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Floods and its Aftermath with a Special Reference to the Great Flood on the Upper Mississippi, Missouri and Illinois Rivers in the USA

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ABSTRACT: Flooding of the floodplains has been occurring from the beginning of civilization. Rivers do need its floodplain to convey excess water during extreme flooding events. During low frequency flooding events, the floodplain may simply act as a storage reservoir rather than conveying the flood flow. The interchange of conveyance and storage in a floodplain is a continuous event and it could occur within the same year and within the same event. During the last hundred years or so and in many countries of the world floodplains have been altered to build cities and towns, grow agricultural products, construct roads, bridges, railroads and others. Each of the human activity has resulted in preventing the floodplain to perform its basic function, namely convey the water or store it when needed. All these activities have resulted in increased damages sustained by the society. This paper will concentrate on the 1993 flood on the Upper Mississippi, Missouri and Illinois rivers and the recent flood that occurred on the mid-section of the Mississippi river bordering the State of Illinois. It will also show a pictorial view of these floods, actions undertaken, flood damages occurred, damages prevented due to flood control measures, and some ideas on floodplain management.

INTRODUCTION

Flooding is a natural occurrence of all the rivers of the world. In some parts of the world the flooding could be extreme and in some other parts it is not that damaging. Damages due to flood occurred because of the actions of man rather than the actions of the rivers. Over the historical times rivers have created floodplains to convey the excess water during flooding events. Humans have decided from ages to settle on the floodplains for water supply, food, transport, recreation, sewage disposal, agricultural production, cooling water and habitation. It is no wonder that most of the older cites of the world is located either on the banks of rivers or in very close proximity to the river. This is also true for all the major and minor rivers of the United States of America. The Mississippi river originating in northern Minnesota travels through 10 States of the United States of America before emptying to the Gulf of Mexico. In this process the river travels more than 3,200 km, drains about 3 million square km of area covering about 40% of the continental USA. Some of the major tributaries of this river are Illinois, Missouri and Ohio. Figure 1 shows the drainage basin of the Mississippi River.

For a detail description of the Mississippi river and its basin, the readers are referred to many articles and papers published in this subject including those by Bhowmik (Bhowmik, 1995, Bhowmik *et al.*, 1995, Bhowmik, 1996).

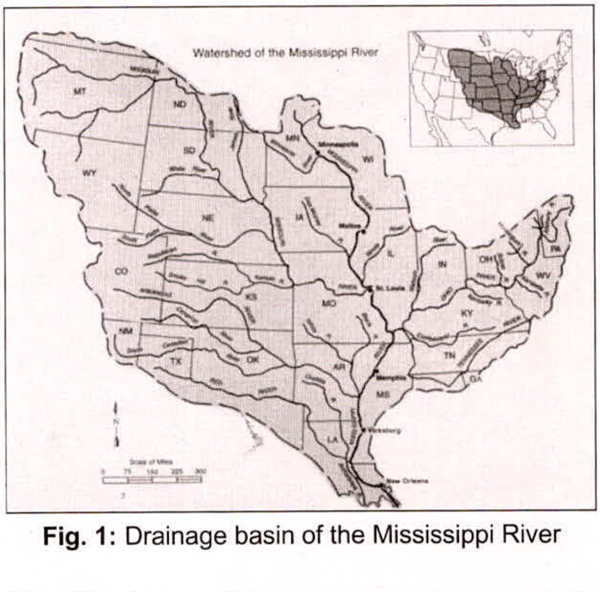

Fig. 1: Drainage basin of the Mississippi River

The Mississippi River assumed its present form after the ice age. When the ice melted, it created what is called 'ice marginal rivers' and at that time the Mississippi River absorbed two other great rivers of the continent and formed the river which is now called the Mississippi River. The Mississippi is also called the Great River of North America.

The 1993 Great Flood essentially covered an area extending from Cairo, at the confluence of the Mississippi and Ohio rivers through Minnesota to the north. This flood also extended through the Missouri River basin. The flood had minimal effect on the Lower Mississippi River. The Upper Mississippi River (UMR) extends from Cairo, Illinois to the headwaters excluding the Missouri River basin. This division has been made for ease in management of various resources. The UMR also contains about 2,100 km navigable river where commercial navigation is extremely important. The UMR is elongated in shape with an average width of 886 km by 1,200 km long. The elevation range of the UMR is from 85 m above msl to 592 m above msl.

Over the years the entire Mississippi River Basin (MRB) has been altered significantly. A total of 27 Locks and dams have been constructed to facilitate the commercial navigation within the UMR. It is especially true during the low flow stages. During the high flow stages, all locks and are completely opened and the river behaves like an open river. This was true at many Locks and Dams during the 1993 Flood and at several locks within the lower part of the UMR during the spring 2008 flood. The characteristic of the UMR is different at different locations such as those from Headwater to Lock and Dam (L&D) 10, L&D 10 to 19, L&D 19 to 26, and L&D 26 to the mouth with the Ohio River. The segment of the river from L&D 26 to the Ohio River is also unrestricted as far as the L&D is concerned. However, the river at many locations within the last segment is restrained by levees.

The Mississippi river watershed is located in temperate continental climate zone. The average precipitation varies from 800 mm in the north to 115 mm near Cairo, Illinois. The UMR also is the recipient of 16 major tributaries with the largest being the Illinois River draining about 749,117 sq km of area. The Missouri River is not used as part of the UMR even though it joins the Mississippi River just above St. Louis.

Floods on the Mississippi River upstream of the confluence with the Missouri River often occur independently of floods at St. Louis and further downstream. Some time, the floods on the Mid-UMR can and do occur due to heavy local rainfall on the local tributaries such those that took place in the spring of 2008. During spring of 2008, extensive amount of rainfall on several tributaries in Iowa resulted in heavy flooding on the River from about Rock Island to St. Louis and a little downstream. The Missouri river drains about 75 percent of the watershed of the MR up to Cairo and as such floods on the MR below St. Louis to Cairo have almost always coincided with major floods on the Missouri River.

The present paper will concentrate on the floods on the UMR extending from Cairo in Illinois through the Headwaters of the Mississippi River. Figure 2 shows the Upper Mississippi River.

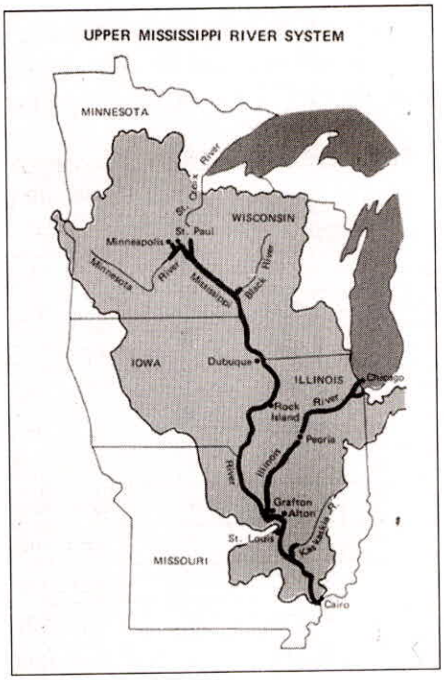

Fig. 2: The Drainage basin of the Upper Mississippi River

The stream flows on the UMR and especially on the river bordering the State of Illinois, Figure 2, have shown some changes over the years. Table 1 shows this variability for three locations, Clinton, Keokuk and St. Louis. Clinton is located below Dubuque, Figure 2, Keokuk is in between Clinton and St. Louis, and St Louis is just downstream of the confluence of the Mississippi River with the Missouri River, see Figure 1. Table 1 shows the variability in average Streamflows on the UMR at three locations.

Table 1: Average Streamflow on the Mississippi River (cubic meters per second)

Period	*Clinton (1874–1992)*	*Keokuk (1879–1992)*	*St. Louis (1862–1992)*
1862–1893	1,566	2,027	5,346
1894–1920	1,393	1,796	4,938
1921–1940	1,075	1,413	4,452
1941–1964	1,301	1,788	4,966
1965–1992	1,425	2,131	5,746
Total record	1,350	1,827	5,099

This table shows a noticeable increase in average streamflow at Keokuk and St Louis between 1965 and 1992.

FLOODS OF 1993, 2008 AND HISTORICAL EVENTS

Some of the variability on the flood flow is shown in terms of Top Ten Floods on the Mississippi River at Clinton, Keokuk and St. Louis through 1993. These values are given in Table 2.

The next analysis will show the top ten stages at two Gaging stations along the Mississippi River at St. Louis and Chester. It should be noted that the Gaging Station at St. Louis is about 113 km upstream of the Gaging Station in Chester along the Mississippi River. The stages arranged in a descending order do not necessarily correspond to the flow also in the same order. The stages along a river is a function of not only the flows but also a variety of constraints such as, constriction within the waterway, flows within the floodplain, storage within the floodplain, antecedent moisture content, tributary inputs, levees, levee breaches and others. Table 3 and 4 show the Ten Highest known Flood stages at St. Louis and Chester along the Mississippi River.

Table 2: Top Ten Flood Discharges on Record at Clinton, Keokuk and St. Louis through 1993, (flows are given in cubic meters per second)

Clinton		*Keokuk*		*St. Louis*	
Date	*Peak Flow*	*Date*	*Peak Flow*	*Date*	*Peak Flow*
April 1965	8,690	July 1993	12,300	August 1993	29,170
June 1880	7,080	April 1973	9,740	Jun, 1903	28,850
May 1888	7,020	May 1965	9,260	May 1892	26,220
July 1993	6,930	May 1888	8,890	April 1927	26,200
June 1892	6,740	June 1892	8,660	June 1883	24,400
Nov. 1881	6,710	Nov. 1881	8,300	July 1909	24,350
April 1969	6,540	April 1960	8,200	April 1973	24,100
April 1952	6,400	June 1880	7,670	June 1908	24,000
April 1920	6,300	June 1903	7,650	April 1944	23,900
April 1951	6,270	Oct. 1986	7,600	May 1943	23.800
Discharge estimates outside of the record					
		June 1951	10,200	April 1785	38,230
				June 1844	36,800
				June 1850	29,850
				June 1855	29,700
				June 1851	28,900
				1828	28,300

Table 3: Ten Highest Known Flood Stages at St. Louis, MO, River Km 290

Order	Date of Crest	Stage (m)	Estimated Peak Discharge (cubic meters/sec)
1.	August 1, 1993	15.12	29,200
2.	April 28, 1973	13.19	24,100
3.	June 27, 1844	12.60	36,800
4.	July 22, 1951	12.29	22,100
5.	July 02, 1947	12.28	22,200
6.	May 24, 1943	12.18	23,800
7.	April 30, 1944	11.94	23,900
8.	July 01, 2008	11.74	20,400
9.	June 10, 1903	11.59	28,900
10.	June 1850	11.32	29,800

Table 4: Ten Highest Known Flood Stages at Chester, Illinois, River KM 177

Order	Date of Crest	Stage (m)	Estimated Peak Discharge (cubic meters/sec)
1.	August 6, 1993	15.17	30,000
2.	April 30, 1973	13.21	25,100
3.	July 02, 2008	12.02	19,800
4.	July 22, 1951	11.99	22,500
5.	July 03, 1947	11.64	25,000
6.	May 24, 1943	11.61	24,700
7.	May 02, 1944	11.41	23,800
8.	July 15, 1969	10.90	NA
9.	Nov. 23, 1985	10.72	17,600
10.	April 27, 1927	10.49	30,000

The above two tables shows quite clearly that the order of the flood stages do not always coincide with the order of the flood peak values.

Over the last 100 plus years significant amount of land use changes have taken place over the entire Mississippi River basin. The corridor of the Mississippi River used to contain a majority of the wetlands in the USA. Over the years most of the wetlands have been drained, tiles have been installed, many streams and rivers channelized, forest cleared to facilitate the agricultural development and urban construction. The river has also been constrained by the construction of levees. Most of the levees were constructed for agricultural purposes or for river training works. Some of the levees were constructed to protect urban areas also.

All these changes have altered somewhat the hydrology and hydraulics of the river. Consequently the flood stages have altered in some places. In some areas, the floodplains do not convey water during flooding season. In many areas, the floodplains act as a storage reservoir rather than as a conveyance channel. Consequently, during extreme flooding events, the river is always attempting to recreate its old floodplains. There are many example of this activity by the Mississippi and Missouri Rivers in the USA and these became quite evident during the Great Flood of 1993.

LEVEE BREACHES

Levee failures during a flooding event could result from a variety of physical, hydraulic, geotechnical, biological and or human induced conditions. During the Great flood of 1993 and those during the 2008 flood, most of these causative factors were instrumental in the failure of levees. Most of the agricultural levees along the Mississippi, Missouri and Illinois Rivers are constructed with sandy materials. Seepage through the levees can and will cause the land-side of the levee sloughing resulting in the failure of the toe and ultimately the levees. Many times it was observed that sand boils were created due to differential pressures between the river-side and land-side of the levees and these boils created seepage holes which ultimately resulted in the failure of the levees. In some instances levees failed by simple over-topping due to extreme high water level within the river. Wave actions due to natural causes or by the river traffic could also result in levee failure when the wave heights are more than the free-board of the levees.

An analysis of the locations of the failed levees along the Missouri River during 1993 flood showed that 72% of the levee failure occurred in areas occupied by one or more active channels within the last 20 years. 17% of the levee failures occurred along downstream channel banks between the initiation and inflection points of meanders. Areas along tributary channels subjected to significant cross flow conditions during flooding also resulted in about 17% of the levee failures. Other areas where levee failures occurred included along chutes or minor subsidiary channels.

All the levee failures were associated with the development of significant scour holes. During the Great flood of 1993 and along the Lower Missouri River between Kansas City and St. Louis, more than 500 scour holes developed due to levee failures. Some of the scour holes scoured sediment up to the Holocene-age sediments (IFMRC, 1994). Table 5 shows number of levees that failed during the Great Flood of 1993 (Meyers and White, 1993).

Table 5: Levee Failures during the Great Flood of 1993 on the Mississippi and Missouri Rivers

Levee Designation	*Total number of Levees*	*Levee Damaged*	*% of the Levees*
Federally Constructed & Maintained	15	3	20
Federally Constructed & Locally Maintained	214	36	16.8
Subtotal of Federally Constructed Levees	229	39	17
Not Federally Constructed And Locally Maintained	1,347	1,043	77
Total	1,576	1,082	68.7

Thus during the 1993 flood 68.7% of the levees failed for one reason or other. The analysis for the 2008 spring flood on the mid section of the Mississippi River is not yet complete. It must be pointed out that the extent of the 1993 flood was significantly larger than that of the 2008 flood. Levees did fail during the 2008 flood but those essentially confined to the Mississippi river and few of its tributaries. Figures 3 and 4 show two photographs of levee breaches from the 1993 flood.

Figure 3 shows a single levee breach during the initial stages of the levee failure, whereas Figure 4 shows levees breaches on two sides of the Illinois River. In this photograph the Illinois River is in the mid areas flanked by tree lines within the confines of the levees on both sides. From Figure 4 and looking straight at the illustration, it is obvious that the water level on the left side of the river, was higher that that on the right side of the photograph. Thus once levee failed at an upstream part of the river, the floodplain on the left filled up with water and as the water level increased it put tremendous amount of pressure on the right side levee which subsequently breached probably due to differential hydrostatic pressure.

Fig. 3: A Levee Breach during the 1993 Flood, Photographs by the US Army Corps of Engineers

Fig. 4: Two Levee Breaches during the 1993 Flood on the Illinois River, photograph by M. Demissie of the Illinois State Water Survey

LEVEE BREACHES AND RIVER STAGES

There has been tremendous amount of discussions on the effects of levees on the flood stages. It is true that levees do and will constrict the river-floodplain thus reducing the conveyance of the entire channel. The stage is of course a function of many parameters including flow area, roughness coefficient, slope, and others. Once the levee constricts a channel, the stage should increase if all other variables remain constant. However, in order for the stage to decrease when the levees are removed, the floodplain and the river must convey water proportionate to their respective flow area. This basic concept has been illustrated by Bhowmik and Demissie (1982).

During and after the 1993 flood, discussions were held at the State, Federal and local levels whether or not some of the levees should be removed so that the river can covey the water on a large and broader area consequently reducing the flood stages. The major problem with this concept is that most of the floodplains within the levees have already been developed and the flow within the levee can no longer be in a state of free flowing thus conveying proportionate amount of water. Thus the floodplains within the levees do act more or less like a storage reservoir rather than as a conveyance channel. Figure 5 shows this effect quite clearly for a segment of the Mississippi River near Quincy, Illinois. This illustration is after McConkey *et al.* (1994).

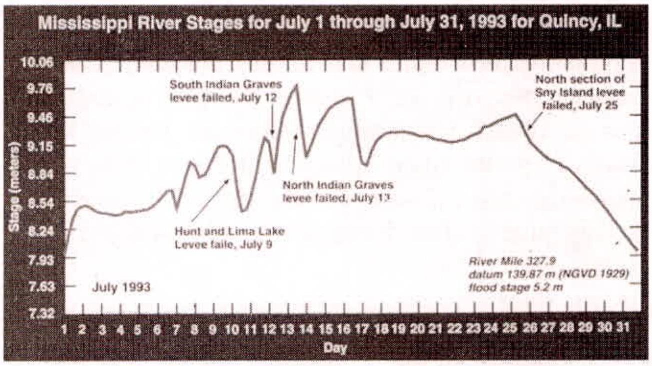

Fig. 5: Flood Stages at Quincy, Illinois during the month of July, 1993, After McConkey *et al.* (1994)

This figure shows that every time a levee failed, the stage within the river dropped but it did not last for longer than one to two days. After that, the river stage started to climb and reached more or less the trend that has already been set. This became true for almost all the levee failures at this location. This clearly illustrates that once the levee failed, the floodplains filled up with water and then it started to act like a storage reservoir rather than as a conveyance channel, same concept illustrated by Bhowmik and Demissie (1982). In order to reduce the flood stages once the levees are removed, the floodplain must be able to convey the water rather than store the same.

FLOOD DAMAGES

The IFMRC (1994) estimated that the 1993 flood on the Upper Mississippi and the Missouri Rivers has caused an estimated damage of about $12 to $13 billion. Out of this damage about 4 to 5 billion was associated with the agricultural damages. The total damage due to 2008 flood on the mid-section of the Mississippi river has not yet been estimated accurately.

DAMAGES PREVENTED

The IFMRC estimated that the flood control measures implemented over the years have prevented significant amount of flood damage. The estimated value is about \$19.1 billion for the 1993 flood. Out of this damage, about \$11.5 billion was on the Missouri river basin. Again, no estimate on the damages prevented during the 2008 flood is available at this time.

FLOOD DURATION

The longest duration of floods along the Upper Mississippi River was that of the 1993 flood. Table 6 shows the duration of flood for a few selected measuring stations along the Mississippi River bordering the State of Illinois. The flood duration indicates the number of days when the water level within the river stayed at or above the flood stage. Longer duration flood do impart larger damages due to the submergence of the flood-plains and the areas around it.

Table 6: Duration of River Stages Exceeding Flood Stages on the Mississippi River along the State of Illinois

Station	*River KM*	*1965 Flood*	*1973 Flood*	*1993 Flood*	*2008 Flood*	*Flood Stage (m)*
St. Louis	290	2	77	146	31	9.2
Chester	177	17	97	195	43	8.2
Thebes	70			167	37	10.1

The River KM shown in Table 6 starts at '0' at the confluence of the Mississippi and Ohio Rivers near the City of Cairo in Illinois. This confluence is 70 KM downstream of the Station at Thebes. The above table shows quite vividly that the 1993 Flood has been the greatest flood since record keeping was initiated.

WATER QUALITY IMPACTS

Any and all floods do and will move tremendous amount of water to the receiving body of the ocean or bay. For the Mississippi River, it is the Gulf of Mexico that receives not only a vast quantity of water but also the farm chemicals and other chemicals including sediments delivered by the river. Since this river drains more than 40% of the continental United States and that this part of the country is also the bread-basket of America, it does transport significant amount of farm chemicals. During the 1993 flood extensive amount of water quality data were collected by the United States Geological Survey as reported by Goolsby *et al.* (1993). Some of the data reported by Goolsby *et al.* (1993) are giver in Table 7.

All the numbers shown are in kilograms per day. Also please note that the measurements at Baton Rouge include the amount of herbicides diverted from the Mississippi River into Atchafalaya River. For those who are not familiar with the Lower Mississippi River, it should be noted that the Mississippi River has a distributary channel called Atchafalaya River which drains somewhat directly to the Gulf of Mexico. A river control structure has been constructed at the confluence of the Atchafalaya and the Mississippi river to prevent the complete diversion of the Mississippi river through the Atchafalaya River during flood stages. Atchafalaya River has a shorter distance to travel before it joins the Gulf of Mexico.

The amount of atrazine delivered to the Gulf of Mexico by the Mississippi River from April to August of 1993 was 539,000 kg. This was 85 and 235 percent higher than the loads delivered during the same period in 1991 and 1992, respectively. About 825 metric tons of nitrate-nitrozen were discharged to the Gulf of Mexico from April–August 1993, a value 37 and 11 percent greater than loads for 1991 and 1992, respectively (Goolsby *et al.*, 1993).

Table 7: Largest Daily Load Estimates for Herbicides at Three Sampling Sites on the Mississippi River (after Goolsby *et al.*, 1993)

Herbicide Year	*Clinton, IA*			*Thebes, IL*			*Baton Rouge, LA*		
	1991	*1992*	*1993*	*1991*	*1992*	*1993*	*1991*	*1992*	*1993*
Atrazine	530	96	780	3,620	1,780	6,240	6,060	2,330	7,110
Alachor	260	27	180	780	160	780	840	210	760
Cyanazine	310	100	750	2,980	890	4,180	2,930	980	3,130
Metolachor	190	46	380	1,830	430	2,400	2,280	1,080	2,250

LESSONS LEARNED

Floods on the Mississippi river did teach us a variety of lessons on the behavior of large rivers. Rivers do need their floodplains to convey the water and that's why it is called 'floodplain'. Moreover floods have occurred in the past and will occur in the future. The Great Flood of 1993 on the Mississippi, Missouri and Illinois Rivers and the subsequent floods on these rivers have also taught us some valuable lessons that must be kept in mind as the society proceed to manage rivers, floods, floodplains, and the watershed. An integrated management of the entire watershed is absolutely necessary to not only manage the floods or floodplains but also to manage the watershed for ecological viability.

A dynamic balance exist in any river system between its water volume, sediment load, gradient and river sediments. Any alteration in any one of these parameters will and do have an equivalent change in other parameters. Extreme floods will create new meander loops or reestablish older loops. It is imperative that a clear understanding is needed to the concept of the 'memory' of the river which is much longer than the memory of the 'human life'. This became extremely clear during the 1993 flood on the Missouri river where many of the cutoffs were breached and the river established the old meander loops. Many of the river bank erosion took place on the outside bank of the river as it should have taken place. Levees and river protection works should not be placed close to the river and thus hampering the conveyance of the river floodplain complex. One of the main reasons of levee failure was seepage through the levees constructed mostly with sandy soils. Data collected showed that the river at many locations scoured during the rising stages of the river and then partially filled during the falling stages of the river.

The confluences of large rivers are very dynamic. During the 1993 flood at least on two locations, the rivers tried to make a cutoff and shortened its lengths. This happened at the confluence of the Missouri and Mississippi Rivers where the Missouri river tried to create a channel shortening its length by about 20 KM. Fortunately the cutoff did not materialize due to some stabilization work that was done on a railroad track. Another area that a cutoff almost took place was at the confluence of the Ohio River with the Mississippi River. Here about 25% of the flow moved through the cutoff. Before the Mississippi was able to create a new channel, some preventive measures were undertaken to stop the cutoff from taking place. These two and many other dynamic behavior by these two great rivers during the 1993 flood showed that the rivers do remember their old channels and that they will try to recreate the same channel if sufficient water for a longer duration is available to the river.

FLOOD CONTROL OR FLOODPLAIN MANAGEMENT?

Society has debated for many years whether or not it will be prudent to work actively to control the floods or the resources should be spent to manage the floodplains. Floodplains being the most fertile ground on an watershed and the river being the main transportation artery for the original settlers, almost all the major cities of the world were settled along river banks. The original settlements were done mostly within the floodplains. The United States House document 465 of the 89th Congress, Second Session, August 1966 declared that " *Floods Are an Act of God: Damage Results from Acts of Men*". Floods are natural and recurring and that the flood risks can never be eliminated. Flood management need to be focused on the floodplains.

Flood could be controlled to some extent by building large detention reservoirs which ultimately will fill up with sediments. Other actions on the watershed could include land use changes, reforestation, building of wetlands, water storage within the entire watershed, enhanced floodplain conveyance, and installation of gates on the agricultural levees. If gates are installed on the agricultural levees, then those gates could be opened during the flood to store the excess water within the agricultural land to prevent high water levels downstream and thus may be protecting high value urban areas. It may be wiser to concentrate on floodplain management.

Floodplain management should include three steps: avoid if possible, protect if it can be done, and finally insure the property if other alternatives can not be implemented. The strategy of the floodplain management should include a shared responsibility, shared challenge and a share in the solutions. Any of the management options had to have multiple objectives with multiple agencies, communities, individuals and a basin wide evaluation. An institutional framework must also be established to coordinate the work. Human health and welfare including the ecological health of the river must also enter in the equation. Finally a performance evaluation had to be included in all the activities.

Future floodplain management will require a system wide evaluation including some projections of the future growth within the watershed and the river corridor. After all, designing floodplain management with the present hydrology may not be valid in the near future when the floodplain and the watershed may be altered completely. Better hydrological predictive relationships will assist in this analysis.

SUMMARY

Floods are recurring phenomena and nobody can or will be able to prevent flooding in the future. It will be wiser to concentrate on the floodplain management rather than trying to control flood altogether. This paper essentially concentrated on two floods, one the Great flood of 1993 on the Upper Mississippi, Missouri and Illinois rivers and the one in 2008 essentially within the mid-section of the Mississippi River. The 1993 flood had one of the largest durations in history, broke numerous records, discharges were at the record levels from Keokuk to St. Louis. This flood also breached 1,082 levees. Both the rivers also attempted to change their courses at several locations. The environmental impacts included both positive and negative aspects. Tremendous amount of farm chemicals were transported by the river including quite a bit of fresh water to the Gulf of Mexico. On the other extensive flooding of the floodplain created newer and desirable fish habitats resulting in better stock of fishes within and outside of the river.

The 1993 flood is also associated with about 12 to 13 billion dollars in damages. However, at the same time the flood control activities implemented historically also prevented about 19.1 billion dollars damages. Rivers demonstrated that it needs its floodplains to convey flood water. Rivers also showed that its memory is much longer than the human memory. It is much more expedient to work with the nature than working against it. The future of floodplain management had to include a multi-objective and multi-dimensional process including a variety of people. The society and the managers must be able to predict what would be the watershed characteristics in the future before some actions are implemented. It might be expedient to mange the floodplains not necessarily the floods.

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Decadal Drought Analysis Using GCM Outputs

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ABSTRACT: With increasing water scarcity around the world, exacerbated by drought incidences in terms of spatial and temporal variation along with the uncertainties associated with climate change, attention must focus on better understanding of different aspects of droughts. This paper discusses the impact of climate change on decadal drought severity and drought duration based on future climate scenarios derived from GCM outputs using downscaling techniques. It is observed that high drought severity and drought duration likely to be occurring for decades 2031–2040, 2041–2050, 2061–2070, and 2081–2090. The least drought decades are likely to be observed during 2021–2030 and 2081–2090. The observations were made based on short-term drought indices (SPI 1 and SPI 3).

INTRODUCTION

Droughts are considered by many to be the most complex but least understood of all natural hazards affecting more people than any other hazard. Droughts are a normal feature of climate and their recurrence is inevitable. However, there remains much confusion within the scientific and policy making community about their characteristics. Research has shown that the lack of a precise and objective definition in specific situations has been an obstacle to understanding droughts which has led to indecision and inaction on the part of managers, policy makers, and others (Wilhite *et al.*, 1986). Droughts have been recognized as one type of environmental disaster and have attracted the attention of environmentalists, ecologists, hydrologists, meteorologists, and so on. The global climate change in recent years is likely to enhance the number of incidence of droughts. While much of the weather that we experience is brief and short-lived, a drought is a more gradual phenomenon, slowly taking hold of an area and tightening its grip with time. In severe cases, a drought can last for many years, and can have devastating effects on agriculture and water supplies. Nearly 50 percent of the world's most populated areas are highly vulnerable to droughts. More importantly, almost all of the major agricultural lands are located there (USDA, 1994). Droughts produce a complex web of impacts that span many sectors of the economy and reach well beyond the area experiencing a physical drought.

Since almost one-half of the earth's terrestrial surface is susceptible to droughts, they are widespread phenomenon having significant social, economic, and environmental impacts. Human civilization has long been deeply affected by the impacts of droughts on economic, environmental, and social sectors (Wilhite, 1993). Only in the current decade large-scale intensive droughts have been observed on all continents. Droughts are the most costly natural disaster (FEMA, 1995; Wilhite, 2000; Svoboda *et al.*, 2002). Of all the 20th century natural hazards, droughts are those that have had the greatest detrimental impact (Bruce, 1994; Obasi, 1994). But droughts are not easily defined and need to be understood in terms of their hydrological, agricultural, and socio-economic impact (Dracup *et al.*, 1980; Wilhite and Glantz, 1985). Droughts impact both surface and groundwater resources and can lead to reductions in water supply, diminished water quality, crop failure, reduced range productivity, diminished power generation, disturbed riparian habitats, and suspended recreation activities, as well as a host of other economic and social activities (Riebsame *et al.*, 1991).

Due to population growth and expansion of agricultural and industrial sectors, the demand for water has increased in many parts of the world. Many other factors, such as climate change and contamination of water supplies, have contributed to water scarcity. The flood and drought events have been experienced with higher peaks and severity levels. The period between extreme events has been shortened in certain regions.

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