Floods

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Background and Nature of Floods

Factors That May Contribute to Floods and Flash Floods

Flooding results from a variety of causes. Within a given climatic region, tremendous variations of flooding occur because of fluctuations within the hydrologic cycle and other natural and synthetic conditions. The meteorologic process can be fast or slow and can lead to flash floods, which are an explosive development, or the process can slowly develop into more predictable river and coastal flooding (1).

FLASH FLOODS

The National Weather Service (NWS) has defined flash floods as those that follow within a few hours of heavy or excessive rain, a dam or levee failure, or a sudden release of water impounded by an ice jam. Because of the short warning time involved, the NWS flood forecasting procedures used for large streams cannot respond fast enough. There is also the difficulty of predicting when and where flash-flood-producing rainfall will occur.

Although most flash floods are the result of intense localized thunderstorm activity or slowly moving (nearly stationary) thunderstorms or lines of thunderstorms, some occur in conjunction with tropical cyclones and extratropical cyclones (2).

A number of factors determine why a given volume of precipitation will cause devastation in one area but only negligible damage in another Forerunners to flash floods usually involve atmospheric conditions that influence the continuation and intensity of rainfall. In the upper reaches of river basins, for example, the flood crest on tributary streams can occur in a matter of hours, or even minutes, from the onset of heavy rain (3). Other factors that can contribute to flash floods include steepness of slopes (mountain terrain), absence of vegetation, lack of soil's infiltration capability, floating debris and ice jams, rapid snowmelt, dam and levee failure, rupture of a glacial lake, and volcanic disturbances (1,2).

It is not surprising to find that the incidence of serious flooding has often shown a marked increase in areas that have been denuded of vegetation. Fast surface runoff occurs on steep slopes and in sites in which the soil's infiltration capacity is reduced. Roofs, pavements, roads, and other solid surfaces have the same effect as an impermeable rock layer, which causes water to move laterally at an increased velocity Floating debris or ice can accumulate at natural or other obstructions, such as bridges and culverts, creating a dam that may back up flood waters. When a barrier of debris or ice is washed out, a surge wave can create a flash flood.

In mountainous terrain, snow can melt precipitously, resulting in rapid rises in headwaters and downstream rivers. Snow covers can melt explosively in association with rainstorms and a sudden warm spell. Rainfall not only contributes to the volume of the runoff but also helps to thaw the snowpacks (1,4,5).

Dam or levee failure, rupture of a glacial lake, volcanic disturbances, and landslides contribute to flash floods. Lava flows and landslides can cross a stream, creating a temporary dam, which causes flooding upstream and a possible surge of water downstream when the barrier is washed out. The rupture of an ice barrier leading to the sudden release of an impounded lake is an unpredictable natural cause of flooding. Fortunately, most of the world's glacially dammed lakes are located in sparsely settled areas, and most flood-associated events do not approach the magnitude of many human-generated disasters (1,4).

RIVER FLOODS

Factors that influence flash flooding can also contribute to river flooding. Other factors that contribute to more insidious river flooding include stream-channel characteristics, character of soil and subsoil, and degree of synthetic modification in the river regime. Atmospheric conditions that influence the continuation or intensity of rainfall, the amount of precipitation that has fallen into the watershed, snowmelt, the amount of water flowing in tributaries upstream, and the degree of soil saturation also influence the severity of river flooding in an area (1,3).

Urbanization, by increasing runoff and decreasing water infiltration to groundwater storage, changes flooding patterns so that both the height of floods and the areas covered by floods increase locally and downstream. Encroachment on floodplains and valley storage by fillings for buildings, levees, constructed navigation facilities, and other structures alters the height and duration of river floods. Such alterations to a basin's hydrologic regime increase the risk to inhabitants and structures (1).

Some river flooding may develop principally as a result of snowmelt. The quantity of snow, the rate at which it melts, and ice jams along waterways increase the magnitude of flood hazards. The quicker the thaw, the more dangerous the potential consequences. The state of the ground during the melting phase is also an important contributing factor. Soil percolation is impossible if the ground is frozen to a great depth, and the frozen surface has the same effect as a city's constructed surfaces. Runoff moves rapidly across the surface to the closest stream channel (1,2).

The interactive effects of soil movement, soil temperature, air temperature, and solar radiation on snowmelt are important but poorly understood factors. The time lag between the onset of above-freezing temperatures and melting of snow cover is usually poorly surveyed. The potential for flooding, however, can be determined by examining a wide range of hydrologic and hydraulic variables, including an examination of the water content of the late winter snow cover and the expected precipitation. A spring snowmelt outlook can alert the public to the possible spring flooding danger (1,5).

COASTAL FLOODS

Coastal flooding—defined as including flooding along the Great Lakes—can result from several factors. An important one is storm surge, which is the result of a major tropical storm or hurricane. Winds generated by revolving storms can drive ocean waters inland and lead to serious flooding. A steady buildup of tide level usually occurs; thus, flood warnings can at least alleviate heavy loss of life.

One type of coastal flooding, however, which is often unpredictable, is the most devastating of all. It is called tsunami. This long sea wave is generated by submarine earthquakes or certain volcanic eruptions (see chapter on volcanoes). When the wave reaches shallower water, the tsunami slows down and increases substantially in height; it can destroy coastlines (1,4). Most recorded tsunamis have occurred in the Pacific and Pacific Coast regions. The islands of Hawaii are particularly prone to tsunami damage because of their location in the mid-Pacific.

The degree of flooding is also influenced by land subsidence in coastal areas, erosion of barriers, and the simultaneous occurrence of river floods at a time of a storm surge—or tsunami—or the state of the tide at the time of the peak flood stage. Seiches, which are waves trapped in a basin, occur in large lakes. These can also have an impact on coastal flooding. Damages from coastal flooding, as from river flooding, can be escalated in urban areas (1).

Historical Review of Floods

Populations have been subjected to floods since the advent of civilization. It has been estimated that floods account for 40% of all the world's natural disasters, and they do the greatest amount of damage (6).

FLOODING OUTSIDE THE CONTINENTAL UNITED STATES

Along the Hwang Ho (Yellow) River in China, the most flood-prone river in the world, floods have periodically inundated the land for 40 centuries. The most lethal flood in recorded history struck there in the fall of 1887 when the river overflowed 70-foot-high levees, destroying 11 cities and 300 villages. An estimated 900,000 people were killed and 2 million made homeless. In northern China in 1939, some 500,000 persons drowned in extensive flooding. Several hundred thousand may have died in China's Shantung Province in 1969, when storm surges raked the coastline and pushed flood tides up the Yellow River Valley (6).

A sudden flood in January 1967 in Rio de Janeiro killed 1,500 people. This flood was followed by another on February 20 of the same year, which took 200 lives and rendered 25,000 homeless (7).

In 1974 heavy rains flooded 80% of Bangladesh and caused 2,500 deaths (7).

England and Europe have had their share of floods. The most devastating British inland flood was in August 1952 in North Devon, around the town of Lynmouth, after 9 inches of rain. Little rivers whose water death was usually only a few inches carried torrents of water tens of feet deep. The landscape was vastly altered, 93 buildings were destroyed, and 34 persons lost their lives (6). The Netherlands flood of February 1953, resulting from the breach of a polder, affected extensive areas of the country and caused 1,795 deaths. In October of 1963, heavy rains caused an enormous landslide that fell into the lake behind the Vaiont Dam in northern Italy. Over 100 million tons of water were displaced over the dam top and crashed into the Piave River Valley, almost obliterating the town of Longorone and several nearby hamlets. In Longorone itself, 1,269 of 1,348 people known to be in the town were killed, and an additional 727 persons were killed in nearby locations (6). In 1967, 450 people were killed in a flood in Lisbon, Portugal (7). In 1985 an estimated 7-15 inches of rain fell in a 10-hour period in Puerto Rico, causing 180 fatalities—127 related to a rock slide and 53 related to flooding (L. Sanderson, personal communication).

FLOODING WITHIN THE CONTINENTAL UNITED STATES

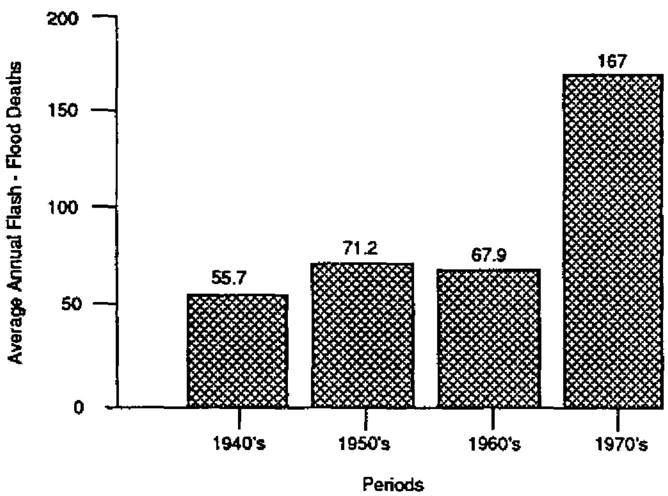
In the United States, nearly every community has some type of a flood problem. Overflowing rivers and streams cause substantial flooding in about half of the communities and over at least 7% of the land area of the nation.

River flooding. One type of flooding is marked by slow, steady rising of the level of a river from melting snow and repeated rainfalls, swelling to its banks, followed by spreading over the land. Rivers turn to seas, houses turn to islands, and crops are buried in mud. In 1913, repeated winter rains caused the Ohio River to overflow its banks, resulting in severe flooding in Ohio and Indiana. Some 730 people lost their lives. In 1927, spring rains caused the Mississippi River to overflow its banks and spread out over 18 million acres of land from southern Illinois to southern Louisiana. All along the river, death came when levees holding back the river broke. A total of 313 persons were killed, and 637,000 were left homeless (6).

Engineering controls—such as the construction of reservoirs and flood walls and the diversion of rivers, as well as increased forestation of watersheds—have reduced river flooding in the past 2 decades.

Flash flooding. Flash floods are distinguished from general river flooding by the very rapid runoff of water after heavy rains. In recent years, flash floods have become the number one weather-related killer in the United States. Deaths from flash floods are approaching 200 each year, compared with an average of less than 70 per year during the preceding 30-year period. Losses from flash floods are now nearly 10 times the levels in the 1940s (8). The average annual number of deaths from flash floods by decade is shown in Figure 1 (2).

FIGURE 1. Average annual flash-flood deaths, by decades*



*Figures are 90% of all flood-related deaths reported by the National Climatic Center, National Oceanic Atmospheric Administration

Source: Reference 2.

The worst flash flood in U.S. history occurred in Johnstown, Pennsylvania, in May 1889 when the South Fork Dam broke after torrential rains, sending the waters of the overflowing Conemaugh Lake Reservoir into the valley below. Among the 2,200 persons who died, 99 entire families were represented. Johnstown experienced another flash flood in 1977 when 8-12 inches of rain fell in the area during the night of July 19-20. Major flash flooding occurred along the Conemaugh River and its tributaries. During the early morning hours, several earthen dams failed. Seventy-six persons were killed, and nearly 2,700 were injured (6).

In 1972, three major flash flood disasters occurred in the United States. Heavy rain accompanied by dam breaks caused flash floods in Rapid City, South Dakota, and Buffalo Creek, West Virginia, causing 236 deaths and 3,000 injuries in Rapid City and 139 deaths in Buffalo Creek. That same year, hurricane Agnes dropped as much as 15 inches of rain in several locations from Virginia to New York. The resultant flooding killed 117 persons and caused damage estimated at $3.1 billion. The entire state of Pennsylvania was declared a disaster area (6).

On the night of July 31, 1976, 10-12 inches of rain fell within a small oval-shaped area over the Front Range of the Rocky Mountains near the head of the Big Thompson Canyon in Colorado. At one location near Glen Comfort, approximately 7.5 inches of rain fell between 7:30 p.m. and 8:40 p.m. An estimated 50 million tons of water were dumped by the rains, mostly in the area between Estes Park and Drake. The canyon was occupied by 2,000-3,000 visitors and summer residents, and 135 people perished in the flood (6).

On September 12, 1977, more than 6 inches of rain fell on Kansas City, Kansas, followed by an additional 5 inches of rain from 7 p.m to 9 p.m. Twenty-five people died in the resulting flash floods (6).

In 1982 an estimated 15 inches of rain fell in southern Connecticut in a 2-day period, resulting in 11 flood-related deaths (9).

In 1985 the heavy rainfall from hurricane Juan, in combination with another tropical depression off the east coast, caused flooding in Louisiana, Alabama, Virginia, West Virginia, and Pennsylvania. In Louisiana, seven people were reported dead and eight missing; the combined flood toll in Virginia, West Virginia, Maryland, and Pennsylvania was reported to be 42 dead and 50 missing (10).

The increased toll from flash floods results from nature, performing as it usually does, colliding with a larger and more urbanized population settling and occupying sites that are ready targets for floods. In the countryside, as evidenced in the Big Thompson Canyon flood, the increased use of mountainous locales and narrow canyons for recreational purposes is exposing growing numbers of unwary visitors to areas susceptible to flash floods.

The list of danger spots is growing. In 1977, more than 15,000 U.S. communities and recreational areas were identified by the Flood Insurance Administration as being susceptible to flash floods. In 1978, the American Meteorological Society urged a concerted effort by Federal, state, and local officials to reduce the losses from flash floods. They called for improved forecasts and warnings, increased regulation of flash-flood-prone areas, certification of dam safety, better information on maximum precipitation and runoff, and programs of public awareness and community warnings (6).

Some evidence suggests that the institution of these measures has decreased the mortality from flash floods. In a review of mortality associated with flash floods from 1969-1981, based on National Weather Service Reports, 2.5 times more deaths occurred in the 14 flash floods in 1969-1976 than in the 18 flash floods in the period 1977-1981. More than twice as many deaths were associated with flash floods for which the survey team considered the warnings inadequate than with those for which the warnings were considered adequate. Warnings deemed inadequate were largely heavy-rain and flash-flood warnings issued for a region within a broad time frame such as the next day rather than for a flash flood in a specific place within a specific, short time frame (11).

Factors Influencing Morbidity and Mortality

Primary Exposures and Effects

ACUTE EFFECTS

Fast-flowing water accompanied by such debris as boulders and fallen trees accounts for the primary flood-related exposure that leads to morbidity and mortality. The way people respond to exposures is a critical factor in the morbidity and mortality associated with such events. The available information on this aspect is limited primarily to anecdotes and descriptive studies and deals only with mortality.

When 7 inches of rain sent flash floods rolling through homes and businesses in Rochester, Minnesota, in July 1978, three elderly patients and a nurse's aide got into an elevator on the first floor to go to a higher floor and escape the rising floodwaters. The floodwaters short-circuited the elevator and instead sent it down into a flooded basement. All four were trapped inside and drowned (6).

Grunfest analyzed the behavior patterns adopted at the time of the Big Thompson Canyon flash flood (12). Comparisons were made of the actions of the survivors and nonsurvivors and the warned and nonwarned populations. Variables were examined such as location before the flood, action taken, grouping of persons, location in the canyon, type of warning received (if any), and number of people in a group. The study sample comprised 54 nonsurvivor groups (129 people) and 58 survivor groups (270 individuals).

Of the 54 groups of people who died, nine groups (17 people) were given an unofficial warning, and five groups (14 people) received an official warning. Persons with recent disaster experience were more likely to take protective action as a result of warnings. An earlier study by Friedsam had shown that older persons were less likely to receive warnings than younger persons regardless of the source (13). However, in the Big Thompson Canyon flood, groups of people > 70 of age were just as likely to receive a warning as younger persons.

Another of Friedsam's finding was that elderly persons were less likely to evacuate than younger persons. This finding was supported in the Big Thompson Canyon study Of nine groups of people > 70 years of age, three did take action and six took no action during the flood.

Those who took some action were more likely to live than those who took none. The number of people in a group was most significant in characterizing the groups as to whether action was taken. Persons who were alone were most likely to do nothing and had the highest risk of being killed, particularly those driving alone through the canyon. Those who were in groups of three to five friends were more likely to take action, such as climbing the side of the canyon, and they had the best chance to survive. Those who were with family groups were more likely to take no action than they were to climb, but those in family groups were still more likely to live than those who were alone. Those who climbed or took other action were more likely *not* to have received a warning than those who did nothing or who drove.

The location of the group in the canyon was most significant in separating the warned from the unwarned, and those in the upper part of the canyon were more likely to live than those in other areas of the canyon. Familiarity with the canyon itself was not a significant factor in separating the survivors from the nonsurvivors.

Kircher *et al.* studied the factors contributing to the successful evacuation of people in the town of Essex, Connecticut, before five dams were destroyed after heavy rainfall. In that situation, all the people complied with the notice to evacuate even though most of them were not aware that they lived in a flood-risk area. Moreover, most had minimal previous flood experience and did not feel that they were personally at risk during the crisis. The mean age of respondents told to evacuate was 60 years. The authors concluded that in Essex characteristics of trust between town officials and citizens were crucial to a successful evacuation (9).

In the Kansas City, Kansas, flash flood in 1977—in which 25 persons died—a policeman told a Chicago Tribune reporter afterward "A lot of people who died didn't have to die. They just could have walked away from it but they didn't." In most areas the flood was not sudden. No wall of water came crashing down over victims. In the shopping area where many of the dead were found, the water rose rapidly but not so quickly as to explain all the deaths. Anybody who walked to high ground (only two blocks away) could have arrived with little more than wet shoes. However, some people did not walk. Witnesses told of one man who drove up behind a string of stalled cars, some of which were in window-deep water. He pulled around them and drove on into the water. He, his wife, and two children drowned. Some persons ran to save their cars even as other cars floated past them. Others ran into underground parking garages, apparently not stopping to think that these would be among the first places to be flooded (6).

In the study of flash floods based on National Weather Survey Reports for 1969-1981, causes of death were recorded for only 190 cases. Of these 190 deaths, 177 (93%) were because of drowning. A large portion (42%) of the drownings were car-related, such as when victims were in cars driven into low areas, across flooded bridges, or off the road into deep water. The other drownings occurred in homes, at campsites, or when persons were crossing bridges or streams (11).

When hurricane Gilbert struck the Yucatan Peninsula and Northern Mexican Gulf Coast in August 1988 with winds of 160 miles/hour, the greatest loss of life was associated with a single flash-flood event. An estimated 200 people drowned in Monterrey, Mexico, when four buses, evacuating people inland, drove into low-lying areas and were swept away by the fast-rushing water from heavy rain that accompanied the hurricane (14).

The findings from the limited database on the actions taken by people in the face of a flood threat are somewhat inconsistent. In the Big Thompson Canyon study, persons who received warnings—official or unofficial—did not take actions that contributed to higher success of survival than those who had no warnings. These findings concurred with those of Friedsam (13) regarding the reluctance of older people to evacuate or take other appropriate action, but not with those of Kircher *et al.* (9), who found that most people who received a warning in Essex did evacuate and that the evacuees were primarily older people. A possible explanation for these inconsistencies may be the different environmental circumstances surrounding the flood. In Essex members of the volunteer fire department knocked on people's doors to warn them and assisted those who needed help in evacuating. In the Big Thompson Canyon flood, most of the warnings were given by word of mouth, and the most appropriate action for survival was to climb to higher ground, which meant scaling the slippery wall of the canyon.

Taking appropriate action may depend not only on the ability to assess such actions and the willingness to take them but also on having the physical stamina to carry them out. In the analysis of the Big Thompson Canyon study, it was not possible to look at all the group actions by age because of inadequate information. It may be that people who climbed to higher ground by scaling the canyon wall—particularly the groups comprising three to five friends—were younger and in better physical condition than the other people studied. People in groups of two or more can help each other perform arduous physical tasks compared with those who are alone. Older individuals and families with young children may not be physically capable of climbing to higher ground.

A consistent finding from the anecdotes as well as the more formal studies is the high proportion of car-related drownings in floods. People seem wedded to and unwilling to abandon their cars. Persons trying to leave a flood-threatened area by car may inadvertently drive into a low-lying area or across a flooded bridge. Their cars may stall because of high water or become blocked by rockfalls, mudslides, fallen trees, or other stalled cars. They may find themselves trapped in their cars while high levels of fast-flowing water descend upon them. In many flash floods, the flow of water can be so fast that it leaves very little time for escape.

LONG-TERM EFFECTS

Several investigators have looked at the long-term health effects from floods.

In 1954 Lorraine conducted a mortality study in the 2-month period after floods in the Canary Islands on January 31 and February 1, 1953. Increased mortality was reported for February and March 1953, compared with the same period in 1952. The increased rate was principally among the elderly and those with predisposing respiratory conditions (15).

Bennett studied 316 flood respondents and 454 nonflood controls for morbidity and mortality over the year after the Bristol floods in England in 1968. He found higher mortality among residents of the flooded sections—especially the elderly people. The health status during the year was worse in the flood group when measured by increased hospital admissions for both males and females and a higher surgery rate for flood-group males who continued to live in their own homes. There was also an increase in new psychiatric symptoms for both males and females (16).

Psychiatric examinations performed on 224 children 2 years after the 1972 flood in Buffalo Creek, West Virginia, showed that 80% of the children were severely emotionally impaired by their experiences during and after the flood (17,18).

Melick interviewed 43 "flood" and 48 "nonflood" male respondents for mental and physical problems 3 years after the 1972 flood caused by tropical storm Agnes in Wyoming Valley, Pennsylvania Flood victims did not report a greater number of illnesses or different types of illnesses from those reported by nonflood victims, but the former group did show longer duration of illnesses. Emotional disturbances occurred in both groups, but they lasted longer for flood-group respondents and their family members (19). Five years after this flood, Logue studied 407 "flood" and 155 "nonflood" female respondents by mailed questionnaire to determine their families' mental and physical health status. Perceived health problems were reported more frequently by flood respondents and their immediate family members. The development of hypertension by the husbands of flood respondents was significantly greater than by the husbands of nonflood respondents in the 5 years after the flood Flood families also reported more respiratory-, gastrointestinal-, and cardiovascular-related health problems. Flood respondents also reported experiencing more "stress" for major life events after the flood (20). In assessing risk factors for hypertension associated with the early recovery period, Logue and Hansen conducted a case-control study of the 31 female flood victims who reported the development of hypertension in the 5-year post-disaster survey. Factors such as property loss, financial difficulties, physical work, use of alcohol, and perceived distress were significantly associated with hypertension. Anxiety and difficulty in sleeping also demonstrated significant positive correlations with hypertension (21).

Benin reported a marked increase in hypertensive disease in Voroshilovgrad, Russia, after the 1964 flood and in Tiraspol, Moldavia, after two successive floods in 1969. In Tiraspol there was an increase in diabetes as well (7).

During the prolonged flooding of the Amur River in 1951-1952, a strong direct association between flood conditions and blood pressure was reported. Blood pressure readings were taken for the entire population of one village (3,600 people) struck by the flood, and almost everyone showed a general increase in blood pressure. Similar testing was done on the population on the other bank of the river, which was not flooded, and only 20%-22% had elevated blood pressure readings (22).

Abrahams studied 234 flood families and 163 nonflood families by interview 3 and 12 months after the Brisbane floods in Australia in 1974. The number of visits to physicians and hospitals by members of the flood group increased after the flood. Psychological problems were more common than physical problems and were more common for females (23). Price extended the Abrahams study, focusing on age-related health effects. He found that women ≥ 65 years of age experienced significantly more psychiatric symptoms than men. This sex difference was not apparent for persons ≥ 65 years of age (24).

In 1978, Janerich *et al.* investigated a reported cluster of lymphoma and leukemia cases in the Canisteo River Valley in New York (25). Before 1974 the combined rates of leukemia and lymphoma for the river-valley towns and the nonriver-valley towns were similar. In the period 1974-1977, after the severe flooding in the river-valley towns from tropical storm Agnes in 1972, there was a small increase in rates of lymphoma and leukemia in the nonriver-valley towns and a statistically significant increase in rates of these problems in the river-valley towns. The rates for other malignancies were unaffected during this period. The data indicated that the increase in leukemia and lymphoma rates occurred in all three river-valley towns, and the rates for the approximately 100,000 people were about 35% higher than would be expected. Examination of statistics on patterns of reproductivity for the four counties for 1970-1977 showed a statistically significant excess of spontaneous abortions in 1973 compared with average numbers for the other years. Except for 1973, the year after the flood, the spontaneous abortion rates in these four counties were consistently lower than for the rest of upstate New York. The excess was greatest in the river-valley towns.

Environmental monitoring failed to link radiation or poor water quality with the effects observed. The sequence of events in this situation led the authors to identify the flood as a possible causative event contributing to leukemia and lymphoma for the 2- to 5-year period after the flood and to increased spontaneous abortions for the year after the flood (25).

These follow-up studies show a consistent pattern of increased psychological problems among flood victims for up to 5 years after the flood. The findings regarding non-psychiatric morbidity are less consistent, but many of the reported morbidity problems such as hypertension and cardiovascular disease—and even leukemia and lymphoma—may be stress related. Greene (26) investigated the relationship of the onset of leukemia and lymphoma to the severe psychological stress by involving feelings of situations loss At the time of diagnosis, most patients were experiencing a severe psychological sense of loss or hopelessness, which was generated by stress events that occurred as long as 4 years before the appearance of clinical disease. Greene observed that the median interval between the stress event and a confirmed diagnosis was 1 year and that a large cluster occurred 11-13 months before the disease was diagnosed. Neither the short latency of leukemia and lymphoma in the Janerich study nor the prolonged high incidence can be clearly explained, but both phenomena are consistent with Greene's observations about stress events in the prodromal period of adult-onset leukemia and lymphoma.

Secondary Exposures and Effects

Floods may cause disruption of water purification and sewage disposal systems, rupture of underground pipelines and storage tanks, overflowing of toxic waste sites, enhancement of vector-breeding conditions, and dislodgement of chemicals stored above ground. Floods may also lead to overcrowding in temporary shelters. These events may contribute to increased exposure to biological and chemical agents. There is limited documentation of disease outbreaks associated with such exposures after floods.

INFECTIOUS DISEASE

An outbreak of leptospirosis occurred after floods in July 1975 in Greater Recife, Brazil. Of 107 reported cases, 105 were confirmed by seroagglutination or hemoculture. *Leptospira icterohaemorrhagiae* was the predominant serotype found (27)

An increase in malaria was reported after heavy rains associated with a hurricane that struck Haiti in October 1963. The percentage of malaria-positive slides tested rose from 2% in September 1963 to almost 26% by the end of February 1964. The highest positive slide rates were for children ≤ 1 year of age. Both sexes were equally affected. Coastal areas showed higher rates than the interior, and localities at altitudes of < 300 meters showed higher rates than localities at higher altitudes. The investigators attributed the epidemic to an interruption of spraying, which left a large reservoir of gametocyte carriers after the hurricane; a lack of shelter, which resulted in a greater exposure of the population to the principal vector; almost complete removal of the insecticide from homes by heavy rainfall; an explosive increase in mosquito breeding due to heavy rainfall; and increased movement of the population in search of refuge from the storm's devastation (28).

Public health officials of Rybnitzky district in Moldavia reported the number of cases of scarlet fever doubled after the 1969 flood. In Tiraspol the number of such cases tripled, and there were twice as many cases of whooping cough. Increased morbidity affecting children was registered during and immediately after the flood. An epidemic of dysentery also occurred after the 1969 floods in Moldavia (7).

In Voroshilovgrad, Russia, after the flood in 1954, rates of typhoid and paratyphoid were almost twice as high as in 1953. A typhoid epidemic also occurred in Kishinev, Russia, after a June 1969 flood Typhoid morbidity there was 9.8/100,000 in 1968 and 14.8 in 1969 (7).

A widespread outbreak of yellow fever in Argentina in 1965-1966 was associated with floods that covered the area at that time (7).

Bissel (29) found a significant increase in typhoid, paratyphoid, hepatitis, and measles in the Dominican Republic after flooding caused by hurricanes David and Frederick on August 31 and September 5, 1979, respectively The author attributed the observed increase in infectious disease to a) flood-caused water transmission of pathogens and b) overcrowding of makeshift refugee centers with insufficient sanitary facilities.

Infectious disease outbreaks in the United States are rare after flooding (30). This may reflect the fact that the reservoir of agents commonly associated with epidemics after floods is relatively low in the United States compared with other parts of the world. However, some potential does exist for waterborne disease transmission of such agents as enterotoxigenic *Escherichia coli*, *Shigella*, *Salmonella*, hepatitis A virus, Norwalk virus agents, as well as the agents that cause leptospirosis and tularemia. There may also be a potential for increased risk of transmission of arboviruses due to increased vector populations from flood conditions.

TOXIC EFFECTS

The release of chemicals during floods has been documented, but information on adverse health effects associated with such exposures is limited.

The flood resulting from the collapse of the Teton Dam in southeastern Idaho in 1976 damaged a large area and led to the release of toxicants into the Snake River. At least three commercial facilities containing pesticides were damaged by the flood, and many farm storehouses were also affected. The flood transported much of the pesticide material stored in containers, broke the containers, and dispersed the pesticides over 240 km of the Snake River. A pesticide-recovery team studied the flooded area for 3 weeks and collected 1,104 containers, about 35% of which contained toxicants such as DDT, dieldrin, polychlorinated biphenyls (PCBs), and organophosphates. It was estimated that < 60% of the lost pesticide containers were recovered. Over 300 samples of fish, plankton, waterfowl, sediments, water, stream drift, aquatic plants, and soil were collected. The levels of PCB and DDT were high in fish and approached the 2,000-μ/kg FDA-proposed tolerance. Very little preflood data on whole fish were available for comparison (31).

Studies have shown that the uptake of a pesticide, such as aldrin ($C_{12}H_8Cl_6$—an aromatic hydrocarbon that affects the central nervous system, liver, kidneys, and skin), is enhanced in rice plants and grains in flooded soils, and the pesticide persists in the plant for a longer period than in nonflooded soils. The aldrin residues dissipated to their half in 90 days in plants from flooded soil compared to 70 days for plants from nonflooded soil. At the 90-day period, the flooded soil-plant residue of aldrin was converted to dieldrin (32).

Heavy rains and floods caused a break in a pipe at a fertilizer plant in the town of Vila Parisi, Brazil, in 1985, spreading a snow-white cloud of ammonia over the village and causing 63 people to seek treatment for symptoms (33).

The lack of documentation of adverse health effects from flood-associated toxic exposures may be attributable to several factors: a) very few, if any, studies have been done to look for such associations; b) the symptoms associated with toxic exposures are often nonspecific and may have a latency period; this may make it difficult to associate an adverse effect with a toxic exposure and particularly one that is flood-related; and c) in the past there has been little recognition of the potential for release of toxic chemicals during flooding, and such releases have gone unrecognized.

Public Health Implications

Prevention and Control Measures

The principal steps to follow for preventing death and injury associated with floods are:

To identify flood-prone areas and take appropriate preventive action, including the following: the institution of engineering controls such as the construction of reservoirs and flood walls, as well as the diversion of rivers; forestation of watersheds; land-use management to prevent new construction in flood-prone areas and deforestation of watersheds; and increased regulation of flash-flood-prone areas and posting of flash-flood warnings in recreational areas subject to flash floods.

To conduct dam inspections and issue dam-safety certification. An ongoing program of dam inspections—for both public and private dams—should be carried out. Necessary structural improvements should be required at dams deemed unsafe. During periods of heavy rainfall, dams should be monitored for signs of failure, and these observations should be conveyed to public officials responsible for issuing warnings and making the decision to evacuate the population at risk.

To identify meteorologic conditions conducive to heavy precipitation and runoff and to issue forecasts and warnings of floods for a specific geographic area within a specific time frame. The present state of the art in meteorology is very effective in identifying storm systems that may have impact on a region of the country with heavy rainfall and cause flooding. It is less effective in identifying storm systems that may affect a very specific geographic area within a specific time frame and cause flash flooding. The National Weather Service (NWS) tries to compensate for this weakness by using local observers in flash-flood-prone areas who monitor precipitation and take periodic measurements of creeks and rivers during periods of heavy rainfall. These observers have been very helpful to NWS's efforts to provide adequate flash-flood warnings. However, local communities should take responsibility for providing some of this information themselves, since the NWS system cannot cover all potential flash-flood areas.

To ensure that the public is made aware of flood and flash-flood-prone areas and of appropriate action to be taken when the potential for such flooding exists. In situations in which warnings can be issued far in advance of the impending flood, evacuation of the public by vehicle is an appropriate course of action. However, in flash-flood situations in which there may be little time between the issuing of the warning and exposure to high-rising water, it is important that the evacuation route does not require passage through low-lying areas or other danger spots such as bridges. In such circumstances it may be best to abandon one's car to avoid entrapment and to climb to high ground on foot. Special attention should be given to persons who are unable to make such a climb—such as the elderly, young children, and the handicapped. Traveling alone into flash-flood-prone areas may be inadvisable. Persons who are alone during a flash flood are advised to join other people and form a support group. Local officials should be certain that people living in or visiting flash-flood-prone areas are familiar with appropriate escape routes and appropriate actions when faced with a possible flash flood.

The principal steps to follow in preventing morbidity and mortality from secondary exposures relating to floods are given in the sections below.

Infectious agents. In preventing enteric disease transmission when water and sewerage systems have been compromised, it is very important to assure that the water and food supplies are safe to consume and to assure safe disposal of human waste (34,35). When water has been contaminated or is suspected (e.g., by a drop in water pressure, discoloration, turbidity, or unusual odors), of having been contaminated, people should drink only water bottled or trucked from a safe source, water brought to a vigorous boil, or water appropriately disinfected until health authorities indicate that public supplies are again safe. Contaminated food supplies, spoiled foods, and foods potentially hazardous because of interrupted refrigeration should be discarded. Health sanitarians should be consulted about the safety of food, water supplies, and other sanitation issues.

Flood victims and relief workers should always wash their hands with soap and water (boiled or chemically disinfected when no regular safe supply is available) before preparing or eating food, after using the toilet, and after participating in flood clean-up activities.

Mass vaccination programs at the time of natural disasters are counterproductive and divert limited personnel and resources from other relief tasks. Such programs may also create a false sense of security and lead to neglect of basic hygiene. There is usually a public demand for typhoid vaccine and tetanus toxoid after floods, despite the fact that no epidemics of typhoid have occurred after floods in the United States. Additionally, it takes several weeks for antibody to typhoid to develop, and even then, vaccination provides only moderate protection. Mass tetanus vaccination programs are also not indicated. Management of flood-associated wounds should include appropriate evaluation of tetanus immunity (and vaccination, if indicated) as at any other time.

When floods occur in areas with endemic arthropod-borne encephalitides, arthropods known to transmit the disease should be monitored and areas should be sprayed if the vector population increases significantly after the flood.

Adequate interim lodging should be provided for flood victims.

When returning to flooded dwellings, people should pay special attention to structural, electrical, and gas-leak hazards. Additional attention should be given to factors contributing to the growth of fungi and bacteria (adequate clean-up, drying out, and disinfection) Local health agencies and utility companies should be consulted on such matters when indicated.

Toxic agents. Supplies of drinking water and food, such as fish, should be tested for toxic chemical and radioactive agents if there is reason to suspect that such substances may have been released during the flood. Soil surrounding toxic-waste sites and storage lagoons should be inspected to determine whether contamination from overflowing of these storage areas during flooding has occurred. Contaminated soil areas should be declared off-limits to the public until appropriate clean-up has been instituted. The public should be warned not to consume contaminated water or fish if toxic substances are found.

Surveillance

MORBIDITY AND MORTALITY RELATED TO FLOODS

There is a need to assess the trends in morbidity and mortality related to river flooding and flash floods to determine if preventive measures have been effective. The responsibility for these assessments, in general, rests with the local and state health departments. In the past the information on flood-related mortality has been limited to the number of deaths per year, thus making it difficult to determine if a high number of deaths in a given year was the result of a high death toll from a few floods or a small number of deaths from many floods. To properly assess trends, it is important to have a surveillance system that will provide information on the average number of deaths and injuries per flood per year. To accomplish this, systematic reporting is needed whereby all floods and associated deaths and injuries are reported to the National Weather Service. The average number of deaths and injuries per flash flood or river flood per year should then be computed for the United States as a whole and for various regions of the country. The circumstances surrounding death and injury should also be reported.

MORBIDITY AND MORTALITY FROM INFECTIOUS DISEASE

During and after a flood, a surveillance system should be instituted to permit the identification of increased cases of communicable disease in the flood-stricken area. Particular attention should be given to those diseases endemic to the area. Emergency room visits, clinic and physician office visits, and hospital admissions can be assessed for such purposes on a regular and, preferably, daily basis. The data should be analyzed to determine if there was a significant increase in communicable disease in the 2 or 3 months after the flood compared with the 2 or 3 months preceding it. If a significant increase in infectious disease is found, an appropriate nonflood community should be evaluated for the same time period to determine if there is evidence for such an increase in that community.

POTENTIAL EXPOSURE TO TOXIC AGENTS

State and local governments throughout the United States should know exactly where and how toxic materials are stored within the areas of their jurisdiction. This should include materials in underground storage tanks and pipelines, as well as toxic materials stored above ground Special attention should be given to these storage areas after a flood to determine whether any of these materials have been released into the environment. If release is suspected, environmental monitoring should be carried out to determine contamination of human pathways of exposure. If evidence for potential human exposure is found, the population at risk should be assessed for associated adverse health effects.

Research Recommendations

Although studies conducted during and after floods have provided some information on factors contributing to the risk of morbidity and mortality, some inconsistencies and questions remain that still need to be resolved:

- The factors influencing actions people take in the face of a flash-flood warning and notice to evacuate should be studied further. Attention should be given to the physical stamina such actions require of people of all ages and varying health status

- Studies should be done to assess the circumstances under which there is sufficient time—after a flash-flood warning is issued—to permit evacuation by car or when it is safer to abandon one's car and escape to higher ground on foot.

- A cohort of flood victims should be followed over time to determine whether they are at higher risk than a comparable group of nonflood victims of having adverse physical and mental health effects.

- Systematic studies should be undertaken to determine whether an increase in certain biological agents results from disrupted water supplies and sewage systems after floods in different regions of the United States. These studies should also look at changes in certain vector populations before and after flooding

- Systematic studies should be undertaken to look at the release of chemical agents during flooding and the potential for contamination of human pathways from such events.

- A reporting system should be established to more accurately assess the number of deaths and injuries associated with each flood and the circumstances surrounding each flood death and injury.

Summary

It is estimated that floods represent 40% of all the world's natural disasters, and that they do the greatest amount of damage. In the United States, flooding—marked by the slow, steady rise of the rivers from melting snow and repeated rainfalls—has been curtailed by engineering controls and increased forestation of watersheds. However, flash floods, marked by the very rapid runoff of water after heavy rains, have in recent years become the number one weather-related killer in the United States. The increased toll from flash floods results from natural events that impact on an increased and more urbanized population's settling and occupying sites that are ready targets for flash floods.

The primary cause of death from floods is drowning. Several studies have found that a high percentage of drownings in flash floods are car-related.

A review of NWS reports has shown that more than twice as many deaths have been associated with flash floods for which the warnings were considered inadequate than with those for which warnings were considered adequate. There are conflicting reports regarding factors that influence the actions people take when receiving a flash-flood warning. Some studies have reported that the elderly are less apt to receive warnings and to evacuate when they do receive warnings. Other studies have not confirmed this pattern. Although some studies have reported that people with previous flood experience were more ready to evacuate, another study of a successful evacuation of an entire community found that the population largely comprised older people with no previous flood experience who willingly evacuated even though they did not sense any immediate danger.

The circumstances surrounding the flood and the physical effort required to reach safety may influence whether people will take appropriate action when faced with the threat of a flash flood. In one study, groups of three to five persons were more apt to take appropriate action and survive than persons who were alone.

Countries outside the United States have reported increased cases of infectious diseases such as leptospirosis, malaria, yellow fever, and typhoid fever after floods, but such increases have not been documented in the United States in the past 3 decades.

Release of chemical agents into the environment during flooding has been documented in both the United States and other parts of the world. Data on adverse health effects associated with such exposures are limited but at least one incident has been recorded in which heavy rains and floods caused the break in a pipe at a fertilizer plant, resulting in symptoms in 63 people due to exposure to ammonia. The paucity of data on health effects associated with such exposures may be in part because few studies have been done to look for such associations after flooding.

Follow-up studies of flood victims show a consistent pattern of increased psychological problems affecting flood victims for up to 5 years after the flood The findings regarding nonpsychiatric morbidity are less consistent, but chronic effects such as hypertension, cardiovascular disease, leukemia, and lymphoma have been found significantly elevated among flood victims compared with controls in several studies These observations, however, need confirmation

Prevention of death and injury from floods can be accomplished by identifying flood-prone areas and taking appropriate preventive action, conducting dam inspections and issuing dam-safety certification, identifying meteorologic conditions that will contribute to heavy precipitation and runoff and issuing warnings of floods for a specific geographic area within a specific time frame, and making the public aware of flood- and flash-flood-prone areas and advising them on appropriate actions to take when faced with a potential flash flood.

Morbidity and mortality from secondary exposures related to floods can be prevented by assuring that water and food supplies are safe to consume and are not contaminated with biological and chemical agents, and by instituting safe human-waste-disposal practices. Soil surrounding toxic waste sites and storage lagoons should be inspected to determine if there has been contamination from overflowing of these storage areas during flooding. Contaminated soil areas should be declared off limits to the public until appropriate clean-up has been completed. Consideration should also be given to potential increases in certain vector populations. Mass vaccination programs at the time of natural disasters are counterproductive.

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