1.2 A Significant Hydrometeorological Event

The flood of 1993 was a hydrometeorological event without precedent in modern US history. The late summer and Fall of 1992 were wetter than normal for the Midwest and coupled with cooler temperatures produced wet soil conditions. A normal winter rainfall was followed by increasingly heavy precipitation throughout the spring, summer and into the early fall. Seasonal rainfall records were shattered in all nine states impacted by the flood. Summer rainfall amounts equaled those computed for storm frequencies having 75 to 300 year recurrence intervals. During the 14 month period from July 1992 to September 1993, rainfall amounts were significantly above average in all but 3 of the 14 months. In Iowa, the rainfall from January through September was the greatest amount, 44.5 inches, in 121 years of record. Evaporation was the lowest on record and cloud cover and soil moisture readings were the greatest in history.

This intense and continuous rainfall, coupled with the wet soil conditions, after a point in time, filled every ditch and channel, every stream and provided record flows on many reaches of the Missouri and Mississippi and their tributaries. By mid-July, river stages exceeded the 100 year discharge at 45 of nearly 500 gauging stations in the region and near 500 year elevations were seen along the Missouri from southeastern Nebraska to near St. Louis and from southern Iowa to above St. Louis on the Mississippi (figure 3)[2]. The duration of the flood added to its impact. The high stages in July were followed in many reaches by late August and early September rises that approached the mid-summer levels. Considerable acreage was underwater for several months as continuing high stages prevented the drainage of floodplains.

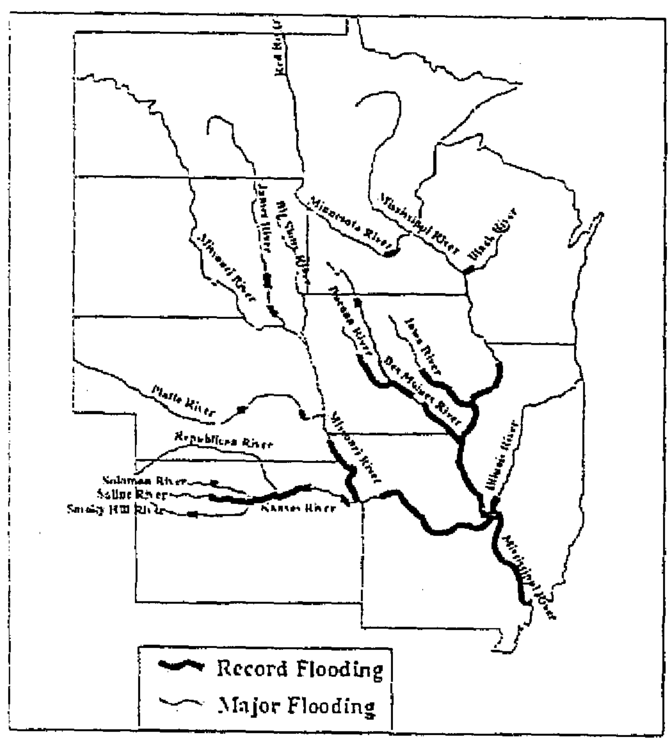

Figure 3. River Reaches with Significant Flooding
Source: US Department of Commerce, NOAA, National Weather Service

1.3 Soil Conditions Prior to the 1993 Flood

The antecedent conditions that gave rise to the Flood of 1993 included, in addition to record rainfalls, wet soil conditions that began in the central Great Plains during the summer of 1992 and rose rapidly with the increasing precipitation and cooling air temperatures of late 1992. July, September, and especially November 1992 were much wetter than normal over the upper Mississippi River Basin. That winter precipitation was near normal, but a wet spring followed. By late March, extremely moist conditions covered much of the region as a result of the wet fall and spring snowmelt runoff. Iowa, which was centrally located in the area of heaviest flooding, experienced the second wettest November - April period in 121 years of record. This period was followed by above-normal precipitation over the upper Mississippi River Basin during April and May. The April - June period was the wettest observed in the upper Mississippi River Basin in the last 99 years. Consequently even before the onset of the heavy summer rains, most upper basin soils were saturated, and many streams and rivers were flowing at well above seasonal normal levels.

1.4 Rainfall

During much of the summer of 1993, a persistent atmospheric pattern of excessive rainfall occurred across much of the upper Mississippi River Basin. The major river flooding resulted primarily from numerous series of heavy rainfall events from June through late July. The recurrence of heavy rainfall was the direct result of a stable upper-level atmospheric circulation pattern with a deep trough to the west of the upper Mississippi valley and a strong ridge along the East Coast (Figure 4). In late July and early August, a change in the upper air circulation pattern brought drier conditions to the Midwest as the trough shifted eastward. Locally heavy thunderstorms generated some additional flooding in parts of the soaked upper Mississippi River Basin during mid-August; however, these rains were associated with a typical summertime pattern and not a return to the anomalous and persistent June and July atmospheric conditions.

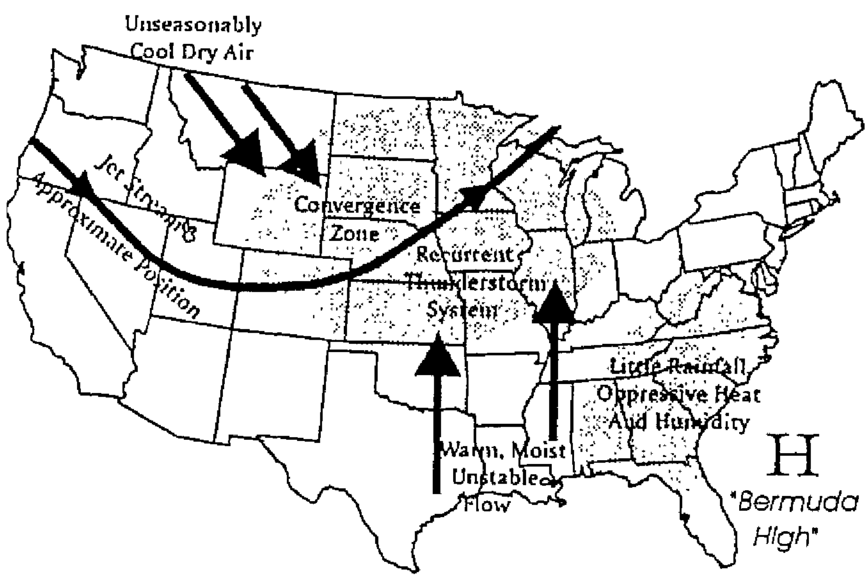

Figure 4. Weather Pattern, June-July 1993
Source: US Department of Commerce, NOAA, National Weather Service

During the June-August 1993 period, rainfall totals surpassed 12 inches across the eastern Dakotas, southern Minnesota, eastern Nebraska, and most of Wisconsin, Kansas, Iowa, Missouri, Illinois, and Indiana. Over 24 inches of rain fell on central and northeastern Kansas, northern and central Missouri, most of Iowa, southern Minnesota, and southeastern Nebraska. Up to 38.4 inches fell in east-central Iowa. Generally precipitation amounts were 200 to 350 percent of normal from the northern plains southeastward into the central Corn Belt.

Rainfall amounts over the upper Mississippi River Basin during the May-August 1993 period are unmatched in the historical records of the central United States. In July, broad areas in the lower Missouri River Basin experienced rainfall amounting to four times normal. The series of storms producing these record rainfalls were remarkable not only in their magnitude but also for their broad regional extent; record wetness existed over 26,000 sq. mi. of the upper Mississippi River Basin. Seasonal rainfall records were shattered in all nine states impacted by the deluge of 1993. Summer rainfall amounts equaled those computed for storm frequencies having 75-year to 300-year recurrence intervals.

1.5 River Flow

The deluge across the upper Mississippi River Basin produced record setting peak flowrates and water levels in many tributaries and in the main stem rivers, including a large reach of the upper Mississippi, over the full reach of the middle Mississippi, and over much of the length of the lower Missouri River. Flooding began in the northern portion of the upper Mississippi River Basin in June and then moved southward with the shifting of the storm-producing weather pattern and the travel of the flood flows downstream as summer progressed.

Rainfall was particularly heavy between June 17 and 20 in southwest Minnesota and northwest Iowa, causing record flooding on the Minnesota River. The next major pulse of precipitation occurred from June 23-25. Runoff from these rains combined with flood flows from the Minnesota River to initiate the first flood crest that moved down the upper Mississippi River. Following a short, dry period, a prolonged siege of heavy precipitation occurred from June 30 to July 11. This included extreme amounts of rainfall on July 9 in Iowa, which produced record flooding on the Raccoon and Des Moines rivers. Just as the crests from these two rivers reached Des Moines, a relatively small, convective pocket dumped several inches of rain on the crests rapidly boosting the river levels and flooding the city's water treatment plant. The intense rainfall during this period also led to record flooding on portions of the lower Missouri River and combined with the crest already rolling down the Mississippi to establish record river stages from the Quad Cities area on the upper Mississippi River downstream to Thebes, Illinois, on the middle Mississippi River. Another major precipitation event occurred from July 21-25. The heaviest rains were focused farther south than the earlier events, with especially heavy rain falling over eastern Nebraska and Kansas, leading to the second major crests on both the Missouri and Mississippi rivers.

Kansas City and St. Louis saw two flood peaks, one caused by the June 30 to July 11 rainfall and the other by rain falling from July 21-25. While flooding from the latter rainfall period did not extend as far upstream on the Mississippi River, new record river levels occurred at many locations downstream and on much of that portion of the Missouri River that flows through Missouri. Above normal rains continued to occur over parts of the flood-affected regionduring August, especially over Iowa where accumulations were twice the normal monthly amount over much of the state. By mid-September, however, rainfall began to diminish and rivers began to recede. Then, at the end of September, a strong system of thunderstorms deposited 1 to 3 inches of rain over the State of Missouri and 7 inches or more from the central part of the state eastward. The consequence was major flash flooding on many tributaries and new flood crests on the lower Missouri and middle Mississippi rivers. Farmlands behind previously breached levees were reflooded and two people drowned in separate incidents. Many roads were washed out and there was much damage to property in Missouri.

2. Impacts of the 1993 Flood

2.1 General

The costs to the nation from the flood were extensive. Thirty-eight deaths were attributed directly to the flood and estimates of fiscal damages ranged from $12 billion to $16 billion. Agriculture accounted for over half of these damages. More than 100,000 homes were damaged. Flood response and recovery operations cost more than $6 billion. Many costs could not be quantified as impacts on businesses in and out of the basin were difficult to calculate and there was no accurate way to assess tax losses to governments. There also were impacts of the flood on the population's physical and mental well-being, but these too were difficult to sum.

The Midwest Flood of 1993, one of the most costly flood events in this nation's history, flooded over 6.6 million acres in the 419 counties in the upper Mississippi Basin. The damages experienced reflected the land-use and settlement patterns within and adjacent to the floodplain. The floodplains along the main stem Mississippi and Missouri rivers and the major tributaries that were inundated generally are used for agriculture, and most areas are sparsely populated. Throughout most of the area, river towns are protected by urban levees, or they are located primarily on a bluff. Floodwaters thus inundated neighborhoods rather than entire communities. Residences, businesses, and industries did receive extensive damages in bottomland areas and along tributaries near Kansas City and St. Louis. Development in these urban areas, however, is largely in the uplands or protected by urban levees that provided flood protection. As a point of comparison, significantly fewer people were impacted by the Midwest Flood of 1993 than were impacted by the 1927 flood on the lower Mississippi River.

Over half of the damages sustained were agricultural damages to crops, livestock, fields, levees, farm buildings, and equipment. The remaining damages were primarily to residences, businesses, public facilities, and transportation. Much of the agricultural damage occurred in upland areas as the result of wet fields and a short growing season rather than inundation by floodwaters. Similarly a portion of residential and business damages was caused by basement flooding due to high groundwater and sewer back-up in areas outside the floodplain.

The National Weather Service (NWS) estimated damages for the Midwest flood at $15.7 billion based on information provided by its field offices. This estimate was based on totals by state, but did not include breakdowns of damage by type. In August 1993, The New York Times published an estimate of nearly $12 billion in damages based on information it obtained from state and federal officials. State and federal officials could not assess all damages until floodwaters receded, and the full extent of agricultural damages was not known until after the end of the growing season. Most of the affected states updated their damage estimates, and the total ranges from $12 billion to $13 billion.

The Review Committee developed an estimate of flood damages using federal payments and making assumptions as to what percentage of damages those payments represent. This information indicates that total damages were more than $12 billion with as much as $4 billion to $5 billion of that total being agricultural damages in upland areas.

Damage estimates for the Midwest flood show marked inconsistencies. No federal agency was responsible for developing accurate assessments of flood damages, nor was funded to do so. The affected states and the Federal Emergency Management Agency (FEMA) conduct preliminary damage assessments to determine if a Presidential disaster declaration is warranted and to estimate the resources necessary for response and recovery. Once sufficient damage has been identified to justify a declaration and once FEMA has a general idea of how resources should be allocated, federal agencies have little incentive to expend resources updating preliminary assessments. Resources are instead focused on tracking and projecting expenditures. The NWS is not funded to estimate total damages but does so to support other missions. The US Army Corps of Engineers (USACE), which in the past estimated flood damages, is no longer funded to do so. (The Review Committee was concerned that decisions involving hundreds of millions of dollars often were made without systematic assessments of flood damages and without a clear understanding by decision makers of the nature and extent of the damages incurred).

2.2 Agriculture

Agriculture is the leading industry in most counties of the nine states affected by the Flood of 1993). The area's 208 million cropland acres represent 32 percent of the nation's farm acreage, 35 percent of total agricultural sales, and almost 60 percent of total national corn, wheat, and soybean acreage. Combined production from Illinois and Iowa alone represent 33 percent of corn and 30 percent of soybean acreage in the United States, but dominant crops and yields vary by state throughout the region. Floodplains comprise approximately 11 percent of total acreage affected by the 1993 flood and 66 percent of this acreage is in agricultural production.

Agricultural damages from the Flood of 1993 had two primary causes: excessive moisture that prevented planting and reduced yields in upland and floodplain areas and actual flooding that destroyed crops and severely damaged many acres of fertile floodplain cropland. It is difficult to separate the factors that influenced crop production during the 1993 growing season in the 9-state region. They included rain, low temperatures, early frost, and floods. More than 70 percent of the crop disaster assistance payments, however, were made to counties in upland areas -- not in main stem river floodplains.

Agricultural damages directly attributed to actual flooding totaled more than $2.5 billion, with an estimated $1.4 billion in lost corn and soybean sales. Most of these losses were restricted to 1993 as the productive capacity of the land was unchanged. There were, however, damages to field fertility and farm infrastructure of at least $100 million.

Each state suffered different types of losses. For example, Missouri with 34 percent of its cropland (5.1 million acres) in the floodplain, had crop damages from flooding on 3.1 million acres causing $247 million in lost sales (Cassidy and Rickert, 1994). In Illinois, only 3 percent of the state's corn and soybean acreage (312,000 and 276,000 acres respectively) were lost to flooding with a loss in sales of $153.4 million (Bhowmik, 1993). Minnesota farmers lost $500 million in crop sales, but most of the damage was caused by wet conditions rather than riverine flooding (Taff and Maki, 1993). Damage from scour and deposition affected 455,000 acres on the Missouri River floodplain representing 20 percent of the flooded cropland along the Missouri and Mississippi rivers. Drainage ditches were filled with sediments, and other agricultural infrastructure was destroyed. Almost 60,000 acres have sand deposition more than 24 inches thick and reclamation costs to restore fertility to damaged cropland were estimated at $190/acre. If cropland restoration required removal of sand, it cost approximately $3,200 to remove each acre-foot of sand. Over $10 million was required remove sediment and debris from ditches (US Department of Agriculture, 1993). Secondary impacts of agricultural losses to a local economy vary substantially with the dependence of that economy on the agricultural sector. Immediate losses are due to lost sales and unemployment. In the long run, the assessed value of land that sustained long-term damage may be reduced which will affect the property tax base of affected communities.

Another secondary effect was a reduction in crop-support payments since crop prices adjusted to the reduced production caused by wet weather in the Midwest and drought in the Southeast in 1993. This loss to farmers was a gain for taxpayers since subsidies represent transfer payments. For corn, these deficiency payments were reduced by more than $2.6 billion (US Department of Agriculture, 1993). These price effects and subsequent reduction in deficiency payments were temporary, as the 1994 crop supply returned to past levels.

It is important to note that the majority of 1993 agricultural damages in the Midwest were caused by wet soil conditions and inundation in upland areas. Damage to inundated cropland in the floodplain was significant with almost complete crop losses behind failed levees. Areas affected by severe erosion and deposition may suffer long-term loss of productivity.

2.3 Residences And Businesses

Estimates vary on the number of homes flooded and families impacted by the Midwest flood. Surveys made by Red Cross workers immediately after the floods identified more than 55,000 flooded residences (American Red Cross 1993). FEMA subsequently verified these damages with Red Cross chapters and developed an updated estimate of 70,545 residences (Shepard, 1994). The New York Times (August 10, 1993), estimated that more than 84,000 residences were damaged. By April 1994, the federal government had received 167,224 registrations for individual assistance and 112,042 applications for the Disaster Housing Program.

Within this latter group, over 90,000 applications were approved. The Disaster Housing Program data indicated that more than 100,000 residences were flooded (US FEMA, 1994).

Businesses sustained significant physical damages particularly in urban areas such as St. Louis County and the Kansas City areas of Missouri. Much of this damage occurred behind levees that failed or were overtopped. The 996 National Flood Insurance Program (NFIP) claims payments made to small businesses) and the 4,667 Small Business Administration (SBA) loans for damages to businesses indicated that in excess of 5,000 individual businesses were damaged (US FEMA, FIA, 1994). No overall damage estimates for businesses were available, but as a measure of this damage, SBA loans to businesses, exceeded $334 million for physical damage and economic injury (Kulik, 1994). Add to these loans NFIP flood insurance payments for small businesses and other non-residential buildings that exceeded $94 million, and the total exceeds $431 million (US FEMA, 1994). In addition to physical damage to buildings and their contents, lost profits and wages from businesses closed by the flood had local and regional impacts. For example, an American Cyanamid Plant near Hannibal, Missouri, was protected by its own levee and not damaged by floodwaters, but the plant was shut down for nearly three months because its access road was inundated when an agricultural levee failed.

2.4 Transportation Systems

Rivers and river valleys historically have been major transportation routes, particularly in the area impacted by the 1993 flood. In the Midwest, transcontinental railroads, interstate highways, and other road systems either follow river valleys or cross them. As a result, physical damages to transportation systems created a significant percentage of total flood damages. In addition to direct damages, indirect costs accrued when transportation routes were inundated by floodwaters, and traffic was halted or detoured.

A major portion of flood damages to public facilities in 1993 involved roads and bridges. These damages ranged from blown culverts and wash-outs on rural roads and city streets to loss of bridges and damages to interstate highways inundated by floodwaters. The repair of flood-damaged roads and bridges generally is funded through the FEMA Public Assistance Program or the Department of Transportation. Funds expended by those agencies when added to the state/local cost share for public assistance indicated that total physical damages to roads and bridges exceeded $250 million (US FEMA, 1994).

• Roads and Bridges

Road and bridge flooding caused indirect losses related to increased transportation costs. In extreme cases, detours of 100 miles were required to travel between adjoining communities that had been connected by a bridge. Often bridges were elevated high above the river to allow for navigation or to minimize hydraulic impacts of floods, but bridge approaches built at or near the natural elevation of the floodplain were inundated by floodwaters. Even though the bridge was undamaged and the approach damage was minimal, the economic impacts on the communities served by the bridge could be extreme, particularly for a long duration flood such as occurred in

1993. For example, Keokuk, Iowa, was cut off from market areas in Illinois and Missouri for several weeks when the approaches to bridges over the Mississippi and Des Moines rivers were inundated. This resulted in serious economic impacts on local businesses. Flooding of the approaches to the bridge over the Mississippi River at Quincy, Illinois for 73 days resulted in an estimated $30 million in lost business to Quincy merchants (Bhowmik, 1993). In addition, many people who lived in Missouri and could not commute to work in Illinois were temporarily unemployed. Ferries were eventually established to address part of this problem. The full magnitude of these losses were reflected in over 36,000 claims approved for a total of $92 million in Disaster Unemployment Assistance.

- **Railroads**

Historically railroads were built in floodplains and river valleys to minimize construction and fuel costs. Main lines continue to parallel both the Missouri and Mississippi rivers. Although generally tracks are elevated on embankments above the elevation of most floods or are located behind levees, they remain subject to major flood events. In 1993 over 800 miles of track were flooded and several main lines were inundated for varying periods of time, but most trains were routed around flooded areas. The Association of American Railroads estimated that railroad damages totaled $182 million, including $131 million in physical damages to tracks, bridges, signals, communication lines, switches, locomotives, rolling stock, and buildings. Additional costs of $51 million resulted from detouring trains around sections of flooded track (Harper, 1993). Repair costs were generally borne by the railroads themselves although $21 million was distributed to railroads through a supplemental congressional appropriation: "Local Rail Freight Assistance."

- **Airports**

Airports often are located in floodplains because of the flat terrain and close proximity to urban areas. The Federal Aviation Administration (FAA) identified 33 airports with varying degrees of flood damage and repair costs exceeded $5.4 million. The airports ranged in size from the Spirit of St. Louis Airport in St. Louis County, Missouri, to airports that were little more than grass landing strips with a few hangars for private aviation. Most of the flooded airports were in Missouri (16) and Iowa (12). The Spirit of St. Louis Airport, an alternate for Lambert-Airport, sustained $1.7 million in damages when a 100-year local levee failed. Other major airports that were flooded include those at Creve Couer and Jefferson City and the Kansas City Downtown Airport. Several smaller airports went out of business (Trilling, 1994).

- **Navigation**

Two types of navigation projects are present in the basin. One, on the upper Mississippi and Illinois Rivers, is slack water navigation created and controlled by a system of locks and dams. The other, open water navigation, is utilized on the Missouri River and middle Mississippi River (the Mississippi below St. Louis). The upper Mississippi River navigation system provides a variety of uses: commercial transportation, recreation, environmental resources, water supplies for domestic and industrial use, and energy production. The Water Resource Development Act of 1986 declared the upper Mississippi River system to be a nationally significant ecosystem and a nationally significant commercial navigation system.

Navigation on the Mississippi River was a primary factor in settlement of the valley. The federal government began to support commercial navigation actively in 1824; first with 4-foot deep channels, then 4.5-foot and then 6-foot channels. The navigation channel projects, authorized by Congress in the 1930s for the Mississippi and Illinois Rivers, extended 9-foot draft navigation upstream to Minneapolis/St. Paul and connected the St. Lawrence-Great Lakes with the Mississippi-Ohio-Missouri navigation systems (Figure 5). The upper Mississippi River 9-foot navigation project has converted the Mississippi River (St. Louis to Minneapolis/St. Paul) into a series of pools at low and normal flow. Navigation dams, each consisting of a row of gates mounted between piers over a low sill, are used to maintain sufficient water depth for navigation. During periods of high flow, the navigation gates are completely opened to allow passage of the flood flows. Construction of the 29 lock and dam projects on the Mississippi River north of St. Louis was completed by 1950. These locks are nearing the end of their economic life span and may soon start to require expensive replacement. Locks and Dam 26 near, Alton Illinois, was replaced during the early 1980s at a cost of nearly $1 billion. Below the southern most lock, Lock 27 at Granite City, Illinois, navigation is maintained through placement of flow regulating structures such as wing dikes and by dredging that channelize, narrow, and deepen the river.

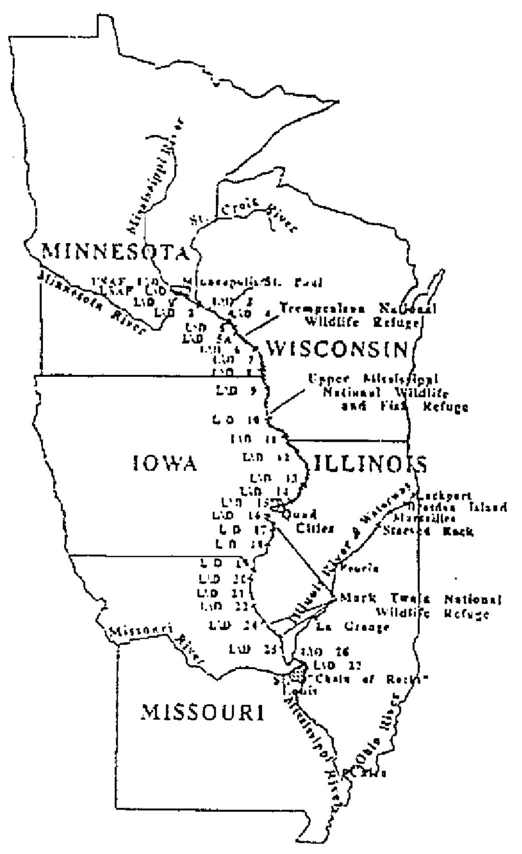

Figure 5. Upper Mississippi River Navigation System
Source: Upper Mississippi River Basin Commission, 1982

Maintenance of the upper Mississippi River navigation system requires periodic dredging at over 200 sites, removing an average of 9.5 million cubic yards of material annually. Two construction projects have supported navigation activities on the Illinois River. The first, the Chicago Sanitary and Ship Canal, completed in 1900, diverted water from Lake Michigan into the Illinois River. The second, a modern lock and dam system, similar to that in operation on the upper Mississippi River, consists of seven separate navigation locks. This system was completed in 1965.

In 1945 Congress authorized a comprehensive navigation plan for the Missouri River system. The result was a 9-foot channel navigation project to channelize and deepen the river from St. Louis upstream to Sioux City, Iowa. Six multi-purpose main stem reservoirs, affecting over 900 river miles, were developed above Gavins Point Dam. One purpose was to provide a regulated release of water for downstream navigation. Downstream of Gavins Point Dam, the river consists largely of a 735-mile navigation channel maintained with wing dikes, channel stabilization and other erosion and sedimentation control devices. Annual water release for navigation is based upon available water supplies. Navigation needs combined with winter releases for water supply and hydropower demands obligate all available water during a normal year. The navigation season on the Missouri River is limited to the ice-free season between April 1 and December 1.

Most of the Upper Mississippi, Missouri and Illinois Rivers were closed to barge traffic from July 11 until August 15, 1993 since the locks were out of operation and movement along the open waterways created wave action that endangered the flood control levees. Severe limitations on barge traffic continued through September, October, and November. The Maritime Administration estimated that losses of revenue to the navigation industry were $300 million per month. More than $165 million were lost in Illinois alone. Regional impacts on jobs from barge and port disruptions were not quantified but were estimated to be greatest in Illinois (US Department of Transportation, 1993).

2.5 Public Facilities and Utilities

The Midwest flood caused extensive damages to water and wastewater treatment plants and other public facilities. Damages to utilities, including water and wastewater treatment facilities and stormsewer systems, exceeded $85 million. Water treatment plants often are located in floodplains to be near well fields or the surface water that supplies the system. In addition, water supply lines must cross floodplains to serve floodplain residents. The EPA identified 200 municipal water systems impacted to some degree by the flood. The most prominent example was the Des Moines Water Works that served the City of Des Moines and adjoining communities. The plant was flooded and remained out of operation for 12 days and water from it was not safe to drink for another seven days. In addition to physical damages of $12 million, significant impacts were felt in the service area. Businesses and government offices closed because of lack of fire protection, and bottled water and portable toilets had to be provided for residents. The economic impact of the shutdown exceeded the cost of repair of the physical damage.

Wastewater treatment plants also tend to be located in floodplains which are generally the lowest point in a community and offer the advantage of gravity flow. Furthermore the effluent from these plants is discharged into major rivers or streams. The impact of flooding ranges from temporary plant shutdown and the discharge of raw sewage into the river during the flood to physical damage that results in extended plant shutdowns and continued discharges of raw sewage or partially treated effluent until such time as the plant can be repaired. A total of 388 wastewater facilities were impacted by the flood (Knight, 1993). Damages to public buildings exceeded $27 million. Water control facilities had more than $20 million in damages, and facilities such as parks and other recreation facilities recorded more than $22 million. These estimates were based on FEMA projections of infrastructure spending that included a 10-percent local cost share.

In general, energy facilities were not directly affected by the flood. Careful siting of the facilities and construction by the utilities of flood control works protected most plants from inundation. However, the previously discussed transportation problems with roads, bridges, railroads and navigation did restrict the activities of many energy systems. Employees were not able to get to the plants and fossil fuel supplies by railroad and barge were disrupted. Although no plants were shut down as a result, several approached the end of their on-site supplies.

2.6 Environmental Hazards

The EPA determined that 59 Superfund sites experienced flooding; however, impacts to the sites were minimal and corrective measures were completed on sites requiring them. In addition 73 solid waste treatment, storage, and disposal sites were flooded. Large propane tanks that were dislodged, floated downriver and created the potential for massive explosions. Besides the large propane tanks, states collected over 18,000 orphaned drums -- each with a potential hazardous or toxic substance -- and a large amount of household hazardous wastes whose disposal was necessitated by the flooding (US EPA, 1994). Daily loads of agricultural chemicals (herbicides and nitrates) transported by the Mississippi River were large relative to previous years; record flooding did not dilute the concentrations of herbicides. Concentrations of two herbicides (atrazine and cyanazine) in some samples from the Mississippi River exceeded health-based limits for drinking water. (Goolsby and Battaglin, 1993). The cumulative impact of any flood-related releases of hazardous materials, including pesticides, herbicides, and other toxic materials has not been yet established. The effects of flooding on groundwater hydrology and groundwater quality also have yet to be determined. In response to concerns regarding the safety of private wells, the Administration established a well-water contamination survey in coordination with the nine flood states (Young, 1994). The EPA performed floodwater quality sampling around major metropolitan areas on the Missouri River. In some cases, drinking water standards were exceeded, but the majority of the readings posed no health risk. Results from sampling of treated drinking water revealed three locations where maximum contaminant levels were exceeded although results from a single sample did not indicate a problem (US EPA, 1993). (USGS) and the National Oceanic and Atmospheric Administration (NOAA) did not find significant changes in water chemistry since the 1993 flood (Goolsby and Battaglin, 1993). Impacts of the flooding on the distribution of contaminated river sediments is also unknown. Studies are underway to determine sediment chemistry and characterize sediment deposition patterns in rivers and streams (US EPA, 1993).

Effects of the flood on public and mental health are largely anecdotal. Some communities noted increases in spousal and child abuse and numbers of calls for police response. Mental health effects of community and individual buyout/relocation are poorly understood. Several studies are underway to assess the human response to the 1993 flood and to evaluate the factors that strain the ability of families to function adaptively to the event. Experience with other floods indicates that outbreaks of Equine, Western, and St. Louis encephalitidies can be expected two years after a flooding event (due to the lag time in amplification of disease vectors). The length of time between the flood event and the appearance of disease adds to the problem of attributing costs (Young, 1994).

3. Vulnerability Reduction

3.1 General

The rivers and streams of the Midwest were focal points for early settlement because they provided sources of drinking water and avenues for transportation and trade. Once settlements were established along rivers, the problem of controlling floods to protect human life and investments became readily apparent. At first small mounds of dirt were thrown up to divert water away from towns, and over the course of time, these mounds became levees and floodwalls. Many people living in floodplains behind those levees and floodwalls remain at risk because of decisions made many years ago. The modern challenge is to reduce those risks.

As settlers spread west they altered prairie, forest, meandering streams, and free-flowing river landscapes to provide arable farmland, raw materials for homes and industry, and transportation. Federal policies encouraged extensive private land development which then required construction of reservoirs and levees for flood protection. Human use thus changed Midwestern landscapes to the detriment of natural ecological systems. The Flood of 1993 raised questions as to what extent these landscape changes contributed to flood frequency and duration.

3.2 Levees and Reservoirs

A flood in 1927 affected millions of people throughout the Mississippi River Basin and demonstrated the inadequacy of the pattern of private flood damage reduction measures begun in 1879. It became a milestone event leading to major changes in national floodplain management policy. The 1928 Flood Control Act, which established a lower Mississippi River flood damage reduction system, and the 1936 Flood Control Act were the first codification of the federal interest in the coordinated development and installation of flood damage reduction measures. The primary method used to prevent damages in those early years was floodplain levees. Starting in 1936 the USACE responsibilities were focused on major rivers and development of congressionally approved plans for reservoirs, levees, channelization, and diversions. The methods used were those determined to be most cost effective for preventing flood damages. The USACE has constructed 76 reservoirs in the upper Mississippi River Basin. These control a drainage area of almost 370,000 square miles and contain a total flood storage volume of 40 million acre-feet of water. Forty-nine are located in the Missouri River Basin where the USACE also operates 22

Bureau of Reclamation reservoirs for flood storage. The majority of the reservoirs are operated to provide benefits on the tributaries where they are located; some are operated to benefit the main stem rivers. In addition to the reservoirs, the USACE has constructed or improved over 2,200 miles of levees for the protection of communities and agriculture in the upper Mississippi River Basin. Though records on the federal levees are kept by the USACE), at the time of the flood, there was no inventory about the estimated 5800 miles of non-federal levees that are in the upper basin.

Flood damage reduction-related activities of the US Soil Conservation Service (SCS)began nationally in 1944 with passage of PL 78-534 authorizing installation of upland treatment and flood damage reduction works in selected watersheds. (In 1995, the SCS was retitled the Natural Resource Conservation Service.) The Watershed Protection and Flood Prevention Act of 1954 (PL 83-566) expanded the SCS flood damage reduction program to the entire nation. During the past 42 years, in the nine Midwestern states affected by the Flood of 1993, the SCS has planned and evaluated over 300 watershed projects covering 40,000 sq. mi. (25.5 million acres). Locally sponsored PL-566 projects resulted in the installation of 2,964 reservoirs that influence the drainage of over 5 million upland acres, and 818 miles of channel work, 75 percent of which is located in North Dakota, Minnesota, and Illinois. The SCS requires 75 percent of the land above a proposed reservoir site to be treated before construction. It is estimated that PL-566 resulted in soil and water conservation treatments on more than 3 million upland acres.

The 1993 flood demonstrated that dams and reservoirs, engineered and built to store and regulate floodwater discharge, can reduce flood damages. All federally funded flood storage reservoirs operated as planned during the 1993 flood. At some facilities, emergency spillway flows occurred when inflow volume exceeded reservoir storage capacity. During the period of peak flooding (April 1 to August 1, 1993), the USACE reservoirs stored 22.2 million acre-feet of flood water. Approximately 18.7 million acre-feet were stored in the Missouri Basin, half of which was stored in the 6 main stem Missouri River reservoirs. Most of the remainder was stored in tributary reservoirs of the Kansas and Osage rivers. About 3.5 million acre-feet of water was stored in the Mississippi River Basin and an additional 1.1 million acre-feet were stored in 2,964 small PL-566 upland flood damage reduction reservoirs. Flood damage reduction reservoirs effectively controlled excess runoff and reduced damages to downstream floodplains during the 1993 flood event. The combined effect of the storage of flood waters in the federal flood damage-reduction reservoirs in the Missouri River basin reduced the average discharge of the Missouri River near its mouth, during the month of July, by 211,000 cfs. This had the effect of lowering the peak stage of the Mississippi River at St. Louis by 5 feet.

Federally constructed levees, in concert with upstream flood-storage reservoirs, protect many large urban areas from potentially significant damage. For example, without levees or floodwalls, portions of low lying areas in Rock Island and Moline, Illinois, and Kansas City would have been devastated. At St. Louis the Mississippi River crested at 49.6 feet on the USGS gage, almost 20 feet above flood stage, yet that portion of the city protected by the large flood wall escaped inundation. During and following the flood there was considerable speculation about the effect of levees on flood levels. Most of the speculation was based upon inferences drawn from comparisons between recent event data, obtained from systematically-measured river flow (discharge) and river level (stage) records, and similar data for historical floods. Such discussions failed to recognize that significant differences in data quality exist between the modern (after 1930) and the historic record. In addition, many other changes have occurred in the upper Mississippi River Basin which have created differences in flow regimes over time.

To ascertain the actual effect existing levees had on peak 1993 Mississippi and Missouri river flood stages, the Review Committee's Scientific Assessment and Strategy Team (SAST) commissioned model runs to analyze unsteady state river flow conditions in several river reaches of the Mississippi and the Missouri.The analyses suggested that if all the levees (other than urban levees) were absent, the peak stage at St. Louis in 1993 would have been reduced by 2.5 feet, but still more than 17 feet above flood stage and almost 4 feet higher than the previous known maximum level recorded during the 1973 event. An independent model commissioned by the St. Louis Post-Dispatch showed that the overtopping and breaching of two levees downstream from St. Louis reduced peak stage at St. Louis by 1.6 feet.

Based on these analyses and previous studies of these rivers, the Review Committee concluded that levees did not cause the 1993 flood. During large events such as occurred in 1993, levees have minor overall effects on floodstage but may have significant localized effects.

Federal Flood damage reduction projects and floodplain management programs, where implemented, worked essentially as designed and significantly reduced the damages to population centers, agriculture, and industry. Reservoirs and levees built by the US Army Corps of Engineers (USACE), prevented more than $19 billion in potential damages. Large areas of Kansas City and St. Louis were spared the ravages of the flood, although several suburbs suffered heavy damages. Watershed projects built by the Soil Conservation Service saved an estimated additional $400 million. Land use controls required by the National Flood Insurance Program (NFIP) and state floodplain management programs also reduced the number of structures at risk throughout the basin although a specific dollar value can not be assigned to these loss prevention efforts. Although flood damage reduction reservoirs and levees reduce the risk of flooding, they do not eliminate it. Given enough rainfall the flood damage reduction storage capacity of a reservoir can be exceeded and water will overtop the spillway. Local flooding may then occur downstream; its extent will depend upon the condition of the stream when the overtopping occurs. Throughout the basin, the Flood of 1993 exceeded the design capacity of many levees and the flood storage capacity of some reservoirs, flooding lands and property of persons who may have thought they were not at risk.

(During the 1993 flood many people suggested that the flood crest could be lowered significantly by opening navigation dam gates before the arrival of flood waters. Hydraulic investigations by the University of Iowa and evaluations of the 1993 flood show that navigation dams cause slight, localized increases in flood height just upstream of a dam. They did not cause increases in flood elevations for the entire Mississippi River System. In the middle Mississippi (from St. Louis to the confluence with the Ohio River) and on the Missouri River, navigation channels have no locks and dams, and the dikes and revetments which are in place cause little or no restriction to flow. **The Review Committee concluded that navigation dams and locks did not cause an increase in the stage heights of the 1993 flood.)**

3.3 Wetlands and Upland Treatment As Vulnerability Reduction Mechanisms

Wetlands occur in poorly drained soils and in areas where water is found at or near the ground surface. Between 1780 and 1980 an estimated 53 percent of the nation's original 221 million acres of wetlands were drained. In the nine Midwestern states affected by the flood 57 percent of the wetlands have been converted to other uses. The Swamp Land Acts of 1849, 1850, and 1860 resulted in the transfer of nearly 65 million acres of wetlands in 15 states from federal to state administration for the purpose of expediting their drainage. United States policy from the mid to the late 1800s has been to cede "overflow and swampy" lands to the states and to convert these lands to productive use. Substantial bottomland timber harvesting began with the arrival of pioneers, and by the 1930s, most wetlands had been converted from natural to agricultural uses and over 84 million acres nationwide had been included in regional enterprises known as drainage districts. By the 1950s, forested wetlands had been reduced to 66.7 million acres, and by the mid-1970s an additional 6.5 million acres had disappeared. Between the mid-1950s and 1970s an average of 458,000 wetland acres were lost each year in the coterminous United States. Agricultural development was responsible for 87 percent of the loss as wetlands were drained, filled, or otherwise converted to cropland. Development in the upper Mississippi River Basin for agriculture and other economic activity, flood damage reduction and navigation greatly altered the original landscape. The characteristics of flood events and the modification of the basin's natural resources reflect these changes.

Upstream land use and land treatment affect downstream flow regimes of rivers and floodplains. In considering floods and floodplain management, knowledge of where and how runoff occurs and which land practices can hold the rain where it falls for as long as possible become critical. Proper management can greatly affect the quantity and quality of water and sediment transported by flood waters. Factors influencing the amount and velocity of runoff include the amount and intensity of precipitation, soil type, land slope, available storage and land cover. Proper management of agricultural lands requires use of protective cover or land conservation practices. In the Midwest cropland erosion can be reduced by using measures such as conservation tillage, terraces, crop rotations, field borders, sediment and debris basins, strip cropping, and permanent vegetation. Such land use practices increase infiltration rates and help hold both water and soil in place. It is estimated that 37 percent of the nation croplands have adequate land treatment installed.

Pre-1850 historical records indicate that even prior to the clearing of wetland areas major floods occurred in the Mississippi River Basin. As part of economic development in the Midwest a substantial percentage of agricultural lands were created by drainage of wetlands and hydric soils. Hydric soils, good indicators of past and present wetland locations, total 10.4 percent of Mississippi and Missouri basin soils. The Review Committee heard numerous times that flooding would have been reduced had more wetlands been available for rainfall and runoff storage. An evaluation of the upper Mississippi River Basin's capacity to store rainfall runoff estimates that the soil profile has 10 times more storage capacity than above ground storage in depressional potholes. Because much of the basin was wet in 1993, particularly the areas that received the highest rainfall, the buffering capacity of the basin was depleted and unable to store water from the rains of June and July.