NATURAL WEATHER-INDUCED HAZARDS: FLOODS, STORMS, FIRES, AND DROUGHT

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Contents

Summary

Floods, droughts, tropical hurricanes, tornadoes, thunderstorms and lightning, and wildfires are all hazards related closely to processes on the earth's surface; they are induced directly by the weather. We call these weather-induced hazards. This article describes the various weather-induced hazards and summarizes their cause,

classification, magnitude–frequency relation, and mitigation. Finally, the close relationship between many weather-induced hazards is emphasized: for example, hurricanes, tropical cyclones, floods, and drought are correlated to the southern oscillation, and can be predicted.

1. Flooding

Floods occur all over the world. Human beings need water, so from ancient times they have often chosen to live by great rivers. The same river that supplies drinking and washing water, fish, and valuable transportation routes provides fine grazing and cropland in its floodplains; however, the river's bounty can turn into disaster. A flood occurs when the level of a body of water rises until it overflows its natural or artificial confines and submerges land in the surrounding area. Because humans tend to develop and inhabit such land, floods can take a high toll in loss of life and damage to structures and buildings.

Flooding occurs when a stream's channel can no longer contain the water flowing through it. Most floods commence with a period of prolonged or heavy rainfall. The volume of the channel of a stream is approximately sufficient to accommodate the average maximum discharge, however, in times of higher discharge, the stream may overflow its banks and flood. Table 1 summarizes the major flood disasters in 1998 around the world (see *Natural hazards*).

Affected region country	Flooding period (months)	Deaths	People affected	Economic loss (US$ millions)
Pakistan	3	300	25 000	-
USA	3	11	18 000	270
Iran	3–4	84	42 000 000	98
U.K.	4	5	300	1 270
Argentina	3–5	20	290 000	2 500
Peru	3–5	340	580 000	-
Paraguay	3–5	55	120 000	-
Tajikistan	3–5	203	20 000	66
Turkey	5	19	514	2 000
Krygyzstan	5	1	10 000	240
Russia	5	15	51 000	-
Romania	6	21	40 000	-
USA	6–7	21	11 000	469
South Korea	7–8	170	116 500	323
China	8–9	4200	180 000 000	20 800
Nepal	8	156	20 000	20
Bangladesh	7–9	1500	30 600 000	3 400
India	8–9	3000	36 000 000	-
Philippines	9	39	708 000	-
Sudan	8–9	–	1 000 000	-
USA	10	29	5 300	1 000

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Vietnam	10–11	267	-	93
Ukraine	11	17	400 000	-
Vietnam	12	40	3 000	15

Source: H.P. Hu et al. 1998, Yangtze River flood 1998, *INCEDE Newsletter* 7, no. 3 (1998), 1–3.

Table 1. Damage caused by major flood events around the world in 1998

1.1. Causes of Flooding

The most common cause of flooding along streams is a high rate of runoff from heavy or prolonged rain. Stream flooding in mountainous areas is also frequently caused by rapidly melting snow or by runoff from a combination of rainfall and melting snow. Floods also occur occasionally through failures of upstream dams. Obstruction of stream channels by ice jams, accumulation of debris, deposits of sediment, and thick vegetation is a major factor in flooding along streams. Channels may become so obstructed that normal flows back up and overflow nearby areas. The debris carried by floods often adds to problems of obstruction. While less frequent, stream flooding can also be caused by landslides, volcanic flows, or other events that block a river or change its course.

Floods along streams are categorized by how quickly they occur. Floods that occur within a few hours of heavy rain or sudden release of water are called "flash floods." Flash floods normally rise quickly to their peak and then subside rapidly. They occur primarily in mountainous areas and along the headwaters of small streams. Floods along larger rivers usually rise much more slowly but may persist for days or even weeks.

Flooding is sometimes caused by something other than overflow. A relatively thin sheet of flooding (a few centimeters to about 60 cm deep) occurs in places where slopes are not steep enough to cause rapid runoff. Flooding can also be caused by the rapid accumulation of surface runoff in low-lying areas. Previously safe areas can also be flooded when streams shift their channels. Such shifts are common on alluvial fans.

Flooding along lake-shores may be either short or long in duration. Short-duration flooding is usually caused by wind-driven waves. Waves also have great erosive powers and a battering effect on structures. Very large lakes sometimes experience a "seiche" in which a combination of wind and changes in atmospheric pressure or an earthquake cause the surface of the lake to oscillate over a period of minutes or hours. The water level in lakes with inadequate outlets can also rise enough in response to large inflows to temporarily flood the lakeshore.

Longer term flooding occurs around lakes and potholes that have no outlet. During years of above average rainfall, these areas may become so full that it takes several years for evaporation to restore the water surface to its customary level. Longer term and even permanent flooding of such areas may also occur if sediment fills the lake to the point that its capacity to store in-flowing water is reduced. Usually dry areas may flood when groundwater levels rise after heavy rains.

Coastal flooding along the Atlantic Ocean and the Gulf of Mexico is usually caused by high winds accompanying hurricanes or tropical storms. Persistent strong winds can pile up water toward the shore, causing a “surge” that can raise the level of the ocean at that point by several meters. The devastating effect of surges is sometimes increased by breaking waves on top of the surge. Surge heights may also be increased when they coincide with high tides. In addition to surges caused by wind, coastal areas like Hawaii and Alaska are subject to another form of large ocean wave called a “tsunami,” usually caused by an underwater earthquake or volcanic eruption. These are often incorrectly referred to as “tidal waves.” A tsunami can also be caused by a large landslide entering a body of water.

Some coastal and inland areas are subject to flooding as a result of subsidence, a gradual sinking of the land. This sinking of the land surface is usually caused by large withdrawals of underground oil, gas, coal, or water but can also result from drought or earthquakes. Subsidence is a serious problem in many mega-cities in coastal areas.

1.2. Types of Floods

1.2.1. Regional Floods

Some regional floods occur seasonally when winter or spring rains coupled with melting snow fill river basins with too much water too quickly. The ground may be frozen, reducing infiltration into the soil and increasing runoff. Such was the case with the New England flood of March 1936 in which more than 150 lives were lost and property damage totaled US$300 million.

Extended wet periods at any time of the year can saturate the soil, so that any additional rain runs off into streams and rivers until river capacities are exceeded. Regional floods have often been associated with slow-moving, low-pressure or frontal storm systems, including decaying hurricanes and tropical storms. Persistent wet meteorological patterns are usually responsible for very large regional floods such as the Mississippi River Basin flood of 1993 wherein damages were US$20 billion.

1.2.2. Flash Floods

Flash floods can occur in several seconds or several hours, with little warning. Flash floods can be deadly because they produce rapid rises in water levels and have devastating flow velocities.

Several factors can contribute to flash flooding, including rainfall intensity, rainfall duration, surface conditions, and topography and slope of the receiving basin. Urban areas are susceptible to flash floods because a high percentage of the surface area is composed of impervious streets, roofs, and parking lots where runoff occurs very rapidly. Mountainous areas are also susceptible to flash floods, as steep topography may funnel runoff into a narrow canyon. Floodwaters accelerated by steep stream slopes can cause the floodwave to move downstream too fast for people to escape, resulting in many deaths. A flash flood caused by 38 cm (15 inches) of rain in 5 hours from slow-moving thunderstorms killed 237 people in Rapid City, South Dakota, in 1972.

Floodwaves more than 9 m high have occurred many miles from the rainfall area, catching people unawares. Even desert arroyos (gullies) are not immune to flash floods, as distant thunderstorms can produce rapid rises in water levels in otherwise dry channels. Early-warning gauges upstream save lives by providing advanced notice of potentially deadly floodwaves.

1.2.3. Ice-Jam Floods

Ice-jam floods occur on rivers that are totally or partially frozen. A rise in stream stage will break up a totally frozen river and create ice flows that can pile up on channel obstructions such as shallow riffles, log jams, or bridge piers. The jammed ice creates a dam across the channel over which the water and ice mixture continues to flow, allowing more jamming to occur. Backwater upstream from the ice dam can rise rapidly and overflow the channel banks. Flooding moves downstream when the ice dam fails, releasing the water stored behind the dam. The flood then takes on the characteristics of a flash flood, with the added danger of ice flows driven by the energy of the floodwave, which can inflict serious damage on structures. An added danger of being caught in an ice-jam flood is hypothermia, which can quickly kill. Ice jams on the Yukon River in Alaska contributed to severe flooding during the spring breakup of 1992.

1.2.4. Storm-Surge Floods

Storm-surge flooding is water that is pushed up onto otherwise dry land by onshore winds. Friction between the water and the moving air creates drag that, depending upon the distance of water (fetch) and the velocity of the wind, can pile water up to depths greater than 6 m. Intense, low-pressure systems and hurricanes can create storm-surge flooding. The storm surge is unquestionably the most dangerous part of a hurricane as pounding waves create very hazardous flood currents.

Nine out of 10 hurricane fatalities are caused by the storm surge. Worst-case scenarios are when the storm surge occurs concurrently with high tide. Stream flooding is much worse inland during the storm surge because of backwater effects.

1.2.5. Dam- and Levee-Failure Floods

Dams and levees are built for flood protection. They are usually engineered to withstand a flood with a computed risk of occurrence. For example, a dam or levee may be designed to contain a flood at a location on a stream that has a certain probability of occurring in any one year. If a larger flood occurs, then that structure will be overtopped. If during the overtopping the dam or levee fails or is washed out, the water behind it is released as a flash flood. Failed dams or levees can create floods that are catastrophic to life and property because of the tremendous energy of the released water.

1.2.6. Debris, Landslide, and Mudflow Floods

Debris or landslide floods are created by the accumulation of debris, mud, rocks, and/or logs in a channel, which form a temporary dam. Flooding occurs upstream as water is stored behind the temporary dam and then becomes a flash flood as the dam is breached and rapidly washed away. Landslides can create large waves on lakes or embayments and can be deadly. Mudflow floods can occur when volcanic activity rapidly melts mountain snow and glaciers, and the water mixed with mud and debris moves rapidly downslope. These mudflow events are also called lahars; after the eruption of Mount St. Helens in 1980, one caused significant damage downstream along the Toutle and Cowlitz Rivers in southwest Washington State, USA.

1.3. Variability of Flooding

A combination of factors determines whether a flood will occur. The quantity of water involved and the rate at which it enters the stream system are the major factors. The flow of water streams must carry varies from day to day, season to season, and year to year. Sometimes there are long spells of little or no rain in an area and flow slows to a trickle. At other times, the same area might have a wet period in which one storm follows another. When the water input exceeds the capacity of the stream to carry that water away downstream within its channel, the water overflows its banks. The most intense rainfall events occur in Southeast Asia, where storms have drenched the region with up to 2 m of rain in less than three days. Floods vary in size depending on such things as the intensity of rain, the area over which the rain falls, and the rate at which snow melts.

The amount of previous rain on a watershed or the current storage in a reservoir may also play a major role in the potential for flooding. Heavy rain on a dry watershed may not result in any flooding while just a small amount of rain on an already saturated ground may cause a flood. Sometimes the separate factors combine to cause only a minor rise in the streams in an area and at other times combine to cause destructive floods. The occurrence of factors that determine the size of floods is largely random. Large floods can occur at any time and may often be impossible to predict more than a short time ahead of the event.

Topography also influences the extent or rate of surface runoff and, generally, the steeper the terrain, the more readily water runs off over the surface and the less likely it is to sink into the soil. Also, the more gradually the water reaches the stream, the better the chances that the stream discharge will be adequate to carry the water away without flooding. Thus, the relative amounts of surface and groundwater runoff, which are strongly influenced by the surface geology of the drainage basin, will affect the severity of stream flooding.

Vegetation have the potential to reduce flood hazards. Vegetation can provide a physical barrier to surface runoff and decrease its velocity; it can also increase the soil's permeability, absorb water, etc. These all reduce the volume of water introduced directly into a stream system.

1.4. Frequency of Flooding

It is not possible to predict when the next flood will come or how big it will be. However, past flooding gives some clue about what to expect. Engineers study long-term records and use statistics to estimate the chance that floods of various sizes will occur.

Flood frequencies, such as the "100-year flood," are determined by plotting a graph of the size of all known floods for an area and determining how often floods of a particular size occur. Long-term flood records make it possible to construct a curve showing discharge as a function of recurrence interval for a particular stream or section of a stream. For example, we can get a flood-frequency curve like that shown in Figure 1 (see *Natural hazards*). Experience might tell us to expect a relatively common small flood of a certain size 33 times over a 100-year period. It would therefore be expected to happen on average once every third year. Thus a flood can be described by its *recurrence intervals*: how frequently a flood of that severity occurs, or an average for that stream.

Expressing this in another way, the stream has a one in three, or 33%, chance of happening in any particular year. This is the *probability* of a flood of a given size occurring in any one year, and it is the inverse value of the recurrence time. This would be called a 3-year flood or a 33%-chance flood. A larger (more unusual, less frequent) flood found to occur on average 10 times in 100 years would be called a 10%-chance flood or a 10-year flood. A flood so large and unusual that it only occurs on average once every hundred years would have a 1% chance of occurring in any particular year and would be called a 100-year flood or a 1%-chance flood.

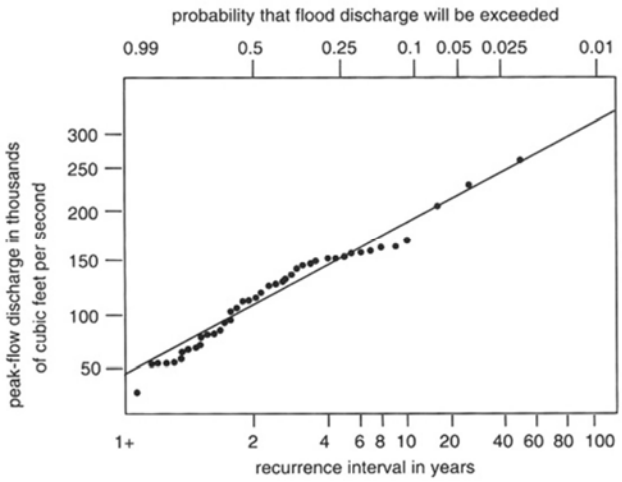

Figure 1. Flood frequencies for the Euphrates River
Source: J.J.W. Rogers and P.G. Feiss, *People and the Earth—Basic Issues in the Sustainability of Resources and Environment.* (Oxford: Cambridge University Press, 1998).

This does not mean, of course, that a 10% flood occurs exactly once every 10 years. A rainy year might see several 10% floods and then there might not be another for many years. Similarly, two or more large floods, like a 100-year flood or even a 500-year flood, could occur back to back. The percentage chance of a flood occurring is based on the average of what is expected over a long time.

The chance of a flood of a certain size occurring and then the same or a bigger flood happening right away is like flipping a coin. Heads coming up once does not mean that the next time it will be tails. Each time the coin is flipped there is a 50–50 chance of either heads or tails. In the same way, when once a flood has passed, the chances are re-set. A 1% flood has a 1% chance of occurring in any one year. And, as soon as it does, the chances are still 1% that it will occur again some time during the following 365 days. The probability of two 100-year flood events in two years is very low (1% × 1%, or 0.01%), but it is still possible.

Streams in heavily populated areas are affected by human activities, and the flood frequency curves change with time. Generally, most human activities have tended to aggravate flood hazards and to decrease the recurrence intervals of high-discharge events, except for measures specifically designed for flood control.

2. Storms

Storms are the result of collisions between greatly contrasting air masses and can occur as local, short-lived phenomena, like thunderstorms, or as events affecting a wide area, like tornadoes and hurricanes.

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Resources on the Internet

http://www.seawfo.noaa.gov/fire

http://tqjunior.thinkquest.org/5818/thunder3.html This site provides information about thunderstorms.

http://www.nssl.noaa.gov/edu/tornado/ This site is entitled “Questions and Answers about Tornadoes.”

http://www.usgs.gov/themes/wildfire.html

http://gis.esri.com/library/userconf/proc95/to200/p175.html

Biographical Sketches

Dr. Li Juan graduated from the Institute of Geophysics, China Seismological Bureau. Her research focuses on seismic hazard and risk analysis, and simulation of rock failure. Member of Chinese Geophysical Society.

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