Understanding Damaging Floods in Iowa: Climate and Societal Interactions in the Skunk and Raccoon River Basins

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REPORT SUMMARY

Overview

Understanding the causes and consequences of flood damage is important because decision makers promulgate and implement flood policies based on their interpretation of the causes and impacts of floods and their expectations for the future. Regrettably, the evaluation of policies in response to floods is hampered by a lack of specific knowledge of the causes and consequences of flood impacts.

As part of a series of studies seeking to improve understandings of damaging floods, this report presents the results of an intensive, prototype case-study that looked at two basins in Iowa, with the objective to document and explain the factors underlying historical flood damage. The study is intensive in that it focuses on a limited spatial scale: Together the two river basins make up about one third of Iowa. The case study is a proto-type because few, if any, analyses have sought to explain past patterns in flood damage in terms of both climatic and societal factors for specific river basins and the communities therein. This study was initiated with the view that to the extent that this prototype analysis can resolve the factors that underlie past damage for specific events, it would provide guidelines for how further research might better resolve these factors at regional, national, or even global scales.

However, neither the United States nor the state of Iowa makes a concerted effort to keep systematic and comprehensive records of flood damage. A thorough record of damaging floods, including types of damage and disruption, losses incurred, and costs of recovery, is necessary to reliably assess and quantify the causal factors that underlie past damages. This report concludes that understanding of patterns in past flood damage is highly limited, primarily because of inadequate data.

The analysis focuses on "damaging floods" as its unit of analysis. Its objective is to distinguish and quantify factors that condition trends in the climatological and societal factors that cause damaging floods. The case study focused on the state of Iowa because, with $7.8 billion in damage over the period for which state-level damage data is available, i.e. 1983-1996, Iowa had the largest flood losses of any state in the nation. The analysis is centered on a case study of two adjacent river basins in Iowa, the Des Moines and Skunk Rivers. The basins exist in the same physiographic region and are very similar in stream slopes, soils, and climate. But they have one major difference: the Des Moines basin has undergone several major anthropogenic changes, including construction of many levees and two large multi-purpose reservoirs on the river's main course. The river also bisects Iowa's largest city, Des Moines, which further affects the runoff characteristics of the basin. In contrast, the Skunk River basin has not experienced the same degree of changes, and encompasses rural farmland without the presence of a large urban area.

The choice of the two adjacent basins with different characteristics is designed to enable a comparative analysis of the temporal trends in damaging floods between two basins with essentially the same climate. Using this approach, called a "paired basin" study by hydrologists, we seek to assess the relative effects of various societal changes on the observed trend in damaging floods. Our assumption is that if any place in the United States is amenable to such an approach, it is surely Iowa, with its dramatic history of flooding and flood damage.

The study of the two "paired basins" consists of two phases. In the first phase, the objective is to define the degree of similarity in the two basins' climatological conditions relevant to flooding in the basins and identify climatological factors leading to hydrologic flooding. In the second phase of the analysis, we identify climatological conditions leading to damaging flooding and characterize the relationship between damaging flooding and climatological conditions.

Types of Floods in Iowa

In this study, we classify historical floods in the two basins into five types based on different meteorological conditions that lead to flooding. These types are:

1. *Flash floods* caused by intense rainfalls over short durations (typically 6 inches or more rainfall during two days or less).
2. *Snowmelt floods* caused when rapid spring warming occurs with considerable snow on frozen ground, leading to rapid runoff.
3. *Snowmelt plus rain floods* which are caused by a mixture of rapid snowmelt occurring with moderate to heavy spring rains.
4. *Warm season floods* resulting from prolonged moderate to heavy convective rainstorms persisting over several days or weeks.
5. *Warm season plus flash floods* which are a result of the multi-day rainfall periods (type #4) plus flash floods during the period of widespread rains.

Conditions affecting the magnitude of the floods in each of the above include antecedent soil moisture, often a reflection of previous precipitation, and time of the year which affects whether there is active vegetation. An early spring flood can be enhanced by the release of ice floes on the rivers that when trapped behind bridges form an artificial "ice dam" that increases inundation above the dam. There are several other geographic factors that affect flooding in a given basin. These include: 1) basin size, 2) basin shape and orientation, 3) land slopes in basin uplands and along the stream courses, and 4) degree of drainage development-geologic age. Other than basin size, the paired basins have similar characteristics for all of these physical conditions.

Summary of the Paired Basin Assessment

The comparison of conditions between the two basins reveals three key findings.

1. First, the human changes to the Des Moines River and its floodplain have markedly altered the temporal distribution of the annual peak flow, but had less effect on the annual peak flow rates.
2. Second, the paired basins experienced comparable trends in total precipitation, in 7-day heavy rainfall frequencies, and the number of days with precipitation. However, of the several precipitation conditions assessed and conceivably related to floods, none increased with time. These conditions include the number of >6-inch rain events, the May-July rainfall across central Iowa, the snow depth, and the frequency of 2-day rainfall events exceeding a 5-year recurrence level. Collectively, the results suggest that the 7-day or longer heavy rainfall events have been the primary factor influencing the changing magnitude of the annual hydrologic floods as reflected in maximum 2- and 7-day flows. This is in agreement with findings from earlier studies of Midwestern floods.
3. Third, the case studies indicate that much of the hydrologic flooding in Iowa is due to prolonged precipitation periods lasting 7 days or more, i.e., flood type 4 as defined earlier. However, all five types have produced floods, and hydrologic flooding in Iowa is simply a result of the climatic position of the state such that it can experience frequently all the weather conditions that lead to the five types of floods.

Relationship of Hydrologic Conditions to Flood Damage

All of the severely damaging floods in two counties in the adjacent basins (Polk and Story) during 1944-1997 occurred during the "warm season", May through August. Three different hydrologic configurations led to high levels of flood damage:

1. Persistent rains for 4 to 6 weeks or more, with record high peak flow in one or more rivers or streams. (For gauges with complete records during 1940-1997, this implies peak streamflow greater than a 50-year recurrence level.)
2. Persistent rains for 4 to 6 weeks or more, with two confluent rivers peaking within one day of each other and peak flow greater than a 10-year recurrence level in at least one of the rivers.
3. Flash flooding due to extremely heavy short-term (2-day) rainfall, combined with peak flow greater than a 10-year recurrence level in at least one river.

Floods that caused only minor damage occurred between March and August, with the March-April flooding induced by melting snow. Most were not preceded by excessive long-term rainfall and involved peak streamflows at the 5- to 9-year recurrence levels. A few in Story County did not involve notably high river flows at all; they resulted from short-term (2- to 3-day) heavy rainfall and their damage was caused by water table flooding or rainwater flooding, exacerbated by inadequate storm sewer capacity.

All hydrologic floods in the top 10% of peak annual flows caused some damage. In contrast, about half of the hydrologic floods having peak flows at the 11-20% level did not cause significant damage.

The floods examined in this study illustrate that a wide variety of climatic and hydrologic conditions can lead to flood damage. Although the most damaging floods were associated with major hydrologic floods, several minor-damage floods apparently did not involve hydrologic flooding on rivers or streams, but instead resulted from heavy local rainfall or from a rising water table associated with saturated soils. In Iowa, saturated soils are frequently mentioned as antecedent conditions preceding hydrologic floods — and this saturation is often the result of persistent rains over a relatively long period. Thus, precipitation conditions that have led to damaging floods include heavy snowpack in late winter, short-term (1 to 7 days) heavy rains in spring and summer, or long-term (4 to 6 weeks or more) persistent rains in spring and summer. On the other hand, similar levels of rainfall in September have not led to damaging floods.

In Iowa, while hydrologic floods are the result of precipitation, only certain types of major precipitation events lead to damaging floods. Furthermore, not all hydrologic floods cause damage and not all damaging floods are hydrologic floods (if these are defined simply as the overspilling of the banks of a stream).

Conclusions

The paired-basin analysis of damaging floods in Iowa provides insight into the relationships of precipitation, hydrologic floods, and damaging floods. The conclusions have significance for understanding the nature of flood damage and the effects of flood policy in Iowa and the United States.

This pilot project was initially designed to systematically (and quantitatively) compare damaging floods in two relatively small-scale river basins with essentially the same climate. The tentative hypothesis was that with the same climate, the differences in flood damage should then be attributable to human-caused changes, either to the basins' hydrology or in terms of changes in exposure that might result from population growth or development. The lack of available data on historical flood damage limits our ability to test the hypothesis in a quantitative manner. Nonetheless, sufficient data exists to systematically compare climate and damaging floods in the two basins. The study leads to conclusions about: (1) relationships between precipitation, hydrologic floods, and damaging floods; (2) the need for better understanding of damaging floods and collection of data on flood damage; (3) the need for improved methods of estimating flood risk that take into account the nonstationarity of climate; and (4) implications for future flood policy.

The climatological analysis of the Skunk River and Des Moines River basins showed that the two basins' share essentially the same climate. The analysis documented the influence of the structural flood control projects on the Des Moines Basin, and corresponding lack of such large-scale engineering in the Skunk River Basin. The analysis found the climatology of the two basins to be consistent with previous studies at a more regional scale.

The systematic comparison of precipitation, hydrologic floods, and damaging floods in the two basins leads to the following conclusions and hypotheses:

- Not all hydrologic floods are damaging floods.
- Not all damaging floods are hydrologic floods.
- Many types of "extreme" precipitation can lead to hydrologic floods, and not all "extreme" precipitation events result in major hydrologic flooding.

The previous three conclusions have significant implications for understanding the relationships of precipitation, hydrologic floods, and damaging floods.

A more complete understanding of the relationship of precipitation, streamflow, and damaging floods depends upon better understandings in two dimensions. First, it would be necessary to obtain improved data on flood damage, both in terms of comprehensiveness and spatial distribution (e.g., with respect to the local basin characteristics). While researchers will find historical data to be difficult, if not impossible, to obtain, technology now exists to begin collecting and archiving such data for future studies. The growth in GIS and other advanced data manipulation technologies lends itself well to such analyses. Given the vast sums currently spent on atmospheric, oceanic, and hydrologic observing systems and data archives, it is not unreasonable to think that corresponding "societal" observing systems might occupy greater attention in future years.

Second, it would be necessary to obtain an understanding of precipitation and hydrology on scales appropriate to understanding damaging floods. Conventional studies at the scale of grid boxes (e.g., 1 degree by 1 degree) and point estimates, will be limited in the information they can provide, as damage occurs at scales smaller than the typical grid box, and point estimates can miss important precipitation events.

The general conclusion is that to better understand damaging floods it is necessary to consider damaging floods as the unit of analysis. With very few exceptions, this has rarely been the case in research. Until such an understanding is obtained little can be said with precision with respect to the nature of future flooding under changing climate conditions. While it would be accurate to state that increasing precipitation would more likely than not lead to increasing flood damages in a particular community, basin, or nationally, it is unrealistic to project the nature or magnitude of those damages, given their complex relationship to precipitation, hydrology, and land use. Previous studies (to which this paired-basin project is related) suggest that the climate "signal" in future damaging floods will be much less than the "noise" of continued increasing occupancy and development of flood-prone areas, as well as political factors.

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1

INTRODUCTION, METHODS, AND DEFINITIONS

Understanding the causes and consequences of flood damage is important because decision makers promulgate and implement flood policies based on their interpretation of the causes and impacts of floods and their expectations for the future. Regrettably, the evaluation of policies in response to floods is hampered by a lack of specific knowledge of the causes and consequences of flood impacts. Indeed, the International Federation of Red Cross and Red Crescent Societies 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, p. 113; cf. Platt 1999).

As part of a series of studies seeking to address the "weakness" identified by the Red Cross, this report presents the results of an intensive, prototype case-study that looked at two basins in Iowa, with the objective to document and explain the factors underlying historical flood damage (see Pielke and Downton 2000; Pielke and Downton, 1999). The study is intensive in that it focuses on a limited spatial scale: Together the Skunk and Des Moines river basins make up about one third of the total areal extent of Iowa. The case study is a proto-type because few, if any, analyses have sought to explain past patterns in flood damage in terms of both climatic and societal factors for specific river basins and the communities therein (Mittler 1997).[1] This study was initiated with the view that to the extent that this prototype analysis can resolve the factors that underlie past damage for specific events, it would provide guidelines for how further research might better resolve these factors at regional, national, or even global scales. This report concludes, however, that understanding of patterns in past flood damage is highly limited, primarily because of inadequate data. These limitations have important implications for policy makers seeking to base flood decisions on the best available knowledge of the consequences of past decisions. The report concludes with a discussion of the implications of the case study for aspects of flood policy.

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[1] This study is a departure from a number of studies conducted at more aggregated levels, see Pielke and Downton (2000) and the discussion of this and related work below.

Background

In the United States, the average annual economic damage related to floods has about doubled 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., Pielke and Downton 2000; USACE 1998; Changnon 1996; FIFMTF 1992), but the state of knowledge is such that the relative contribution of each factor is poorly understood, particularly in the context of specific communities. The United States case is 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 1996).

Recent research has focused on developing an improved quantitative understanding of extreme weather impacts related to the inter-relationship of atmosphere and society in the context of hurricanes and other extreme events (e.g., as summarized in Kunkel et al. 1999). 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. It is logical that policy making might be improved with a better understanding of the factors which underlie those trends. Consequently, a better understanding of damaging floods has important implications for policy making.

Methods and Definitions

The analysis focuses on "damaging floods" as its unit of analysis (Pielke 2000). Its objective is to distinguish and quantify factors that condition trends in the climatological and societal factors that cause damaging floods. The analysis is centered on a case study of two adjacent river basins in Iowa, the Des Moines and Skunk Rivers.

What is a flood?

Typically, in climate research and policy making, a "flood" is defined 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 task force in the U.S. 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, pp. 1-6).

Hydrologists recognize other types of flooding, many of which are associated with flood damage. Ward (1990) defines a flood broadly as "a body of water which rises to overflow land which is not normally submerged." This definition covers river and coastal flooding, flooding in shallow depressions which is caused by water-table rise, rainwater flooding on level surfaces and sheetwash flooding on low-gradient slopes (both resulting solely from torrential rainfall), and flooding caused by the backing-up or overflow of artificial drainage systems.

In Iowa, the following types of flooding (described by Smith and Ward 1998) are likely to occur and sometimes cause damage:

- Overspilling: Flow exceeding the capacity of a stream channel and overflowing the natural banks or artificial embankments. (Such floods are referred to as "hydrologic floods" in the remainder of this report.)
- Water-table flooding: Inundation that occurs in wet conditions when an already shallow water-table rises above the level of the ground surface.
- Rainwater flooding: Flooding of flat areas where the surface is hard or crusted, when heavy rainfall collects into surface ponds.
- Sheetwash flooding: Unimpeded lateral spread of water where there are no clearly defined channels.

In urban areas, the following additional types of flooding may occur:

- Overflow of artificial drainage systems: Flooding that occurs when urban stormwater drains become surcharged and overflow.
- Subsurface flooding: Inundation of underground facilities, such as basements and subways, as a result of rising groundwater levels.

Each of these types of floods can lead to damage.

What is a damaging flood?

To focus research on the societal impacts of floods, this report defines a damaging flood as a flood in which individuals and/or society suffer losses related to the event. Losses span a wide range of categories (e.g., social, environmental, etc., as described in Heinz Center 2000), however, this report focuses on economic/property damages. Understanding the relationship of the various types of flooding and those events that lead to damage is complex for a number of reasons. First, flooding that results directly from rainwater or groundwater may go undocumented unless it causes damage. Second, while streamflows are measured continuously, some hydrologic floods (those of the overspill type) may actually have little relationship to flood damage. Consequently, there is great potential for confusion in discussions of floods. Typical parlance refers to "flooding" as overspilling (i.e., hydrologic floods), but this is a subset of flood events, and these events do not always lead to damage. Understanding damaging floods requires a broad definition of "flooding" and consideration of the subset that results in damage.

For example, the Red River of the North, at Grand Forks-East Grand Forks, flows north along the Minnesota-North Dakota border into Canada. At what river height does a flood occur? According to Harrison and Bluemle (1980, p. 23) "the Red River officially reaches flood stage at a gauge reading of 28 feet." Over the 98-year period for which records are available, the Red River exceeded the official flood stage in 40 years, meaning that a flood occurred on average every 2.5 years. But "relatively little damage is done by floods less than 40 feet" (Harrison and Bluemle 1980, p. 34). The Red River exceeded 40 feet in 16 of 98 years. Indeed, of the significant losses which occurred during 1950-1979, all occurred at flood levels greater than 40 feet (Harrison and Bluemle 1980, p. 4). From this example, it is clear that not all hydrologic floods are damaging floods. In the Grand Forks community 60% of all "official floods" require no response by the community.

In Iowa, the National Weather Service works with federal, state, and local officials to determine the flood stage at river gauges. Flood stage is defined as the height at which overspilling causes damage. Although the process of altering flood stage can be controversial and difficult to coordinate[2], stages are supposed to be changed to keep up with changing floodplain conditions (Peter Corrigan, pers. comm., August 1999).

Policy makers are particularly concerned with those floods which cause damage. 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, when policy makers, scientists, and the media discuss floods, with few exceptions, the discussion fails to distinguish hydrologic from damaging floods, leading to an implicit equivalence of hydrologic floods with damaging floods.[3] For example, discussion of the possibility of future climate change has focused on the possibility of more "floods" (see, for example, IPCC 1996 and Karl et al.1997). When climatologists discuss such floods, as they typically are referring to hydrologic floods; but when policy makers discuss floods they typically are referring to damaging floods. The poor relationship between what climatologists, hydrologists, and other physical scientists call floods and those floods which actually cause damage has limited what can be reliably said about the causes of observed trends in damaging floods.

[2] Changing the flood stage at a given location may require coordination between the National Weather Service, U.S. Geological Survey, U.S. Army Corps of Engineers, and state, county, and city officials.

[3] A notable exception is the US Army Corps of Engineers which employs methodologies for developing "stage-damage" relationships (Moser 1994).

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 can be 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 15% of the variance in flood damage.[4] The relation between precipitation and damage 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.[5] Figure 1-1 summarizes various factors that can result in a damaging flood (Pielke and Downton 2000). Losses would not occur without the presence of the flood waters, and also, human occupancy of the floodplain. Therefore, to understand the causes of damaging floods requires knowledge of the interrelated physical and societal factors which underlie the physical and societal processes.

Figure 1-1
Factors Contributing to Damaging Floods

Case Study Objective

In this study the objective is to compare two similar river basins of relatively small size to begin to develop an understanding of the complexities involved with attribution of trends in flood damage to related trends in climate, land use, development, etc.

The case study focused on the state of Iowa because, with $7.8 billion in damage over the period for which state-level damage data is available, i.e. 1983-1996, Iowa had the largest flood losses of any state in the nation. This pilot study focuses on flooding in two adjacent basins in central Iowa, the Des Moines River and the Skunk River. The basins exist in the same physiographic region and are very similar in stream slopes, soils, and climate. But they have one major difference: the Des Moines basin has undergone several major anthropogenic changes, including construction of many levees and two large multi-purpose reservoirs on the river's main course. The river also bisects Iowa's largest city, Des Moines, which further affects the runoff characteristics of the basin. In contrast, the Skunk River basin has not experienced the same degree of changes, and encompasses rural farmland without the presence of a large urban area.

The choice of the two adjacent basins with different characteristics is designed to enable a comparative analysis of the temporal trends in damaging floods between two basins with

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[4] The relationship refers to a correlation (significant at a 95% confidence level) between annual precipitation averaged over the coterminous United States and the natural log of economic losses for the period 1932-1996, see Pielke and Downton (2000).

[5] Of course, there are certain dam breaks and other floods that are not caused directly by climate factors, but instead by human error.

essentially the same climate. Using this approach, called a "paired basin" study by hydrologists, we seek to assess the relative effects of various societal changes on the observed trend in damaging floods. Our assumption is that if any place in the United States is amenable to such an approach, it is surely Iowa, with its dramatic history of flooding and flood damage.

2
DAMAGING FLOODS IN IOWA AND THE NATION

Not all hydrologic floods result in economic losses to society. They even bring benefits, for example, when agricultural land is replenished with soil and nutrients deposited by flood waters. A flood is detrimental to society when it causes death, damage, or other disruption of human activities (cf. Heinz Center 2000). A thorough record of damaging floods, including types of damage and disruption, losses incurred, and costs of recovery, is necessary to reliably assess and quantify the causal factors that underlie past damages. Thus, it is surprising that neither the United States nor the state of Iowa makes a concerted effort to keep systematic and comprehensive records of flood damage.

Flood Damage Records

No agency of the United States government has formal responsibility for collecting and evaluating detailed flood loss information (NWS 1998). The National Weather Service reports loss estimates for significant flooding events, based on information collected at its numerous field offices, but this is not a primary mission of the agency. Uninsured or self-insured losses may often go unreported. Agricultural losses are difficult to estimate accurately and consistently. Sources of information have changed as new types of assistance have become available. It is likely that reporting of flood losses has increased in the last two decades, with increasing use of the National Flood Insurance Program, availability of Small Business Administration loans for disaster recovery, and expanded federal disaster assistance programs (Burton et al. 1993).

At the national level, the best available annual estimates of "direct damage due to flooding that results from rainfall and/or snowmelt" are maintained by the National Weather Service for the period 1903 to present. At the state level, annual flood loss estimates are readily available only since 1983, when the U.S. Army Corps of Engineers (USACE) began publishing an annual flood damage report for Congress. The USACE (in annual reports, 1990-1997) cautions that these are preliminary estimates which are compiled rapidly at the end of the fiscal year and their "accuracy and completeness cannot be assured". The 10-year summary tables published by the USACE reproduce the estimates that were reported each fiscal year; they are not updated to account for more recent or more accurate information.

Prior to 1983, technical reports issued by the USACE and the U.S. Geological Survey (USGS) did not routinely provide flood damage estimates. Reports often relied on newspaper accounts to illustrate the damage incurred: Anecdotal descriptions mention flooded streets, closed bridges, people evacuated, and homes flooded to the first- or second-story level (USACE 1966, USACE 1970). Dollar losses in a specific area or sector are sometimes mentioned, but no attempt is made to estimate total damage.

National Trends in Flood Damage

Losses due to flooding in the United States in the years 1932-1997 are shown in Figure 2-1 (based on NWS damage estimates, adjusted for inflation). An increasing trend is evident, with average damage (in 1995 dollars) of about $1 billion per year in the 1940s and about $5 billion per year in the 1990s. Statistical models show that population growth can be an important factor in explaining the upward trend in flood damage during that period (Pielke and Downton 2000); that is, exposure to the flood hazard has increased.

Figure 2-1
U.S. Flood Damages, 1932-1997

Pielke and Downton (2000) present an analysis of measures of precipitation which were most closely associated with damaging floods in the nine climatic regions of the conterminous U.S. during 1983-1997. In the majority of the regions, losses were most highly correlated with episodes of a few days of intense rainfall; however, in two regions of the upper Midwest (one of which included Iowa), losses were most highly correlated with the number of wet days. This suggests that, in the upper Midwest, prolonged periods of precipitation are also likely to be an important factor related to damaging floods.

Flood Damage in Iowa

Iowa's annual flood losses from 1983 to 1997 are shown in Table 2-1 (based on USACE estimates and adjusted for inflation). There is no discernable trend over this short time period, but 1993 losses stand out, far surpassing losses in all other years combined.

Table 2-1
Annual Flood Losses in Iowa by Hydrological Year

Table 2-2 ranks the 48 conterminous states according to their total flood damage during the 15-year period, 1983-1997, and shows damage per capita, based on 1990 population. Iowa ranks number one in total damage for the period, and number two (after North Dakota) in per capita damage. Other states of the upper Midwest (Missouri, North Dakota, and Illinois) also rank high on the list with over $3 billion in total damage.

Table 2-2
Flood Losses in each of the Conterminous 48 States, Fiscal Years 1983-1997 (States Ranked by Total Losses)

The nine states of the vast upper Mississippi River basin suffered an estimated $20 billion in direct damage in the great flood of 1993 (Pielke 1996). In terms of damage, this is the worst flood on record in the United States (Changnon 1996). The weather patterns of 1993 were similarly unprecedented, as described by Kunkel (in Changnon 1996, p. 52):

> Highly unusual and persistent weather patterns persisted across the central United States for most of the summer of 1993 and brought copious rainfall almost daily

to the Midwest. By nearly every conceivable measure, the rainfall was unique and record-breaking. Unprecedented heavy daily rainfalls ... deposited several inches of rain over large areas of 10,000 miles or more. June-August rain totals were double and even triple the normal amounts as a result of the barrage of heavy rains. For example, Webster City, IA, received 37.5 inches of rain, nearly three times its normal June-August total (13 inches) and more than central Iowa usually receives in an entire year.

In eight of the nine states of the Upper Mississippi basin, total flood damage during 1983-1997 is dominated by the 1993 flood. Table 2-3 shows, for each state, the highest and second highest year's damage, as well as 1993 damage as a percentage of total damage during the 15-year period. Five states incurred over $1 billion in damage in the 1993 floods, far exceeding damage in any other years. The only comparable flood damage magnitudes (affecting a much smaller area) occurred in 1997 in North Dakota and Minnesota, the result of catastrophic flooding on the Red River of the North. (Other years in which two or more states in the region suffered severe damage are 1984 and 1986, evident in the "second-highest damage" column.)

Table 2-3
Years of Highest Flood Losses in the Nine States of the Upper Mississippi Basin, Fiscal Years 1983-1997 (Losses are in millions of 1995 dollars)

Iowa ranks number one in the region in both the "highest damage" and "second-highest damage" years in Table 2-3. Thus, Iowa has been particularly vulnerable to damaging floods in recent years. Annual records of statewide flood damage in Iowa are not available prior to 1983. However, a chronology of Iowa's major floods is available through 1989 (USGS 1991) and has been augmented in Table 2-4, which provides a listing of major floods in Iowa, 1944-1997.

Table 2-4
Major Damaging Floods in Iowa, 1944-1997

The different damage estimates in Table 2-4 and Table 2-1 highlight the inconsistencies in reporting of flood damage. Estimates for 1984 and 1990 (in 1995 dollars) include Iowa's major floods but are substantially smaller than the USACE estimates in Table 2-1.

Federal Disaster Assistance Related to Floods in Iowa

Beginning in the 1950s, the Federal government has played an increasing role in helping states and local communities recover from damaging floods. The Federal Government provides assistance in the form of federally-backed flood insurance and various forms of disaster aid, coordinated by the Federal Emergency Management Agency (FEMA), established in 1979.

FEMA organizes disaster response and recovery efforts and provides support for mitigation programs for many types of catastrophic events (http://www.fema.gov/). Once a state governor requests and the President has declared that an event is a major disaster or emergency, FEMA is authorized to provide financial assistance to individuals, businesses, and state and local governments to help them rebuild. Historically, floods have been a factor in well over half of the Presidential disaster declarations (Sylves 1998).

Under the Robert T. Stafford Disaster Relief and Emergency Assistance Act (PL100-707), a governor must request assistance and the President may then make a declaration of major disaster or emergency. The Act and subsequent administrative rules provide general criteria for evaluating the gubernatorial requests, but avoid specific criteria in order to assure presidential discretion. According to FEMA Director James Lee Witt, each event or incident is evaluated individually on its own merits (Platt 1999). A declaration of major disaster or emergency is issued to a state, within which one or more counties are declared as disaster sites. FEMA classifies disaster declarations by "primary incident type", and we have grouped disasters of type "flood", "flood and tornado", "severe storm", "coastal storm" and "dam/levee break" as flood-related disasters because these incidents frequently involve flooding as a major cause of damage.

From 1965 through 1997, the state of Iowa received 18 flood-related Presidential disaster declarations (one every two years, on average). In the 1993 flood, all 99 of Iowa's counties were designated as disaster sites. Other declarations involved from 4 to 68 counties. On average, there were 27 counties per declaration. Counties in the Des Moines or Skunk River basins were included in 13 of the 18 Presidential declarations. [6]

[6] From a complete list of counties that received flood- or hurricane-related disaster site designation from December 24, 1964 through March 3, 1998 from FEMA (Mike Buckley, personal communication).

3
IOWA CASE STUDY: OVERVIEW

Background and Organization

This study focuses on Iowa's Des Moines and Skunk River basins (Figure 3-1), which lie adjacent to each other, in the same physiographic region in the central part of the state. Their climate, stream slopes, and soils are similar, though they differ significantly in terms of the anthropogenic influence on the runoff of each basin. While agriculture is the dominant land use in both basins, the Des Moines basin contains the urban area of Des Moines, as well as two major flood control projects, the Red Rock and Saylorville Dams. The Skunk River basin contains no large urban area, and is free of major water control projects with the exception of channelization of 115 miles of river in the northern part of the basin (INRC 1957).

Figure 3-1
Des Moines and Skunk River Basins

Flooding in Iowa is not confined to a specific season; there have been severe spring floods brought on by spring melt, and severe summer and fall floods as a result of heavy or sustained precipitation. However, as discussed later in this report, most damaging floods have occurred in the spring and early summer and are the result of long periods of heavy precipitation.

Understanding the geography, climate, and also the roles that people have played in altering Iowa's landscape is essential to explaining the characteristics of the floods which cause damage. This section of the report characterizes the setting and explains how anthropogenic changes have affected flooding in the Des Moines and Skunk River basins.

Description of the Two Basins

Geography and Topography[7]

The Des Moines River drains 14,540 square miles of Minnesota, Iowa, and Missouri. This study is concerned with the 12,925 square miles of land that it drains in Iowa (see Figure 3-1). The East Fork Des Moines River joins the West Fork Des Moines River just below Humboldt, in the north-central part of the state, to form the Des Moines River. Tributaries of the Des Moines River which are included as part of the Des Moines basin include Boone River, Raccoon River, Middle River, Walnut Creek, Beaver Creek, and Lizard Creek, as well as many small streams.

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[7] This section's discussion of the Des Moines basin relies heavily on INRC (1953) and for the Skunk Basin, INRC (1957), unless otherwise noted.

The elevation at the headwaters of the Des Moines River in Minnesota is about 1,900 feet; at the confluence with the Mississippi, the elevation is about 476 feet. The basin is divided into two topographic provinces that correspond to the Wisconsin and Kansas drift areas. The first, in the north part of the basin, is younger, and the latter more mature. The transition between the two is abrupt and occurs near the middle of the basin. Soils in the Wisconsin drift area tend to be fertile. Water in this part of the basin often fills shallow marshes and "potholes." The flat relief sometimes encourages ponding, which is detrimental to agriculture. In the southern part of the basin, long-term erosion has caused the productivity and depth of the soil to vary. For agriculture, drainage is less of a problem in this part of the basin.

The Skunk River basin is considerably smaller than the Des Moines River basin, having a drainage area of only 4,355 square miles. The South Skunk River originates in the extreme southern part of Wright County, near Williams, Iowa. It joins the North Skunk River, which flows from the Southwest corner of Marshall County, in Keokuk County, southeast of Sigourney, Iowa. Tributaries of the Skunk River include Squaw Creek, Indian Creek, and Cedar Creek, in addition to many small streams.

Like the Des Moines River basin, the Skunk River basin is divided into a younger topographic region characteristic of the Wisconsin drift in the north part of the basin, and an older topographic region in the south. The highest point in the Skunk River basin, about 1,200 feet, is located near the headwaters of the South Skunk River, while the lowest point near the Mississippi is about 529 feet (Heinitz and Wiitala 1978). Prior to agriculture in the Skunk River basin, the basin was known for its wide, boggy bottomlands, which made crossing it in a wagon extremely difficult. Although farmers have since drained much of the land in the lowlands in order to make farming possible in the rich soil, ponding can still be a problem in the basin.

History of Settlement

Iowa has been farmed for as long as people have lived in the state. Prior to European exploration and settlement in the 1700's, central Iowa was populated by the Ioway tribe, farmers and gatherers who were part of the Oneota peoples.[8] Today, Iowa has many small farming communities, with a few larger towns and cities. Des Moines is the only large urban area in either the Skunk or Des Moines River basin. Cities in the Des Moines basin having a 1990 population larger than 10,000 people include Fort Dodge, Boone, Ottumwa, Keokuk, and Fort Madison. The only cities in the Skunk River Basin with a 1990 population greater than 10,000 are Ames, Newton, and Oskaloosa. Ames, the largest city in the Skunk River basin, is the site of the state's land-grant university, Iowa State University (ISU), which was founded in 1858.

Climate

Climatologists classify Iowa's climate as "humid continental," with warm to hot summers, and cool to cold winters. All of the climatic conditions have exhibited marked variability from season-to-season and year-to-year. This analysis focuses on the central and southern parts of the state that encompass the two river basins (Figure 3-1).

[8] See www.ioweb.com

According to the Iowa State Climatologist, Harry Hillaker, two weather patterns are typically related to large-scale flooding in Iowa (USGS 1991). The first pattern is a stationary jet stream accompanied by cold temperatures that results in large accumulations of snow, which then melt rapidly over frozen ground as temperatures rise in late February or March. Additional precipitation can intensify the flooding. The second pattern is the result of extended thunderstorm systems producing significant amounts of rainfall in late spring or early summer.

Annual average precipitation varies from a low of 25 inches in extreme northwestern Iowa to a high of 33 inches in the southeast. Across the state the annual precipitation gradient is in a SE (high)-NW (low) orientation, and this gradient is typical in each of the eight cold season months, September through April. Because the Des Moines and Skunk basins each have SE-NW orientations, they should, on average, have comparable precipitation amounts with the lowest amounts in their upper reaches and the greatest in their lower reaches in the southeast. In the warm season, May through August, much of the precipitation in Iowa is from thunderstorms. As a result, the monthly average values exhibit little longitudinal or latitudinal variability across Iowa. The year's peak month of rainfall is June with 5 inches the average amount for the two basins. These four months, on average, produce 16 inches of rain in the two basins, half of the annual total.

Over the period of record, measurable precipitation fell an average of 105 days a year with heavy rains much less frequent. Also, most locales in central Iowa experience 2 to 3 days a year with 2 inches or more rainfall. Heavy rainfall frequencies show a North-South gradient across central Iowa. For example, based on historical data the 24-hour rains that have occurred once in 5 years vary from 3.8 inches in the north to 4.3 inches in the south. The 10-year values vary from 4.3 to 5 inches, and the 25-year values range from 5 inches in the north to 5.8 inches in the south.

Most snowfall occurs in the December-March period, peaking in January. The average snowfall across the two basins also has a North-South gradient, ranging from 36 inches in the north to 25 inches in the extreme south. December through February are the driest months with much of the precipitation falling as snow.

Temperature conditions are relevant to streamflow and flooding in these two basins. The first freezing temperatures of the fall occur in mid October, and the last of the spring occur, on the average, in early May. The average number of days with temperatures below freezing varies from an average of 125 days in the extreme south end of the basins to 150 days in the north.

Translation of the average climatic conditions into flood expectations would suggest the following hypotheses:

1. The lower reaches of the rivers have more frequent and more intense hydrologic flooding than the upper reaches.
2. Snow-related flooding is worse in the north and should occur later than in the south with the prime period for snow-melt floods being in April.

3. The precipitation distribution is similar across the two side-by-side basins meaning that on average, they have comparable precipitation conditions.
4. Flash floods due to localized intense, short-duration rainstorms are more likely in the southern sections, and concentrated in the May-September period.

Types of Floods in Iowa

In this study, we classify historical floods in the two basins into five types based on different meteorological conditions that lead to flooding.[9] These types are:

1. *Flash floods* caused by intense rainfalls over short durations (typically 6 inches or more rainfall during two days or less).
2. *Snowmelt floods* caused when rapid spring warming occurs with considerable snow on frozen ground, leading to rapid runoff.
3. *Snowmelt plus rain floods* which are caused by a mixture of rapid snowmelt occurring with moderate to heavy spring rains.
4. *Warm season floods* resulting from prolonged moderate to heavy convective rainstorms persisting over several days or weeks.
5. *Warm season plus flash floods* which are a result of the multi-day rainfall periods (type #4) plus flash floods during the period of widespread rains.

Conditions affecting the magnitude of the floods in each of the above include antecedent soil moisture, often a reflection of previous precipitation, and time of the year which affects whether there is active vegetation. An early spring flood can be enhanced by the release of ice floes on the rivers that when trapped behind bridges form an artificial "ice dam" that increases inundation above the dam. There are several other geographic factors that affect flooding in a given basin. These include: 1) basin size, 2) basin shape and orientation, 3) land slopes in basin uplands and along the stream courses, and 4) degree of drainage development-geologic age. Other than basin size, the paired basins have similar characteristics for all of these physical conditions.

Human Influences on Flooding

Human activities within a river basin have potential to alter the frequency and/or intensity of floods. These activities include land use changes, shifts in rural drainage management, stream course changes (channelization), releases of water from reservoirs, construction of levees, and levee failures during a flood. There is every reason to expect flooding to change over time due to ever-changing land uses and modifications of river courses to reduce flooding or obtain water supplies.

In the Des Moines River basin, the engineering works designed to minimize damaging flooding include dams and levees. Two major flood-control dams, the Red Rock and Saylorville, exist in the basin. Red Rock Dam, located between Des Moines and Tracy, was built during 1960-1969 to provide flood control for Ottumwa (W. Koellner, pers. comm. June 1999). The dam has

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[9] These five types of floods can be thought of as a cross-cutting dimension with respect to the more general definition of flooding on pp. 7-9.

clearly affected the river and the floodplain above and below it. Above the dam, Lake Red Rock has provided recreation and wildlife habitats but has also created flooding on easement lands above the dam, especially since the level of the pool was increased to accommodate sediment buildup (W. Koellner, pers. comm.). Below the dam, the river's flow and flood pulse have been regulated. Commonly this results in a straightened channel and heightened erosion of the river banks. This effect is illustrated by river channel capacity changes. In the 1960's below Red Rock Dam, 22,000 cubic feet per second (cfs) was bank-full; now, after 1993, 104,000 cfs is actually less than bank-full (W. Koellner, pers. comm.). Stream bank riprapping has been necessary to minimize erosion. During a large flood such as 1993, when more water is let into the channel to avoid overtopping the dam, erosion and scour can be a serious problem.

Saylorville Dam, located between Saylorville and Des Moines, was built during 1965-1975 to provide flood control for the city of Des Moines. There are three other dams near Saylorville. They are the Big Creek Dam, the Big Creek Diversion, and the Big Creek Terminal. One negative effect of the Saylorville complex is that the city of Des Moines often has to pump seepage water below the dam (M. Klapp, pers. comm. June 1999).

Many of the communities in the Des Moines River basin have flood-control levees. Des Moines itself has publicly- and privately-built levees. Below the city, some communities bordering uncontrolled streams and Lake Red Rock have eyebrow, or ring, levees.

In the Skunk River basin, there are no major dams or flood control works. Dams were proposed in the past and were either determined by the USACE to be not cost-effective or shelved due to strong opposition from conservation groups. The Skunk itself, however, is highly channelized through parts of the basin. In projects completed by 1927, the channel was straightened in Story, Polk, Jasper, Marion, and Mahaska Counties. Erosion has been a problem where the channel has been straightened due to the loss of the natural flood pulse.

4
A "PAIRED BASIN" HYDRO-CLIMATIC ASSESSMENT OF DES MOINES AND SKUNK RIVER BASINS

The hydrologic and climatic analyses described in this section define and interpret temporal trends in hydrologic floods on the two adjacent river basins (see Figure 3-1). The two river basins are different sizes but have similar physiographic and climatic conditions and therefore should have similar hydrologic responses. One of the objectives of this phase of the study is to define the degree of similarity in the two basins' climatological conditions relevant to flooding in the basins. This section of the report discusses the climate and streamflow data for the paired basins, assesses temporal trends in hydrologic flood flows and relevant precipitation conditions, and identifies weather conditions associated with the major hydrologic floods.

Data

Climate Data

Daily precipitation data is the primary data set used to assess meteorological conditions. The primary source of daily precipitation data is the National Weather Service's cooperative observer network. This network, in operation since the late 1800's, consists of about 2 stations per county. Data are available in digital form from the National Climatic Data Center for 1948-present and from the Midwestern Climate Center for 1896-1947. Thus, daily data for the two basins is available in digital form back to the turn of the century.

We identified weather stations with historical data back to 1930 located in and around the paired basins; these stations are shown in Figure 4-1. The dataset for each sub-basin includes data from all stations in sub-basins to the northwest. For example, in the Des Moines River Basin, the entire basin (basin 7) includes all precipitation stations numbered 1 through 7, sub-basin 6 includes all precipitation stations numbered 1 through 6 , and so on. In the Skunk River Basin the entire basin (Basin 9) includes precipitation stations numbered 8 and 9. For each station there were daily values for precipitation, temperature (maximum and minimum), snowfall, and snow depth (the latter two are available digitally since 1947). These data were used to calculate various basin-wide scenarios involving heavy precipitation (>1-year and >5-year recurrence levels) for duration times of 1 day, 2 days, and 7 days. Potential flash flood events were assessed using basin-average 1- and 2-day rainfall events greater than the 5-year recurrence level, and by identifying 2-day events producing 6 inches or more rainfall at individual weather stations.

Figure 4-1
Precipitation Stations with Data From 1930 to Present

For snow-melt floods, the amounts of snow cover on various spring dates were identified. Years with above median and average depths at each station were identified and basin-wide values were calculated. Possible snowmelt floods were identified using these periods of above normal snow cover and finding dates when rapid warming occurred (temperatures rising to 10 degrees above freezing for a week or longer).

Other relevant precipitation measures were employed to assess temporal changes. These included the total annual precipitation, the number of days with measurable precipitation, the May-June rainfall and the June-July rainfall. These 2-month periods were assessed since most major hydrologic floods occurred during the May-July period.

Streamflow Data

Figure 4-2 shows the nine U.S. Geological Survey (USGS) streamgauges measuring flow in the Des Moines and Skunk River basins used in analysis in this study. These gauges and their length of record are listed in Table 4-1. The annual flow data, including the amount of flow and the height of water level, are available for all floods during the period of record.

Figure 4-2
Four Unaffected Sub-Basins and Streamgauges[10]

Table 4-1
Streamgauges With Long Records in the Des Moines and Skunk River Basins

Streamflow, or discharge, is the volume of water that passes a given point within a given period of time (commonly stated in cubic feet per second). Streamflow is computed based on measurements of velocity, gauge height (water-surface elevation relative to a base height), and channel width. The peak flow on a given day is the instantaneous discharge at the highest gauge height measured on that day. The annual peak flow is the annual maximum of the daily peak flows (that is, the maximum instantaneous flow in that year). For the purpose of this analysis, "annual" refers to water year (October 1 through September 20). The mean flow in a specified period is the average of the daily mean discharges during that period. This part of the analysis focuses on the annual peak flows and the maximum 2-day and 7-day mean flows. Hereafter, these are referred to as 2-day and 7-day flows. The most extreme hydrologic floods are expected to be associated with high annual peak flows, while the 2-day and 7-day flows provide a basis for assessing long-term trends in streamflow and for comparing flooding with various precipitation conditions.

The USGS identified four of the nine streamgauge sites on the two paired basins as having "long-term quality flow data," defined as unaffected by anthropogenic changes during this century (Kunkel et al. 1992). These stations are part of the hydroclimatic data network (HCDN). Thus, they are considered those most suitable for temporal analysis of "unaffected" flows and floods. These sub-basins include the Des Moines River at Stratford, the Raccoon River at Van Meter, the South Skunk River at Ames, and the Skunk River at Augusta. As shown in Figure 4-2,

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[10] The Augusta sub-basin includes the Ames sub-basin.

these four basins are not immediately adjacent. The sizes of the Skunk River basin and the Raccoon River sub-basin are similar, offering a good basis for comparison of their temporal responses to precipitation.

Several of the hydrologic analyses are based on comparisons of the conditions in the Raccoon River, the Des Moines River (at Keosauqua), and the Skunk River (at Augusta). All have complete records from 1915 to 1997. The Raccoon and Skunk are of similar size, located at the same general latitude (and climatic conditions), and are both considered basins with largely unaffected flows. The three-basin comparisons allow the conditions in the Skunk and Raccoon to serve as controls for the flood conditions measured in the affected parts of Des Moines basin.

Weather Conditions

Various precipitation measures in the three sub-basins were examined for trends during 1930-1997. The statistical significance of the trends is shown in Table 4-2, based on a 95% confidence level. No trend is evident in the frequency of 2-day heavy (>5-year recurrence) rain events. However, the frequency of 7-day heavy (>1-year recurrence) rain events, annual precipitation, and days with precipitation all show statistically significant upward trends in the Des Moines and Raccoon basins. In the Skunk basin, the trend estimates are similar to those in the other two basins; however, only the number of days with precipitation meet the requirement of statistical significance. (The Skunk's trends in 7-day rain events and total precipitation would be significant if a 90% confidence level were used). The trend estimates indicate that the number of 7-day heavy rain events was increasing by about one event in 20 years. The annual precipitation increases were 0.06 to 0.09 inch per year, and the increases in the number of precipitation days were about one day per 5 years during the 67-year period beginning in 1930. The estimated trends for these four precipitation variables relevant to flooding are quite similar across the three basins during the 1930-1997 period, supporting a conclusion that it is reasonable to compare flood conditions in the basins.

Table 4-2
Precipitation Trends in the Des Moines, Skunk, and Raccoon Rivers, 1930-1997

In addition, studies of flash floods in Illinois (which has a climate similar to Iowa) showed that most flash floods occurred as a result of 6 or more inches of rain falling in periods of a few hours up to 36 hours, and that most of these events were reported at once-a-day weather stations as 2-day events (Changnon and Vogel 1980). Hence, for each of the nine basins, the incidences of 2-day rains of 6 inches or more during 1930-1997 were assessed, as indicators of potential flash floods. Table 4-3 shows the decadal counts of extremely heavy rainfall events (> 6 inches in 2 days) at one raingauge within three adjacent areas of comparable size (about 4,000 square miles). The areas are the lower third of the Des Moines basin (below the confluence of the Raccoon and Des Moines Rivers), the Skunk River basin, and the Raccoon River basin.

Table 4-3
Number of Extremely Heavy 2-day Rainfall Events (6 inches or more) at Individual Weather Stations, 1930-1997

The basins show different time distributions of heavy rain events: The Raccoon shows an increase with time, the lower Des Moines shows no marked time change, and the Skunk shows a decrease with time. The 68-year frequency of heavy rain events is similar in the three basins, with 25 occurrences on the lower Des Moines, 20 on the Raccoon, and 18 on the Skunk. Thus, there is no consistent time-trend, and there are no marked spatial differences in total incidence of rain events capable of producing flash flooding.

Many major hydrologic floods in Iowa occur in the May-July period, so the yearly values of total rainfall in the May-June and June-July periods from 1930 to 1997 were selected for analysis. The basins include the four unaffected sub-basins and the entire Des Moines basin. The time trends of all basins for both periods appear to be essentially unchanging, although all show the marked maximum values associated with the record 1993 conditions. Table 4-2 shows that trends are not statistically significant for either of the 2-month periods. These results further indicate climatological similarity of the precipitation conditions between the paired basins. They also suggest that no increase in major hydrologic flooding should be expected during the 1930-1997 period.

Snowdepth measurements on February 1 indicate conditions near the end of the major snow period. Most high values occurred during 1969-1985 on all five basins, although the Skunk sub-basins had relatively higher values in 1996 than the Des Moines River sub-basins. The February 1 data indicate no long-term trends in the annual amount of snow cover from 1947 to 1997 over the four unaffected sub-basins and the entire Des Moines basin (at Keosauqua).

Snowdepth measurements on March 15 indicate conditions at the time when the spring snowmelt typically begins. Most high values came early and between 1951 and 1980, suggesting a temporal decline in the potential for snowmelt floods. Table 4-2 indicates that the small decreasing trends are similar in the three basins, but are not statistically significant.

The ten most intense 2-day basin-mean rainfall values were determined for each of the basins (Figure 4-3). As expected, the smaller basins have the higher amounts since these events are caused by small to moderate scale intense rainstorms that are not large enough to cover, for example, the entire Des Moines basin with large amounts of rain; hence, it has lower peak rainfall values for 2-day periods. Comparison of the times of occurrence of the top ten values in the basins show little agreement due to the small-scale nature of these events. However, heavy rains in 1993 achieve the top ten listing for all basins.

Figure 4-3
Top Ten 2-Day Heavy Precipitation Events, 1930-1997

The assessment of the characteristics of precipitation on the paired basins shows they are climatologically alike in all respects. The spatial differences in the heavy 2-day rain events is solely due to the small-scale nature of these storms which seldom spread across two of these basins. Three of the precipitation conditions show increases with time, but most conditions considered to be related to floods show no change with time.

Hydrologic Floods

Annual Peak Flood Levels

We compared the annual peak flows for the entire Skunk River basin (at Augusta), the entire Des Moines River basin (at Keosauqua), and the Raccoon River (Van Meter) (Figures 7a-c). Table 4-4 shows that the trend estimates are positive in all three basins for the 1915-1997 period, but only the trend in the Raccoon is statistically significant.

Figure 4-4a
Gauge Heights for Peak Flows at Skunk River at Augusta, Hydrologic Years 1903-1997

Figure 4-4b
Gauge Heights for Peak Flows at Des Moines River at Keosaoqua, Hydrologic Years 1903-1997

Figure 4-4c
Gauge Heights for Peak Flows at Raccoon River at Van Meter, Hydrologic Years 1915-1998

Table 4-4
Trends and their Statistical Significance for Various Measures of Annual Maximum Hydrological Floods for the Des Moines, Skunk, and Raccoon Rivers

Gauge height measurements are more appropriate than flow rates for judging the effect of human changes in the basin such as restraining the stream course by the use of levees. Table 4-4 indicates that the annual peak gauge height values on the Skunk and Raccoon increased only slightly with time (statistically insignificant on the Skunk). In contrast, the Des Moines gauge height values show a substantial increasing trend (0.14 feet per year) which is highly statistically significant, although all of the Des Moines flow measurements show insignificant trends. Given the lack of corresponding increases in precipitation this increasing trend reflects the anthropogenic changes to the Des Moines River, with gauge heights increased markedly where levees have restricted the flow, but maximum flows reduced through the use of reservoirs.

The peak gauge heights on the Des Moines River show little or no trend from 1912 into the early 1970s, followed by a major upward shift (Figure 4-4b). This shift occurred at the time the two major reservoirs were completed, and is likely an indication of their influence on raising water levels at peak flow. The influence of these relatively recent changes on the river's flow characteristics is further illustrated by trends in annual peak flows during the more recent 1947-1997 period, when the trend in the Des Moines River peak flow was about -0.8 cfs per year (essentially zero), as compared to +159 cfs per year on the Skunk River.

Maximum 2-Day and 7-Day Flows

Instantaneous peak flows are extremely variable, therefore they are less reliable than other measures for estimating long-term trends. Therefore, our trend analysis focuses primarily on annual maximum 2-day and 7-day mean flows. Table 4-4 shows that the trends in maximum 2-

day and 7-day flows are positive for all three basins, but only on the Raccoon are they statistically significant.

Nine of the top ten 2-day flows on the Raccoon basin, and seven of the top ten on the Skunk basin, occurred after 1960. However, only three of the top ten 2-day flows on the Des Moines came after 1960, and the 2- and 7-day flows both decreased somewhat after 1970, revealing the influence of the two reservoirs built at about that time. Again, there is clear evidence that the human changes to the Des Moines River altered the temporal distribution of the maximum 2-day and 7-day mean flows and kept them from increasing with time.

Figure 4-5 presents the flood frequency curves for the annual maximum 2-day flows and the recurrence intervals for the three basins. For any given return period, the Des Moines River values exceed those of the smaller basins. The curves fit to the Skunk and Raccoon values have similar slopes, but the Des Moines River curve is markedly steeper and reflects the many hydrologic differences that exist within that basin. The 1993 and 1947 floods on the Des Moines were events far from the fitted curve indicating they were extreme events with respect to the 88-year sampling period. Similarly, the 1993 flood on the Raccoon River was exceptional, but no such extreme values were sampled on the Skunk during its 82-year record.

Figure 4-5
Flood Frequency Curves for Annual Maximum 2-Day Flow

Most maximum 7-day flows occurred between March and October in all three basins. There is a suggestion of double peaks in the flow values, with one in late spring and another in mid-summer. The spring maximum is related to spring snow melts (flood types 2 and 3), whereas the summer maximum is tied to multi-day heavy convective rainstorms and sometimes also exceptionally heavy rains (types 4 and 5). The magnitude of the 7-day flows diminishes in August and early September, but increases slightly in mid-fall.

Precipitation Conditions before Major Hydrologic Floods

Two case studies illustrate pre-flood conditions. One is based on extreme 7-day floods that affected all three basins and the other is based on the conditions preceding the top ten peak flows on the two unaffected basins of comparable size, the Skunk River and Raccoon River. The aim of these more detailed case investigations was to better understand and define the critical pre-flood conditions.

Case Studies of Flood Types

Four major hydrologic floods which exemplify four of the flood types were selected to better determine the specific precipitation conditions that cause each type. The four floods were defined based on the magnitude of the 7-day flows and those selected occurred in all three basins and ranked among each basin's top annual events during the 1915-1997 period. The start dates of these 7-day floods were March 31, 1960, March 20, 1979, June 20, 1990, and July 9, 1993. The relevant precipitation conditions before each flood are described in Table 4-5.

Table 4-5
Primary Precipitation Conditions Preceding the Top Four Ranked Peak 7-Day Floods on the Raccoon, Des Moines, and Skunk River Basins During 1930-1997

The 1960 flood was a typical type 2 snow-melt flood resulting from high temperatures in late March and the rapid melting of about 1.5 feet of snow. The 1979 spring flood was a classic example of a type 3 flood. It had rapid melting of above average snow cover (but less than in 1960), and the flow was enhanced by much above normal spring rainfall that fell in a 12-day period when the snow was rapidly melting and the ground still frozen. The summer flood in 1990 was a typical type 4 flood derived from much above average rainfall occurring on a series of 11 days but without any flash flood producing heavy point rainfalls. The July 1993 flood had the characteristics of a type 5 flood with a run of 12 days of moderate to heavy rains accompanied by 6-inch rains at three individual stations that created flash flood conditions in parts of the three basins. These differences in the conditions producing four severe hydrologic floods on the three adjacent basins illustrate that (1) similar conditions prevailed across all three basins, and (2) major hydrologic flood-producing conditions can and do assume different characteristics.

The potential for flash floods to be the cause of the maximum flows was also examined. The dates of the incidences of heavy rain events (over 6 inches of rain in 2-day periods) at individual weather stations in the Raccoon basin, the Skunk basin, and the lower Des Moines basin were compared with the date of the start of the maximum 2-day flows. If the heavy rain event occurred within four days of the start of the maximum flow, it was assumed the rain event was related to the maximum. On the lower Des Moines, 6 of the 19 heavy rain events occurred within four days before the maximum flow, and two of the six flows were high ranked, one in 1993 (#1), the other in 1946 (#6). The other four flows were low ranked among the 68 values between 1930 and 1997. On the Raccoon basin 7 of the 16 heavy rain events occurred within four days in advance of the maximum flows, and four of these seven were high ranked flows: 1993 (#1), 1986 (#2), 1973 (#5), and 1947 (#6). On the Skunk basin 6 of the 14 heavy rain events occurred within four days before the maximum flows occurred, and the 2-day maximum flows were high ranked in three cases: 1973 (#1), 1993 (#3), and 1930 (#5). The frequencies of heavy rain events (at a point) occurring just before annual 2-day maximum flows reveal that between 32 and 44 percent of all flash flood situations were associated with annual maximum flows.

Investigation of the high ranked cases on all three basins reveals that the flash flood rains were all associated with 9-day or longer periods of moderate to heavy rainfall. Thus, they were a part of a type 5 flood. Importantly, the flash flood conditions from the >6-inch rain events contributed to the large magnitude of the maximum flows and their high ranks. The low-ranked maximum flows associated with the other >6-inch events were largely due to the events and not other rainfall, and were typical of the type 1 floods (flash flood only).

Case Studies of Top Ten Floods

A thorough analysis of the meteorological causes of major floods was done for the Raccoon River at Van Meter and the Skunk River above Augusta. Both basins are characterized by a lack of major modifications to the basin throughout the streamflow record. They are also similar in size although the Skunk River Basin is slightly larger. They are both at similar latitudes. The Skunk is elongated while the Raccoon River Basin is more rounded in shape.

The peak flows for the Skunk River each year were ranked and show a significant gap in flows between the rank 10 and rank 11 events. For this reason, the top ten events were chosen for the Skunk River. It should be noted that these include both catastrophic floods and other major floods of slightly lower flows that did not cause catastrophic damage. Analysis of the ranked peak flows for the Raccoon River did not indicate a similar break between the rank 10 and rank 11 events. However, for the sake of consistency, the top ten events for the Raccoon River were also chosen for this analysis.

Identification of the meteorological causes of these floods was performed by identifying precipitation stations with lengthy records covering the entire period of streamflow records on these two basins. Daily precipitation, snowfall, snow depth, and temperatures were extracted for these stations. The data were averaged to produce a daily mean climate time series for each basin, as input to determination of the causes of the flood events.

Tables 4-6 and 4-7 list the events, in chronological order, for the Skunk and Raccoon Rivers, respectively. Also shown in each table is the rank of the flood event, the type of flood, and the key meteorological events causing the flood. These events are identified in terms of whether they are rainfall or snowmelt events. The beginning and ending dates of the period of rain or snowmelt are also given. The value in parenthesis is the total basin-average rain over the period or the basin-average snow depth at the beginning of the melting period. Finally, the date and amount of the maximum single day basin-average rainfall or snowmelt is listed. Regarding the type, a flood was identified as a flash flood type (1) if the rain occurred over a 1- or 2-day period. A flood was identified as a mixed type (5) if the duration was 3 days or more and at least one station in the basin received at least 6 inches over a 1 or 2 day period.

Table 4-6
Meteorological Causes of Major Floods, Skunk River at Augusta

Table 4-7
Meteorological Causes of Major Floods, Raccoon River at Van Meter

Major floods on the Skunk River above Augusta (Table 4-6) generally occurred in the spring or early summer. Only one event (1965) did not occur during this time period. The 1930 event was a type 1 (flash) flood. The 1960 event was a type 2 (snowmelt) flood. The 1973 event was a type 3 (mixed snowmelt and rain) flood. All the other floods were either multi-day rain events (type 4) or a mix of multi-day rain and flash flood events (type 5). The rainfall data indicate that flooding on the Skunk River above Augusta requires a basin-average rain amount (or snowmelt equivalent) of about 4 inches or more occurring over less than a 1- to 2-week period. It is important to note that snowpack densities are generally 0.2-0.3 cm^3 H_2O/cm^3, i.e., a snowpack of 10 inches depth would be equivalent to 2 to 3 inches of rain.

All of the floods on the Raccoon River at Van Meter occurred in the spring or early summer. Of the ten floods, three were of the flash flood type, one was of the snowmelt type, and one was a mixed snowmelt and rain flood. The other five were multi-day rain events, types 4 and 5.

Multi-day rain events are the dominant causal factor on both the Raccoon and Skunk Rivers; however, the flash flood type is more frequent on the Raccoon River than on the Skunk River. Basin shape might explain this observation. Most heavy rain events tend to move from west to east or southwest to northeast. The Raccoon River basin is oriented in an east to west direction, along the path of heavy storms. The Skunk River basin is more elongated and oriented northwest to southeast, and thus perpendicular to the track of heavy storms. Consequently, in contrast to the Skunk River basin, a large portion of the Raccoon River basin might be affected by a heavy rain event. The flow record indicates that somewhat lesser basin average precipitation amounts are capable of causing major flash floods on the Raccoon River at Van Meter (in the range of 2 to 4 inches). However, the data indicate that for multi-day rain events, more than four inches of precipitation over a period of less than one to two weeks are needed to create a major hydrologic flood in both the Raccoon and Skunk River basins.

On both basins, the dominant meteorological cause of the major hydrologic floods is the multi-day precipitation event (types 4 or 5). Snowmelt floods can occur in these basins, but major snowmelt floods are rare and there have been none since 1979. Flash floods can occur on both basins. The concentration of major floods in early spring and summer can be attributed to several factors. First, snowmelt flooding is most likely in the early spring when warm temperatures can melt an existing snowpack rapidly. Second, intense convective precipitation (responsible for the high multi-day totals in types 4 and 5) generally does not occur during the cool season from about October through March. However, during the warm season, particularly May through September, high atmospheric moisture levels occur and create conditions that are favorable for heavy convective precipitation.

Another important factor is soil moisture, which affects the ability of the soil to absorb rain or melting snow. There is a rather pronounced seasonal cycle in soil moisture. Soil moisture values generally reach their peak in early to middle spring and then begin a slow decline. From about mid-summer through the middle of autumn, soil moisture levels are generally rather low and there is a significant capacity for absorption of rainfall by the soils. This factor is probably important in reducing runoff from late summer heavy rainfall events. An increasing trend in total annual precipitation and number of days with rain contributes to an increasing trend in soil moisture levels, thereby increasing the susceptibility of these basins to flooding.

Summary of the Paired Basin Assessment

The analysis of hydrologic floods and the associated precipitation conditions reveals three key findings.

- First, the human changes to the Des Moines River and its floodplain have markedly altered the temporal distribution of the annual peak flow, but had less effect on the annual peak flow rates.

- Second, the paired basins experienced comparable trends in total precipitation, in 7-day heavy rainfall frequencies, and the number of days with precipitation. However, of the several precipitation conditions assessed and conceivably related to floods, none increased with time. These conditions include the number of >6-inch rain events, the May-July rainfall across central Iowa, the snow depth, and the frequency of 2-day rainfall events exceeding a 5-year recurrence level. Collectively, the results suggest that the 7-day or longer heavy rainfall events have been the primary factor influencing the changing magnitude of the annual hydrologic floods as reflected in maximum 2- and 7-day flows. This is in agreement with findings from earlier studies of Midwestern floods (Changnon and Kunkel 1995).

- Third, the case studies indicate that much of the hydrologic flooding in Iowa is due to prolonged precipitation periods lasting 7 days or more, i.e., flood type 4 as defined earlier. However, all five types have produced floods, and hydrologic flooding in Iowa is simply a result of the climatic position of the state such that it can experience frequently all the weather conditions that lead to the five types of floods.

5
DAMAGING FLOODS IN THE PAIRED BASIN

The study of damaging floods in the two basins had to be narrowed considerably because of the lack of flood damage data (discussed in section II). A research trip to Iowa to meet with local officials and newspaper offices resulted in a thorough search for information on flood damage from the 1940s to the present but produced few documents containing quantitative damage estimates. Damage descriptions in technical reports, newspaper articles, and local histories are most plentiful for the largest city in each basin, Des Moines in the Des Moines River basin and Ames in the Skunk River basin. Therefore, our analysis of damaging floods focuses on those two cities and their surrounding counties, Polk and Story County, respectively.

This section is organized as follows: First, it briefly compares the physical and social characteristics of the two counties. Second, it identifies the major hydrologic floods in each county, based on annual peak flow in the major rivers and precipitation in the relevant watershed areas. Third, the damaging floods in each county are identified and classified according to the severity of the damages. Finally, it systematically compares the damaging floods with the hydrologic floods and discusses some of the factors contributing to flood damage in the two counties.

Data

Descriptions of damaging floods are available from a variety of sources. The most comprehensive reports are those prepared by agencies such as the U.S. Army Corps of Engineers (USACE), the U.S. Geological Survey (USGS), the Natural Resources Conservation Service (NRCS), the Iowa Department of Natural Resources (IDNR), and the now defunct Iowa Natural Resources Council (INRC). Often the reports focus on particular areas of interest to those agencies; thus, far more historical damage information is available for the most heavily populated areas of the basins, while little information is available for small towns and rural areas. Gauge height and discharge data were obtained for the major rivers and creeks that affect the cities of Des Moines and Ames. Peak flow data (annual and all daily peaks above base) were downloaded from the USGS website (waterdata.usgs.gov/nwis-w/IA/). Streamgauges used in this part of the study are summarized in Table 5-1.

Table 5-1
Streamgauges for Streams near Des Moines and Ames

Precipitation data are from NWS weather stations which had historical data back to 1930 (a subset of those used in section IV). For the period 1947-1997, basin-wide average precipitation was computed for 11 stations in the upper Des Moines basin, 7 stations in the Raccoon basin, and 3 stations on the outskirts of the upper South Skunk basin north and west of Ames.[11] From the daily values, 2-day, 7-day, 4-week, and 6-week precipitation totals were computed, which were then used to identify the "major" precipitation events (i.e. those events which exceed the 5-year recurrence level) of each duration. This section of the report focuses mainly on the major 7-day and 6-week precipitation events. In addition, daily precipitation data from two weather stations in Ames (covering 1940-1964 and 1964-1997, respectively) and one station in Des Moines (covering 1940-1997) provide localized information for those cities.

Flood-related Characteristics of Polk and Story Counties

Polk County is located about halfway down the Des Moines River basin.[12] The Des Moines River runs directly through the downtown area of the city of Des Moines, joining with the Raccoon River just south of downtown (Figure 5-1a). Tributaries to these rivers also flow through Des Moines, including Walnut Creek (which flows from the north to join the Raccoon River in West Des Moines) and Fourmile Creek (which flows through the eastern side of Des Moines). Thus, Polk County and the Des Moines urban area are subject to runoff from two relatively large basins (6,245 square miles in the upper Des Moines basin and 3,441 square miles in the Raccoon basin). Saylorville Dam, in northern Polk County, was completed in 1975 and protects the city from flooding of the Des Moines River.

Figure 5-1a
Des Moines

Polk County population grew from 196,000 in 1940 to 327,000 in 1990, an increase of 67%. The city of Des Moines grew somewhat more slowly, from about 160,000 in 1940 to 201,000 in 1990 an increase of about 25%; however, the county's population increase was associated with substantial growth in the city's suburbs.

Story County is located in the upper reaches of the South Skunk River basin. The South Fork of the Skunk River flows into Ames from the north and parallels the east side of the city (Figure 5-1b). Squaw Creek flows into Ames from the northwest and follows a path through the Iowa State University (ISU) campus to its confluence with the South Skunk at the southeast corner of the city. The drainage area above Ames is small for both streams (about 329 square miles in the Skunk basin and 227 square miles in the Squaw Creek basin). The floodplain of the Squaw Creek basin is relatively narrow and has little storage capacity for flood waters, contributing to flash flood risk (Snyder and Associates 1996).

Figure 5-1b
Ames

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[11] These five types of floods can be thought of as a cross-cutting dimension with respect to the more general definition of flooding on pp. 7-9.

[12] The northeast corner of Polk County extends into the South Skunk River basin, including the sparsely populated rural area northeast of the little town of Elkhart. Our analysis includes only the part of Polk County which is in the Des Moines basin.

The population of Story County grew from 33,400 in 1940 to 74,300 in 1990. Much of this growth took place in the city of Ames, which nearly quadrupled from 12,600 people in 1940 to 47,200 in 1990. Between 1965 and 1993, major facilities were added to the ISU campus and commercial development along Squaw Creek increased substantially (Snyder and Associates 1996).

Despite their difference in population, there is considerable similarity in the flood vulnerabilities of the two counties. The major city in each county is located at the confluence of two rivers, and climate conditions in the two basins are quite similar (as shown in section IV). However, two differences should be noted between the flood-related characteristics of Polk and Story Counties: (1) Des Moines is protected by Saylorville Dam and many levees, while Ames is not protected by any large flood-control structures; (2) the drainage area above Des Moines is large, while the drainage area above Ames is small, making it more susceptible to flash floods with a relatively short flood-warning period.

Major Hydrologic Floods Affecting Des Moines and Ames

In this section, a "major hydrologic flood" on a river or stream is defined as a flood in which the peak streamflow is in the top 20% of the annual peak flows at a gauging station between 1940 and 1997. The number of major hydrologic floods depends on the length of record at the station, with a maximum of 12 flood years since 1940. The record of major hydrologic floods from gauging stations in and near the city of Des Moines is shown in Table 5-2, and that for stations in and near the city of Ames is shown in Table 5-3. In both tables, floods which are in the top 10% of annual peak flows are shown in italics. Occasionally, one or more secondary peaks exceeding the specified levels will occur in a given year, and these are listed on the right side of the tables.

Table 5-2
Major Hydrologic Floods in the Upper Des Moines Basin near Des Moines, Iowa

Table 5-3
Major Hydrologic Floods in the South Skunk Basin near Ames, Iowa

On the upper Des Moines River (2nd Avenue and Saylorville stations in Table 5-2), flood peaks were highest in June 1947, June 1954, April 1960, April 1965, and July 1993. In these same months, flood peaks were also highest on the Des Moines River below the confluence with the Raccoon. In contrast, on the Raccoon River, flood peaks were highest in June 1947, July 1958, July 1973, July 1986, and July 1993. The predominance of severe floods on the upper Des Moines before the 1965-1975 construction of Saylorville Dam suggests that the dam has had an important role in reducing peak flows in Des Moines.

On the upper South Skunk River (near Ames in Table 5-3), flood peaks were highest in May 1944, June 1954, June 1990, July and August 1993, and June 1996. The record on Squaw Creek is short, going back only to 1965, but shows its highest peaks in June 1975, June 1990, July 1993, and June 1996. These months are also highest-ranked below the confluence of the two streams.

In many cases, major floods occurred at about the same time in both basins. However, some severe floods have been more localized. In particular, there were no major hydrologic floods in the Des Moines area at the time of the June 1975 or June 1996 floods in Ames; similarly, there were no major hydrologic floods in Ames at the time of the July 1973 and July 1986 floods on the Raccoon River.

Major Precipitation Events in the Basins Upstream

Myriad creeks and streams wind through the small towns and rural areas of Polk and Story Counties. Extreme precipitation events within the basins may lead to flooding of streams and, perhaps, of areas outside normal floodplains. Note that precipitation can be "extreme" in various ways (intensity, duration, geographic extent), ranging from a brief but intense local downpour to long-term, widespread, heavy rain or snowfall. This part of the study considers basin-wide average precipitation over each of the upper basins for both 7-day and 6-week periods, in order to determine whether widespread medium- or long-term precipitation periods are related to the most damaging floods.

Table 5-4 lists the major 7-day and 6-week precipitation events in the three basins during 1947-1997, defined as the periods of each duration in which basin-wide average precipitation exceeded the 5-year recurrence level. Precipitation events which exceeded the 10-year recurrence level are shown in italics. All of the major precipitation events occurred during the warm season, May through September.

Table 5-4
Major Precipitation Events in Basins Affecting Polk and Story Counties

Differences associated with seasonality can be seen between the major precipitation events in Table 5-4 and the major hydrologic floods in Tables 5-2 and 5-3.

1. The March and April hydrologic floods do not correspond to any of the major precipitation events, presumably because they are associated with rapidly melting snow which accumulated over an extended period.

2. There were no major hydrologic floods in September during 1940-1997; yet heavy September rains have occurred fairly frequently (7-day events in Septembers of 1962, 1965, 1973, 1978, 1989; 6-week events ending in mid- to late-September in 1951, 1965, and 1977). Therefore, major precipitation events alone (as defined here) are not sufficient to cause major hydrologic floods. During this period of the year soil moisture levels are generally low, thus, infiltration capacity is high.

3. During May-August, at least half of the major 6-week precipitation events in each basin are associated with major hydrologic floods (5 of 9 in the upper Des Moines, 5 of 8 in the Raccoon, and 4 of 8 in the Skunk). In some cases, the flood occurred

before the end of the 6 weeks, but at least 3-1/2 weeks into the rainy period.[13] Slightly less than half of the major 7-day precipitation events are associated with major hydrologic floods (3 out of 8 in the upper Des Moines, 3 of 6 in the Raccoon, and 4 of 9 in the Skunk). Of those 7-day events associated with floods, all but one are part of a major 6-week precipitation event. Thus long-term precipitation (4 to 6 weeks) appears to be an important factor leading to warm-season floods. (Note, however, that nearly half of the major precipitation events, including some of the most extreme, were *not* associated with major hydrologic floods at the locations in Tables 13 and 14.)

Several conclusions can be drawn about the relationship between precipitation and hydrologic floods in this part of Iowa. First, it is clear that not all basin-wide major precipitation events result in major hydrologic floods, and not all hydrologic floods are the result of basin-wide heavy rainfall. The relationship depends on the season. In March and April, rainfall is relatively light and floods are the result of snowmelt (although even light rains hasten melting). In May through August, major precipitation events, particularly those lasting longer than 4 weeks, frequently lead to hydrologic flooding. However, similar levels of basin-wide precipitation occurring in September have not led to hydrologic floods during the period studied. Therefore, seasonal conditions which are not usually present in September (such as high soil moisture) also influence hydrologic flooding.

Damaging Floods in Polk and Story Counties

Identification of Damaging Floods

Damaging floods in the 1940s through the 1960s in Polk and Story Counties are described in reports of the U.S. Army Corps of Engineers (1970, 1966). More recent damaging floods were identified by interviewing officials in Iowa, searching files of the Des Moines Register the Ames Daily Tribune, and the NWS Office of Hydrology, and examining the list of Presidential declarations of major flood disaster since 1965.

In Des Moines, "major floods" which "caused much property damage" occurred in 1851, 1903, 1944, 1947, 1954, and 1965 (USACE 1970). The report also mentions minor damage in other years, with explicit mention of an April 1960 flood. Flood-related Presidential Disaster Declarations were issued for Polk County in 1965, 1969, 1974, 1990, and 1993. Newspaper accounts and NWS reports mention additional floods in 1973, 1984, and 1986.

In Ames and Story County, a report issued shortly before the 1996 flood identified the "most severe floods of record" as those in 1918, 1944, 1947, 1954, 1958, 1960, and 1965, 1975, 1984, and 1993 (Snyder and Assoc. 1996). The flood of 1975 caused substantial damage in Ames, warranting a special report (Lara and Heinitz 1976). Flood-related Presidential disaster declarations were issued for Story County in 1969, 1974, 1990, 1991, 1993, and 1996.

[13] 6-week events ending September 1 and 2 occurred in the Skunk Basin and are considered May-August events. One of them was associated with a flood, which occurred in mid-August.

These lists of damaging floods are likely to be incomplete: some floods that caused minor damage may have been overlooked because of low news coverage. However, a broad spectrum of damage levels are represented, allowing comparisons of severe and minor floods and of hydrologic and damaging floods.

Classification of Damaging Floods

Using descriptions of the damaging floods from the preceding references, we have derived the flood damage classification system shown in Table 5-5. It is used to group floods by damage level.

Table 5-5
Flood Damage Classification (Derived from descriptions of damaging floods in Iowa, 1944-1997)

Assignment of the damage level depends on both the severity and scope of the impacts. The spatial extent and number of people impacted are important factors influencing total losses and recovery. This is especially evident in the distinction between the "moderate" and "severe" damage levels. Resources are far more stressed when a flood inundates a large area or a large proportion of the population in a region. For example, when just one transportation route is temporarily unavailable others can be easily substituted, but if many are disrupted alternatives become increasingly expensive. Similarly, temporary housing for a few displaced people is relatively easy to arrange, but the facilities needed to house many displaced people may not exist. The severe and widespread flood of 1993, which caused billions of dollars in losses and months of disruption of commerce, transportation, agriculture, and personal life for a large portion of the population in a 9-state region, provides an extreme example of how costs and disruption multiply as a flood increases in scope.

Table 5-6 classifies the damaging floods in Polk County by damage level, with brief descriptions of the types of damage in each flood. Table 5-7 provides similar information for damaging floods in Story County. Estimates of dollar losses are included in the descriptions if available; however, the estimates for different floods come from disparate sources, include different aspects of damage, and thus are not directly comparable.

Table 5-6
Classification of Damaging Floods in Polk County, 1944-1997

Table 5-7
Classification of Damaging Floods in Story County, 1944-1997

Most-damaging Floods in Each County, 1944-1997

The four most damaging floods in each county, shown in Tables 5-8 and 5-9, were identified and ranked based on available descriptions. The rankings should be regarded as tentative because the available descriptions are sketchy and inconsistent. Therefore we look at the eight worst floods as a group, to describe their damages and assess their hydrologic characteristics.

Table 5-8
Most-Damaging Floods, 1944-1997: Polk County, Iowa

Table 5-9
Most-Damaging Floods, 1944-1997: Story County, Iowa

Most damage descriptions tended to focus on urban damages; therefore, we have not systematically compared agricultural damages in this study. All of these floods resulted in extensive damage to homes and/or businesses. At least two caused disruption of public utility services (1993 in Des Moines, 1944 in Ames). Most caused widespread damage over a large area.

All eight most-damaging floods occurred during May through August. In terms of Iowa's hydrologic flood types (described in section 3), all but one were "warm season floods" (types 4 or 5), resulting from prolonged moderate to heavy convective rainstorms persisting over several weeks (several months in the 1993 floods). Some of the Polk County floods also involved flash flooding upstream in the upper Des Moines or Raccoon basins. Just one of the most-damaging floods appears to have been caused exclusively by flash flooding (type 1) — the 1944 flood in Story County. (None of the most-damaging floods were "snowmelt floods".)

All eight most-damaging floods involved major hydrologic flooding on one or both of the major rivers at streamgauges just above or within the city. In every case, peak flow on at least one river was above the 10-year recurrence level (i.e. there was less than a 10% chance that such a flood would occur in any given year). In seven of the eight floods, either one river had a record high peak flow for the 54-year period or two streams peaked almost concurrently. The exception is the flash flood in Ames in 1944, to be discussed in more detail below.

Three of the Polk County floods were preceded by six weeks of persistent basin-wide rainfall (above the 10-year recurrence level in either the upper Des Moines or Raccoon basins). The flood with somewhat lower long-term rainfall occurred in May 1986, when April snowmelt also contributed to soil saturation. Thus, widespread, persistent rains which lead to saturated soils and heavy runoff throughout the basin appear to be the dominant cause of the most-damaging floods in Polk County. The second flood in 1986 (July 1) was a flash flood caused by short-term heavy rainfall in the Raccoon basin.

Our precipitation data for the upper South Skunk basin is based on only three weather stations which are located slightly outside of the basin. The average precipitation levels shown in Table 5-9 do not suggest that there would be major floods, except in 1993; but these measurements may not be good indicators of precipitation in or near Story County. Therefore, daily precipitation measurements at two weather stations in Ames were examined and are summarized in the last row of Table 5-9. The floods in both 1975 and 1996 were preceded by 6 weeks of persistent rainfall in Ames; in 1993 the rainfall persisted much longer. Like the floods in Polk County, the most-damaging floods in Story County usually are associated with persistent rains and saturated soils, but the available data do not allow us to judge whether the storms were widespread or localized.

The flash flood in Ames in 1944 appears to be a unique case. Ames precipitation was relatively light during the 6 weeks preceding the flood. On May 19-20 there was a deluge: 8.2 inches. The flooding was described as follows: "The downpour of May 19 fell within such a short period of time that water was running in the streets to depths of several feet. Water fell so fast that homes located on relatively high ground experienced torrents of water pushing in grade windows and filling their basements" (Brown 1999). "Almost every basement within the city was under inches of water because of inadequate drainage and sewer capacities" (USACE 1966). Thus, it appears that much of the damage in the 1944 flood was caused by rainwater flooding, in addition to some river flooding.

Moderate-damage Floods, 1944-1997

These are floods which caused some serious damage within a relatively small area. Of the moderate-damage floods listed in Tables 17 and 18, only the 1954 flood on the Des Moines River involved record high flow on a major river; however, all but one had flows greater than the 10-year recurrence level. The exception is the 1991 flood in Story County, which caused little flooding in Ames but much damage along small streams in outlying communities.

The moderate-damage group includes both June "warm season floods" and an April "snowmelt flood". The three June floods in Story County were preceded by six weeks of persistent rainfall in the upper South Skunk basin (exceeding the 10-year recurrence level in 1947 and 1990, exceeding the 5-year recurrence level in 1991). Very little rain preceded the April flood in Polk County.

In Polk County, two factors contributed to making the April 1960 flood much less damaging than the June 1954 flood. (1) April floods occur before most spring planting has begun and cause little agricultural damage, while in June 1954 there was substantial agricultural damage. (2) In April 1960, farm homes in the Des Moines River valley were flooded but central Des Moines was protected by levees, some of which had been built within the previous few years; in contrast, in 1954 a levee broke causing the flooding of about 50 homes in Des Moines (USACE 1970).

In Story County, the worst of the moderate-damage floods was in June 1990, with significant damage to residential and commercial property in one section of Ames and to roads and bridges in the county (Daily Tribune 6/5/91).

Minor-damage Floods, 1944-1997

At the "minor" damage level, local governments and citizens in Iowa appear to be accustomed to coping with the inconvenience of a few flooded basements, temporarily flooded streets, and the need for occasional repairs to roads and bridges. The use of floodplains as parks and golf courses may be planned with the expectation of occasional flooding. If planting is not delayed too much, the inundation of croplands in the spring may be beneficial, offsetting occasional crop damage losses. Costs in the minor-damage floods result primarily from flood fighting efforts, crop damage, road repairs, and cleanup of small numbers of flooded homes and businesses.

"Snowmelt floods" (types 2 or 3) in late March and April caused minor damage in both Story County (1960) and Polk County (1965 and 1969). Peak streamflow in the Des Moines River exceeded the 10-year recurrence level in 1965, while peak flows in the 1960 (Story) and 1969 (Polk) floods exceeded the 5-year recurrence level. Over two inches of rain in seven days in Des Moines may have hastened the snowmelt in both of the April floods.

"Warm season floods" (types 4 or 5) with minor damage occurred in May, June, and July in Polk County. In 1944, peak streamflows in the Des Moines River exceeded the 5-year recurrence level, while in the more recent floods of 1973, 1974, and 1984 peak flows exceeded the 10-year recurrence level in either Walnut Creek (1973, 1974), the Raccoon River (1973), or the Des Moines River (1984).

The minor-damage floods in Polk County were not preceded by the kind of basin-wide persistent rainfall that characterized most of the severe and moderate floods. None had 4-week or 6-week rainfall exceeding the 10-year recurrence level (although the 5-year recurrence level was exceeded in the Raccoon basin in the 1973 (6-week) and 1984 (4-week) floods). Neither did the 7-day rainfall exceed the 10-year recurrence level. The only notable extreme rainfall was just before the 1973 flood — when 2-day rainfall in the Raccoon basin exceeded the 10-year recurrence level on July 1-2.

In Story County, "warm season floods" with minor damage occurred in June, July, and August. Only one of these had a peak flow higher than the 10-year recurrence level: the flood of June 1954 on the South Skunk River. Two others had peak flows exceeding the 5-year recurrence level (June 1974 and June 1984). Surprisingly, three floods which caused minor damage in Ames and have been described as "notable" (USACE 1966) did not have peak flows exceeding the 5-year recurrence level, therefore do not qualify as hydrologic floods on a major river.

These "mystery floods" in Story County (August 1954, July 1958, and June 1965) require further explanation. Damages in two of these floods appear to be the result of flash flooding. In 1954, heavy precipitation events (> 6" in 2 days) occurred in Ames and at several other stations in the upper South Skunk basin on August 22-23. In 1958, localized downpours of 2-4 inches occurred in Ames and nearby communities on July 2 and 4 (Daily Tribune 7/2/58, 7/5/58). Thus, the mystery floods of August 1954 and July 1958 can be attributed to rainwater flooding, aggravated by the overflow of storm drains described in Table 5-7.

In the last mystery flood, June 1965, news reports describe highly localized flooding on the west edge of Ames. "Nearly 1.5 inches of rain raised the water table in this area so high, small springs were bubbling from between the cracks of the highway paving" (Daily Tribune 6/5/65). Roads, basements, and businesses in the area were inundated as flooding of a small spring created a lake over 4 feet deep (Daily Tribune 6/7/65). Thus, the damages in June 1965 can be attributed to water table flooding.

Rainwater flooding and backing up of storm drains have been a recurring cause of damage in Story County throughout the 1944-1997 study period. Localized heavy rainfall events can produce flooding in areas well outside the river floodplains (as described above in the severe flash flood of 1944). Inadequate storm sewer capacities in Ames and outlying small communities are mentioned in descriptions of four of the minor-damage floods (August 1954, 1958, 1965, 1984), in the moderate-damage 1947 and 1991 floods and in the severe-damage 1944 flood (USACE 1966, Daily Tribune 6/5/91).

Factors Contributing to Flood Damage

Relationship of Hydrologic Conditions to Flood Damage

All of the severely damaging floods in Polk and Story counties during 1944-1997 occurred during the "warm season", May through August. Three different hydrologic configurations led to high levels of flood damage:

1. Persistent rains for 4 to 6 weeks or more, with record high peak flow in one or more rivers or streams. (For gauges with complete records during 1940-1997, this implies peak streamflow greater than a 50-year recurrence level.)
2. Persistent rains for 4 to 6 weeks or more, with two confluent rivers peaking within one day of each other and peak flow greater than a 10-year recurrence level in at least one of the rivers.
3. Flash flooding due to extremely heavy short-term (2-day) rainfall, combined with peak flow greater than a 10-year recurrence level in at least one river.

Floods which caused only minor damage occurred between March and August, with the March-April flooding induced by melting snow. Most were not preceded by excessive long-term rainfall and involved peak streamflows at the 5- to 9-year recurrence levels. A few in Story County did not involve notably high river flows at all; they resulted from short-term (2- to 3-day) heavy rainfall and their damage was caused by water table flooding or rainwater flooding, exacerbated by inadequate storm sewer capacity.

All hydrologic floods in the top 10% of peak annual flows caused some damage. In contrast, about half of the hydrologic floods having peak flows at the 11-20% level did not cause significant damage.

The floods examined in this study illustrate that a wide variety of climatic and hydrologic conditions can lead to flood damage. Although the most damaging floods were associated with major hydrologic floods, several minor-damage floods apparently did not involve hydrologic flooding on rivers or streams, but instead resulted from heavy local rainfall or from a rising water table associated with saturated soils. In Iowa, saturated soils are frequently mentioned as antecedent conditions preceding hydrologic floods — and this saturation is often the result of persistent rains over a relatively long period. Thus, precipitation conditions that have led to damaging floods include heavy snowpack in late winter, short-term (1 to 7 days) heavy rains in spring and summer, or long-term (4 to 6 weeks or more) persistent rains in spring and summer. On the other hand, similar levels of rainfall in September have not led to damaging floods.

In Iowa, while hydrologic floods are the result of precipitation, only certain types of major precipitation events lead to damaging floods. Furthermore, not all hydrologic floods cause damage and not all damaging floods are hydrologic floods (if these are defined simply as the overspilling of the banks of a stream).

Relationship of Development and Flood Protection to Flood Damage

In Ames, rapid population growth and related development have been major factors in changing flood risk. A report on flooding through 1965 in Story County noted, "damages from these floods have been relatively light [because] the flood plains have not been extensively developed" (USACE 1966). Between 1965 and 1993, a comparison of aerial photos taken over the city of Ames shows substantial growth in commercial and public facilities within the Squaw Creek flood plain, including five major facilities and a student housing complex on the Iowa State University campus (Snyder and Assoc. 1996). Scattered commercial and residential growth occurred in the Skunk River flood plain during this time, as well.

The enormously damaging flood of 1993 spurred substantive actions to reduce vulnerability. With aid from FEMA, 26 of the most flood-prone homes in Ames were bought out and demolished, with plans to convert the area into a park (Daily Tribune 9/1/94). The Masonic Lodge was demolished (Daily Tribune 6/28/96) and the County Human Services building was destroyed with plans to rebuild it in a safer location (Daily Tribune 2/2/96, 7/3/97). In the town of Nevada in Story County, 12 flood-damaged houses were bought out (Daily Tribune 8/3/95). In addition, ISU commissioned an engineering study to recommend flood mitigation projects for better protection of the university campus. A Flood Review Task Force was formed to identify ways to diminish flooding and reduce flood impacts in the Ames area.[14] As a result, some buildings were flood-proofed, and the city developed a new flood warning system involving a network of community volunteers and easily readable flood stage markers.

Some of these actions paid off in June 1996. Hydrologically, in parts of Story County the 1996 flood was worse than the 1993 flood (Daily Tribune 6/17/96, 6/18/96), and peak flow on the South Skunk near Ames was higher than in 1993 (Table 5-3). However, peak flow on Squaw Creek was substantially lower than in 1993, hence ISU suffered little damage. The new flood warning system gave an early alert of the impending flood, and the community mobilized flood prevention efforts much more quickly than it had in 1993. The city of Ames suffered $1.4 million damage in 1996, compared to $3 million in 1993 (Daily Tribune, 6/25/96).

It is worthwhile to compare flood damage in 1996 with that in 1975. Peak flows on both Squaw Creek and the South Skunk were considerably higher in 1996, and heavy precipitation in northern Story county contributed to flash flooding in 1996 which was not present in 1975. Population and development had increased substantially by 1996. Yet, damage to the city, in real dollars, was less in 1996 than in 1975: Estimated damage to Ames homes and businesses totaled $700,000 in 1975 [$1.79 million in 1995 dollars], while estimated damage to homes, businesses,

[14] The task force was formed by the City of Ames, Iowa State University, Story County, and the Iowa Department of Transportation. It commissioned the Snyder and Associates (1996) report.

and public lands was $1.4 million [$1.37 million in 1995 dollars] in 1996. The buyout and demolition of buildings in a particularly flood-prone area near Squaw Creek in 1994 appears to have reduced the potential damage (Daily Tribune 6/19/96). FEMA and Story County have continued to pursue this strategy: After the 1996 flood, buy-out and destruction of seven homes was arranged in an area just north of Ames (Daily Tribune 12/29/97).

Changes in Streamflow and Flood Damage

Section IV showed that the Des Moines, Raccoon, and Skunk basins are similar in their climate and hydrology, except for human changes (including two major reservoirs) designed to control flooding on the Des Moines River which appear to have helped in preventing extremely high peak flows. The examination of hydrologic floods at Des Moines in this section gives a similar result, with only one of the top five hydrologic floods on the upper Des Moines River occurring after 1970 (the 1993 flood, which overtopped the Saylorville Dam spillway.)

The available flood damage information is not appropriate for computing trends in flood losses; however, it is possible to compare the frequency of damaging floods in the early and late periods of the study. Numbers of hydrologic and damaging floods in Polk and Story Counties for the 27-year periods, 1944-1970 and 1971-1997, are shown in Table 5-10(a) and (b). Clearly, in both counties, the *numbers* of hydrologic and damaging floods changed little from one period to the next.

Table 5-10a-d
Comparison of Frequencies of Hydrologic and Damaging Floods in Two 27-Year Periods

The counties differ, however, in a comparison of the *severity* of damaging floods between the two periods. Table 5-10(c) indicates that the proportion of floods causing moderate-to-severe damage in Polk County changed little between the two periods. In contrast, the proportion of floods causing moderate-to-severe damage in Story County increased from 33% in the earlier period to 71% in the later period (Table 5-10(d)). In the later period in both counties, the moderate-to-severe damage category is dominated by floods in the decade of the 1990s.

The fact that the frequency of moderate-to-severe damage has not increased in Polk County is further evidence of the protection provided by Saylorville Dam, although damage continues to occur on the less-controlled Raccoon River and Walnut Creek. In Story County, the large increase in the proportion of floods which cause moderate-to-severe damage appears to be the result of substantial increases in population and development in and near the floodplain.

6
ROLE OF STATE AND FEDERAL POLICIES

This report has focused on several of the key factors contributing to damaging floods (Figure 1-1), including climate, hydrology, population, and development. Government policy is an additional important factor influencing exposure to flood risk.

Flood Policy in Iowa

Residents of Iowa have always reaped benefits and suffered losses related to Iowa's climate. Iowa is a major agricultural producer in large part due to the significant amount of rain that falls on the fertile soil--and the fertile soil itself is in part a result of past floods. In other words, the same conditions that cause hydrologic floods in Iowa also provide tremendous benefits. Clearly, policy makers have no desire to remove all flood risk from Iowa; because in order to do so, they would lose corresponding benefits. The challenge for Iowa's decision makers, then, is to decide how to balance benefits from flooding against the damages from flooding. But this challenge leads to some difficult questions: how should Iowa measure benefits and damages?

Reducing flood risk has been a legislative goal in Iowa for some time. In 1947, well before floodplain legislation was seriously discussed at the national level, the Iowa legislature formed a special committee to study flooding in Iowa. This resulted in the formation of the Iowa Natural Resources Council (INRC) in 1949. One of the Council's objectives was to protect the floodplain and floodplain development. At that time, the Council had very little regulatory authority; they were mainly planners (Jack Reissen, pers. comm.).

In 1957, the Iowa Legislature gave the Council permitting authority over the floodway and in 1965, legislation was again amended to include the entire floodplain (Reinig 1981). The INRC ceased to exist in 1983; since then floodplain authority has existed within the Iowa Department of Natural Resources (DNR) (Bill Cappuccio, pers. comm.). Currently, the DNR has regulatory authority from a statutory standpoint of all floodplain development in Iowa. The DNR can also delegate authority to local entities, which it sometimes does (Jack Reissen, pers. comm.).

The Iowa DNR keeps no damage data on flooding, so it is difficult, perhaps impossible, to use historical trends in damage to determine how well Iowa's policy programs have served the public. On a broader scale, it is impossible to determine whether trends in flood damage over a long period of time in Iowa have paralleled the national trend of increasing flood damage. This presents no way of comparing the effectiveness of state policies to the effectiveness of national policies. For the future, the Department of Public Defense, the organization responsible for responding to disasters in Iowa, has started to keep flood loss data beginning in the early 90's (Jerry Ostendorf, pers. comm.).

In the wake of the Midwest flood of 1993, Iowa initiated a review and long-term planning of flood mitigation strategies. Instructions from FEMA encouraged states to focus on acquisition of flood-damaged properties (buyouts), rather than other mitigation options such as elevation or floodproofing (Godschalk et al. 1999, p. 197). Federal funds, earmarked for the Midwest, became the force propelling buyout programs (Godschalk et al. 1999, p. 202). Iowa's flood management officials worked with FEMA to decrease future flood risk through buyouts of flood damaged property. Buyouts now have become the primary focus of flood mitigation in Iowa (Jerry Ostendorf, pers. comm). Iowa has completed about 1200 buyouts since 1993. As reported in section 5 of this study, the buyouts and other mitigation strategies in Ames appear to have paid off when another major flood hit in 1996.

Some buyout projects in Des Moines have led to controversy between the city and FEMA. In the Valley Junction area, where federal funds were used to buy flood-damaged properties, the USACE has been building a new protective levee. Godschalk et al. (1999, p. 207) report: "FEMA officials fear that once the levee is certified to protect the area from 100-year floods, the city will attempt to sell the acquired lots for subsequent development. FEMA officials have been vocal about their belief that such an action would violate the intentions behind the buyout program and that if the lots are resold, at the very least the city should be required to repay the federal government for the original acquisition costs." In the Frisbee Park area of Des Moines, the city agreed to a buyout in the area, and is now planning to redevelop the area with the addition of a levee. The levee may provide some protection to this area, but as Ostendorf puts it, "Once in a floodplain, always in a floodplain" (Jerry Ostendorf, pers. comm.; William Cappuccio, pers. comm.; Mike Klapp, pers. comm.).

As mentioned in Section 5, other post-1993 actions in Ames and Des Moines seek to reduce flood risk in these communities. In addition to buyouts and floodproofing, Ames formed a network of community volunteers to respond in a flood situation and has installed easily readable flood stage markers, so that volunteers can see when streams in the city are approaching flood stage (Snyder and Associates 1996). Des Moines recently became a FEMA Project Impact community.[15] Also, the National Weather Service initiated the Advanced Hydrologic Predication System (AHPS) in Des Moines. AHPS provides both short- and long-term river stage predictions via the internet.

Federal Flood Policy

The federal role in disaster recovery and mitigation increased markedly in the last half of the 20th century (Platt 1999). In recent years, Iowa's floodplain policies have been strongly influenced by national floodplain legislation. In the opinion of the Acting Chief of the Water Quality Bureau of the Iowa DNR, Jack Reissen, the meshing of federal and state programs has worked rather well (Jack Reissen, pers. comm.), though two elements of the federal program have hampered floodplain management in Iowa somewhat. First, federal disaster assistance may discourage some Iowans from purchasing flood insurance. Second, national flood insurance guidelines based

15 Project Impact is supposed to help communities prepare for future flood events by implementing preventative measures (www.fema.gov).

on the concept of the "100-year flood" may negatively affect responsible floodplain use in some parts of Iowa.

Flood Insurance and Disaster Assistance

Flood insurance is available to flood-prone communities through the National Flood Insurance Program (NFIP), which was established in 1968 and has been administered within FEMA since 1985. Previously, flood insurance was generally unavailable from the private sector and most states and communities did not regulate floodplain development. The NFIP makes federally-backed flood insurance available in communities that agree to adopt and enforce floodplain management ordinances to reduce future flood damage (http://www.fema.gov/nfip/). Sales of flood insurance were disappointingly low in the first several years of the program, so subsequent legislation added provisions requiring the purchase of flood insurance in order to qualify for federally-backed home mortgages in flood-prone areas. Legislation in 1994 strengthened the NFIP by tightening requirements for the purchase of flood insurance and by providing incentives for flood mitigation through land use planning, relocation, flood proofing, and technical assistance to local communities.

Compliance with required flood insurance continues to be an issue in its implementation. After floods in Texas in 1989, Kunreuther (1996) reported that 79% of owners of damaged property, who were supposed to take out flood insurance when granted a mortgage, were uninsured at the time of the disaster. At the time of the 1993 flood, Iowa had only 6,440 flood insurance policies in effect although there were an estimated 50,000 flood-prone properties (Godschalk et al. 1999, p. 214). Many in North Carolina whose homes were flooded in 1999 during Hurricane Floyd did not know that their homes were located in a floodplain, and had not been told of the insurance requirement by realtors or mortgage lenders (National Public Radio, "All Things Considered", 9/11/1999). Many property owners buy flood insurance policies when they first obtain mortgages but drop them later (Smith and Ward 1998, cf. Pynn and Ljung, 1999).

A number of studies argue that the expectation of disaster aid reduces a person's willingness to buy flood insurance and can undermine programs designed to prevent flood damage (Platt 1999, Holliday et al. 1998; Phillippi 1995). A leading official in the Iowa DNR suggests that federal disaster assistance creates a disincentive for some Iowa residents to purchase flood insurance through the NFIP: According to Jack Reissen, the Acting Chief of the Water Quality Bureau of the Iowa DNR, "I think people would be forced to be more serious about flood plain management if we started cutting back disaster assistance (Jack Reissen, pers. comm.). In interviews, state officials expressed their impression that some residents of Iowa feel there is little reason to pay for flood insurance on a month-to-month basis when disaster assistance regularly helps those who haven't purchased it. More generally, aid and insurance both may be counter-productive if they continue to encourage settlement in high-risk areas: "There is no incentive to avoid either new building or occupancy in high-risk areas if losses are to be funded by the general taxpayer", either through disaster assistance or subsidized insurance premiums (Smith and Ward, 1998, cf. Platt 1999).

The "100-year flood" Standard and Floodplain Land Use

Under the NFIP, the federal government makes flood insurance available to communities that complete maps of their floodplains and enact floodplain land use restrictions. Floodplain maps delineate a stream's floodway and "100-year" floodplain. Communities must ensure that building within the floodway—the stream channel itself and its immediate overbank—is prohibited. Within the flood fringe—the area between the floodway and the line delineating the 100-year flood—the first floor of all buildings built after 1974 must be raised to or above the 100-year flood elevation.

The regulatory 100-year flood is defined using a probabilistic method that uses historical flow information to estimate flood risk. The 100-year flood is simply the flood that has a 0.01 chance of occurrence in any given year. The actual 100-year flood boundary can shift from year to year as additional streamflow data are added to the existing hydrologic record[16], but the statutory 100-year floodplain usually remains the same after the initial mapping study. Initial mapping studies are often based on a relatively short period of record (typically 30 years), much shorter than the return period of 100 years being estimated. With short streamflow records, the estimated values are very sensitive to the statistical function assumed to represent the distribution of flood events. Also, a single very large flood can change recurrence intervals drastically, even if longer records are available to calculate the thresholds for recurrence intervals. For example, when the 1993 discharges were used to update recurrence intervals in Iowa, discharges at the 10, 25, 50, and 100 recurrence intervals increased for 62 streamflow gauging stations in Iowa (Eash 1997).

The use of longer records may not provide a more accurate estimate of future risk of a 100-year flood. Our knowledge that climate is nonstationary (Bryson 1997) means that the present risk may in fact be quite different from the risk in the past. If future climate changes in a manner similar to past changes, we can all but be assured that the present calculations of the 100-year flood will soon be in error, no matter how long the record being used. Thus, with a non-stationary system, a longer record does not necessarily mean greater accuracy in risk estimation over a finite period, particularly one shorter than 30 years, the typical length of a mortgage and the time scale of almost all of societal decision making.

Since 100-year boundaries can and do change from year to year, the "de-facto standard" (Jack Reissen, pers. Comm.) established by the statutory 100-year floodplain exposes property to unnecessary risk, in some cases. Buildings just outside of the statutory 100-year flood boundary are not regulated to the strict standards of buildings inside the boundary. According to Bill Cappuccio, Iowa's NFIP coordinator, it's common for developers to build directly outside the statutory floodplain. Sometimes developers build houses with basements just outside of the statutory floodplain (Bill Cappuccio, pers. comm.). In cases like these, the basements are almost certainly within the actual floodplain, and in some years the first floor of the dwellings are also in the floodplain.

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[16] See Miller, Pielke, and Downton 2000 for a further discussion of this.

7
CONCLUSIONS

The paired-basin analysis of damaging floods in Iowa provides insight into the relationships of precipitation, hydrologic floods, and damaging floods. The conclusions have significance for understanding the nature of flood damage and the effects of flood policy in Iowa and the United States.

This pilot project was initially designed to systematically (and quantitatively) compare damaging floods in two relatively small-scale river basins with essentially the same climate. The tentative hypothesis was that with the same climate, the differences in flood damage should then be attributable to human-caused changes, either to the basins' hydrology or in terms of changes in exposure which might result from population growth or development. The lack of available data on historical flood damage limited our ability to test the hypothesis in a quantitative manner. Nonetheless, sufficient data exists to systematically compare climate and damaging floods in the two basins. The study leads to conclusions about (1) relationships between precipitation, hydrologic floods, and damaging floods; (2) the need for better understanding of damaging floods and collection of data on flood damage; (3) the need for improved methods of estimating flood risk that take into account the nonstationarity of climate; and (4) implications for future flood policy.

1. Relationships of precipitation, hydrologic floods, and damaging floods

The climatological analysis of the Skunk River and Des Moines River basins showed that the two basins share essentially the same climate. The analysis documented the influence of the structural flood control projects on the Des Moines Basin, and corresponding lack of such large-scale engineering in the Skunk River Basin. The analysis found the climatology of the two basins to be consistent with previous studies at a more regional scale (e.g., Kunkel et al. 1992, Changnon and Kunkel 1995).

The systematic comparison of precipitation, hydrologic floods, and damaging floods in the two basins leads to the following conclusions and hypotheses.

- Not all hydrologic floods are damaging floods.

"Hydrologic" floods refer to the overspilling of the banks of a river or stream, and flood levels are defined in many different ways. Methods of determining the flood stage of a river differ between jurisdictions (as described in section I), and may or may not be related to whether the overspilling will cause damage to people or property. In this study, "major hydrologic floods" at a streamgauge are defined as those in which the peak discharge level is in the top 20% of historical annual peak flows.

In the two basins of this study, about half of the major hydrologic floods that were in the top 11-20% of annual peak flows did not cause significant (or documented) damage. As common sense would suggest, as hydrologic flooding becomes more extreme, the likelihood of damage increases. For example, all of the major hydrologic floods that were in the top 10% of annual peak flows documented in the two basins resulted in damage. Furthermore, all of the record high river flows during the 58 years in this study resulted in severe or moderate damage.

Some (of the few) studies on damaging floods have assumed that damage necessarily increases with the magnitude of flow in a damaging flood (e.g., Moser 19XX, Smith 1993). In general, this study supports that assumption. However, community action to reduce flood risk changes the relationship. For example, after adjustment for inflation, flood losses in Ames, Iowa, were greater in 1975 than in 1996 even though peak flows at Ames were lower in 1975 on both rivers. Thus, the relationship between hydrologic flooding and damages is highly contextual.

- Not all damaging floods are hydrologic floods.

In several instances of historical flooding in the two basins, damage was documented in cases when the hydrologic record alone would suggest little out of the ordinary. In Ames, the U.S. Army Corps of Engineers (1996) documents three "notable" damaging events in 1954, 1958, and 1965 which were not in the top 20% of annual peak flows. These damaging floods resulted from rainwater and water-table flooding, not from the overflow of the banks of local streams. They were caused by precipitation, but were not major hydrologic floods.

In this study, the damaging floods that did not involve notable river flows caused only minor damage. This provides further support for the hypothesis that the relationship between hydrologic and damaging floods is most tightly coupled in cases of extreme flooding, and the relationship weakens considerably in events of lesser magnitude.

- Many types of "extreme" precipitation can lead to hydrologic floods, and not all "extreme" precipitation events result in major hydrologic flooding.

This conclusion is not fundamental to this study, but worth highlighting. Iowa, because of its particularly geography, geology, hydrology, and hydraulics experiences a number of flood types which depend on the antecedent meteorological conditions. These are flash, snowmelt, snowmelt plus rain, warm season, and warm season plus flash flooding. In Iowa, much of the major hydrologic flooding is due to prolonged precipitation periods lasting seven days or more (i.e., warm season floods). However, hydrologic flooding can occur with respect to each of the five flood types. Whether a particular precipitation event results in a hydrologic flood depends on the context, which includes season, soil moisture, location of precipitation with respect to the drainage, and so on.

For example, hydrologic floods documented in March and April were not associated with particular precipitation events, but presumably resulted from rapidly melting snow that had accumulated over an extended period. In the month of September, numerous extreme precipitation events occurred over 7-day and 6-week periods, but there were no major hydrologic floods in September during 1940-1997. The closest relationship between rainfall and hydrologic floods exists during the warm season (May through August), i.e., when most hydrologic floods occur.

The general conclusion is that the definition of an "extreme" precipitation event is highly contextual in *both* time and space. One would not expect to see the same relationship between precipitation and hydrologic floods in, say, Colorado, as in Iowa. Similarly, if the exact same precipitation event occurred in the exact same location within Iowa, but in different seasons, in one case a hydrologic flood might occur, and in another it might not. An "extreme" precipitation event, if it is to be related to hydrologic flooding and ultimately to flood damage, is better defined in terms of its context than as a space- and time-invariant threshold.

This results in an important lesson for the climate community. In seeking to document, understand, and project "extreme" precipitation, contextual measures are more likely to have relevance to understandings of flooding than are absolute measures.

- The previous three conclusions have significant implications for understanding the relationships of precipitation, hydrologic floods, and damaging floods.

Not all "extreme" precipitation events result in hydrologic floods, not all hydrologic floods are damaging, and not all damaging floods are hydrologic floods. The relationship of "extreme" precipitation, hydrologic flooding, and damaging flooding is most tightly coupled in cases of major flood damage, and increasingly less so in cases of moderate and minor damage. For example, the 1993 flood was "extreme" by all measures: precipitation, streamflow, and damage. Clearly, precipitation, hydrologic flooding, and damage were each closely related. But this extreme case appears to be unrepresentative of the more common combination of climate, hydrologic, and damage events. It would be a mistake to base understandings of flood damage on the most extreme events. Relationships are much more complex and, indeed, less intuitive with respect to the more common types of damaging floods. Even so, it is important to recognize that events like the 1993 event have historically resulted in a significant proportion of documented flood losses in the United States. This raises the possibility that flood policy should consider distinguishing in some fashion "overwhelmingly extreme" events, like the 1993 Midwest Flood, from those more common events that that are merely "extreme." (Policy is discussed in greater detail below.)

2. Better understanding of damaging floods is needed

Remarkably little data is available on the economic losses caused by damaging floods in Iowa. The period since 1983 has the best records, but even they are likely to be comprehensive only in cases of extreme damage, such as occurred in 1993. If Iowa, the number-one ranked state in terms of flood damages in the latter part of the twentieth century, has such a poor record of damaging floods at the basin or sub-basin level, then it is reasonable to assume that the situation is much the same in other locales, especially those that experience fewer floods.

This leads to an important lesson from this project: It is unlikely that data on necessary temporal and spatial scales is readily available in the United States that would allow researchers to assess accurately, at the community level, the contributions of climate and society to observed trends in damaging floods. Consequently, aggregate analyses (e.g., at the national level, e.g. Pielke and Downton 2000) are likely to be the most reliable assessments of the role of climate in flood damage trends. This highlights the need to ensure that national-level data on historical flood damage is systematic and unbiased.

A more complete understanding of the relationship of precipitation, streamflow, and damaging floods depends upon better understandings in two dimensions:

First, it would be necessary to obtain improved data on flood damage, both in terms of comprehensiveness (e.g., Heinz Center 2000) and spatial distribution (e.g., with respect to the local basin characteristics). While researchers will find historical data to be difficult, if not impossible, to obtain, technology now exists to begin collecting and archiving such data for future studies (cf. Mileti 2000, Heinz Center 2000). The growth in GIS and other advanced data manipulation technologies lends itself well to such analyses. Given the vast sums currently spent on atmospheric, oceanic, and hydrologic observing systems and data archives, it is not unreasonable to think that corresponding "societal" observing systems might occupy greater attention in future years.

Second, it would be necessary to obtain an understanding of precipitation and hydrology on scales appropriate to understanding damaging floods. Conventional studies at the scale of grid boxes (e.g., 1 degree by 1 degree) and point estimates, will be limited in the information they can provide, as damage occurs at scales smaller than the typical grid box, and point estimates can miss important precipitation events (e.g., Petersen et al. 1999).

The general conclusion is that to better understand damaging floods it is necessary to consider damaging floods as the unit of analysis (Pielke 2000). With very few exceptions, this has rarely been the case in research. Until such an understanding is obtained little can be said with precision with respect to the nature of future flooding under changing climate conditions. While it would be accurate to state that increasing precipitation would more likely than not lead to increasing flood damages in a particular community, basin, or nationally, it is unrealistic to project the nature or magnitude of those damages, given their complex relationship to precipitation, hydrology, and land use. Previous studies (e.g., Pielke and Downton 1999, 2000) suggest that the climate "signal" in future damaging floods will be much less than the "noise" of continued increasing occupancy and development of flood-prone areas, as well as political factors.

Finally, the findings of this case study provide empirical evidence at a much greater level of detail that supports the conclusions of several previous studies, at national and regional levels, of the relationship of precipitation and damaging floods (i.e., Pielke and Downton 1999, 2000).

3. Improved methods of estimating flood risk, and less reliance on the 100-year flood standard, are needed

In a recent report on improving flood frequency analysis, the National Research Council wrote that

> "essentially, the problem facing flood managers, engineers, and everyday citizens . . . amounts to making a *forecast* for the next several decades of what the flood [frequency] statistics will be and then acting on that forecast" (NRC 1999, p. 95).

And as the Iowa case study shows, with respect to damaging floods, the relevant forecast is more complicated than simply projecting aggregate future precipitation or hydrology. It also involves understanding climate and hydrology at scales relevant to flood damage as well as conditions which are largely independent of climate, such as local population growth, development, and river modification, that influence both hydrology and flood damage.

Yet, in the United States, national--and hence most local--flood policy decisions are based on a highly flawed assumption of the actuarial soundness of the so-called "100-year" flood. The following sections discuss the implications of this flawed assumption for decision making in terms of variability and stationarity. The following sections consider each in turn.

Variability

The Iowa case study shows that damaging floods can often be the result of the confluence of a number of events, none of which individually are particularly notable. For instance, moderately wet antecedent soil conditions coinciding with a heavy 7-day rainfall could result in a damaging flood; whereas, when occurring alone, the rainfall or antecedent soil condition would not have resulted in a damaging flood (see Klemeš 1993). Likewise, in populated areas where rivers meet, floods may cause much less damage when each river peaks at separate times compared to when rivers peak concurrently. This suggests the need for greater attention to combinatorial approaches to understanding flood frequency. The analogy usually used to explain flood frequency is balls in a bag.[17] A more appropriate analogy might be a slot machine. An interesting question that might be asked is how closely flood damage is related to the statutory 100-year flood.

While year-to-year climate variability may determine whether this year's damages are more or less than last year's, whether the next 20 years worth of damages are more or less than the last 20 years is more likely to be dominated by changes in societal exposure (cf. Pielke 1999, Pielke and Downton 2000). This suggests that over the longer term, society has much more control over the flood damages that it experiences. Rather than being subject to the uncontrollable vagaries of nature, society (and in particular a wealthy nation like the United States) determines the future

[17] The analogy assumes that a bag contains 100 marbles: 99 clear and 1 black. Every time a black marble is pulled out of the bag it represents a 100-year flood. Each time a marble is drawn, it's placed back in the bag so that on every draw there is a chance of pulling out a black marble (FIFMTF 1999, p.60).

flood damages it experiences. As Mileti (2000) has observed, we have the power to "design future disasters."

Stationarity

"The history of climate is a non-stationary time series" (Bryson 1997, p. 452). By this Bryson means that "climatic distributions are inherently non-Gaussian, often multi-modal, usually skewed to some extent, *and the characteristics of the distributions may change with time*" (emphasis added, p. 452). Further, Bryson asserts that "there are no true climatic 'normals' . . . Environment and climate change on timescales from near instantaneous to millions of years . . . There can be no perfect climatic or environmental analogues in the last million years"(p. 454). Such assertions are not controversial in the climate community, indeed the widely accepted hypothesis of anthropogenic climate change is consistent with these assertions (cf. Porporato and Ridolfi 1998, IPCC 1996, Knox 1993). Consequently, in the delineation of fixed, regulatory "100-year" floodplains in local communities around the nation, flood policy in the United States is based on a fundamental assumption directly contrary to Bryson's assertions.

Estimates of peak streamflows associated with the 100-year flood can change substantially in relatively short periods of time (mentioned in section 4). The general consequences, according to the National Research Council are as follows:

> The worst consequence of falsely designating such floodprone areas to be in the regulatory floodplain would be the requirement of building restrictions that in the future prove unnecessary. The worst consequence of falsely designating such floodprone areas to be out of the regulatory floodplain would be a prolonged delay in solving acute flood problems, a delay that could have catastrophic results" (NRC 1999, p. 7).

In either case costs will be borne. Because the option of inhabiting only those regions that are not floodprone is simply unrealistic, decision makers will always have to make structural and non-structural flood policy decisions based on some conception of the future. Because climate is non-stationary and because the future cannot be known with certainty, this means that optimal planning for floods, such as has been envisioned with respect to designation of the 100-year floodplain, is simply a myth. The 100-year floodplain, itself a dynamic feature of floodprone regions, once established in static regulation cannot accurately represent flood risk. And even if regulations could be made dynamic (e.g., by varying flood insurance premiums), risk still could not be accurately represented, because to some degree the climate future will always be uncertain.

4. Flood policy and the uncertain future

Because decision making is always forward looking, all flood policy decisions will be based, implicitly or explicitly, on some conception of the future (Sarewitz et al. 2000). Predicting the future climate is fraught with difficulties, as noted by the National Research Council, "our ability to provide useful climate change predictions may stay barely ahead of the actual progress of time, if at all" (NRC 1999, p. 97). Because of the mismatch between the assumptions underlying present policy approaches and the realities of climate and climate forecasting, the NRC concluded that "new diagnostic, prognostic, and decision frameworks need to be developed" (NRC 1999, p. 99).

One such framework would consider "the dynamic risk and its estimation uncertainty" and would need "to consider length of record, length of planning period, the nature of climatic non-stationarity and causal relations between the climatic factors and the floods" (NRC 1999, p. 100). Assuming that the NRC report is referring to hydrologic floods and that decision makers are concerned with the impacts of floods, the results of the analysis of Iowa floods and previous work suggest that the investigation of "causal relationships" should be considered with respect to damaging floods.

One conception of a decision framework that would meet these objectives is for decision maker(s) to explicitly project forward the damages that they expect their community to be able to bear in future years in terms of the magnitude, but also with respect to the categories that are to be counted (e.g., economic, environmental, agricultural, etc. cf. Heinz Center 2000). The emphasis would be on assessing the community's ability to cope with floods of various magnitudes, and not on predicting what those magnitudes will be. Then as experience unfolds the decision maker(s) could compare what actually occurs with respect to the baseline, judge success or failure and responsibility for the outcome(s). This would place the decision maker(s) in position to adjust either the response actions with respect to future flood damage, or to reevaluate the baseline metric of success or failure. Today's flood policy proceeds in such an incremental fashion; however, there is little thought given to the metrics of success or failure with respect to flood policy, hence decision making can be disproportionately driven by a response to the most recent disaster or shaped by misinterpretations of floods (see, e.g., Pielke 1999).

Under such a "baseline" approach to policy in response to damaging floods, it would be important for decision makers to recognize that year-to-year fluctuations in damage are driven by various climate-related factors (including random chance) but on decadal time scales trends in damage are dominated by local population growth and development. This fundamental nature of factors that condition damaging floods add additional support to the need to take a longer-term view and to understand the societal factors that lead to damaging floods.

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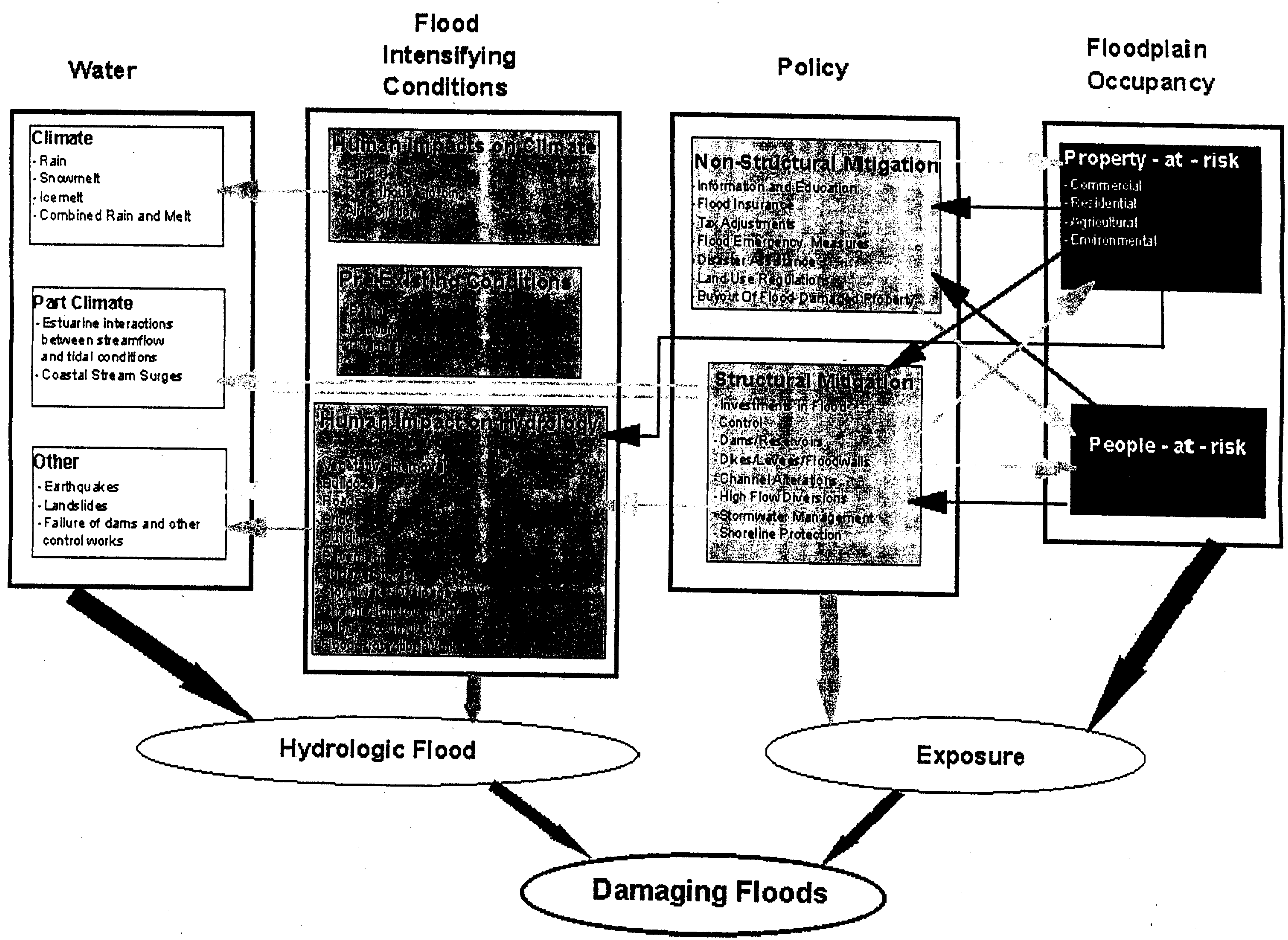

Water
Flood Intensifying Conditions
Policy
Floodplain Occupancy
Climate
- Rain
- Snowmelt
- Icemelt
- Combined Rain and Melt
Part Climate
- Estuarine interactions between streamflow and tidal conditions
- Coastal Stream Surges
Other
- Earthquakes
- Landslides
- Failure of dams and other control works
Human Impacts on Climate
Pre-Existing Conditions
Human Impact on Hydrology
Non-Structural Mitigation
Information and Education
Flood Insurance
Tax Adjustments
Flood Emergency Measures
Disaster Assistance
Land Use Regulations
Buyout Of Flood-Damaged Property
Structural Mitigation
- Investments in Flood Control
- Dams/Reservoirs
- Dikes/Levees/Floodwalls
- Channel Alterations
- High Flow Diversions
- Stormwater Management
- Shoreline Protection
Property - at - risk
- Commercial
- Residential
- Agricultural
- Environmental
People - at - risk
Hydrologic Flood
Exposure
Damaging Floods

Figure 1-1

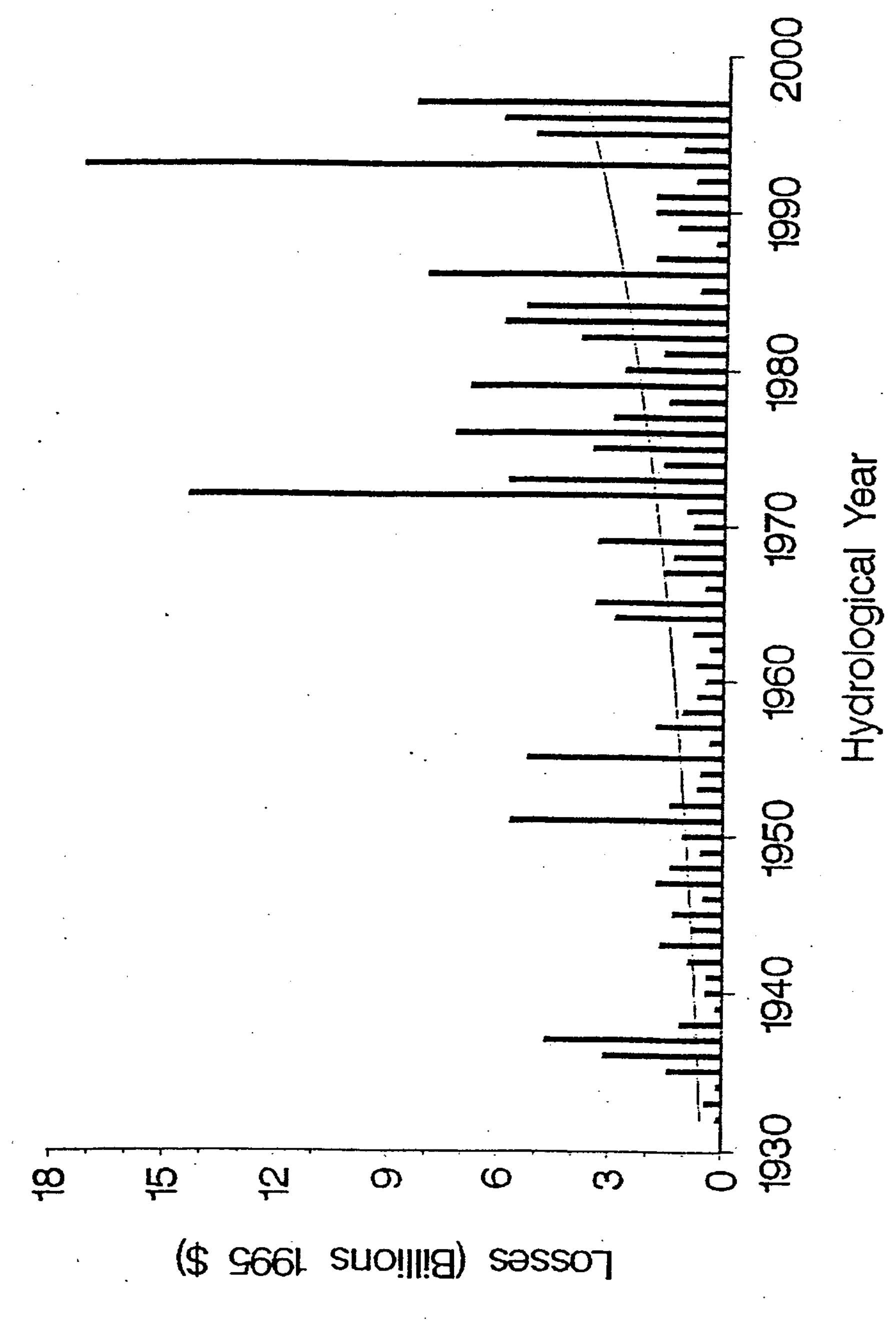
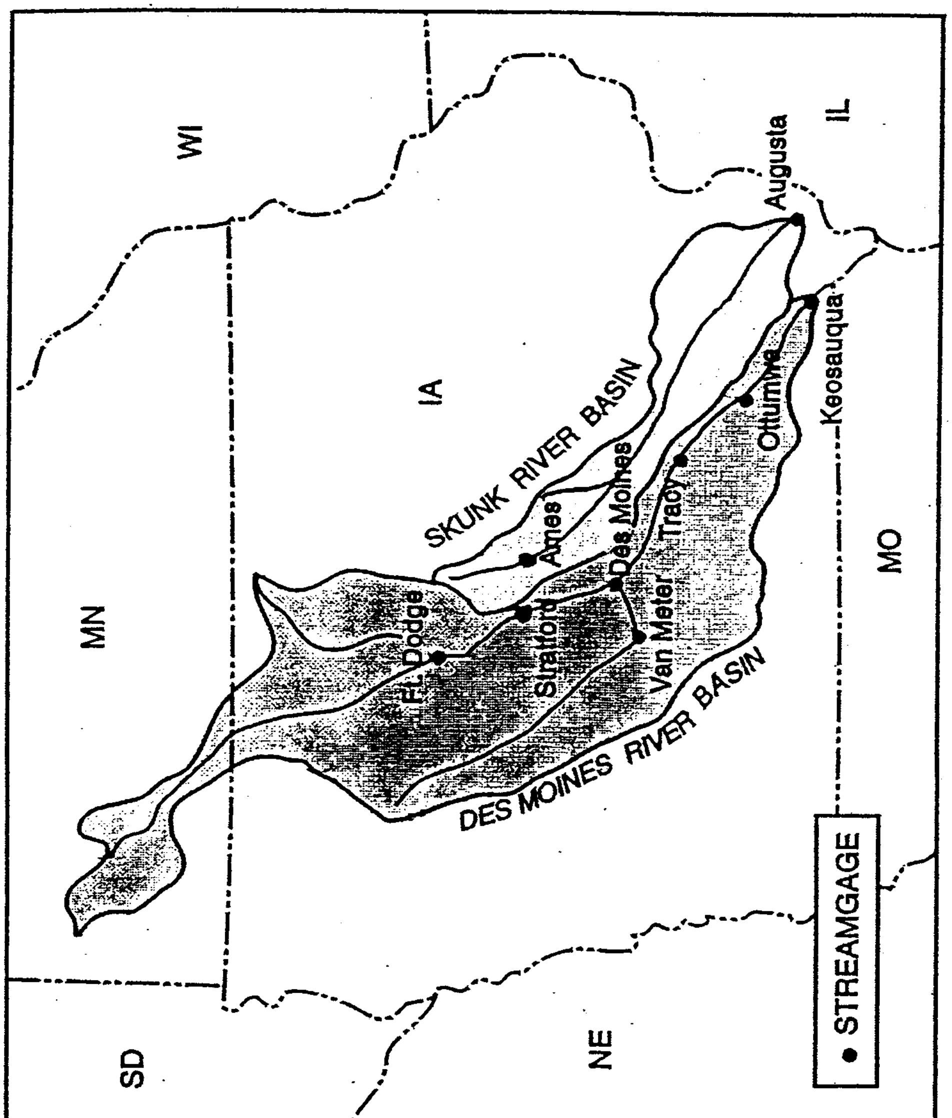

Losses (Billions 1995 $)
0
3
6
9
12
15
18
1930
1940
1950
1960
1970
1980
1990
2000
Hydrological Year

Figure 2-1



SD
MN
WI
IA
NE
MO
IL
SKUNK RIVER BASIN
DES MOINES RIVER BASIN
Ft. Dodge
Stratford
Ames
Des Moines
Van Meter
Tracy
Ottumwa
Augusta
Keosauqua
• STREAMGAGE

Figure 3-1

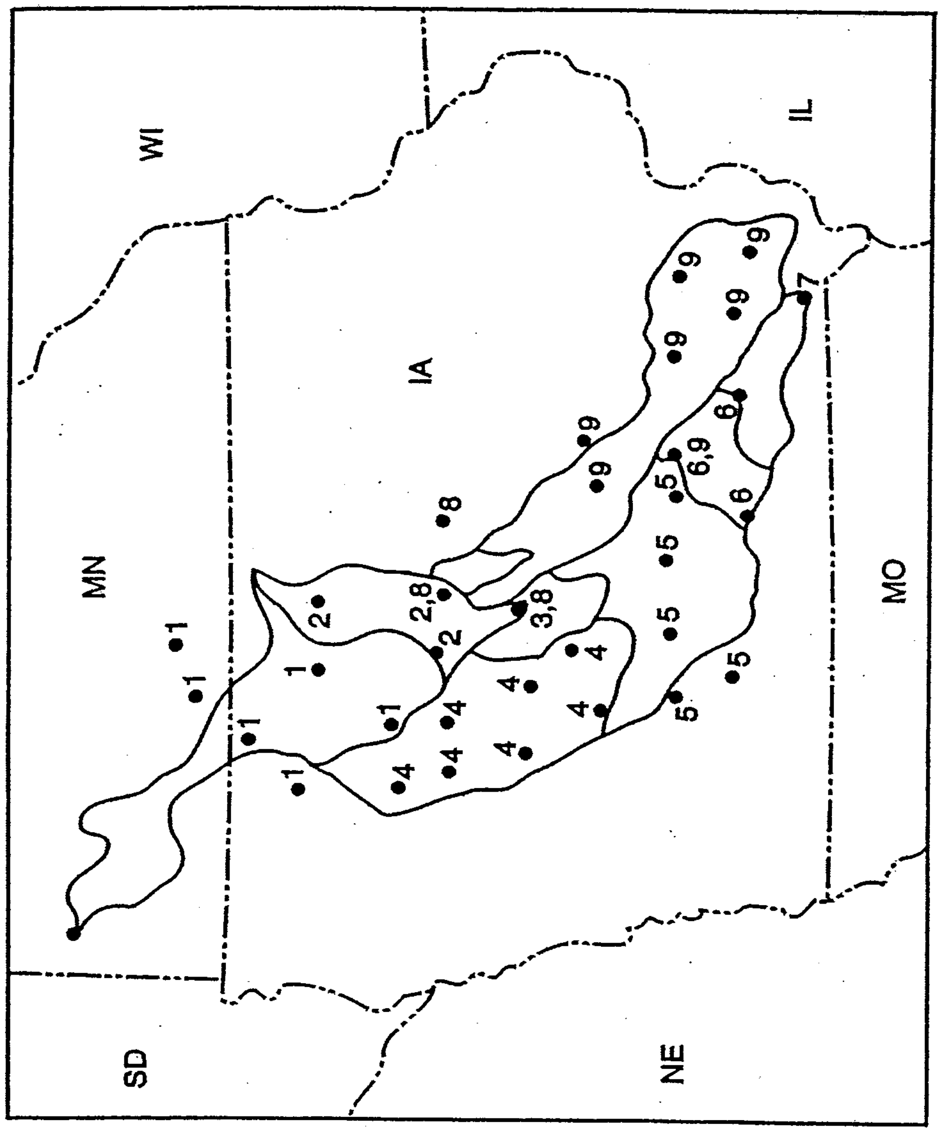


Figure 4-1

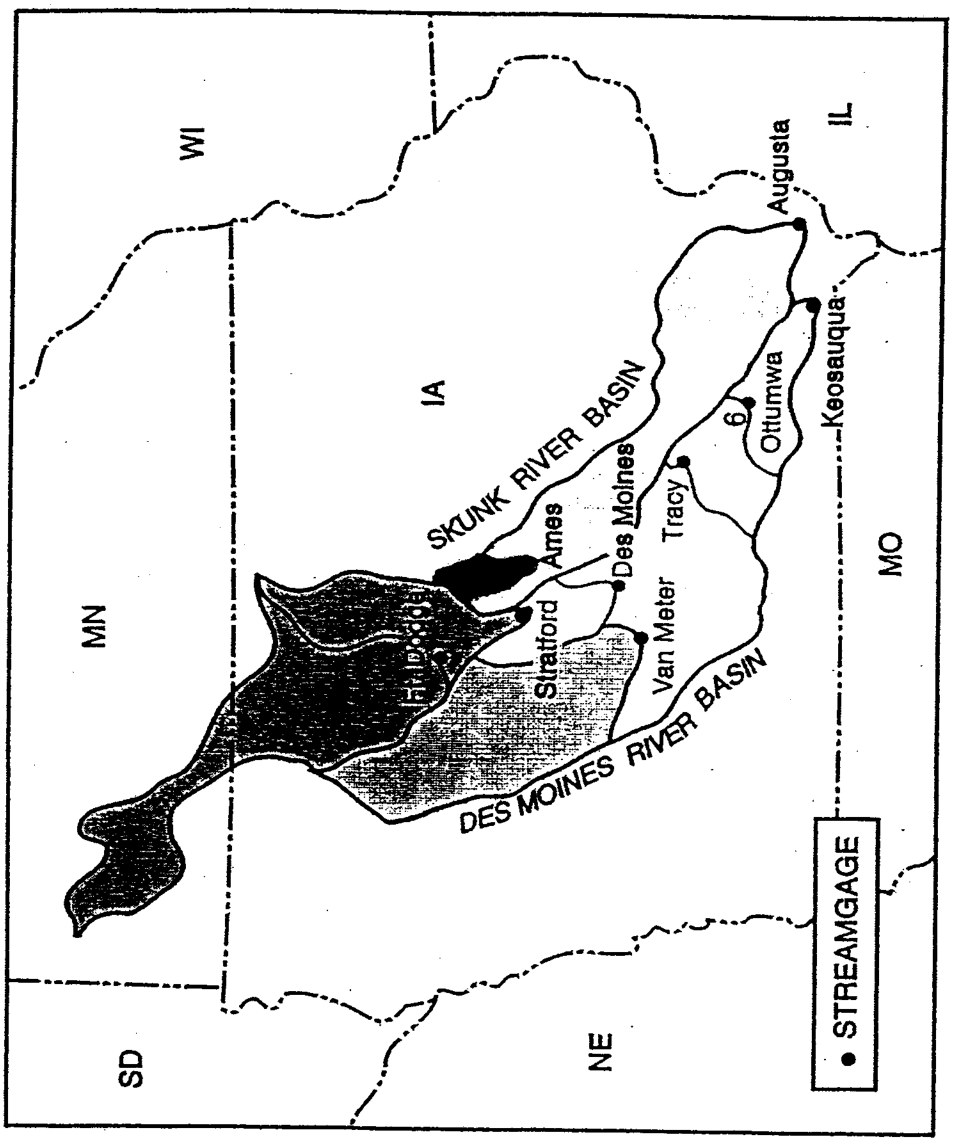

WI
MN
SD
IA
NE
IL
MO
SKUNK RIVER BASIN
DES MOINES RIVER BASIN
Ames
Des Moines
Stratford
Van Meter
Tracy
Ottumwa
6
Keosauqua
Augusta
• STREAMGAGE

Figure 4-2

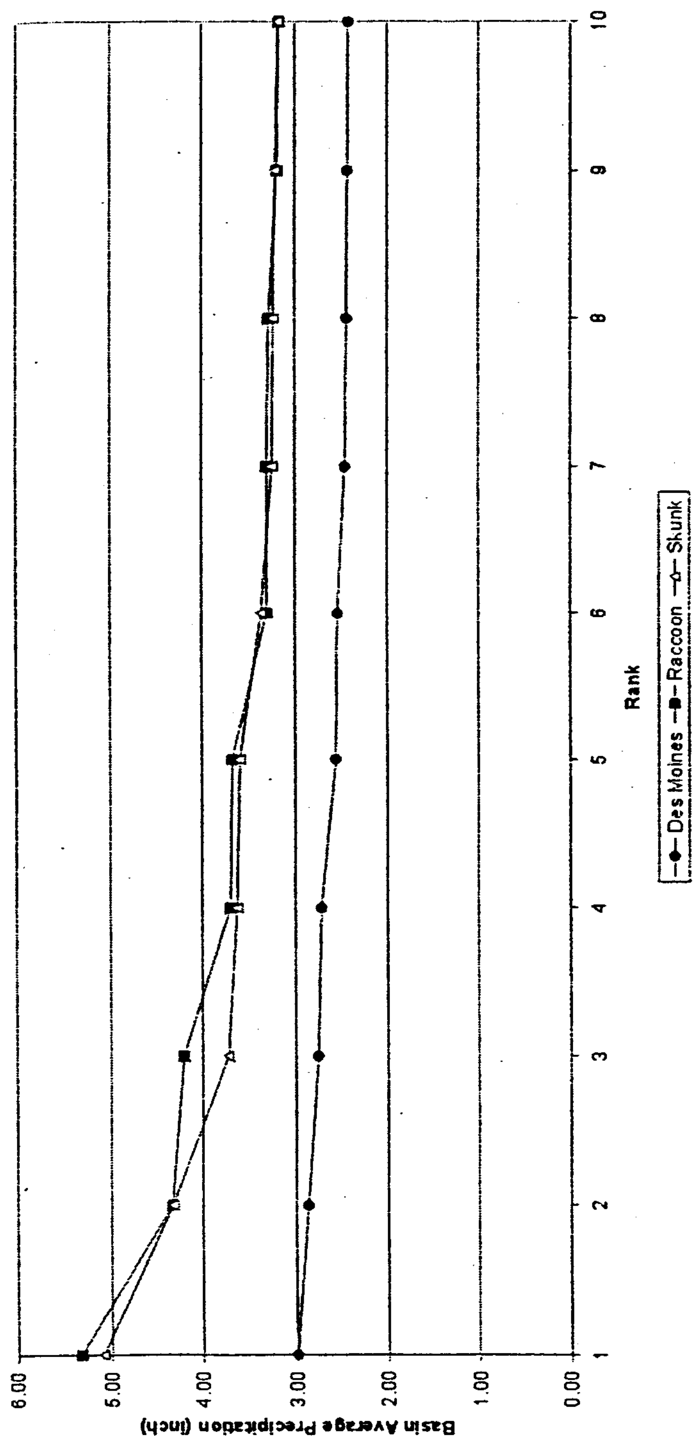
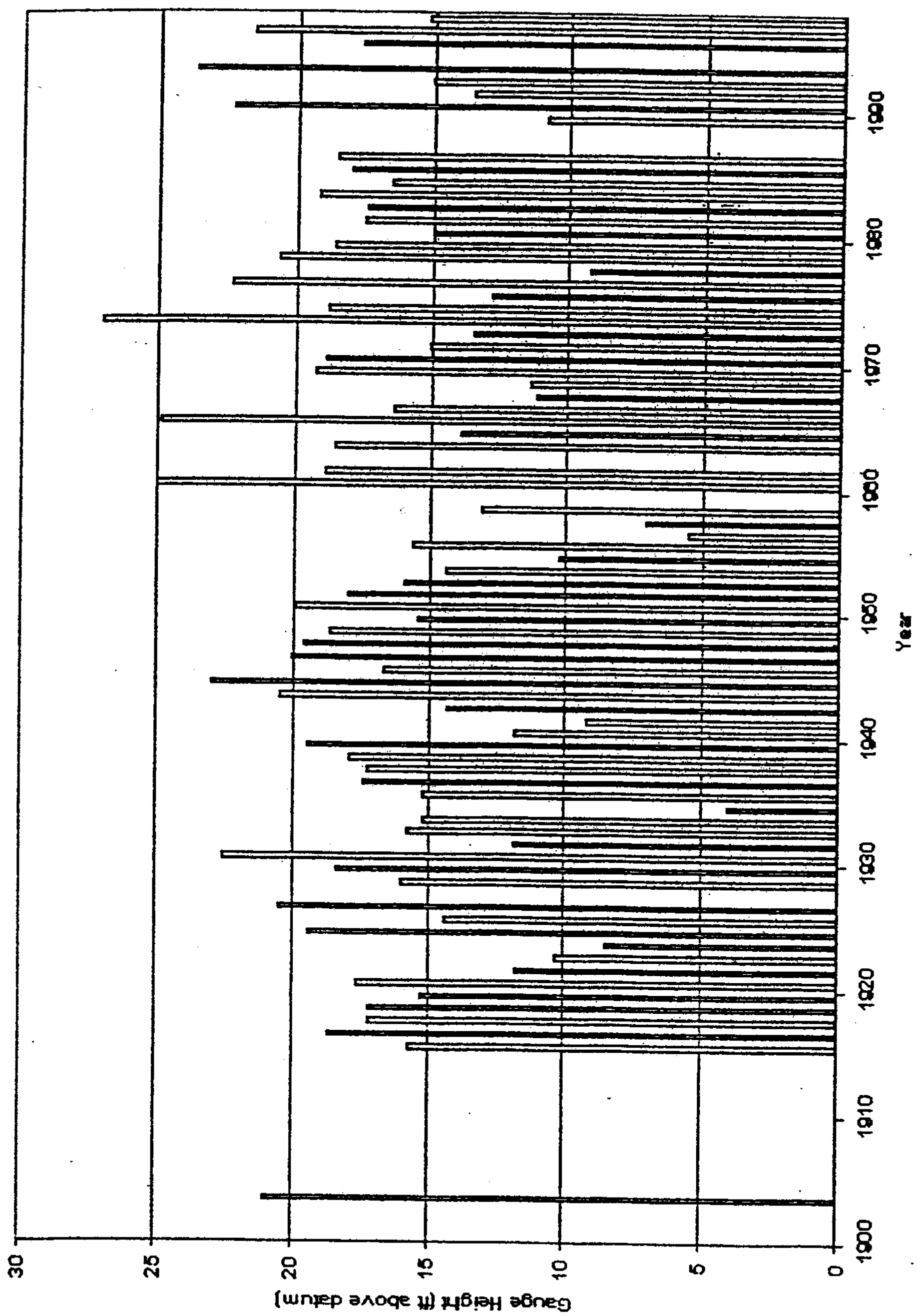

Basin Average Precipitation (inch)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
Rank
1
2
3
4
5
6
7
8
9
10
Des Moines
Raccoon
Skunk

Figure 4-3



Gauge Height (ft above datum)
0
5
10
15
20
25
30
Year
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990

Figure 4-4a

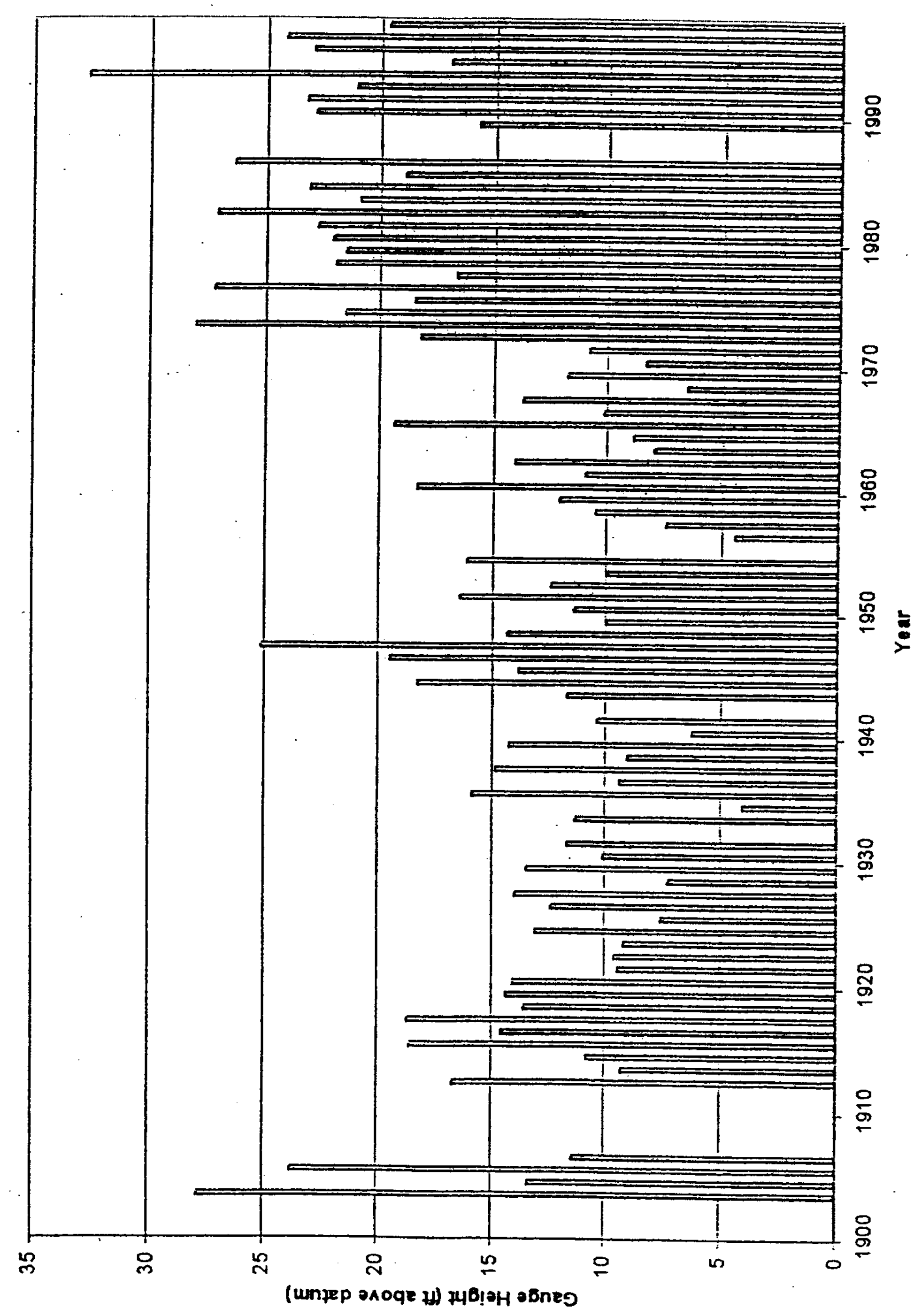
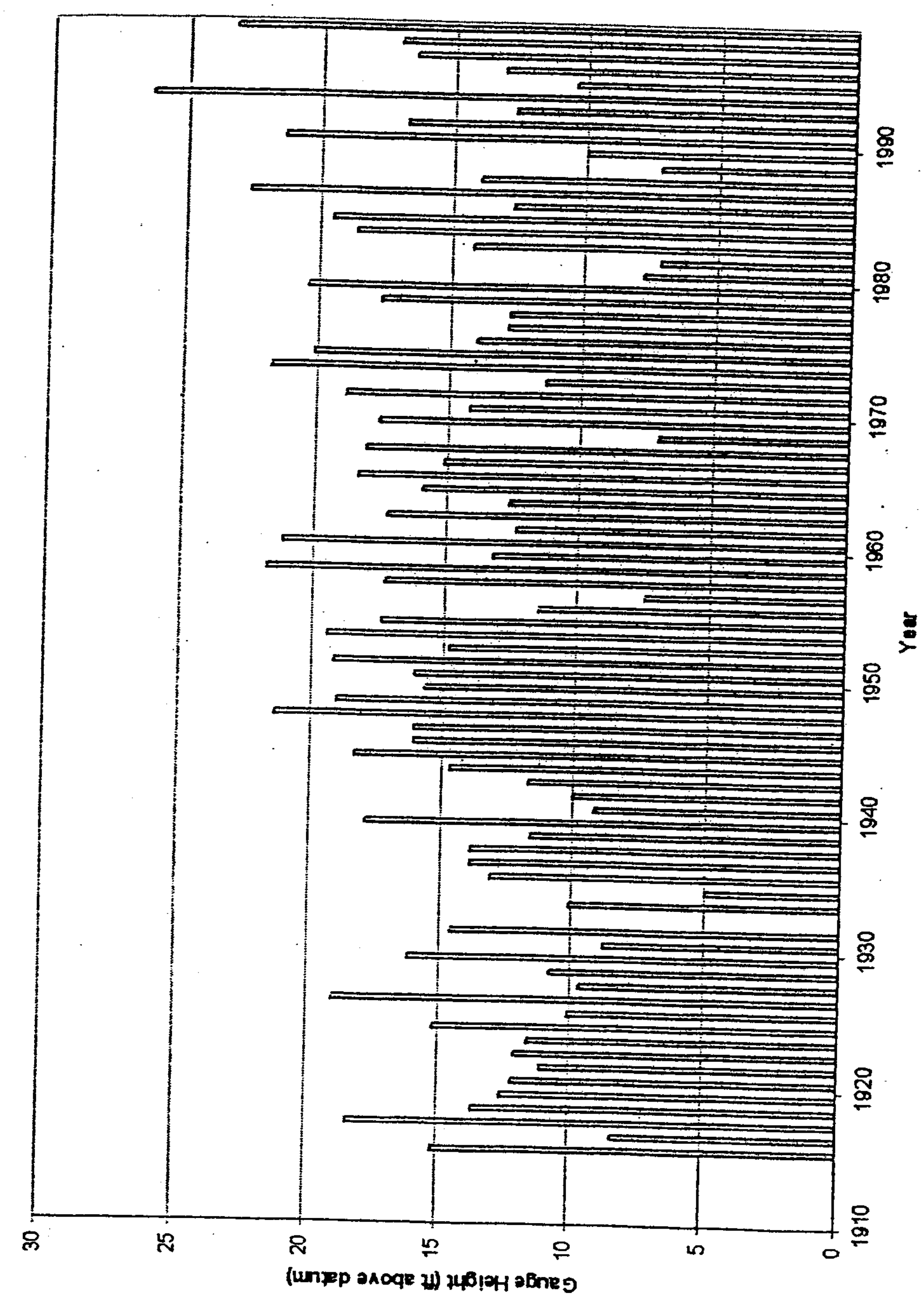

Gauge Height (ft above datum)
Year
0
5
10
15
20
25
30
35
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990

Figure 4-4b



Gauge Height (ft above datum)
30
25
20
15
10
5
0
1910
1920
1930
1940
1950
1960
1970
1980
1990
Year

Figure 4-4c

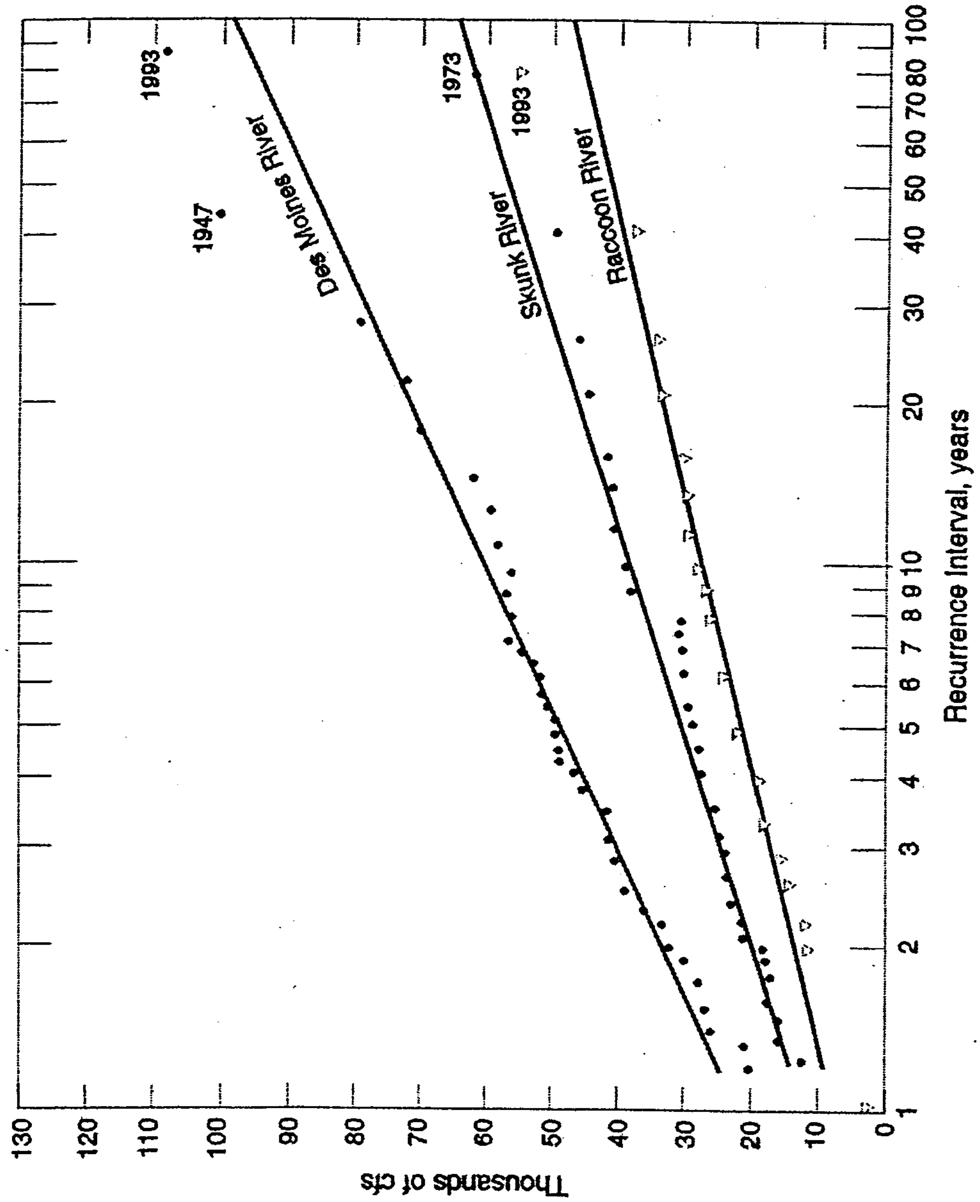

Thousands of cfs
Recurrence Interval, years
Des Moines River
Skunk River
Raccoon River
1993
1947
1973
1993

Figure 4-5

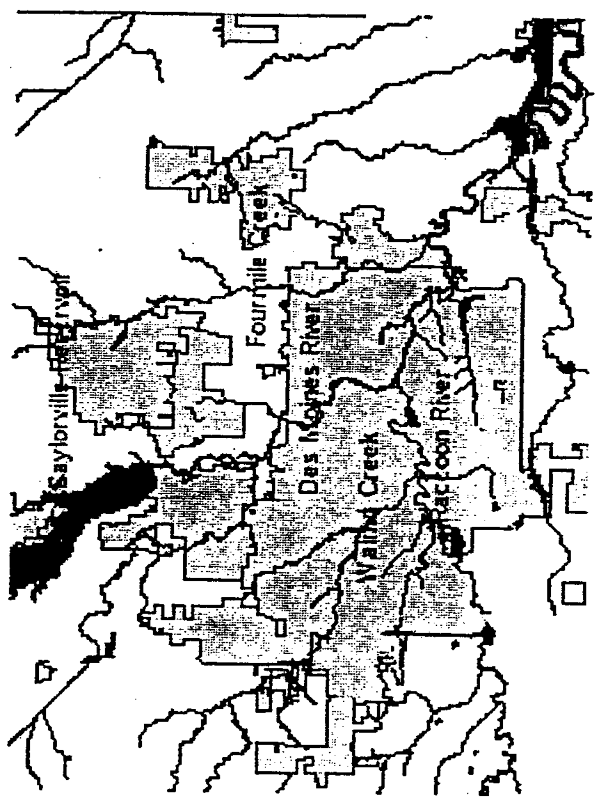


Figure 5-1a

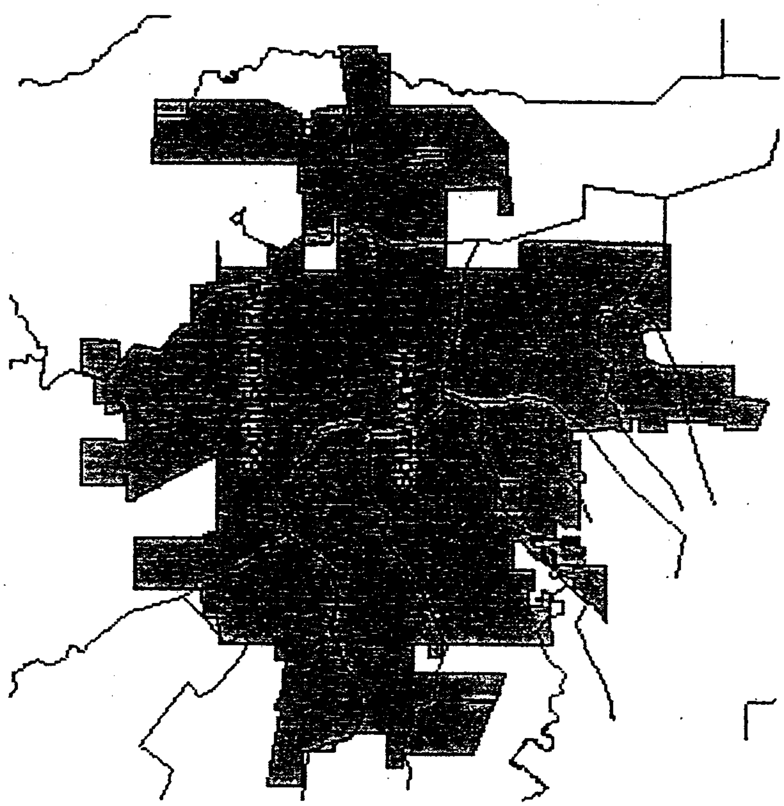


Figure 5-1b

Table 2-1
Annual Flood Losses in Iowa by Hydrological Year*, 1983-1997.

Hydrological Year	Damage (Million 1995 dollars)
1983	0.00
1984	848.58
1985	0.07
1986	60.35
1987	21.63
1988	0.00
1989	8.71
1990	402.71
1991	215.86
1992	54.51
1993	6,004.04
1994	9.32
1995	3.50
1996	161.36
1997	3.52

Source: USACE 1993, 1998

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* Hydrological years are October through September (e.g. HY1983 is 10/1/1982 - 9/30/1983).

Table 2-2
Flood Losses in Each of the Conterminous 48 States, Fiscal Years 1983-1997 (States Ranked by Total Losses)

Rank	State	Total Damage (Millions 1995$)	Per Capita Damage (1995$)
1	Iowa	7794.15	2806.93
2	Louisiana	6880.19	1630.39
3	California	5421.91	182.19
4	Missouri	4224.62	825.59
5	North Dakota	3825.73	5988.93
6	Illinois	3694.24	323.19
7	Oregon	3450.18	1213.86
8	Texas	2827.39	166.45
9	Minnesota	1800.59	411.56
10	Mississippi	1677.19	651.79
11	Oklahoma	1612.12	512.50
12	Wisconsin	1501.13	306.87
13	Utah	1480.48	859.32
14	Virginia	1439.84	232.71
15	West Virginia	1394.28	777.41
16	South Dakota	1238.65	1779.66
17	Kansas	1151.27	464.68
18	Arkansas	1004.65	427.38
19	New York	910.64	50.62
20	Arizona	883.40	241.02
21	Florida	854.03	66.01
22	Kentucky	852.56	231.34
23	Washington	828.30	170.20
24	Pennsylvania	736.33	61.97
25	Nebraska	714.26	452.52
26	Michigan	694.65	74.73
27	Nevada	656.10	545.92
28	New Jersey	590.61	76.40
29	Colorado	533.91	162.07
30	Indiana	510.78	92.13
31	Georgia	493.38	76.16
32	Ohio	441.73	40.72
33	Alabama	353.80	87.56
34	Tennessee	292.02	59.87
35	Massachusetts	246.93	41.04
36	North Carolina	218.10	32.90
37	Idaho	180.81	179.60
38	Maine	167.93	136.76
39	Connecticut	137.44	41.81
40	Vermont	124.24	220.77
41	New Mexico	120.76	79.70
42	South Carolina	116.09	33.30
43	Maryland & DC	111.56	20.70
44	Montana	86.39	108.11
45	Wyoming	59.82	131.89
46	New Hampshire	57.13	51.50
47	Delaware	10.10	15.16
48	Rhode Island	0.98	0.98

Table 2-3
Years of Highest Flood Losses in the Nine States of the Upper Mississippi Basin, Fiscal Years 1983-1997 (Losses are in millions of 1995 dollars.)

State	Highest Year's Damage	Second-Highest Year's Damage	Total Damage, 1983-1997	1993 Damage as % of Total
Illinois	2,762 (1993)	297 (1983)	3,694	74.8%
Iowa	6,004 (1993)	849 (1984)	7,794	77.0%
Kansas	576 (1993)	242 (1986)	1,151	50.0%
Minnesota	1,008 (1993)	711 (1997)	1,801	56.0%
Missouri	3,587 (1993)	206 (1986)	4,225	84.9%
Nebraska	308 (1993)	142 (1984)	714	43.1%
North Dakota	3,263 (1997)	433 (1993)	3,826	11.3%
South Dakota	799 (1993)	291 (1984)	1,239	64.5%
Wisconsin	945 (1993)	213 (1996)	1,501	63.0%

Table 2-4
Major damaging floods in Iowa, 1944-1997

Year	Dates	Area Affected	Description of Damage
1944	May 18-23, June 27	Skunk River basin (May); Little Maquoketa, Maquoketa, and Wapsipinicon Rivers (June)	Extensive crop losses. Damage: $4.8 million (May), $1 million (June). [Total: $46 million in 1995 dollars]
1947	June 5-7, 13-18, 23-26	Nearly statewide	Extensive rural and urban damage. Damage: $48 million. [$306 million in 1995 dollars]
1952	Apr. 12-24	Missouri and Mississippi Rivers	Damage: Missouri R., $43.4 million; Mississippi R., $4.6 million. [Total: $259 million in 1995 dollars]
1953	June 7-8, 10	NW Iowa (Floyd R.), Middle Raccoon River	Extensive damage in Sioux City. Floyd R. damage: $34 million. [$182 million in 1995 dollars]
1954	June 10, 18-24	North-central, central, and parts of NW Iowa	Mainly agricultural losses. Damage: $28 million. [$148 million in 1995 dollars]
1958	July 2-3	E. Nishnabotna River basin, South Raccoon River	Rural and urban damage. Damage: $5.7 million. [$27 million in 1995 dollars]
1965	Apr. 6-12, Apr. 24-May 1	Mississippi River; Little Sioux, Cedar, upper Iowa, Des Moines River basins	Mississippi R. damage, $25.8 million; damage in Cherokee, $660,000. [Total: $114 million in 1995 dollars]
1969	Apr. 7-14, 21-29	Big Sioux and Mississippi Rivers; upper Des Moines, Little Sioux, Rock R. basins	Rural and urban damage. Damage: $8.2 million. [$30 million in 1995 dollars]
1984	June 8-12, 17-21	Missouri and upper Des Moines River basins	Damage: $110 million. [$156 million in 1995 dollars]
1990	May 19-21, June 16-23	West-central Iowa (May), Southern 2/3 of Iowa (June)	Rural and urban damage. Damage: $3 million (May), $88 million (Jun.). [Total: $105 million in 1995 dollars]
1993	June - Aug.	Statewide	Unprecedented urban and rural damage, major disruption of transportation.

Table 4-1
Streamgauges With Long Records in the Des Moines and Skunk River Basins

Gage Name	Analysis ID	Length of Record	Area (square miles)
Des Moines Basin			
Des Moines at Fort Dodge	1	1905-06, 1914-27, 1947-97	2265
Des Moines at Stratford	2	1968-97	5452
Des Moines as Des Moines	3	1902-03, 1906, 1915-61, 1997	6245
Raccoon River at Van Meter	4	1915-68	3441
Des Moines at Tracy	5	1903, 1920-97	12479
Des Moines at Ottumwa	6	1903, 1917-97	13374
Des Moines at Keosauqua	7	1903-06, 1912-97	14038
Skunk River Basin			
South Skunk at Ames	8	1921-97	315
Skunk at Augusta	9	1903, 1915-97	4303

Table 4-2
Precipitation Trends in the Des Moines, Skunk, and Raccoon Rivers, 1930-1997

Basin		2-Day Rains (5-year recurrence)	7-Day Rains (1-year recurrence)	Annual Total Precip.	No. Days with Precip.	May-June Precip.	June-July Precip.	March 15 Snowdepth
Des Moines River	trend	-0.002	0.006	0.08	0.22	0.007	0.023	-0.06
	standard error	0.005	0.003	0.03	0.07	0.016	0.015	0.04
	statistical significance	--	4%	2%	<1%	--	--	--
Skunk River	trend	-0.001	0.006	0.06	0.19	-0.005	0.007	-0.06
	standard error	0.006	0.004	0.04	0.07	0.019	0.018	0.03
	statistical significance	--	--	--	2%	--	--	--
Raccoon River	trend	-0.004	0.008	0.09	0.22	0.017	0.021	-0.05
	standard error	0.008	0.004	0.04	0.07	0.018	0.017	0.04
	statistical significance	--	3%	1%	<1%	--	--	--

Table 4-3
Number of Extremely Heavy 2-day Rainfall Events (6 Inches or More) at Individual Weather Stations, 1930-1997

Decade	Lower Third of Des Moines Basin	Raccoon Basin	Skunk Basin
1930-39	1	1	3
1940-49	4	1	3
1950-59	3	3	2
1960-69	4	3	5
1970-79	4	5	4
1980-89	2	3	0
1990-97	7	4	1
Total	25	20	18

Table 4-4

Trends and Their Statistical Significance for Various Measures of Annual Maximum Hydrological Floods for the Des Moines, Skunk, and Raccoon Rivers

Basin		Annual Peak Flow (cfs)	Annual Peak Gauge Height (feet)	Maximum 2-Day Flow (cfs)	Maximum 7-Day Flow (cfs)
Des Moines River	trend	55	0.14	31	20
	standard error	88	0.02	78	68
	statistical significance	--	<1%	--	--
Skunk River	trend	59	0.02	60	58
	standard error	52	0.02	50	39
	statistical significance	--	--	--	--
Raccoon River	trend	100	0.04	95	66
	standard error	49	0.02	40	29
	statistical significance	4%	2%	2%	3%

Table 4-5
Primary Precipitation Conditions Preceding the Top Four Ranked Peak 7-day Floods on the Raccoon, Des Moines, and Skunk River Basins During 1930-1997

March 31-April 6, 1960: Snow depths were 17 to 19 inches deep on the 3 basins on March 15 and were 0 on March 31. Rainfall in the 15 days before April 3 averaged between 0.5 and 0.7 inches (much below normal).
March 20-26, 1979: Snow depths on March 1 were 11 inches (Skunk) to 17 inches (Des Moines) deep on March 1, and by March 15 the depths were 2 inches on Skunk, 8 inches on the Raccoon, and 16 inches on the Des Moines (farther north). Melting had begun during this period, and by April 1 no snow cover remained. The amount of rainfall for the 12 days preceding the flood's initiation was 2 to 3 inches on the basins, and all fell in the 6 days before the flood (four times the average).
June 20-26, 1990: Moderate to heavy daily rains fell on 9 of the 11 days preceding this flood. The basin mean totals were 7.4 inches on the Raccoon, 6.2 inches on the Des Moines, and 7.1 inches on the Skunk. These values were 400 to 600 percent above average. No 6-inch rains fell at any gauge.
July 9-15, 1993: Moderate to heavy rains fell on 11 of 12 days preceding this flood. Two >6-inch point rains occurred on July 9 in the Raccoon and Des Moines basins, and one in the Skunk basin, all indicative of flash flood conditions. The 12-day mean rainfall totals were 8.1 inches on the Raccoon, 8.2 inches on the Des Moines, and 9.8 inches on the Skunk.

Table 4-6
Meteorological Causes of Major Floods, Skunk River at Augusta

Date of Peak Flow	Rank	Type	Key Events	Maximum 1-Day Precip.
6/1/03	6	5	Rain/May 20-June 1 (8.35")	May 30 (2.22")
6/17/30	7	1	Rain/June 13-15 (5.38") Rain/June 4-6 (1.98")	June 14 (3.18") June 5 (0.93")
5/26/44	5	4	Rain/May 19-25 (4.48") Persistent rains from Apr 10	May 19 (1.25")
4/3/60	2	2	Snowmelt/Mar. 17-31 (24")	March 28 (4.5")
9/24/65	4	4	Rain/Sept 14-21 (6.22") Rain/Sept 4-10 (2.99")	Sept 20 (1.91") Sept 7 (1.15")
4/23/73	1	3	Rain/Apr 20-22 (2.68") Rain/Apr 16 (1.09") Snowmelt/Apr 11-16 (10")	Apr 21 (1.28")
4/27/76	9	4	Rain/Apr 18-26 (5.40")	Apr 24 (2.51")
6/23/90	8	4	Rain/Jun 13-23 (7.02")	Jun 17 (2.59")
7/10/93	1	5	Rain/Jul 5-14 (6.43") Rain/Jun 29-Jul 1 (1.69")	Jul 9 (3.28")
6/15/98	2	4	Rain/Jun 8-15 (4.99") Rain/May 31-Jun 5 (1.14")	Jul 15 (1.47")

Table 4-7
Meteorological Causes of Major Floods, Raccoon River at Van Meter

Date of Peak Flow	Rank	Type	Key Events	Maximum 1-Day Precip.
6/13/47	3	1	Rain/Jun 12-13 (2.57") Wet late spring	Jun 12 (2.16") June 1 (1.26")
7/3/58	6	1	Rain/Jul 2-3 (2.66")	Jul 2 (2.28")
4/2/60	8	2	Snowmelt/Mar 20-31 (17")	Mar 27 (3.50")
7/4/73	5	5	Rain/Jul 1-4 (4.77")	Jul 1 (2.30")
5/19/74	9	4	Rain/May 11-19 (5.05")	May 18 (1.70")
3/19/79	10	3	Snowmelt/Mar 10-19 (21") Rain/Mar 18-19 (1.19")	Mar 16 (4")
7/1/86	4	1	Rain/Jun 29-30 (3.30")	Jun 30 (2.26")
6/16/90	7	4	Rain/Jun 13-25 (7.40")	Jun 17 (1.76")
7/10/93	1	5	Rain/Jul 5-14 (6.43") Rain/Jun 29-Jul 1 (1.69")	Jul 9 (3.28")
6/15/98	2	4	Rain/Jun 8-15 (4.99") Rain/May 31-Jun 5 (1.14")	Jul 15 (1.47")

Table 5-1
Streamgauges for Streams near Des Moines and Ames

City	Streamgauges
Des Moines	Des Moines River at 2nd Avenue, Des Moines (USGS #05482000) Des Moines River Near Saylorville (USGS #05481650) Walnut Creek at Des Moines (USGS #05484800) Raccoon River at Van Meter (USGS #05484500) Des Moines River Below Raccoon River at Des Moines (USGS #05485500)
Ames	South Skunk River near Ames (USGS #05470000) Squaw Creek at Ames (USGS #05470500) South Skunk River Below Squaw Creek (USGS #05471000)

Table 5-2
Major Hydrologic Floods in the Upper Des Moines Basin near Des Moines, Iowa*

Rank	Annual Peak			Secondary Peak		
	Date		Flow (cfs)	Date		Flow (cfs)
Des Moines River at 2nd Avenue, Des Moines (1940-1961): Station #05482000						
1	*1954*	*June 24*	*60,200*			
2	*1947*	*June 26*	*39,500*			
3	1960	April 1	36,200			
4	1944	May 23	34,000			
Des Moines River Near Saylorville (1954, 1962-1997): Station #05481650						
1	*1954*	*June 24*	*60,000*			
2	*1965*	*April 10*	*47,400*			
3	*1993*	*July 21*	*45,700*			
4	1962	April 3	31,000			
5	1984	June 22	30,100			
6	1991	June 10	26,000			
7	1969	April 18	23,800			
Walnut Creek at Des Moines (1972-1997): Station #05484800						
1	*1986*	*May 10*	*12,500*			
2	*1973*	*July 1*	*9,000*			
3	1974	June 9	8,160			
4	1990	June 16	7,780			
5	1993	August 29	6,460			
Raccoon River at Van Meter (1940-1997): Station #05484500						
1	*1993*	*July 10*	*70,100*			
2	*1947*	*June 13*	*41,200*			
3	*1986*	*July 1*	*40,200*			
				1947	*June 25*	*38,000*
4	*1973*	*July 4*	*35,600*			

5	*1958*	*July 3*	*35,200*			
6	*1990*	*June 16*	*34,600*			
				1993	August 29	33,900
				1973	July 1	32,400
7	1960	April 2	32,300			
8	1974	May 19	30,400			
9	1979	March 19	29,900			
10	1984	April 30	28,500			
11	1951	March 31	27,700			
12	1948	March 19	26,700			
Des Moines River Below Raccoon River at Des Moines (1940-1997): Station #05485500						
1	*1993*	*July 11*	*116,000*			
2	*1947*	*June 26*	*77,000*			
3	*1960*	*April 2*	*68,900*			
4	*1954*	*June 24*	*67,300*			
5	*1965*	*April 11*	*65,500*			
				1947	*June 13*	*59,500*
6	*1984*	*June 19*	*58,400*			
7	1951	March 31	54,800			
8	1944	May 24	53,200			
9	1962	April 3	48,600			
10	1974	May 20	48,400			
11	1986	July 2	47,900			
12	1991	June 10	45,900			

* Floods which are in the top 20% of the annual peak flows at a gauging station between 1940 and 1997. Those in the top 10% are in italics. Additional major floods in a year are listed on right.

Table 5-3
Major Hydrologic Floods in the South Skunk Basin Near Ames, Iowa*

Rank	Annual Peak			Secondary Peak		
	Date		Flow (cfs)	Date		Flow (cfs)
South Skunk River Near Ames (1940-1997): Station #05470000						
1	*1996*	*June 17*	*14,000*			
2	*1993*	*August 16*	*11,200*			
				1993	*July 9*	*11,100*
3	*1954*	*June 10*	*8,630*			
4	*1944*	*May 20*	*8,060*			
5	*1990*	*June 17*	*6,600*			
6	*1947*	*June 13*	*6,550*			
7	1960	March 30	6,210			
8	1974	June 23	5,780			
				1947	June 23	5,400
9	1951	March 29	5,320			
10	1977	August 16	5,300			
11	1965	April 6	5,260			
12	1975	June 28	5,230			
Squaw Creek at Ames (1965-1997): Station #05470500						
1	*1993*	*July 9*	*24,300*			
2	*1996*	*June 17*	*12,700*			
3	*1990*	*June 17*	*12,500*			
4	1975	June 27	11,300			
				1993	July 17	11,000
				1993	July 11	8,250
				1993	August 16	7,600
5	1984	June 13	7,180			
6	1979	March 19	5,300			

South Skunk River Below Squaw Creek (1944, 1954-1997): Station #05471000						
1	*1993*	*July 9*	*26,500*			
2	*1996*	*June 17*	*24,400*			
				1993	*August 17*	*24,200*
3	*1975*	*June 27*	*14,700*			
4	*1990*	*June 17*	*13,000*			
5	1944	May 19	10,000			
6	1979	March 19	9,430			
7	1960	March 30	9,260			
8	1954	August 28	8,700			
9	1971	February 20	8,610			

* Floods which are in the top 20% of the annual peak flows at a gauging station between 1940 and 1997. Those exceeding the top 10% are in italics. Additional major floods in a year are listed on right.

Table 5-4
Major Precipitation Events in Basins Affecting Polk and Story Counties*

Rank	6-Week Events			7-Day Events		
	Ending Date		Amount (inches)	Ending Date		Amount (inches)
Upper Des Moines River Basin (11 Weather Stations)						
1	*1993*	*July 18*	*15.72*	*1954*	*June 21*	*6.12*
2	*1979*	*August 29*	*12.43*	*1962*	*September 4*	*5.02*
3	*1954*	*July 3*	*11.83*	*1967*	*June 10*	*4.77*
4	*1990*	*June 19*	*11.74*	*1987*	*July 12*	*4.76*
5	*1965*	*September 30*	*11.22*	*1993*	*July 14*	*4.60*
6	1969	August 1	10.88	1973	September 30	4.51
7	1951	July 11	10.86	1969	June 29	4.45
8	1991	June 5	10.83	1960	May 22	4.44
9	1994	July 16	10.52	1962	July 5	4.44
10	1947	July 6	10.49	1990	June 19	4.40
Raccoon River Basin (7 Weather Stations)						
1	*1967*	*June 29*	*15.00*	*1954*	*August 27*	*6.59*
2	*1990*	*June 19*	*14.34*	*1967*	*June 11*	*6.57*
3	*1993*	*July 23*	*13.66*	*1990*	*June 19*	*6.41*
4	*1965*	*September 30*	*12.87*	*1978*	*September 18*	*6.14*
5	*1947*	*June 23*	*12.29*	*1993*	*July 14*	*5.99*
6	1987	August 18	11.38	1965	September 9	5.84
7	1954	August 28	11.07	1987	July 12	4.99
8	1973	July 4	11.05	1973	July 7	4.77
9	1951	September 12	10.96	1973	September 30	4.76
10	1984	June 28	10.54	1989	September 10	4.54
South Skunk River Basin Above Ames (3 Weather Stations)						
1	*1993*	*July 18*	*19.35*	*1993*	*July 14*	*7.69*

2	*1990*	*June 19*	*14.73*	*1954*	*August 27*	*6.48*
3	*1965*	*September 28*	*14.33*	*1955*	*July 10*	*6.20*
4	*1947*	*June 23*	*14.09*	*1990*	*June 19*	*5.97*
5	*1969*	*July 18*	*13.81*	*1967*	*June 10*	*5.84*
6	1993	September 1	13.63	1969	July 9	5.61
7	1991	June 5	12.86	1993	August 16	5.61
8	1967	July 9	11.99	1983	July 4	5.16
9	1977	September 12	11.94	1987	July 15	4.98
10	1979	September 2	11.32	1965	September 21	4.85

* Six-week and seven-day periods in which basin-wide average precipitation exceeds the top 20% level for events of that duration between 1947 and 1997. Events exceeding the top 10% level are in italics.

Table 5-5
Flood Damage Classification (Derived from descriptions of damaging floods in Iowa, 1944-1997)

Damage Level	Description of Damage	Likely Extent of Impacts				
		Disruption of Normal Activities	Recovery Time	Spatial Extent	# People Suffering Losses	Total $ Losses and Repair Costs
Minor	A few flooded basements; obstructed roads and bridges, possibly requiring minor repairs; parks and golf courses inundated; croplands inundated, delaying (but not preventing) planting or causing minor crop damage.	Inconvenience; disruption for very few	A few days for most activities	Small part of urban area; a few farms	Small	Low
Moderate	Some families relocated and businesses closed while structures cleaned and repaired; some inventory losses; roads or bridges washed out; some major crop damage.	Considerable disruption	Weeks (could be months for a few)	Small area of moderate damage; larger area of minor damage	Medium	Medium (high for a few, low for most)
Severe	Like "moderate" level, plus at least one of the following: (1) structures damaged beyond repair; (2) extended disruption of water, sewer, electricity or telephone; (3) large numbers of people displaced; (4) major disruption of commerce or agriculture; (5) high losses for many.	Major disruption	Weeks to months	Usually a limited area of severe damage, plus large area of moderate damage	Large	High for many

Table 5-6
Classification of Damaging Floods in Polk County, 1944-1997

Severe Damage

1947: June 25-27. Extensive damage to homes, businesses and agriculture. Des Moines damage estimate: $850,000, plus $150,000 for flood-fighting (USACE 1970). [Totals $6.4 million in 1995 dollars.]

1986: May 10 and June 30-July 1. Walnut Creek flood (May 10) damaged 107 businesses and 521 homes in Des Moines, W. Des Moines, and Clive; damage estimate: $16 million [$21.4 million in 1995 dollars]. Raccoon River flood (July 1) caused extensive crop damage and damage to public and private property, some of it in Polk County. (NWS field office reports, May-June 1986)

1990: June 16-19. Extensive rural and urban damage; over 1200 Des Moines homes affected by flooding of Des Moines River, Walnut Creek, and Fourmile Creek (Schaap).

1993: July-August, peaking July 10-11. Major damage to urban area, agriculture, and transportation; 5000 people evacuated; Des Moines water plant flooded July 11 halting all public water service (Changnon 1996).

Moderate Damage

1954: June 23-24. Extensive agricultural damage; dike failure led to flooding of 50 homes in Des Moines. City damage estimate: $1.2 million, plus $375,000 for flood-fighting (USACE 1970). [Totals $8.3 million in 1995 dollars.]

1960: April 1. Farm homes flooded north of the city in the Des Moines River valley; central Des Moines was protected by levees, but 1000 people evacuated from homes (USACE 1970).

Minor Damage

1944: May 23-24. No damage description available. Listed as one of several Amajor@ floods which caused property damage by one source (USACE 1970) and as an Aoutstanding@ flood but not as severe as floods of 1903 or 1947 by another source (INRC 1953).

1958: July 1-2. Agricultural damage on Raccoon River; minor damage to recreational interests in Des Moines area (Climatological Data National Summary, July 1958).

1965: April 8-11. Presidential disaster declaration for Polk County. In Des Moines, about 300 families evacuated, roads and a few homes flooded (USACE 1970).

1969: April 7-29. Presidential declaration of flood disaster for Polk County, but no damage description available.

1973: July 1-4. Sandbagging required on Raccoon River, one levee broke (Des Moines Register, 7/5/73).

1974: June 9-10. Presidential disaster declaration for Polk County. Flooded farm fields; flooded basements and streets in Des Moines (Des Moines Register, 6/11/74).

1984: June 19-22. Saylorville Dam spillway overflowed; sandbagging on Des Moines River, some homes evacuated, parks and recreation areas flooded (NWS field office report, June 1984).

Table 5-7
Classification of Damaging Floods in Story County, 1944-1997

Severe Damage

1944: May 19-20. In Ames, heavy business losses, most basements flooded, telephone service disrupted (USACE 1966). Crop losses in county (USGS 1991).

1975: June 27. Extensive damage to homes, businesses and Iowa State University (ISU); crop losses in county. Ames damage estimate: over $300,000 to ISU, $500,000 to Ames businesses, $200,000 to dwellings (USGS 1976). [Totals $2.55 million in 1995 dollars.]

1993: July-August, peaking July 9 and August 16-17. Major buildings and many homes damaged; major agricultural losses. Ames damage estimate: Almost $10 million (Snyder and Assoc. 1996), including $3 million losses to city (Daily Tribune 6/25/96) and $6.5 million to ISU (Daily Tribune 7/8/94). [Totals $10.5 million in 1995 dollars.]

1996: June 17. In Ames and small towns in north of county, damaged homes and businesses, washed out roads and bridges (Daily Tribune 6/17/96); 5000 acres of farmland inundated in county (Daily Tribune 6/19/96). Ames damage estimate: $1.4 million (Daily Tribune, 6/25/96). [$1.37 million in 1995 dollars.]

Moderate Damage

1947: June 13. Many homes evacuated, basement flooding, sewers backed up in Ames; crop damage in Squaw Creek area; but damage was Amuch less@ than in 1918 and 1944 floods (USACE 1966).

1990: June 16-23. Significant damage to residential and commercial property (Brown 1999); businesses flooded in Ames; damage to roads and bridges in county (Daily Tribune 6/5/91). Damage estimate for county: $750,000 (Daily Tribune 6/5/91). [$860,000 in 1995 dollars.]

1991: June 4. Damage to six towns in eastern Story County included flooding of 30 homes in Maxwell and a school in McCallsburg; no serious damage in Ames except a few flooded basements from backed up storm sewers (Daily Tribune 6/5/91).

Minor Damage

1954: June 10 and August 22-27. In June, roads closed in Ames, flooding of park caused light damage to recreational facilities. In August, several homes evacuated; storm sewers backed up; basements, roads and park flooded. (USACE 1966)

1958: July 3-4. Squaw Creek flooded, storm sewers inadequate, basements, roads and park flooded (Daily Tribune 7/5/58, USACE 1966).

1960: March 30. Sandbagging on Squaw Creek, flooded roads (USACE 1966).

1965: June 4-5. Mostly agricultural damage. Inadequate storm sewer capacity; flooding of basements and a few businesses in a small area in Ames (USACE 1966).

1974: June. Presidential declaration of flood disaster for Story County, but no damage description available.

1984: June 13. Flooded basements and backed up sewers throughout Ames; a few flooded businesses and homes; some agricultural damage (Ames Daily Tribune 6/13/84, 6/14/84).

Table 5-8
Most-Damaging Floods, 1944-1997: Polk County, Iowa*

Year of flood	**1993**	**1947**	**1990**	**1986**
Date of flood	July-August, peaking July 10-11	June 25-27	June 16-19	May 10 and July 1
Damage rank & class	#1. Severe	#2. Severe	#3. Severe	#4. Severe
Nature of damages	Major damage to urban areas, agriculture, and transportation. Des Moines water plant flooded July 11 halting all public water service.	Extensive damage to homes, businesses and agriculture. Des Moines damage est.: $850,000, plus $150,000 for flood-fighting [total $6.4 million in 1995$].	Extensive rural and urban damage; over 1200 Des Moines homes affected by flooding.	Damage to 521 homes and 107 businesses in Des Moines area May 10. Damage est.: $16 million [$21.4 million in 1995$]. Crop and property damage July 1.
Hydrologic flood type	Warm season + flash floods	Warm season flood	Warm season flood	Warm season flood (May); flash flood (July)
Peak streamflow levels (on major rivers)	Des Moines R: top 10% Raccoon R: Record high Below confl.: Record high	Des Moines R: top 10% Raccoon R: top 10% Below confl.: top 10%	Des Moines R: No flood Raccoon R: top 10%	Des Moines R: No flood Raccoon R: top 10% Walnut Cr.: Record high
Peak streamflow description	Raccoon peaked July 10, Des Moines peaked July 21.	Des Moines and Raccoon peaked one day apart.	Raccoon and Walnut Cr. Peaked concurrently June 16.	Walnut Cr. peaked May 10, Raccoon peaked July 1.
Precipitation levels (over two basins)	6-wk: Record high, DM top 10%, Raccoon 7-day: top 10%, both	6-wk: top 20%, DM top 10%, Raccoon	6-wk: top 10%, both 7-day: top 20%, DM >top 10%, Raccoon	6-wk: >top 50%, Raccoon ending May 14.
Precipitation description	Unusually persistent heavy rains over both upper Des Moines and Raccoon basins. "Flash rains" at 1 station in upper Des Moines and 2 in Raccoon basin July 8-9.	Persistent rains for 6-week period over both basins. "Flash rain" at 1 station in Raccoon basin June 22-23.	Persistent rains for 6-week period over both basins. 4.23" rain in Des Moines on June 16.	2-day: >5-yr recur, Raccoon "Flash rains" at 2 stations in Raccoon basin June 30; 3.32" rain in Des Moines on June 29.

* Recurrence levels and record highs are based on 1940-1997 measurements of peak streamflow and 1947-1997 measurements of basin-wide mean precipitation.

Table 5-9
Most-Damaging Floods, 1944-1997: Story County, Iowa*

Year of flood	1993	1975	1996	1944
Date of flood	July-August, peaking July 9 and August 16-17	June 27	June 17	May 19-20
Damage rank & class	#1. Most severe	#2. Severe	#3. Severe	#4. Severe
Nature of damages	Major buildings and many homes damaged; major agricultural losses. Ames damage est.: $10 million [$10.5 million in 1995$].	Extensive damage to homes, businesses, and Iowa State University. Crop losses in county. Ames damage est.: Over $1 million [$2.6 million in 1995$].	Damaged homes and businesses, washed out roads and bridges, 5000 acres of farmland inundated in Story County. Ames damage est.: $1.4 million [$1.37 million in 1995$].	In Ames, heavy business losses, most basements flooded, telephone service disrupted. Crop losses in county.
Hydrologic flood type	Warm season + flash floods	Warm season flood	Warm season flood	Flash flood
Peak streamflow levels (on major rivers)	July: S. Skunk: top 10% Squaw: Record high Aug: S. Skunk: top 10% Squaw: top 20%	South Skunk: top 20% Squaw Creek: top 20% Below confl.: top 10%	South Skunk: Record high Squaw Creek: top 10% Below confl.: top 10%	South Skunk: top 10% Squaw Creek: Not available Below confl.: top 20%
Peak streamflow description	S. Skunk and Squaw Cr. peaked concurrently, both July 9 and August 16.	S. Skunk and Squaw Cr. Peaked one day apart.	S. Skunk and Squaw Cr. Peaked concurrently June 17.	
Precipitation levels (over upper basin; stations are distant from Ames)	6-wk: Record high (July) 7-day: Record high (July) 2-day: Record high (July)	4-wk: >most likely yearly event	6-wk: >most likely yearly event	Not available
Precipitation description	Unusually persistent heavy rains over basin and in Ames, June through August.	Localized persistent rains over Ames area in 6-week period preceding flood.	Localized persistent rains over Ames area in 6-week period preceding flood.	8.21" rain in 2 days at Ames. Light rainfall in the preceding 6 weeks, but none in the preceding 10 days.

* Recurrence levels and record highs are based on 1940-1997 measurements of peak streamflow and 1947-1997 measurements of basin-wide mean precipitation.

Table 5-10a-d
Comparison of Frequencies of Hydrologic and Damaging Floods in Two 27-Year Periods

(a) Number of severe hydrologic floods in Des Moines (Des Moines and Raccoon Rivers) and Ames (South Skunk River and Squaw Creek)		
	1944-1970	**1971-1997**
Annual peak flows greater than 10-year recurrence level: Des Moines	7	7
Ames	3	4

(b) Number of damaging floods in Polk and Story Counties		
	1944-1970	**1971-1997**
Years having damaging floods: Polk County	7	6
Story County	6	7

(c) Damage levels in Polk County floods		
	1944-1970	**1971-1997**
Severe or moderate damage: Years Number Percentage in period	1947, 1954, 1960 3 43%	1986, 1990, 1993 3 50%
Minor damage: Years Number Percentage in period	1944, 1958, 1965, 1969 4 57%	1973, 1974, 1984 3 50%

(d) Damage levels in Story County floods		
	1944-1970	**1971-1997**
Severe or moderate damage Years Number Percentage in period	1944, 1947 2 33%	1975, 1990, 1991, 1993, 1996 5 71%
Minor damage Years Number Percentage in period	1954, 1958, 1960, 1965 4 67%	1974, 1984 2 29%