usually first appear on satellite pictures. They are monitored using all available sources, and may ultimately be tracked by reconnaissance aircraft. The resulting information is made available to all countries, and conversion of this information to specific forecasts and warnings is the responsibility of national weather services.

This excellent observational network, in conjunction with the relatively slow speed with which tropical cyclones move, makes it possible to inform the public of the latest position of a tropical cyclone and its likely path over the next 5–10 hours. Forecasts of the storm's position 24 hours ahead are typically in error by about 100 miles, and the error of a 48-hour forecast is about double that. For longer periods, the error increases considerably. The significance of precise forecasting of tropical cyclones is that often the only effective step to take to protect the local population is evacuation. Evacuation takes time, and if the wrong population is evacuated, the results can be disastrous. To evacuate on the basis of a 48-hour forecast that may be in error by 200 miles is risky; to wait until the forecast is likely to be accurate to within 25 miles may not leave sufficient time for evacuation.

In addition to forecasting the storm's movement, it is helpful to forecast winds, rainfall, and storm surges, in order to predict the total amount of flooding.

Rainfall is nearly always heavy in a tropical cyclone and may total as much as 3–12 inches during a one- or two-day period. Total rainfall can vary considerably between storms. In mountainous countries, the rainfall can be particularly heavy. Japanese and Chinese records frequently show more than 24 inches of rain during the passage of a typhoon over large areas in the mountains. Forecasts of the time of onset, intensity, and duration of rainfall are essential to flood forecasting. This is both a meteorological and hydrological challenge. Where the elapsed time between heavy rain and flooding is short (for a city within the watershed or a small island with a mountainous interior), the flood forecast must be based entirely on the rainfall forecast. For a longer, elapsed time where the water flows downstream for many hours or even for days before doing damage, flood forecasting is based mainly on the analysis of stream flow measurements at successive points along the river, together with the accumulated total of rain that has already fallen and the actual water level within rivers.

Forecasting of storm surges is largely based on empirical methods. Computer models of storm surges have been developed, but they usually have to be carefully tailored to specific locations and are still being refined and assessed. Much research is under way to develop dynamic models that will provide numerical predictions to supplement empirical formulas. Whatever approach is used, it is essential to have an adequate information base concerning the local topography and bathymetry, tide data, and historical climatic data concerning past storm surges and winds associated with tropical cyclones.

Warnings and Warning Response

The most effective actions that can be taken in response to a warning of a tropical cyclone are evacuation of people and protective storage of valuable property. Successful evacuation requires considerable prior planning and coordination of warning systems and evacuation plans. It has proven practical and effective in the United States, as in the case of Hurricane Betsy in 1965, when 300,000 people were evacuated and only 75 lives were lost. In the U.S., warning systems are highly developed, as 2 million people are reached promptly by the typical warning. Despite this, it is not always successful; some coastal residents of the area hit by Hurricane Camille in 1969 did not evacuate, apparently because they underestimated the potential destructiveness of the storm. Evacuation has so far proved impractical in countries like Bangladesh, where communications and transportation facilities are poor, where the radio station may be off the air during critical hours of the night, and where local attitudes and motivation are not conducive to taking the appropriate actions when a warning is received.

With the present capabilities for forecasting tropical cyclones, "overwarning," or issuing a warning to a broader area than will actually be affected, must be expected. The extent of overwarned area depends on the precision of the forecast, and is likely to be greater in countries where there are less data, more widely spaced weather stations, and less sophisticated forecasting techniques.

The current international warning system recognizes two levels of warning. When the forecast indicates that a tropical cyclone will strike land within 48 hours, a "cyclone warning" is issued. This signals agencies involved in disaster preparedness to undertake preplanned steps in anticipation that the cyclone will strike. When the storm is within 24 hours of landfall, a "cyclone watch" is issued. This marks the beginning of the emergency response period during which appropriate operations, including evacuations, are undertaken. This use of the terms "warning" and "watch" is different from the usage with regard to tornadoes and severe thunderstorms in the United States, where "watch" refers to the alerting stage and "warning" to the imminent stage.

For many nations, the present international warning system is inadequate. Some of the island nations of the south Pacific are spread out over enormous distances, with outer islands isolated from radio contact with a potential warning issuer. A 48-hour warning may be inadequate for some people and industries. The fishing industry may need more than 48 hours warning to allow all fishing boats to reach safe harbors; cement plants may need 3 or 4 days to shut down operations and protect equipment.

The Disastrous Impact of Tropical Cyclones

The most serious immediate consequence of tropical cyclones is loss of life. Between 1960 and 1970, 17 major tropical cyclones killed more than 300,000 people. The death rate is significantly higher where communications are poor and warning systems and evacuation plans are inadquate. The number of deaths is likely to increase as population pressures force more and more people into vulnerable locations, such as low-lying agricultural areas and overcrowded slums in coastal cities.

Damage to buildings is caused primarily by wind. Few buildings are blown over; buildings are pulled apart by winds moving swiftly around and over them, lowering air pressure on the outside and creating suction so that the building virtually explodes. It is a common belief that heavier buildings, such as those made of concrete block are safer, simply because the materials are stronger. While it is true that a well built and properly engineered block house offers a greater margin of safety than other types of buildings, safe housing can be and has been provided using a variety of materials.

Tropical cyclones destroy and damage public infrastructure, food supplies, and food distribution systems. They may destroy or damage facilities that are critical not only for responding to disasters, but for maintaining a safe environment and public order, such as communication installations, electric power generating and transmitting facilities, water storage, pumping and purifying facilities, sewerage treatment facilities, hospitals, and police and fire stations. Towers and transmission lines may fall as a result of resonance from high winds. Large buildings may be damaged by wind resonance, flying debris, or erosion that undermines their foundations. Transportation facilities such as roads, bridges, railways, airports, and seaports may be damaged by high winds and flooding.

Tropical cyclones disrupt agriculture and destroy crops. High winds destroy standing crops, especially grains, and damage orchards and forests. Flooding from intense rain damages certain crops, especially tubers, and may cause excessive erosion. Storm surges scour and erode topsoils, deposit salts on fields, and may increase the salinity of subsurface water. Access to markets for buying and selling crops may be impeded by damage to roads, bridges, and railways.

Vulnerability to Tropical Cyclones

The vulnerability of a community to tropical cyclones depends on three factors: location in an area prone to tropical cyclones; geography of the immediate vicinity; and degree to which people, structures, and infrastructure are likely to be severely damaged should a cyclone strike. Urban and rural communities on low islands or in unprotected, low-lying coastal areas or river deltas are particularly vulnerable to cyclones. Exposure of land and buildings can affect wind speed at ground level. Irregular terrain, dense housing, and forests tend to slow the wind, while open country, flat seashore, and rolling plains permit very strong winds close to the ground. Some settlement patterns may create a "funnel" effect that increases the wind speed between buildings.

Generally, buildings most vulnerable to tropical cyclones are lightweight structures with wood frames, especially older buildings in which wood has deteriorated and weakened walls. Houses made of unreinforced or poorly constructed concrete block are also vulnerable.

RIVER AND STREAM FLOODS

Flooding is the most universal geophysical disaster. It occurs on all continents where there is rainfall and low lying coastal plains. Every watershed is a potential site for flooding. Every coastline at risk from tropical cyclones or tsunamis is susceptible to flooding.

Of all the natural disasters except droughts, floods affect the most people. The number of people affected by floods is increasing more rapidly than the number affected by droughts. Floods are caused not only by rain, but by human changes to the earth's surface. Deforestation, farming, and urbanization increase runoff from rains; consequently, storms that previously would have caused no flooding today inundate vast areas (Figure 14-5).

People contribute to floods by reckless building in flood-prone areas, poor watershed management, and by failing to control and contain floods. Irrigation of dry lands creates moisture conditions that can produce extensive and heavy rain. This can be particularly important in desert areas where large lakes are built to store water either for irrigation or for use of nearby communities.

Types of Floods

There are two major types of floods: floods in rivers and streams, generally caused by melting of winter snow or intense rainfall, and floods in low lying coastal areas, generally caused by tsunamis or other major

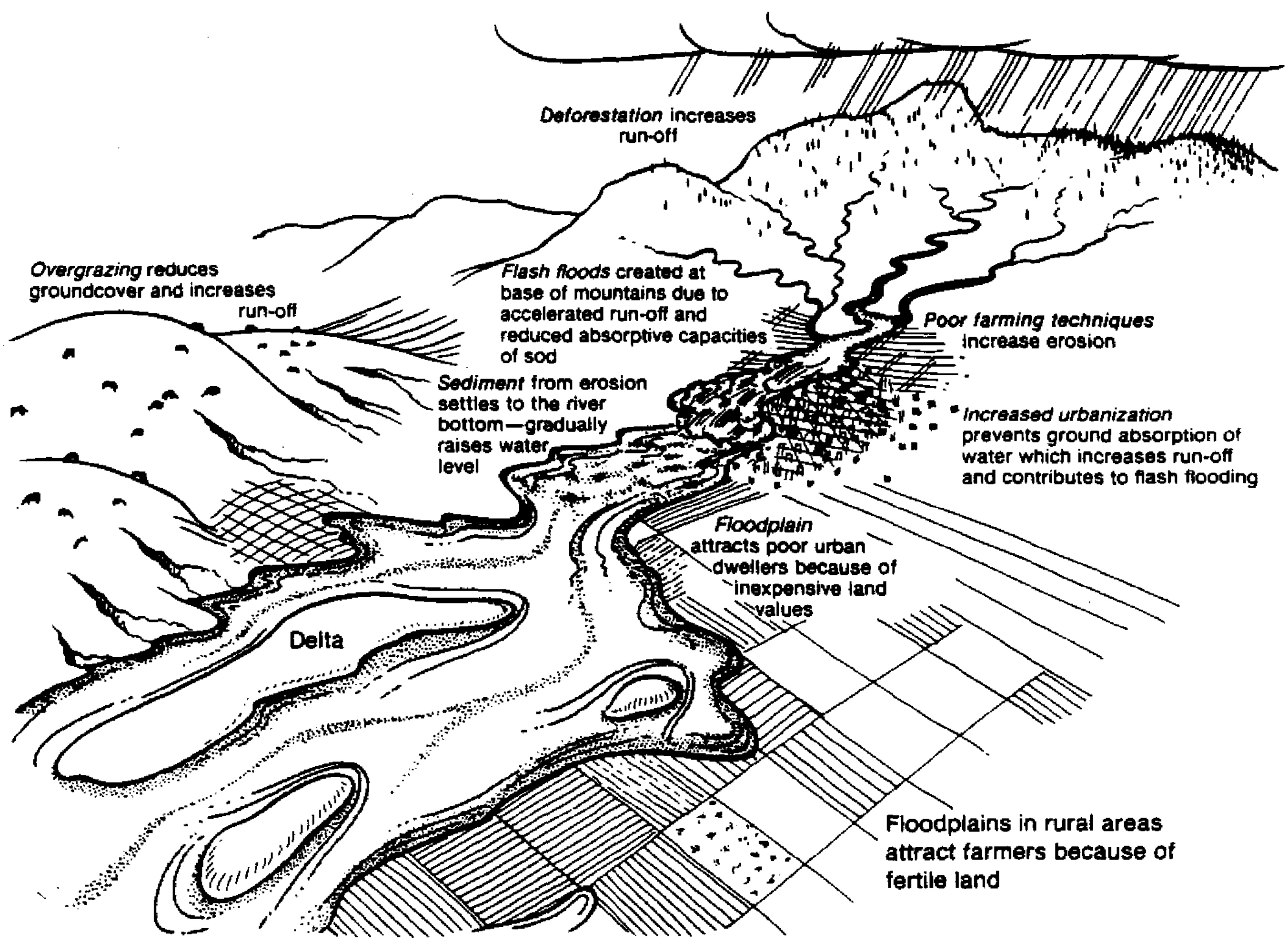


Figure 14-5. Flooding and its causes. (U. WI. DMC)

storms at sea. Coastal river deltas can experience both types, sometimes simultaneously.

Riverine flooding is generally defined as high stream overflow of natural banks or levees. Flooding is a natural characteristic of rivers. Floodplains are an integral part of the river system. These are normally dry land, but can act as natural reservoirs and temporary channels for flood waters. If more runoff is generated than the banks of a stream can contain, water overtops the banks and spills into the floodplain. Floods can also occur in streams that have no floodplain. These are generally narrow streams in mountain canyons, and the floods often occur as flash floods, carrying rocks, soil, and tree branches downstream as a situation analogous to a debris flow. Flooding can occur when abnormally heavy rain falls on flat terrain at such a rate that the soil cannot absorb the water and the water cannot run off.

Flash floods and streamless floods usually occur very quickly during or after a period of heavy rain. Floods characterized by overtopping banks into a floodplain may occur hundreds of miles from the location of rain or snowmelt, and days or weeks may elapse between the initial triggering event and the flood.

Flash flood duration can be minutes or hours. They generally are caused by torrential rain over small and widely dispersed streams. Runoff from the intense rainfall results in high flood waves. Water flows quickly, reaches a peak, and diminishes. Flash floods often carry large concentrations of sediment and debris. Flash floods are particularly common in mountainous areas and desert regions, but are a potential threat wherever the terrain is steep, surface runoff rates are high, streams flow in narrow canyons, and severe thunderstorms are prone to occur.

Riverine floods are caused by precipitation over large areas or by melting of the winter's accumulation of snow, or both. Riverine floods differ from flash floods in their extent and duration. Riverine floods take place in river systems whose tributaries may drain large geographic areas and which may encompass many independent river basins. Floods on large river systems may last anywhere from a few hours to a few days. The size of the catchment area, amount of rain or snowmelt, condition of the ground (presence or absence of snow, ice, and vegetation), presence or absence of an impervious surface (such as paved streets and parking lots), and topography within the watershed all contribute to the speed with which excess water reaches the rivers and, consequently, to the time and depth of flooding. On very large rivers, such as the Nile and the Mekong, the river flow changes slowly in the lower reaches. Floods are usually the aggregate result of many widespread rainfalls with some (often considerable) contribution from snowmelt.

Floodplains

People have long been attracted to floodplains. Rivers deposit topsoil, so the land is fertile. Floodplains are flat and near water, so irrigation, plowing, and transport are easy. Settlements along the lower reaches of Egypt's Nile, India's Brahma-putra, and Iraq's Euphrates are all examples of floodplain civilizations.

Floodplains are desirable places to live, not only in agricultural societies, but also in industrial countries where large cities use the river water for industry, and the river mouth as a seaport.

The floodplain of a river is a clearly definable physical feature of its valley. Floodplains are built up of layers of sediment deposited by the river when it periodically overflows its banks. Steep narrow valleys in mountainous regions have no floodplains, but a complex system of rivers and tributaries in a lowland region may have a floodplain several hundred kilometers wide. There is a natural tendency for a river to deposit sediment in its channel during times of low flow, so that an equilibrium is arrived at wherein the river comfortably fills its main channel under normal conditions and spreads out onto its floodplain during periods of high flow.

Examples of Riverine Floods: Bangladesh and China

Bangladesh is a riverine country where recurrent flooding is common and has agricultural significance. Every year, large areas are submerged during the monsoon season and fertilized by the soil deposited by flood waters. However, if flood water remains stagnant, major disasters can result. This happened during the summer and fall of 1974. when flood waters covered nearly half of the country and remained stagnant for more than a month. More than 1,000 people died as a direct result of the floods, and nearly 30,000 died of subsequent disease and starvation. More than 400,000 houses were destroyed or severely damaged; 36 million people suffered severe hardship, and losses to agriculture were estimated at more than $300 million.

The devastation caused by these floods was the result of more than just a chance act of nature. Neglect and absence of appropriate management were important contributing factors. When the country had been under colonial rule, regular dredging had helped to maintain adequate river depths. After independence, however, dredging was neglected, and the rivers silted up. At the same time, much forest land was cleared without thought to the impact on flooding. Slow environmental degradation over a period of years left Bangladesh virtually defenseless against destructive flooding.

The most devastating effect of the floods was on agriculture. Although agriculture accounts for 60% of the gross domestic product of Bangladesh and employs 80% of the population, the country has not become agriculturally self sufficient. As much as 90% of the 4 million acres flooded were planted with rice. Little could be replaced, since the replanting season had already passed.

Food supply problems were compounded by absence of a buffer stock, lack of foreign exchange, and failure of timely food shipments. Many people who escaped drowning died of starvation.

At the time of the floods, the country was in the midst of a serious balance of payments crisis. Reduced revenues from export of jute coincided with the need for massive imports of food. The result was a severe trade imbalance and marked increase in the national deficit. Per capita income suffered, and distribution of income became more inequitable. The countryside became increasingly impoverished as many small landholders lost both crops and land. The decline in agriculture led to higher levels of unemployment. Masses of destitute rural people moved to the cities, where job opportunities proved equally scarce. In addition. there was a 50% inflation rate, fueled by escalating prices of essential commodities that were in short supply. Thus the floods, in addition to causing loss of life and destruction of property and resources, caused deterioration in the national economy, increased unemployment, and high inflation, disrupting the once moderately equitable nature of Bangladesh society.

The Yellow River in China has the dubious distinction of being responsible for more human deaths than any other single geographic feature on the earth's surface. For nearly 2,500 miles, the river flows through easily eroded loose soils found in the mountains and plateaus of northern China, picking up enormous quantities of silt. The river may contain as much as 40% silt when it reaches Kaifeng. From there, it travels another 500 miles to the sea across the Yellow Plain, which is a massive alluvial fan 500 miles wide, that slopes more steeply than a true river delta and spreads around both sides of the mountains of Shantung. Despite the slope, the river is unable to carry its sediment load, and overflows its banks, depositing silt. The entire plain is made up of these silt deposits.

From Kaifeng, 15 channels radiate across the plain. Each time the river overtops one of them, it causes enormous floods before returning to a single channel. These floods have drowned large numbers of people on the crowded plain, and many more have died from famines due to crop destruction. In three floods since 1887, the Yellow River has killed over 6 million people.

The only flood protection available is a system of levees that were started more than 2,500 years ago. These levees must be constantly raised, and this is all done by hand labor. There is nothing with which to build them except the silt. As a result of constant silt depositing and levee raising, the Yellow River now crosses its plain about 25 feet above the surrounding countryside, between inner and outer levees that form a belt 12 miles wide. Silt is the cause of the problem, for it is continually deposited in the river channel. The river keeps rising to higher levels, and there is no option except to build the levees higher. As a result, the Yellow River now has no tributaries for more than 400 miles, and millions of people live below the river level under constant threat of flooding. There are no hills in the plain, and no escape route in the event of a flood. The average area flooded each year is about 3,000 square miles. Because the plain is below river level, it cannot drain, and some regions remain flooded to the horizon for a year at a time. When a major levee break lets the river escape, it fills a braided course that may be 15 miles for up to 10 years before settling into a new channel.

An Example of a Flash Flood: Big Thompson Canyon

A much smaller scale stream flood that can be a local disaster is the flash flood, which usually results from short-lived, extremely heavy rain within a single watershed that occurs with very little warning. On the night of July 31, 1976, a flash flood occurred in the Big Thompson Canyon in northern Colorado. This is a narrow, scenic gorge that winds eastward toward the plains from the town of Estes Park, at the eastern edge of the Colorado Rockies. The canyon is one of the most scenic in the Rocky Mountain region, and is the main link between the plains and Rocky Mountain National Park. Before the flood, the population of the canyon was about 600 permanent and more than 1,000 part-time residents. There were many tourists attracted by trout fishing, streamside motels, and campgrounds.

On the night of July 31, the canyon was filled with tourists. There may have been a total of more than 2,000 people. The rain began early that evening, and by 11:00 P.M. more than 10 inches of rain had fallen in some areas. (The average annual precipitation in the area is less than 16 inches.) Heavy rain fell over a 70 square-mile area in the central portion of the Big Thompson watershed between 6:30 and 11:00 P.M. The heaviest rain, totalling more than 12 inches, fell on the slopes at the western end of the canyon. Sometime between 7:30 and 8:30 P.M., police began warning people to evacuate. By 9:00 P.M., a disastrous flood was in progress, accompanied by landslides and rockfalls. The swollen river carried huge boulders, uprooted trees, automobiles, and houses. At least 139 people died and 88 others were injured; 316 homes, 45 mobile homes, and 52 businesses were destroyed, and 73 additional mobile homes suffered major damage.

Flood Forecasts and Warnings

Forecasting of riverine floods is based primarily on current and recent rainfall rates; ground cover and soil conditions over the drainage basin; water equivalent of snowpack; recent, current, and anticipated temperatures; and continual monitoring of river stages. In small headwater regions, a forecast of crest height and time of occurrence is all that is needed; the rapid rise and fall of the stream makes the period during which the water is above flood stage relatively short. In lower reaches of large river systems, the rates of rise and fall are slower and duration of the flood becomes important. Forecasts of riverine flooding can be very accurate where sufficient data and sufficient stream gauges are available, and can be issued hours or days ahead of the flood. The further downstream the area of concern lies, the greater is the lead time and reliability of the warning.

Forecasting of flash floods depends on highly refined forecasts of local precipitation, a skill that is not very advanced. Where weather radar is available, torrential rainfalls that lead to flash floods can be detected as they occur, and this is often the only advance indication available. Hence, the lead time for flash flood forecasts may be very short, perhaps only several minutes.

Satellite imagery is a very effective way of monitoring floodplains, provided cloud cover does not obscure the view. Satellite techniques are probably more effective in assessing the extent of a flood and predicting its impact than in forecasting the flood itself.

The Consequences of Floods

The impact of a single flood depends on the depth and duration of flooding, the speed of moving water, and the rate at which the water rises. These factors affect survivability of buildings, degree of damage, and lead time available for evacuation before routes are inundated. The aggregate impact of flooding on a community depends on the frequency with which floods occur and any tendency for them to occur in certain seasons. Depending on timing, floods can have a relatively major or minor effect on crops. Floods that occur during the winter and that contain flowing ice may do considerably more damage than floods that contain only water.

Floods kill more people than they injure; death is usually by drowning. A possible secondary direct effect of floods in some locations is increased incidence of waterborne and vectorborne disease.

Floods destroy and damage houses and other small buildings. Houses may be washed away by the impact of rapidly moving water, especially in flash floods. Houses that remain intact may be inundated by water, and severe damage may result. The water may scour, erode, and undercut a house's foundation or the earth beneath the foundation, which may result in collapse. Massive objects borne by the flood may strike standing houses and cause considerable damage.

Floods can have a major impact on agriculture and food supplies, primarily through submersion of crops and drowning of livestock. Stored crops may become saturated with water and spoil. Topsoil may be eroded sufficiently that land productivity is greatly reduced. In some agricultural areas, silt deposits add nutrients to the soil. Flooding may revitalize wetlands, recharge ground water, and help maintain riverine ecosystems by providing breeding, nesting, feeding, and nursery areas for fish, shellfish, and waterfowl.

In many great river systems, portions of watersheds lie within different nations. Activities that cause or exacerbate flooding, such as deforestation, overgrazing, and erosion, carried out in one nation may lead to extreme flooding in another nation downstream.

TORNADOES

Tornadoes are the most dramatic example of a class of storms, often called severe local storms, that includes thunderstorms and hailstorms. Whereas large extratropical storm systems hundreds of miles in diameter can be accompanied by strong winds and heavy precipitation in the form of rain or snow, such storms do not often cause major disasters. Severe local storms a few miles to a few tens of miles in diameter are often accompanied by unusually strong, gusty winds that can cause severe damage, by heavy local rain that can cause flash floods, and by lightning, hail, and sometimes tornadoes. These intense vortices may be only a few hundred feet in diameter, but can contain winds in excess of 300 miles per hour, capable of tearing roofs off houses and lifting houses, trees, and vehicles hundreds of feet through the air. These storms tend to form in large numbers along a squall line or throughout a region, and tornadoes have been known to occur in swarms, with as many as several dozen affecting an area of hundreds of thousands of square miles in a single day.

Tornadoes and other severe local storms result from intense, local atmospheric instability, usually caused by solar heating of the earth's surface, which causes intense convective columns. These storms usually cannot be predicted. Forecasts can be issued identifying areas in which conditions are ripe for their formation, but individual storms themselves form quickly and are usually detected after they have formed.

About 100,000 thunderstorms occur within the U.S. each year. Of all natural hazards within the U.S., thunderstorms with associated winds, rain, hail, lightning, and tornadoes rank first in number of deaths, second in number of injuries, and third in property damage.

Tornadoes are the most violent event associated with thunderstorms. Tornadoes occur in many parts of the world, but are most frequent and fierce in the U.S. As many as 1,000 tornadoes may strike in the U.S. each year, mostly in the central plains and southeastern states, although they have occurred in every state, mostly in the spring and summer.

The most common type of tornado is small and lasts only a minute or two, causing minor damage over a track often less than 300 feet wide and 1–2 miles long. Most tornado-related deaths, injuries, and property damage are caused by relatively infrequent, large, and long-lasting tornadoes whose paths may be more than 1 mile wide and more than 100 miles long over a period of several hours.

Much of the damage is caused by wind, windborne debris, and collapse of damaged structures. In one instance, a schoolhouse was demolished and 85 pupils were carried nearly 500 feet with none killed; in another instance, five railway coaches, each weighing 70 tons, were lifted from the track and moved tens of feet. The high winds within tornadoes make missiles of small objects; blades of straw may be embedded in fenceposts like spears. A killer tornado has not yet struck the center of a large city; should that occur, it would be a major disaster.

A tornado is an intense vortex in which air spirals inward and upward. It is frequently, but not always, visible as a funnel cloud hanging part or all of the way from the generating storm to the ground. The upper portion of the funnel consists of water droplets, while the lower portion usually consists of dust and soil being sucked up from the ground. The funnel may be anywhere from a few meters to a few hundred meters in diameter, and anywhere from tens of meters to several kilometers high. It may undergo many changes in appearance during the tornado's lifetime. A funnel may be tall and slender or short and squat. There may be a single well-defined funnel, or multiple funnels, or funnels that appear to consist of several "ropelike" strands. Tornadoes are often noisy, and their roar has been compared to that of a freight train.

Examples of Tornado Outbreaks

In March, 1925, a tornado struck Missouri, Illinois, and Indiana, killing 689 people. On April 11, 1965, an outbreak of at least 37 tornadoes struck Iowa, Wisconsin, Illinois, Indiana, Michigan, and Ohio, killing 271 people, injuring more than 3,000, and causing $300 million in damage. On April 3 and 4, 1974, an outbreak of 147 tornadoes struck Illinois, Indiana, Michigan, Ohio, West Virginia, Virginia, Kentucky, Tennessee, North Carolina, South Carolina, Georgia, and Alabama, killing 335 people, injuring more than 5,500, affecting more than 27,000 households, and causing more than $600 million in damage. More than half of the deaths were caused by fewer than 5% of the tornadoes; the worst of these struck Xenia, Ohio. It cut a swath of destruction half a mile wide and 16 miles long, killed 34 people, injured 1,150, and damaged or destroyed 2,400 homes and most of Xenia's business district. On May 31, 1985, 43 tornadoes struck in Ohio, Pennsylvania, New York, and southern Ontario, killing 87 people.

Tornado Prediction and Warning

Although conditions that are favorable to tornado formation can often be predicted a number of hours in advance, the areas in which these conditions are found may cover hundreds of thousands of square miles. It is impossible to predict where individual tornadoes will occur. When a warning is issued, a tornado has already formed and the threatened population may have only tens of seconds or perhaps a few minutes within which to take cover. Thorough education regarding shelter is the most effective way to reduce deaths and injuries. In the U.S., when tornadoes are considered likely within a well-defined region, a "tornado watch" is issued. When a tornado is actually detected, either visually or on radar, a "tornado warning" is issued. This means that a tornado is on the ground nearby and that people should take shelter immediately.

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