# 8

# FLOOD IMPACTS ON SOCIETY

## Damaging floods as a framework for assessment

*R.A. Pielke, Jr*

## INTRODUCTION

By any measure, floods have a significant impact on society. The Red Cross estimates that over the twenty-five-year period ending in 1995, more than 1.5 billion people worldwide have felt the impact of floods.[1] Of that total, they estimate that more than 318,000 people were killed and more than 81 million were made homeless. In addition, over the period 1991–95, flood-related damages totaled more than US$200 billion (not inflation-adjusted) worldwide, representing close to 40 percent of all economic damages attributed to natural disasters in this five-year period.[2] In the 1990s, significant flood damages occurred in Eastern Europe (1997, damages totaling US$4–6 billion), the United States and Canada (1997, US$1.75 billion), China (1996, US$26.5 billion), Central Europe (1993 and 1995, US$4 billion) and the United States Midwest (1993, US$16 billion) (PartnerRe, 1997).

Reliable and accurate knowledge of flood impacts is important because decision-makers allocate scarce resources to flood-related concerns on the basis of their interpretation of trends in and causes of impacts and their expectations for the future. Regrettably, implementation of policies in response to floods is hampered by a lack of specific knowledge of trends in flood impacts on society and, more importantly, the causal factors which underlie those trends. Indeed, the International Federation of Red Cross and Red Crescent Societies (IFRCRCS) has written that

> the lack of systematic and standardized data collection from disasters, man-made or natural, in the past is now revealing itself as a major weakness for any developmental planning. Cost–benefit analysis, impact analysis of disasters or rationalization of preventative actions are severely compromised by unavailability and inaccuracy of data or even field methods for collection.
>
> (IFRCRCS, 1997: 113)

For instance, consider the case of the United States, where the average annual economic damages related to floods increased from the 1970s to the 1990s (Pielke, 1999). Some have speculated that the trend is indicative of a change in climate (e.g. Hamburger, 1997), some blame population growth and development (e.g. Kerwin and Verrengia, 1997), others place the blame on federal policies (e.g. Coyle, 1993), and still others suggest that the trend distracts from the larger success of the nation's flood policies (e.g. Labaton, 1993). Empirical evidence from a number of cases clearly shows that climate, population growth and development, and policy each play a role in trends in damaging flooding in the United States (e.g. Changnon, 1996; Federal Interagency Floodplain Management Task Force (FIFMTF), 1992), but the state of knowledge is such that the relative contribution of each factor is poorly understood. The United States case seems typical of the more general circumstance: policy-makers face difficulties in assessing the magnitude and causes of the flood problems that they face and in evaluating the effectiveness of past responses (Pielke, 1999; Weiner, 1996a).

While recent research has focused on developing a better quantitative understanding of extreme weather impacts related to the interrelationship of atmosphere and society in the context of hurricanes and other extreme events (e.g. Pielke and Landsea, 1998; Pielke and Pielke, 1997; Changnon *et al.*, 1997; Changnon, 1996; Glantz, 1996), an understanding of floods remains elusive. In the public and private sectors, individuals and groups make decisions at national, regional, local, and individual levels that take into consideration trends in the societal impacts of floods and the factors which underlie those trends. It is logical that policy mistakes might be avoided with a better understanding of the factors which are responsible for observed changes in damaging floods. Consequently, a better understanding of damaging floods has important implications for policy relevance. This chapter presents the concept of the "damaging flood" as a unit of analysis for better understanding historical flood impacts and their significance for decision-making.

## FLOODS AND DAMAGING FLOODS

### What is a flood?

Typically, a "flood" is defined hydrologically in terms of a river's height or volume, which exceeds the river's average state over some length of time. According to the World Meteorological Organization, a flood is defined as a "(1) Rise, usually brief, in the water level in a stream to a peak from which the water recedes at a slower rate. (2) Relatively high flow as measured by stage height or discharge. (3) Rising tide" (WMO, 1992). According to a high-level flood task force in the United States, a flood is "the increase in volume of water within a river channel and the overflow of water from the channel onto the adjacent floodplain" (FIFMTF, 1992: 1–6). Within the broad category of floods are specific types of floods (see Chapter 1, Table 1.4). These definitions of floods, while useful for hydrological and meteorological purposes, are not particularly useful for research on societal impacts as not all hydrologic floods cause losses.

### What is a damaging flood?

Consider Figure 8.1, which shows a cross-section of the Red River of the North, at Grand Forks–East Grand Forks, which flows north along the Minnesota–North Dakota border into Canada. At what river height does a flood occur? According to Harrison and Bluemle (1980: 23), "the Red River officially reaches flood stage at a gauge reading of 28 feet (8 metres)." Figure 8.2 shows river stages at East Grand Forks for the period 1882–1979, with a dotted line marking the official flood stage. Over this ninety-eight-year period, the Red River exceeded the official flood stage in each of forty years, meaning that a flood occurred on average every 2.5 years. But "relatively little damage is done by floods less than 40 feet (12.19 metres)" (ibid.: 34). The Red River exceeded 40 ft (12.19 m) in sixteen of ninety-eight years. Indeed, of the significant losses which occurred in the period 1950–79, all occurred at flood levels greater than 49 ft (12.19 m) (ibid.: 4). Table 8.1 shows the effects that different river heights have on the Grand Forks community.

From the example of the Red River, it is clear that not all hydrological floods are damaging floods. In the Grand Forks community 60 percent of all "official floods" require no response by the community. Undoubtedly, a similar situation is to be found in other communities. The researcher who studies the societal impacts of flooding is particularly concerned with those floods which cause damage, just as the hurricane impacts researcher has a unique interest in studying landfalling hurricanes.[3] For any particular river the volume or height that causes damage varies over time with changes in the river channel resulting from human or non-human interventions (e.g. channel alterations, levees, floodplain land use, etc.), as well as the characteristics of the human occupancy of flood-prone regions.

Surprisingly, almost all discussion of floods fails to distinguish the subset of damaging floods, leading to an implicit equivalence of hydrologic floods with damaging floods.[4] For example, discussion of the possibility of future climate change has focused on the possibility of more "floods" (see, for example, Intergovernmental Panel on Climate Change (IPCC), 1995, and Karl *et al.*, 1997). When climatologists discuss such floods, they typically are referring to hydrologic floods; but when policy-makers discuss floods, they typically are referring to damaging floods. This situation is problematic as hydrologic floods are not well correlated with flood damage. The poor relationship between what climatologists, hydrologists, and other physical scientists call floods and those



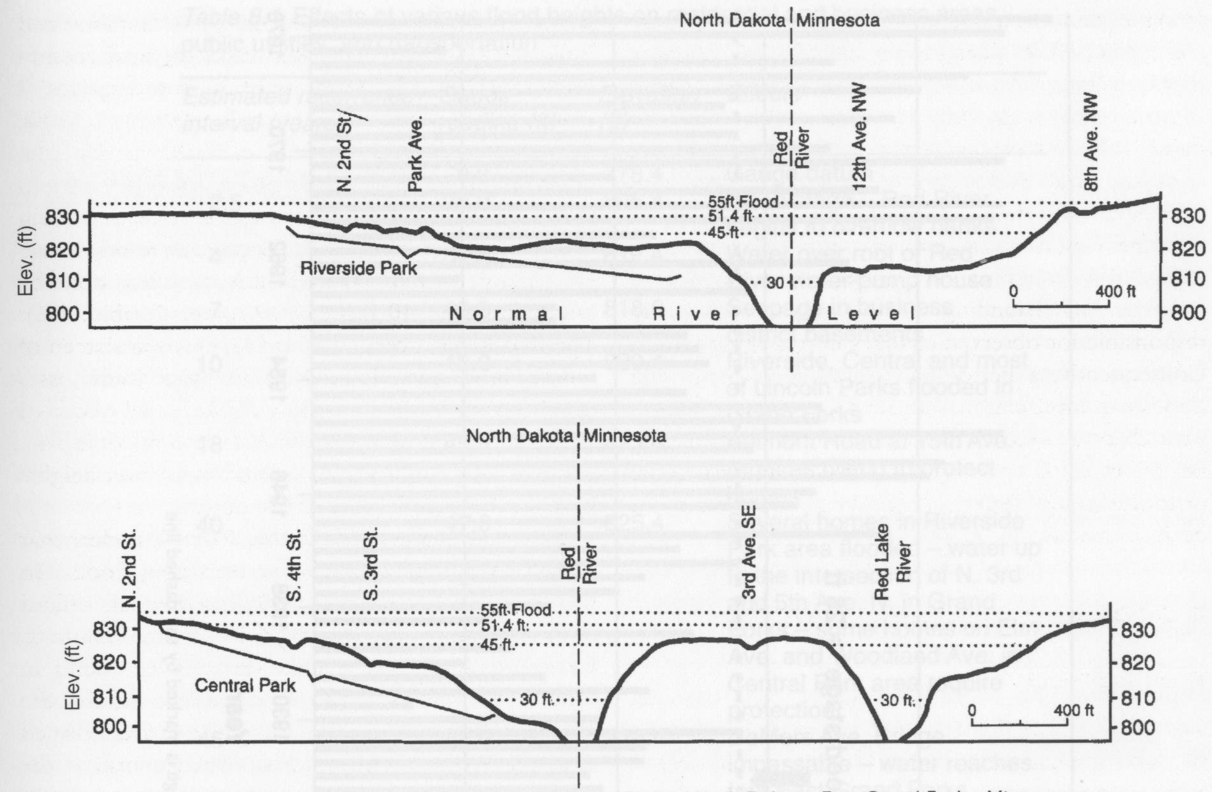


*Figure 8.1* Profiles of the flood hazard areas in the vicinity of Grand Forks, North Dakota–East Grand Forks, Minnesota
*Source*: Harrison and Bluemle, 1980

floods which actually cause damage has limited what can be reliably said about the causes of observed trends in flood damage. To focus research on the societal impacts of floods, this chapter defines a damaging flood as a flood in which individuals and/or society suffers losses related to the event.

### What causes damaging floods?

At first blush, one might be tempted to assert what seems obvious: precipitation (i.e. rain or snow) causes damaging floods. But the relationship between precipitation and damage is a complex one, particularly when one aggregates precipitation and flood damage over more than a single drainage basin. Consider that in the United States, variation in national annual precipitation explains less than 25 percent of the variance in flood damages.[5] The relation between precipitation and damages is shaped by countless intervening factors such as land use, river-channel modifications, structural and non-structural mitigation measures, etc. Consequently, in almost all cases, a damaging flood results from a combination of physical and societal processes.[6] Losses would not occur without the presence of the floodwaters, and human occupancy of the floodplain. Therefore, to understand the causes of damaging floods requires knowledge of interrelated physical and societal factors which underlie physical and societal processes.

## UNDERSTANDING DAMAGING FLOODS

A focus on damaging floods points the analyst in the direction of outcomes that matter to most decision-makers: Who is impacted? In what degree? And what is to be done? But to understand damaging floods one must look closer at the methodology of impacts assessment.

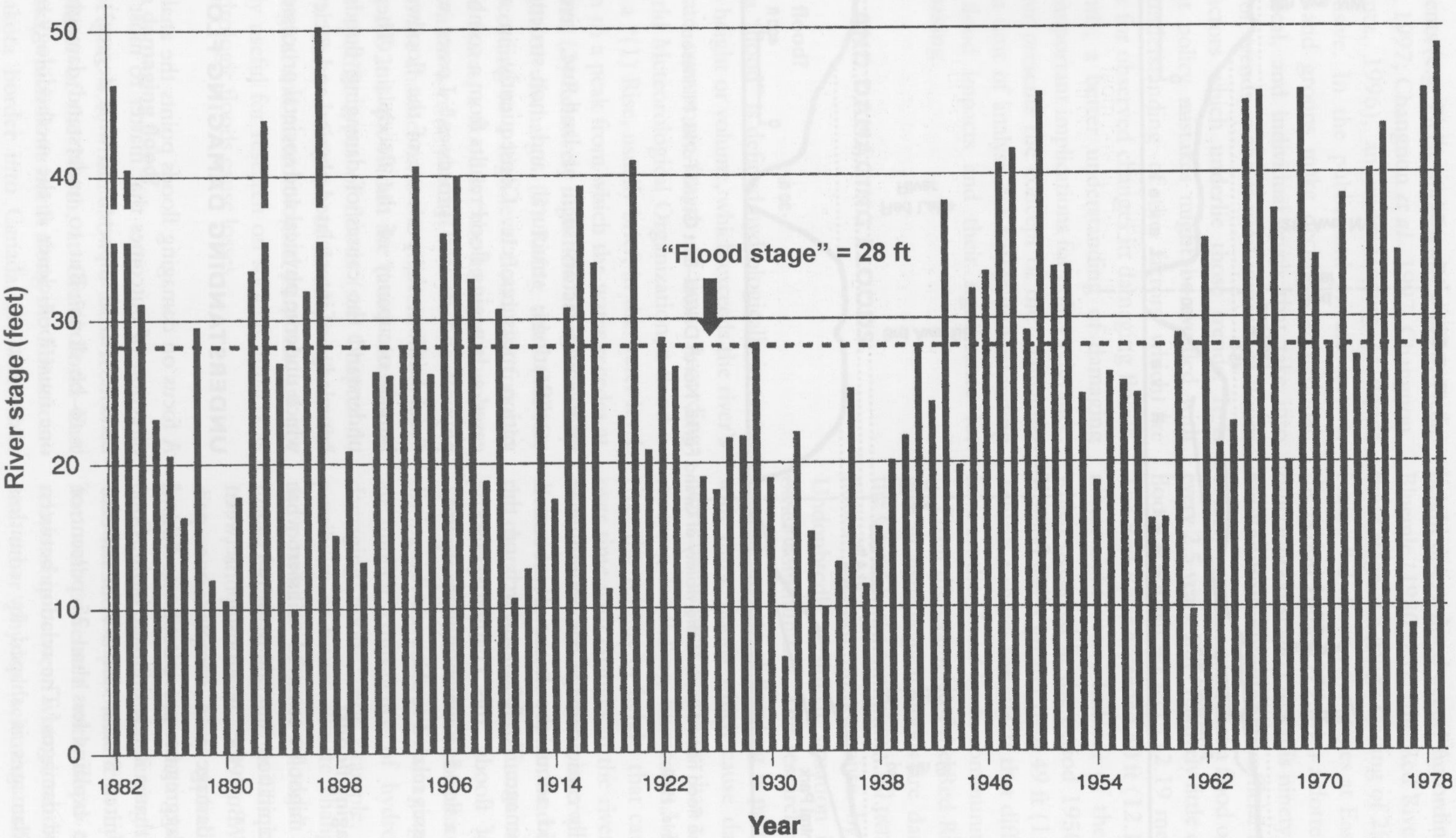


*Figure 8.2* Red River height at East Grand Forks, 1882–1978. The official flood stage is marked by the dashed line

*Table 8.1* Effects of various flood heights on residential and business areas, public utilities, and transportation

| *Estimated recurrence interval (years)* | *Gauge reading (ft)* | *Elevation (ft)* | *Effects* |
|---|---|---|---|
| | 0.0 | 778.4 | Gauge datum |
| 2.5 | 28.0 | 806.4 | Flood stage – Red River begins to overflow banks |
| 4 | 34.0 | 812.4 | Water over roof of Red River water-pump house |
| 7 | 40.5 | 818.9 | Seepage in business district basements |
| 10 | 42.0 | 820.4 | Riverside, Central and most of Lincoln Parks flooded in Grand Forks |
| 18 | 45.0 | 823.4 | Belmont Road at 15th Ave. requires diking to protect homes |
| 40 | 47.0 | 825.4 | Several homes in Riverside Park area flooded – water up to the intersection of N. 3rd and 5th Ave. N. in Grand Forks – some homes on Elm Ave. and Woodland Ave. in Central Park area require protection |
| 45 | 48.0 | 826.4 | DeMers Ave. Bridge impassable – water reaches top; East Grand Forks flooded – parts of downtown Grand Forks flooded |
| 70 | 51.2 | 829.6 | All railroad bridges impassable – this is the estimated height of the 1852 flood |
| 150? | 53.6 | 832.0 | Water reaches top of Lincoln Park dike |
| 500? | 55.0 | 833.4 | This is the estimated maximum probable flood for the two-city area – the greater part of both cities would be covered by shallow water |

*Source*: Harrison and Bluemle, 1980: 35

**What is a flood-related loss?**

Flood damages (or losses) have been defined as the "destruction or impairment, partial or complete, of the value of goods or services, or of health, resulting from the action of flood waters and the silt and debris they carry. Easy to define, flood losses are difficult to set down in dollar figures" (Hoyt and Langbein, 1955: 77; and see Parker, Chapter 1). An understanding of losses is needed to understand the costs and benefits of floodplain occupancy. As the Task Force on Federal Flood Control Policy noted in 1966

(p. 13), "it may well be that the advantages of floodplain location outweigh the intermittent costs of damages from floods. Further, there are some kinds of activity which can only be conducted near a watercourse." Because of the methodological difficulties in assessing flood damages, as well as the limited data available, "taking all in all, it is evident that any evaluation of flood damage is only a rough approximation" (Hoyt and Langbein, 1955: 79). Nevertheless, so long as a historical record of flood damages is collected in a systematic manner, it can provide some insight as to trends in flood impacts on society (Pielke and Downton, 1999; Federal Emergency Management Agency, 1997; Yen and Yen, 1996).

### How are flood-related losses determined?

In the aftermath of any extreme event there is a demand for a bottom-line measure of damages in dollars. There are many valid ways to measure the losses associated with a flood. Any assessment of impacts resulting in an estimate of total damages associated with a disaster must pay explicit attention to assumptions guiding the analysis in order to facilitate interpretation of the estimate. The analyst thus needs to pay attention to at least five factors that can undermine interpretation of information on flood losses: contingency, attribution, quantification, aggregation and comparison.[7]

#### *Contingency: the problem of multiple-order impacts*

When a community is damaged by a flood, the flood leaves an obvious path of destruction: homes, businesses, and crops may be destroyed or damaged; public infrastructure may also be compromised; and people may suffer injuries or loss of life. Such obvious impacts can be called "direct impacts" because of the close connection between event and damages. The costs associated with direct impacts are generally easiest to assess because they come in discrete quantities. Insurance payouts are one measure of direct impacts, as are disaster aid, public infrastructure reconstruction and debris removal. Direct impacts are generally negative (losses).[8]

Secondary impacts (see pp. 30–3) are those that are related to the direct impacts of a damaging flood and can be negative (losses) or positive (benefits). Generally, secondary impacts result in the days and weeks following a damaging flood. For example, a flood might destroy a water treatment plant (Changnon, 1996). The direct impact is the cost associated with rebuilding the plant; secondary impacts might include the costs associated with providing fresh water for local citizens. In general, such secondary impacts are more difficult to assess because they require estimation and are part of an existing social process; for example, estimating the costs of providing fresh water in lieu of that which would have been provided by the plant requires some sense of what would have occurred without the flood impact. Further-order impacts on time scales of months and years occur and can easily be imagined. For example, a flood might destroy a number of businesses in a community, resulting in a decrease in tourist visits, which in turn leads to a shortfall in sales tax collection. As a result, community services that had been funded from sales tax revenues may suffer, leading to further social disruption and thus additional costs. An example of a positive impact might be the influx of disaster aid into the community which stimulates the local economy. Estimation of the costs or benefits associated with such impacts is difficult to accomplish with much certainty because of numerous confounding factors. In short, a damaging flood can serve as a shock to a community that leaves various impacts which reverberate through the social system for short and long periods. Pulling the signal of the reverberations from the noise of ongoing social processes becomes increasingly difficult as the impact becomes further removed in time from the event's direct impacts.

#### *Attribution: the problem of causation*

Related to contingency is attribution. In the aftermath of any "natural" disaster, people are quick to place blame on nature: "The flood caused billions of dollars in damages." However, it is often the case that "natural" disasters are a consequence of human failures. Damage is often a result of poor decisions of the past and inadequate preparation rather than simply the overwhelming forces of nature. It is often at the intersection of extreme events and poor preparation



that a disaster occurs. Gross tabulations of damages neglect the question of why damage occurred, and often implicitly place blame on nature rather than on human decisions.

#### *Quantification: the problem of measurement*

The problem of measurement is exemplified in the following question: How much is a life worth? Or, put in practical terms, how much public money are people willing to pay to save one more life in the face of an environmental hazard? According to a review by Fischer *et al.* (1989), the public assigns between US$2.0 million and US$10.9 million as the value of a human life. The difficulties associated with assigning an economic value to a human life are representative of the more general problem of assessing many of the costs and benefits associated with a flood's impact. Similar questions might include: What is the value of a lost ecosystem, park, or unrecoverable time in school, etc.? What are the costs associated with psychological trauma? The difficulties in quantifying the cost of a life are representative of the more general problem of placing a monetary value on damages that are not directly economic in nature.

A flood affects many aspects of society that are not explicitly associated with an economic measure (e.g. psychological well-being). As a consequence, any comprehensive economic measurement of any particular flood's impact necessitates the quantification of costs associated with subjective losses. The assumptions that one brings to assessment of value can affect the bottom line. Therefore, when an economic measure of losses is needed (itself a choice made by the analyst), care must be taken to make such assumptions explicit in the analysis.

#### *Aggregation: the problem of benefits and spatial scale*

As mentioned above, flood impacts are not all negative; however, estimates of impacts rarely consider benefits. Consider the following example: Following a flood that severely damages agricultural productivity in a region, commodity prices rise nationwide. Thus, while farmers in the affected region see losses, farmers outside of the region may actually see significant benefits. At a national level the flood might conceivably have net economic benefits. The example of farmers seeing gains or losses, depending upon where they farm, points to two related issues: benefits and spatial scale. Arguably, following every disaster some individuals and groups realize benefits in some way from the event. Methodologically, should such benefits be subtracted from a hurricane's total impact? Further, the picture of damages depends upon the scale of the analysis. For the same event a local community may experience complete devastation, the region moderate impacts, and the nation positive benefits. Transfers of wealth, including who gains and who loses, further complicate the picture. Because there are multiple valid spatial scales from which to view a flood's impacts, careful attention must be paid to the purposes of loss estimates. Furthermore, it is important to remember that impacts go beyond those things that can be expressed in monetary terms; suffering and hardship are losses independent of scale.

#### *Comparison: the problem of demographic change*

As a consequence of the challenges facing meaningful impact assessment, comparing damage across time and space is problematic. Many floods of the past would certainly have left a greater legacy had they occurred in more recent years because of the increased population in many of the world's flood-prone regions. Yet damage statistics often go into the historical record noting only the event and economic damage (usually adjusted only for inflation). Such statistics can lead to mistaken conclusions about the significance of trends in flood damage. Because population and property at risk to hurricanes changed dramatically during the twentieth century in many locales, such statistics may grossly underestimate our vulnerability. Therefore, care must be taken in the use of bottom-line damage estimates to reach policy conclusions.

#### *Bottom line: apples with apples, oranges with oranges*

There are many valid ways in which to measure the losses associated with a flood. There is no one "right" way. The method chosen for assessment of damages depends upon the purposes for which the measurement is made, and therefore must be determined on a case-by-case basis. No matter what method is employed when assessing or using the costs and benefits associated with a flood's impact, the analyst needs to ensure at least two things. First, he or she needs to make explicit the assumptions which guide the assessment: What is being measured, how, and why. Second, compare apples with apples and oranges with oranges. If the purpose is to compare the impacts of a recent flood with a historical flood or a flood to a hurricane, the methods employed ought to result in conclusions which are meaningful in a comparative setting.

### How is floodplain management to be addressed in a framework of damaging floods?

"Floodplain management" refers to "a continuous process of making decisions about whether and how floodplain lands and waters are to be used" (FIFMTF, 1994: 8; and see Smith, Chapter 15). Such decisions have a direct impact on the frequency and magnitude of damaging floods. An understanding of the relationship of floodplain management and damaging floods is central to evaluation of the successes and/or failures of flood-related decision-making. Improved decision-making depends upon understanding the causes of damaging floods, including the positive and negative contributions of floodplain management.

In the past, floodplain management has included structural (e.g. levees) and non-structural measures (e.g. land-use regulations) which have associated costs and benefits. For instance, Table 8.1 shows that in Grand Forks, North Dakota, one neighborhood requires a dike for protection when the Red River reaches 45 ft (13.72 m). All else being equal, when the Red River reaches 45 ft (13.72 m), the dike prevents the hydrological flood from becoming a damaging flood; without the dike the flood would be damaging. This example suggests that apart from any direct impacts of this particular event, the costs and benefits of the dike ought to be considered in the impacts associated with damaging floods. The more general principle is that structural and non-structural flood mitigation are themselves "impacts" associated with floods and ought to be incorporated in discussions of the costs and benefits of floods to society.

Just as is the case with damaging floods, the impacts of flood mitigation can be direct or secondary, positive or negative. For example, Tobin (1995: 365) defines a "levee effect" which can serve to actually *increase* the potential for flood losses.

> Once [a levee] has been constructed, however, the structure may generate a false sense of security to the extent that floodplain inhabitants perceive that all flooding has been eliminated. With the incentive to take precautions removed, few residents will be prepared for remedial action in the event of future floods. Even more costly, however, this false sense of security can also lead to greater development in the so-called safe areas, thus adding to the property placed at risk . . . when the levee does fail, the increase in development can actually raise losses even higher than if no levee system had been constructed in the first place.

The "levee effect" can increase society's vulnerability to floods in two ways: by creating a sense of complacency, which can serve to reduce preparedness, and by creating incentives to build structures in areas subject to flooding. Tobin observes that a comprehensive study of the "levee effect" has yet to be undertaken, which is representative of the relatively poor understanding of the costs and benefits of flood mitigation.[9]

## A CASE STUDY: DAMAGING FLOODING RELATED TO THE 1993 MIDWEST FLOODS IN THE UNITED STATES

### Economic effects

The flood of 1993 resulted in more than $20 billion (1993 dollars) in direct economic damages (Changnon, Chapter 18, and Table 8.2).[10] In the aftermath of the event, analysts paid more attention to assessment of the flood damages and why they occurred. In November 1993, Congress authorized the Army Corps of Engineers to conduct a "comprehensive, system-wide study to assess flood control and floodplain management in the areas that were flooded in 1993" (Floodplain Management Assessment (FPMA), 1995: 1).[11] Part of this assessment included a tabulation of the economic costs of the 1993 event. The Corps's study found that there were US$3.85 billion worth of agricultural damages resulting from damages over more than 14 million ha of farmland (pp. 3–10ff.) (Plate 8.1 – in color section between pp. 34–5). The report found more than US$760 million worth of residential damages with 57 percent (US$431 million) of this total from the St. Louis District. Other urban damages (e.g. damages to commercial and industrial structures and public buildings) totaled more than US$1.6 billion (with 40 percent in the Kansas City District and 37 percent in the St. Louis District). The report found that more than US$2.69 billion had been spent on disaster relief, emergency response, and human services.



*Table 8.2* Current dollar estimates of 1993 Midwest flood-related damages

| *Type of loss* | *Amount of damage ($ billions)* | *Source(s)/Notes* |
|---|---|---|
| Common insured private property | 1.02 | Zacharias (1996) |
| Federal disaster package: | 4.25 | IFMRC (1994) |
| State and local costs: | | |
| State | 1.00 | Changnon (1996) |
| Local | 0.08 | Changnon (1996) |
| Agriculture | | |
| Damages | 8.45 | Zacharias (1996) |
| Environment | | Bhowmik (1996); Sparks (1996) |
| Transportation: | 1.92 total | Changnon (1996); see also Eiben and Changnon (1994) |
| Rail | 0.41 | |
| Barge | 0.92 | |
| Highway | 0.58 | |
| Levees | 1.75 | Schnorbus *et al.* (1994) estimate costs of rebuilding between $1.5 and $2 billion |
| Federal flood insurance claims | 1.31 | IFMRC (1994) |
| Tourism losses | 0.30 | Changnon (1996) |
| TOTAL | 20.10 | Direct damages |

*Source*: Based on Changnon (1996) and updated and extended where possible

The Galloway Report (Interagency Floodplain Management Review Committee (IFMRC), 1994) found that the federal agencies had spent more than US$4.2 billion on the flood (Table 8.3), and federal insurance paid out more than US$1.3 billion in claims (Table 8.4). In addition, the federal government approved more than US$620 million in disaster-related loans, primarily through the Small Business Administration, but also the Rural Development Administration, and the Farmers Home Administration (IFMRC, 1994).

The transportation sector was also hard hit by the flood. The inability of barges to navigate the river because of the flood contributed to an estimated loss of US$600 million to the industry and US$320 million to local economies through secondary impacts (Changnon, 1996). The railroad industry suffered about US$269 million in damages and US$169 million in lost revenues, with almost the entire amount of recovery borne by the railroad industry. Some railroads did benefit from the flood; for instance, the Illinois Central saw revenues increase by US$18 million (ibid.). Highways and bridges were also extensively damaged by the flood, causing more than US$430 million worth of damages, and US$150 million in lost revenue to business. Again, there were a few beneficiaries, with several trucking companies gaining about US$13 million in additional revenue owing to the increased demand for transportation

*Table 8.3* Summary of federal agency expenditures by state for the Great Flood of 1993 in millions of 1993 dollars

| *State agency* | *Total* | *Illinois* | *Iowa* | *Kansas* | *Minnesota* | *Missouri* | *Nebraska* | *N. Dakota* | *S. Dakota* | *Wisconsin* |
|---|---|---|---|---|---|---|---|---|---|---|
| USDA | 1,699.9 | 63.3 | 376.2 | 69.7 | 446.2 | 141.6 | 77.2 | 100.6 | 155.7 | 109.0 |
| FEMA | 1,098.0 | 197.5 | 189.8 | 111.7 | 62.9 | 291.5 | 58.8 | 37.1 | 36.9 | 46.4 |
| HUD | 500.0 | 94.9 | 107.7 | 40.6 | 29.8 | 152.1 | 24.4 | 22.2 | 14.1 | 14.4 |
| DOC | 201.3 | 8.4 | 48.5 | 17.9 | 7.9 | 51.9 | 0.6 | 2.9 | 1.6 | 0.8 |
| USACE | 253.1 | 70.3 | 9.7 | 11.0 | 0.3 | 128.7 | 1.0 | 0.0 | 0.0 | 0.0 |
| HHS | 75.0 | 7.4 | 22.8 | 4.2 | 4.0 | 19.3 | 2.3 | 2.2 | 2.6 | 3.9 |
| Educ. | 100.0 | 1.4 | 11.1 | 0.2 | 0.8 | 4.5 | 0.4 | 0.8 | 0.5 | 0.3 |
| Labor | 64.6 | 10.0 | 15.0 | 10.0 | 5.0 | 15.0 | 3.0 | 2.0 | 3.1 | 1.5 |
| DOT | 146.7 | 33.3 | 22.1 | 23.6 | 7.3 | 73.5 | 3.0 | 3.6 | 3.9 | 2.8 |
| EPA | 34.0 | 5.3 | 4.6 | 3.1 | 2.2 | 7.6 | 2.0 | 1.2 | 3.7 | 2.4 |
| DOI | 41.2 | 11.8 | 2.1 | 1.3 | 6.0 | 5.1 | 0.5 | 0.8 | 0.9 | 4.8 |
| Total | 4,213.8 | 503.6 | 809.6 | 293.3 | 572.4 | 890.8 | 173.2 | 173.4 | 223.0 | 186.3 |

*Source*: Interagency Floodplain Management Review Committee (IFMRC) 1994: 23–25
*Note*: State expenditures do not always sum to agency total because not all agency costs are broken down by state
*Key*:
USDA = US Department of Agriculture
FEMA = Federal Emergency Management Agency
HUD = Housing and Urban Development
DOC = Department of Commerce
USACE = US Army Corps of Engineers
HHS = Health and Human Services
DOT = Department of Transportation
EPA = Environmental Protection Agency
DOI = Department of the Interior

*Table 8.4* Summary of federal flood insurance claims by state for the Great Flood of 1993 in 1993 dollars for the Federal Crop Insurance Corporation (FCIC) and the National Flood Insurance Program (NFIP)

| *State program* | *Total* | *Illinois* | *Iowa* | *Kansas* | *Minnesota* | *Missouri* | *Nebraska* | *N. Dakota* | *S. Dakota* | *Wisconsin* |
|---|---|---|---|---|---|---|---|---|---|---|
| FCIC | 1,017.0 | 25.4 | 281.2 | 40.4 | 353.9 | 27.7 | 49.0 | 139.3 | 54.1 | 46.0 |
| NFIP | 297.3 | 61.4 | 23.4 | 10.7 | 1.7 | 192.3 | 4.8 | 0.3 | 0.8 | 2.0 |
| Total | 1,314.3 | 86.8 | 304.6 | 51.1 | 355.6 | 220.0 | 53.8 | 139.6 | 54.9 | 48.0 |

*Source*: Interagency Floodplain Management Review Committee (IFMRC), 1994: 27

because of the lack of barge traffic (ibid.). In addition, thirty-three small airports were inundated, needing US$5.4 million worth of repairs. In spite of the extensive impacts of the 1993 flood a team of analysts from the Federal Reserve Bank in Chicago found that it "has had a surprisingly limited impact on the flow of economic activity in the region" (Schnorbus *et al.*, 1994: 1).

While, according to one estimate, more than 1.6 million ha of farmland were "severely eroded" during the Great Flood (Bhowmik, 1996: 105), some farmers benefited from the disaster. For example, many farmers in Indiana, Iowa, and Ohio translated good crops and elevated crop prices into a very successful year (Zacharias, 1996). For some, recovery in the aftermath of the flood came quickly. The year after the flood, farmers reaped a near-record corn and soybean crop, with much of the land inundated in 1993 back in production by 1994 (Wright, 1996).

The flood also had ecological impacts – both positive and negative (see Hillman, Chapter 12). For example, while many plants and animals benefited from the flood, it also contributed to the deaths of many trees in inundated regions. The floodwaters remove oxygen from the soil – oxygen that is necessary for tree roots to bring water to the higher branches and leaves. An ironic consequence is that many trees with their bases submerged in water shriveled up and died from a lack of water (Sparks, 1996).

The flood also contributed to the spread of the zebra mussel from the Great Lakes into the lower reaches of the Mississippi River system. The zebra mussel, a native to Europe, was accidentally introduced to the Great Lakes in the mid-1980s by ships traveling between Europe and the North American inland waterway system. The flood of 1993 brought the mussel downstream, with "densities approaching 100,000 mussels per square yard of river bottom" reported in the Lower Illinois River during the flood (ibid.: 151). The impacts of the mussels are extreme: they can "overgrow and kill native clams and mussels, plug engine cooling systems and municipal and industrial water intakes, and increase the water resistance of boat hulls" (ibid.: 152).

The flood also carried a great amount of agricultural and industrial chemicals downstream and eventually into the Gulf of Mexico. The ecological impacts – on the river and the Gulf of Mexico – of the transport of these chemicals have yet to be determined (Goolsby *et al.*, 1993). The transport of nutrients in the river to the Gulf of Mexico exacerbated the problem of the 3,219–6,438 $km^2$ "dead zone" of oxygen-poor water outside the mouth of the Mississippi.

### Casualties

According to Hewings and Mahidhara (1996), fifty-two people lost their lives as a direct impact of the flood. Others lost their lives in events indirectly related to the main flooding. For instance, in the state of Missouri, Wilkins (1996) claims fifty fatalities related to the flood, with thirty of those occurring in flash flood events (see Wilkins, Chapter 33). An example of a second-order fatality is the death of a construction worker who fell to his death while repairing a bridge more than a year after the flood. More than 74,000 people were forced from their homes. This is about 10 percent of the number of people forced to evacuate from the path of Hurricane Andrew in south Florida in August 1992. The lower number of evacuees is largely due to the lower population density in the Midwest compared to south Florida. Estimates indicate that more than 56,000 homes, and perhaps as many as 100,000, were in some way affected by the flood. More than 14,000 people sought refuge from the flood in Red Cross shelters (Wilkins, 1996). More than 500 counties were eligible for disaster aid (Figure 8.3). About 200 water treatment plants were disrupted by the flood, and Des Moines, Iowa, was without drinking water for almost three weeks (Wilkins, 1996).

### The impacts of flood-control structures on the floods

#### *Levees*

About 70 percent of all levees in the upper Midwest failed during the flood (Bhowmik, 1996). Following the floods there was much debate about the impacts of levees on the flood stages. No one doubted that levees protected many urban areas from damage; it



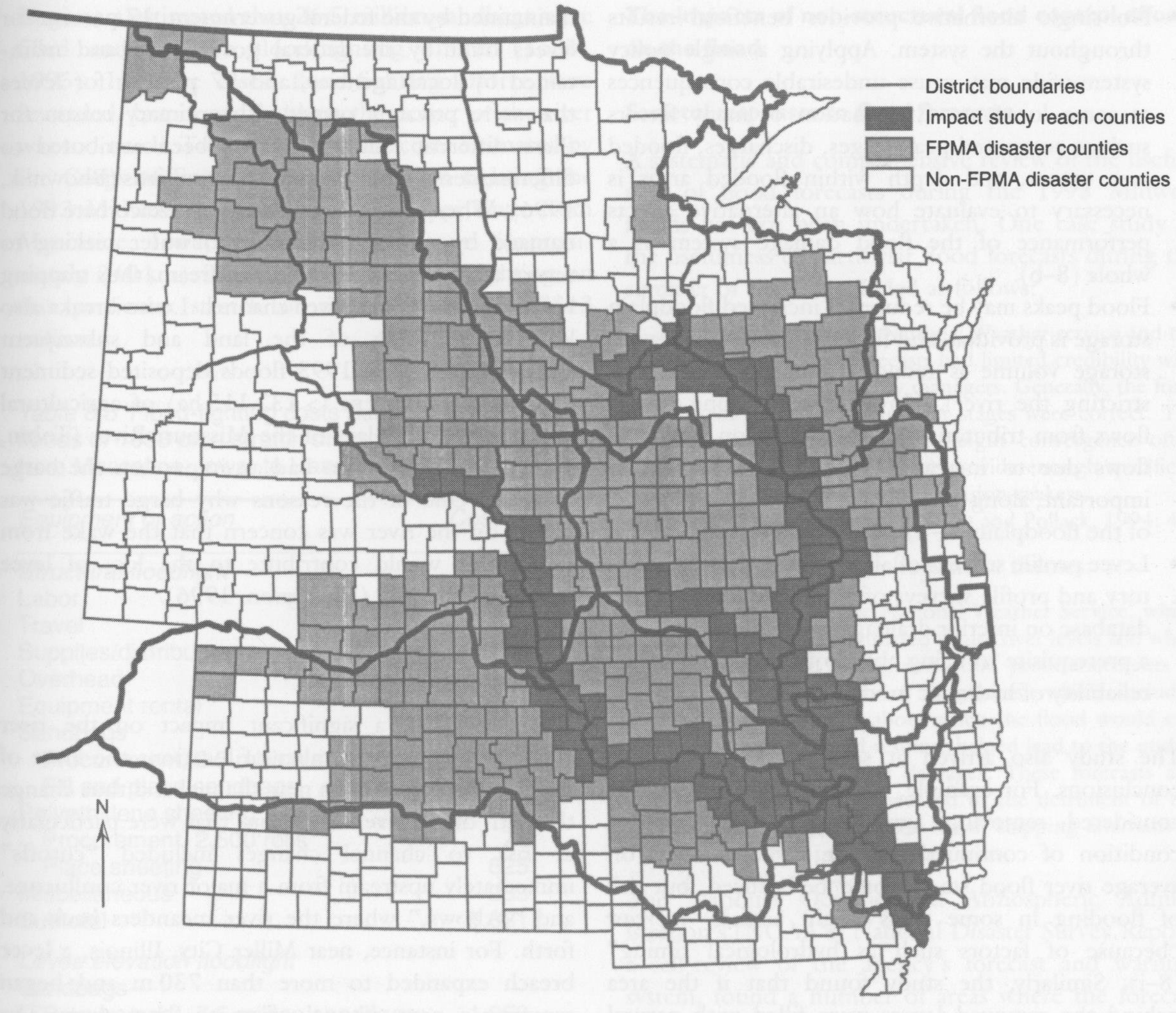


*Figure 8.3* United States counties declared eligible for disaster aid in the 1993 Midwest flood
*Source*: Floodplain Management Assessment, 1995

was the levees that protected unoccupied agricultural land that were the focus of the debate. (Whether urban areas ought to be built behind levees is another question.) Some went so far as to argue that levees were a primary cause of the 1993 flood, while others argued that the levees had no impact on the floods. The truth was found to be somewhere in between.

The Army Corps of Engineers conducted a system-wide study using hydraulic modeling to assess what the impacts of the 1993 flood might have been had the physical characteristics of the river system been different (FPMA, 1995: ch. 8). On a system-wide basis the analysis considered what the flood might have looked like by removing all agricultural levees, setting back all agricultural levees, establishing uniform-height levees, raising all levees above the observed level of the 1993 flood, removing existing reservoirs, and reducing upland runoff. The analysis also considered a number of other factors, but not on a system-wide basis.

The hydraulic study's conclusions included the following (pp. 7–9):

- No single alternative provides beneficial results throughout the system. Applying a single policy system-wide may cause undesirable consequences at some locations. Examination of many factors such as computed peak stages, discharges, flooded area extent, and depth within flooded areas is necessary to evaluate how an alternative affects performance of the flood damage system as a whole (8–b).
- Flood peaks may be reduced if increased floodplain storage is provided, and flood peaks may increase if storage volume is reduced (e.g. by levees constricting the river). However, the timing of the flows from tributaries, or the effects on timing of flows due to increased storage, can be just as important, along with the "roughness coefficients" of the floodplain (8–d).
- Levee profile surveys of all federal levees, an inventory and profile surveys of all private levees, and a database on interior drainage and ponded areas are a prerequisite to being able to further advance the reliability of hydraulic modeling (8–e).

The study also arrived at several counter-intuitive conclusions. For example, under the alternative that considered removing agricultural levees under a condition of continued farming, it found that on average river flood stage would be reduced, but risk of flooding in some areas might actually *increase* "because of factors such as hydrological timing" (8–i). Similarly, the study found that if the area behind the removed levees were filled with natural floodplains rather than agriculture, then the "risk of flooding for most urban areas would remain the same" (8–j). In short, "modeling results demonstrated that agricultural levee removal does not always provide uniform stage and discharge reduction." The 1995 Corps of Engineers study confirmed a conclusion from a year earlier in the Galloway Report: "Levees did not cause the 1993 flood. During large events such as occurred in 1993, levees have minor overall effects on flood stage but may have significant localized effects" (FPMA, 1995).

One finding following the flood was the differing technical capabilities of federal and private levees. Of the 1,082 levees that failed, out of a total of 1,576, the failure rate was 20 percent for levees built and maintained by the federal government, 17 percent for levees built by the federal government and maintained by local agencies, and 77 percent for levees that were privately owned. The primary reason for these different failure rates has been attributed to different design and construction standards (Bhowmik, 1996). When levees do fail, they can exacerbate flood damage by creating a barrier to water seeking to return to the river channel downstream, thus trapping water outside of the river channel. Levee breaks also lead to scouring of the land and subsequent sedimentation. The 1993 floods deposited sediment on about 60 percent (> 132,115 ha) of agricultural land in the floodplain of the Missouri River (Tobin, 1995). The levees also had an impact on the barge industry. One of the reasons why barge traffic was halted on the river was concern that the wake from the barges would contribute to the loss of levee structural integrity (Changnon, 1996).

### *Channel engineering*

The flood had a significant impact on the river channel itself. In a number of locations the force of the flood began to cut a new channel and thus change the path of the river. Locations that were particularly at risk to channel changes included "cutoffs" immediately upstream from a major river confluence, and "oxbows," where the river meanders back and forth. For instance, near Miller City, Illinois, a levee breach expanded to more than 730 m and began scouring a new channel of up to 21 m deep. The water flowing from the breach in the new channel rejoined the river 10 km downstream, cutting off a 32-km stretch of the river called Dogtooth Bend. As the floodwaters receded, the river returned to its previous channel and the new stretch of river disappeared. Had the cutoff remained, the increased velocity of the river over this stretch would have presented problems for commercial shipping (Bhowmik, 1996).

### *Flood fighting*

For many, mention of the Midwest flood of 1993 evokes images of communities and homeowners piling sandbags to hold the waters back. The Corps of Engineers estimated that 26.5 million sandbags were filled and used in flood-fighting efforts (Tobin, 1995). In some cases, flood-fighting efforts were rewarded, but in many others the power of the river was too much. Table 8.5 shows the costs estimated by the Corps of Engineers associated with fighting the 1993 Midwest floods on the Mississippi River from Muscatine, Iowa, to Hannibal, Missouri (approximately 240 km). The total cost for flood fighting on this particular stretch of river was about US$43 million.

*Table 8.5* Flood-fighting costs during the Midwest floods of 1993 on a stretch of the Mississippi River from Muscatine, Iowa, to Hannibal, Missouri

| *Equipment or action* | *Cost ('000 $)* |
|---|---|
| *Structural floodfight* | |
| Labor | 1,190 |
| Travel | 118 |
| Supplies/distribution | 125 |
| Overhead | 217 |
| Equipment rental | 694 |
| Sandbags | |
| Procurement, 2.5 million sandbags | 653 |
| Fill and place sandbags | 1,880 |
| Polyethylene sheeting | |
| Procurement, 2,500 rolls | 76 |
| Place sheeting | 625 |
| Miscellaneous | 253 |
| Subtotal | 5,831 |
| *Levee elevation floodfight* | |
| Sandbags | |
| Procurement, 7.5 million sandbags | 1,960 |
| Fill and place sandbags | 5,630 |
| Polyethylene sheeting | |
| Procurement, 7,500 rolls | 229 |
| Place sheeting | 1,880 |
| Push up levee backslope | 13,700 |
| Sub total | 23,400 |
| Levee grade restoration | |
| Regrade levee | 13,700 |
| Sub total | 13,700 |
| Total | 42,900 |

*Source*: Floodplain Management Assessment 1995: 9–3, based on estimates by the US Army Corps of Engineers



## The impacts of non-structural flood control efforts on the flood

### *Societal responses to flood forecasts*

A systematic and comprehensive review of the usefulness of flood forecasts during the 1993 Midwest floods has not been undertaken. One case study of the usefulness of particular flood forecasts during the summer of 1993 concluded as follows:

> By the end of July, the National Weather service and the Corps of Engineers forecasts had limited credibility with the public and emergency managers. Generally, the forecasts for rising or falling river stages were correct. The exact timing and the exact height convergence often missed the mark and did not provide enough specificity for individual and corporate decision-makers.
> (Gruntfest and Pollack, 1994: 40)

Changnon (1996: 27) echoes these themes:

> Flood forecasts of the National Weather Service, which often sizably underestimated future river levels and when the crests would occur, and flood pronouncements of the US Army Corps of Engineers, which included optimistic statements about when the flood would end and navigation would resume, helped lead to the underestimation of the flood damages. These forecasts and pronouncements likely worked to the detriment of the strategies used to fight the flood, shipping alternatives, and other flood-impacted endeavors.

The National Oceanic and Atmospheric Administration's (NOAA's) National Disaster Survey Report, a self-review of the agency's forecast and warning system, found a number of areas where the forecast process (including warning, dissemination and response) could be significantly improved (Department of Commerce (DOC), 1994: 9-1-27). In addition, the survey team recommended that NOAA support a "comprehensive, external study to evaluate and quantify benefits derived from hydrologic forecasts" (Recommendation 2.2, 9-1). It is unclear to what extent action has been taken on this recommendation. Nevertheless, a need clearly exists for such a study (or studies) to better assess the usefulness and value to society of flood forecasts (cf. Gruntfest and Pollack, 1994).

### Insurance

The National Flood Insurance Program (NFIP) experienced a significant impact due to the 1993 flood. Insurance industry payments for damaged property in the region totaled US$1.017 billion and crop insurance paid out US$1.65 billion. In spite of the large losses, "there were no reported insolvencies for companies writing crop insurance as a direct result of the 1993 flood losses" (Zacharias, 1996: 176). At the end of the financial year of 1993 the Federal Insurance Administration (FIA), which oversees the NFIP, had obligated more than US$110 million more than it had available (Government Accounting Office (GAO), 1994). Consequently, the FIA borrowed from the US Treasury to cover the difference.

Of the claims filed following the Midwest flood, 15.4 percent (2,483 out of 16,167) of federal flood insurance claims were for structures located outside of the area of the 1 percent annual chance flood (i.e. in the unsubsidized B, C and X zones) (FPMA, 1995). This means that the vast majority were for property owners in the area of the floodplain with greater than 1 percent annual chance of inundation. One study found that half of the mortgaged homes in the flooded areas did not have flood insurance (Bipartisan Task Force on Funding Disaster Relief (BTFFDR), 1995). Another study found that "less than 42,000 households out of the 803,000 residing in special flood-hazard areas had purchased flood insurance at the time of the floods" (Kunreuther, 1996: 173).

In 1994, Congress amended the NFIP in a number of respects, including (BTFFDR, 1995: 13–14):

- prohibition of federal disaster relief in flood disaster areas to persons who fail to obtain and maintain required federal flood insurance;
- establishment of civil monetary penalties for regulated lenders who fail to ensure that their borrowers who are required to purchase flood insurance do so;
- establishment of new incentives for community floodplain management programs.

In addition, the Crop Insurance Program was also amended significantly (see BTFFDR, 1995: 14–15 for discussion). One observer commented that "in one sense the Great Flood of 1993 did not tell agricultural policy makers anything new." It did, however, provide "the impetus for agricultural policy makers to reform both the funding and management of weather-related disasters in agriculture" (Zacharias, 1996: 180). As a consequence, Congress passed and the President signed a bill into law in 1994 (Public Law 103-354) that reformed the federal crop insurance program. Several key elements of the law included a requirement that farmers participate in the crop insurance program if they are to receive any other form of aid from the Department of Agriculture, a catastrophic coverage policy, and limitations on Congress's ability to pass *ad hoc* disaster relief payments. Some observers suggest broader changes in the role of insurance in reducing vulnerability to extreme events including, for example, the adoption of all-hazards insurance (Kunreuther, 1996).

## USING THE FRAMEWORK OF DAMAGING FLOODS TO UNDERSTAND TRENDS IN DAMAGING FLOODS IN THE UNITED STATES

Figures 8.4 and 8.5 show the data kept by the National Weather Service on flood-related losses and fatalities in the United States from 1903 to 1997.[12] Figure 8.4 also shows the trend of flood-related losses. The more recent period contains more losses and deaths (Wood, 1993, using a different data set, finds a similar trend). Pielke and Downton (1999) provide a systematic analysis of the factors that condition the trend in losses, finding that climate and growth in national (not floodplain) population and wealth explain the trend of increasing damages. Of the annual deaths related to floods, 80–90 percent are caused by flash floods and 40 percent of these "are related to stream crossing or highway fatalities" (Zevin, 1994: 1267). As in the case of trends in people at risk to floods, analysts have sought to use trends in flood damages as a proxy for trends in property at risk to floods.

However, it is at least as difficult to form definitive conclusions about exposure from the damage data as it is from the casualty data. Flood damages occur



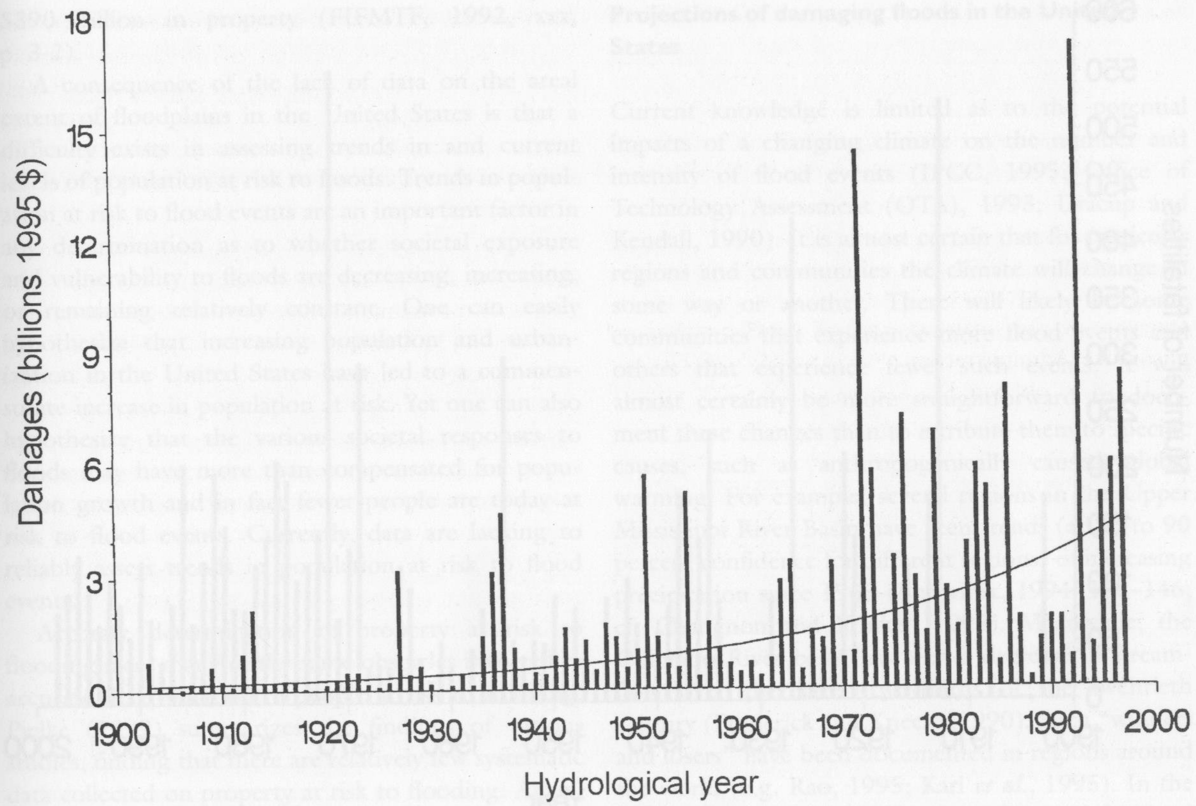


*Figure 8.4* Flood damages in the United States, 1903–97. The trend is a transformed linear trend computed on a logarithm of damages
*Source:* United States National Weather Service

every year in various places around the United States. Such damages, *per se*, are not sufficient evidence of a policy problem. Because of the lack of systematic data on the number of people at risk to floods, trends in flood casualties, for which relatively systematic data are available, are sometimes used as a proxy for trends in population at risk.

Similarly, an assumption underlying many analyses is that a rise in flood-related casualties is indicative of a rise in the number of people at risk to flood events. Unfortunately, at least three confounding factors limit the use of trends in flood casualties as a proxy for trends in the gross number of people who are vulnerable to floods. First, many flood-related deaths are concentrated in single extreme events, such as a hurricane or a severe flash flood. Second, society has taken many steps to reduce its level of exposure, with mixed results. This means that a moving baseline of exposure underlies any record of flood-related casualties. Consequently, there may be a number of trends within a trend record of flood casualties (level of exposure, success and failures of mitigation efforts, etc.). Finally, the data on flood casualties are generally not perceived to be accurate enough to lead to definitive conclusions (F. Richards, National Weather Service, personal communication). The longest continuous record of flood casualty data is that of the National Weather Service (1903 to the present). However, there are different sources of data which have different numbers (e.g. Red Cross data in FIFMTF, 1994; Wood, 1994; Yen and Yen, 1996). For these reasons, trend data on flood-related casualties

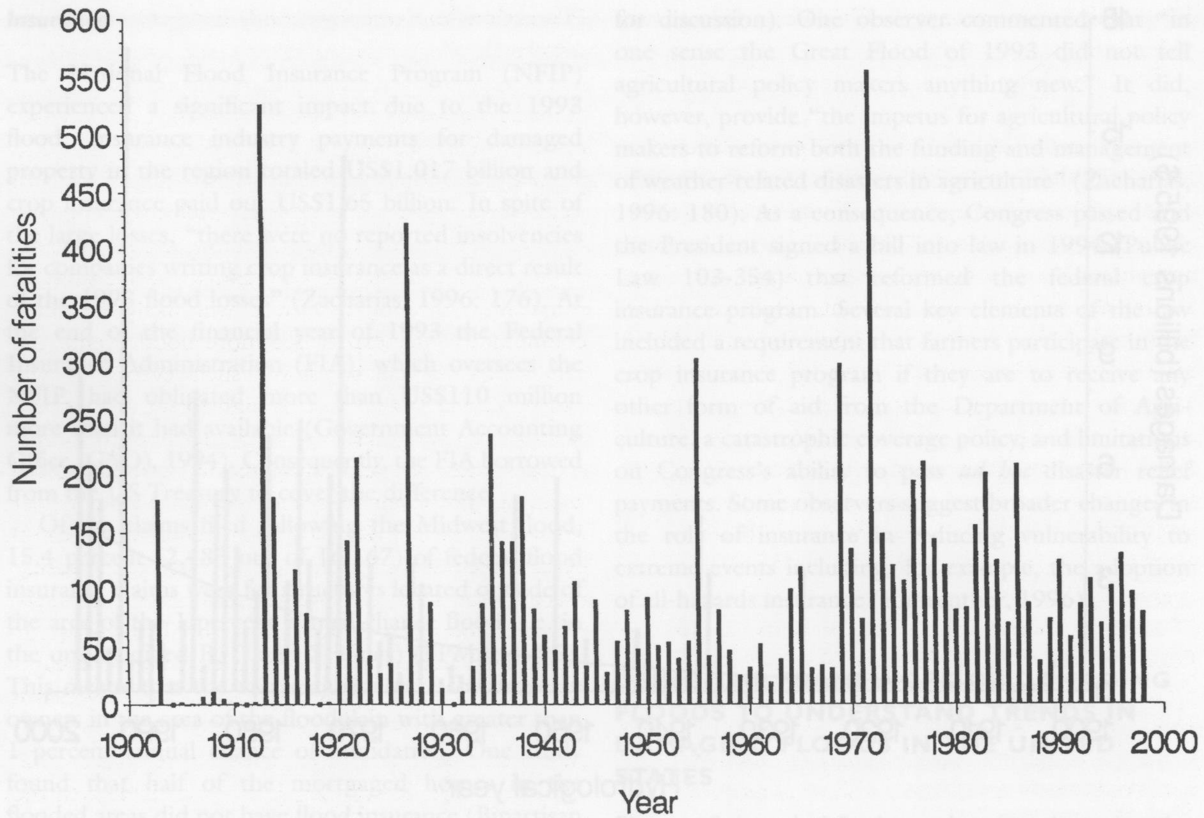


*Figure 8.5* Flood deaths in the United States, 1903–97
*Source:* United States National Weather Service

do not lend much insight into broader questions of trends in exposure to floods.

### Factors conditioning the trends in flood damages in the United States

Flood events in recent years provide vivid evidence that people and property in the United States remain extremely exposed to floods. However, data are lacking (or unavailable) that would allow accurate and useful determination of the trends in and current level of societal exposure to floods. The 1992 assessment of floodplain management in the United States found that "the actual amount of United States land in floodplains has not been clearly determined, nor has the amount of property and other economic investments at risk to flooding been firmly established" (FIFMTF, 1994: 3-1). A review of various estimates of flood-prone regions in the United States shows considerable disagreement as to the areal extent of flood-prone regions, the number of people who inhabit those areas, and the amount of property at risk to flooding. In 1942 Gilbert White estimated that 14.2 million ha of United States land was subject to flooding (White, 1945). In 1955 Hoyt and Langbein (1955) estimated that 10 million people live or work within the nation's 20 million ha of flood-prone land. The 1955 estimate equates to 7 percent of the population living on flood-prone regions, which comprise about 3 percent of the United States land area. A 1978 study estimated that 4.5 million households were in flood hazard areas. A 1987 study classified about 38 million ha of land as US floodplains containing 9.6 million households with $390 billion in property (FIFMTF, 1992, xxx, p. 3-2).

A consequence of the lack of data on the areal extent of floodplains in the United States is that a difficulty exists in assessing trends in and current levels of population at risk to floods. Trends in population at risk to flood events are an important factor in any determination as to whether societal exposure and vulnerability to floods are decreasing, increasing, or remaining relatively constant. One can easily hypothesize that increasing population and urbanization in the United States have led to a commensurate increase in population at risk. Yet one can also hypothesize that the various societal responses to floods may have more than compensated for population growth and in fact fewer people are today at risk to flood events. Currently, data are lacking to reliably assess trends in population at risk to flood events.

Accurate determination of property at risk to flooding faces many of the same obstacles involved in accurate determination of people at risk to flooding. Pielke (1999) summarizes the findings of various studies, finding that there are relatively few systematic data collected on property at risk to flooding. Again, the lack of data limits what can be said about trends in exposure to flooding. It is likely that the Federal Insurance Administration, which operates the National Flood Insurance Program, has in its records data on property at risk to floods for the communities which it has worked with since the early 1970s. However, these data have seen only limited use, for example in determination of repetitive losses and substantial damages of over 50 percent, and have yet to be systematically assessed from the standpoint of trends in societal exposure and vulnerability to floods.

Differences in the estimates of people and property at risk to floods are attributable to actual demographic changes, but also to differences in floodplain definitions, and simply to the fact that the data have not been collected and systematically analyzed. The data that do exist allow only for gross generalizations based on national-level data (Pielke and Downton, 1999). The data limitation is one of the factors which constrains what can be authoritatively concluded about trends in societal exposure vulnerability to floods in the United States (cf. Changnon *et al.*, 1997).



### Projections of damaging floods in the United States

Current knowledge is limited as to the potential impacts of a changing climate on the number and intensity of flood events (IPCC, 1995; Office of Technology Assessment (OTA), 1993; Dracup and Kendall, 1990). It is almost certain that for particular regions and communities the climate will change in some way or another. There will likely be some communities that experience more flood events and others that experience fewer such events. It will almost certainly be more straightforward to document these changes than to attribute them to specific causes, such as anthropogenically caused global warming. For example, several regions in the Upper Mississippi River Basin have seen trends (at 80 to 90 percent confidence for different regions) of increasing precipitation since 1965 (Bhowmik, 1994: 132–146; cf. Changnon and Kunkel, 1995). Meanwhile, the Colorado River basin has seen a decrease in streamflow over the latter two-thirds of the twentieth century (Frederick and Kneese, 1990). Such "winners and losers" have been documented in regions around the world (e.g. Rao, 1995; Karl *et al.*, 1995). In the United States (about 6 percent of the earth's land surface) recent decades have seen an increasing trend (at various levels of confidence) in precipitation and consequently streamflow (Karl *et al.*, 1996; Lins and Michaels, 1994).[13]

The uncertain climatic future has at least three implications for societal responses to floods. First, there is a continued need to understand how climate has changed in the past. So much attention is focused on gaining a better predictive understanding of what the future might bring that we often neglect the wealth of data about what the past has brought. Second, there is a need to better understand successes and failures in responding to past climatic extremes. While we do not know exactly what the future will bring, we do in many cases know that our responses to past events have been less than optimal. Thus, at a minimum we should take care to ensure that we are at least prepared to deal with the variability and extremes that have already occurred and been documented (Glantz, 1988). Finally, the uncertainty in the climate future underscores the need to better understand the societal dimensions of the climate threat and to take those preparedness, mitigative, and adaptive measures that make sense on the basis of our understanding of the certain past and uncertain future. A first step in that effort is to better understand societal exposure to variability and extreme events.

No matter what the climate future holds, flood impacts on society may continue to worsen. A study conducted by the US Congressional Office of Technology Assessment concluded that "despite recent efforts, vulnerability to flood damages is likely to continue to grow" (OTA, 1993: 253). The study based this conclusion on the following factors, which have very little to do with climate:

- Populations in and adjacent to flood-prone areas, especially in coastal areas, continue to increase, putting more property and greater numbers of people at risk.
- Flood-moderating wetlands continue to be destroyed.
- Little has been done to control or contain increased runoff from upstream development (e.g. runoff caused by paving over land).
- Many undeveloped areas have not yet been mapped (mapping has been concentrated in already developed areas), and people are moving into such areas without adequate information concerning risk.
- Many dams and levees are beginning to deteriorate with age, leaving property owners with a false sense of security about how well they are protected.
- Some policies (e.g. provision of subsidies for building roads and bridges) tend to encourage development in floodplains.

On the basis of these trends and projections it seems clear that in addition to continued investments to improve our understanding of the earth's climate, complementary investments are also needed to better understand the relationship of society and climate.

## CONCLUSION

From the perspective of policy, it is important to distinguish damaging floods from hydrologic floods. Flood damages include those economic losses typically associated with flood impacts, but also should include consideration of environmental impacts and difficult-to-quantify societal impacts. A focus on damaging floods directs attention to those questions which matter most to decision-makers: Who is impacted? In what degree? And what is to be done?

A critical aspect of damaging floods is the role played by floodplain management decisions which, putatively, have been implemented in order to reduce vulnerability to floods. Assessment of particular floodplain management decisions is difficult as the historical loss record provides insufficient information with which to judge successes or failures. Consider that losses might increase under a successful floodplain management policy (i.e. the losses might have been larger without the policy) or decrease under an unsuccessful policy (i.e. the losses might have been even smaller without the policy). Consequently, to understand the role that policy plays in shaping flood losses, floodplain management itself must be considered as part of the context of damaging floods, and not as an external factor.

Society's understanding of trends in damaging floods and their underlying causes has advanced in piecemeal fashion. The result, to borrow a cliché, is that we know more and more about the particulars of flood losses, but less and less about how these particulars fit into a coherent picture. As suggested by the case of the United States, an integrated understanding of damaging floods remains to be achieved. If the ultimate goal of floodplain management is to reduce societal and environmental vulnerability to floods, then an integrative framework of damaging flooding might lead analysts and decision-makers to better evaluate past decisions and to improve upon them in future action.

## NOTES

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1 The total is those killed, injured, made homeless, or otherwise affected (International Federation of Red Cross and Red Crescent Societies (IFRCRCS), 1997: 119, table 3) (cf. Miller, 1997).

2 Source: IFRCRCS (1997: 124, table 10).

3 Close to 100 percent of all hurricane losses in the United States are related to landfalling storms. Further, more than 80 percent of damages are related to the strongest storms (i.e. the top 20 percent in terms of intensity, Saffir–Simpson categories 3, 4, 5 and 6).

4 A notable exception is the US Army of Corps of Engineers, which employs methodologies for developing "stage-damage" relationships (Moser, 1994). See also Smith (1993).

5 The relationship refers to a correlation (significant at a 95 percent confidence level) between annual precipitation averaged over the coterminous United States and the natural log of economic losses for the period 1932–97. See Pielke and Downton (1999) for discussion.

6 Of course, there are certain dam breaks and other floods which are caused not by climate factors, but instead by human error.

7 This section on methodology draws on the discussion of impacts assessment methodology described in Pielke and Pielke (1997: 131–138).

8 The discipline of economics has a systematic framework for understanding costs and benefits (i.e. direct/indirect, tangible/intangible, etc.).

9 There are some notable exceptions, including Mittler (1997), Parker (1995), Correia *et al.* (1994), Mirtskhoulava (1994), FIFMTF (1992) and Burby *et al.* (1985). There is also a large literature on particular aspects of floodplain management. See Weiner (1996b) and FIFMTF (1994) for a review of the literature in the United States.

10 This number is significantly larger than was estimated during the event, which resulted in less aid being delivered to the region than was needed (Changnon, 1996). Changnon (1996: 27) argues that contemporaneous "underestimation of losses and hence in aid required were partly due to poor data and inadequate collection of information by government sources."

11 Congress requested the Floodplain Management Assessment (FPMA) of the Upper Mississippi and Lower Missouri River basins in the Financial Year of 1994 Energy and Water Development Appropriations Act, P.L. 103–126.

12 Data are kept by "water year," which runs from 1 October through 30 September the following year. For example, Water Year 1996 started on 1 October 1995 and ended 30 September 1996.

13 Although ongoing research calls into question the strength of the relation of precipitation and streamflow (Lins and Slack, 1997).

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