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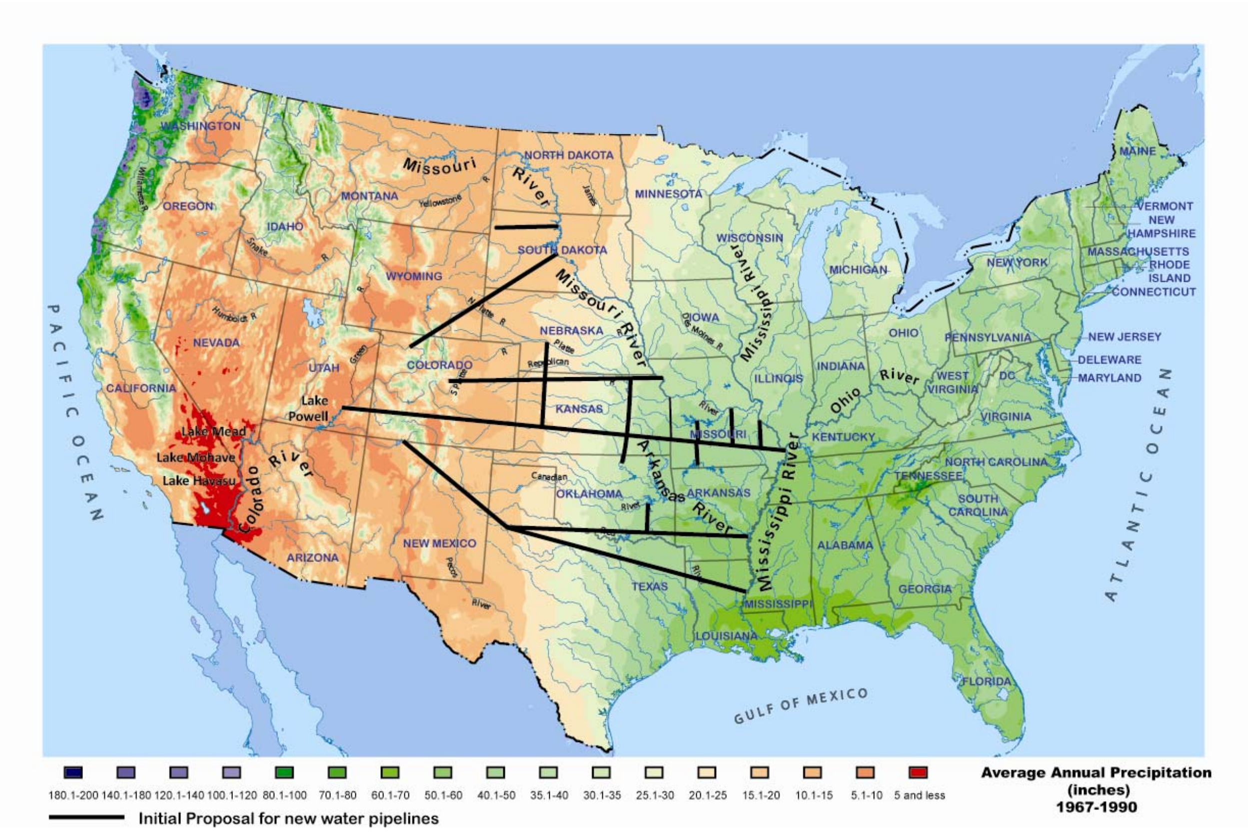
NATIONAL SMART WATER GRID™



AMERICAN FRESH WATER MANAGEMENT | RONALD A. BEAULIEU

Disclaimer

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NATIONAL SMART WATER GRID™

PUMP FRESH WATER FROM MISSISSIPPI, ARKANSAS, AND MISSOURI RIVERS TO THE COLORADO RIVER AND WESTERN STATES

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ABSTRACT

The United States repeatedly experiences floods along the Midwest's large rivers and droughts in the arid Western States that cause traumatic environmental conditions with huge economic impact. With an integrated approach and solution these problems can be alleviated. Tapping into the Mississippi River and its tributaries, the world's third largest fresh water river system, during flood events will mitigate the damage of flooding and provide a new source of fresh water to the Western States. The trend of increased flooding on the Midwest's large rivers is supported by a growing body of scientific literature. The Colorado River Basin and the western states are experiencing a protracted multi-year drought. Fresh water can be pumped via pipelines from areas of overabundance/flood to areas of drought or high demand. Calculations document 10 to 60 million acre-feet (maf) of fresh water per flood event can be captured from the Midwest's Rivers and pumped via pipelines to the Colorado River and introduced upstream of Lake Powell, Utah, to destinations near Denver, Colorado, and used in areas along the pipelines. Water users of the Colorado River include the cities in southern Nevada, southern California, northern Arizona, Colorado, Utah, Indian Tribes, and Mexico. The proposed start and end points, and routes of the pipelines are documented, including information on right-of-ways necessary for state and federal permits. A National Smart Water Grid™ (NSWG) Project will create thousands of new jobs for construction, operation, and maintenance and save billions in drought and flood damage reparations tax dollars. The socio-economic benefits of NWSG include decreased flooding in the Midwest; increased agriculture, and recreation and tourism; improved national security, transportation, and fishery and wildlife habitats; mitigated regional climate change and global warming such as increased carbon-capture; decreased salinity in Colorado River water crossing the US-Mexico border; and decreased eutrophication (excessive plant growth and decay) in the Gulf of Mexico to name a few. The National Smart Water Grid™ will pay for itself in a single major flood event.

EXECUTIVE SUMMARY

The National Smart Water Grid™ Project would alleviate fresh-water-related problems for the United States by mitigating floods along the Midwest's Rivers and by providing fresh water to mitigate droughts in the arid Western States. The Mississippi River has the third largest drainage basin in the world, exceeded in size only by the watersheds of the Amazon and Congo Rivers. The Mississippi River Basin covers more than 1,245,000 square miles, includes all or parts of 31 states and two Canadian provinces, and roughly resembles a funnel that has its spout at the Gulf of Mexico. Captured flood water can be pumped via pipelines from areas of flood to areas of drought or high demand.

Where will the money for infrastructure construction and operations come from? Sale of captured fresh water! The value of 60 maf fresh water is estimated between $30 B and $140 B and could be realized from the capture of water from a single major flood. Floods are anticipated to repeat frequently. Even minor floods will provide the opportunity to capture large volumes of fresh water. ***Thus, the National Smart Water Grid™ will pay for itself in a single major flood event.***

Water will be captured only during flood events at or above the regulated surface elevation, defined as Action Stage Level, and transported via pipelines to reservoirs along the pipeline routes and to approved destinations. The amount of water available for capture ranges from 0.5 maf to 60 maf per flood event, depending directly on the rainfall that causes the flood. This fact is supported by data diligently collected by several U.S. agencies and documented in this report.

The National Smart Water Grid™ Project will take many years and could be built in phases. The first phase could provide the most flood relief and deliver water to the most impacted drought areas. Subsequent phases could be built according to available resources and associated needs.

The National Oceanic and Atmospheric Administration (NOAA) provide real time data on river hydrology, including precipitation and river water level, using gauges. New slotted drains over arch-pipes integrated into levee walls could capture water at flood level and gravity feed flood water to interim storage tanks. Huge pumps that auto-activate at high water and work continuously until the flood subsides would draw the water from interim storage tanks and transport it through interstate pipelines. NOAA's predictive modeling of precipitation and water level could determine when and how much water can be captured from the river at specific locations and transported away from the river to mitigate the flood consequences. Smart grids use digital technology that allows utilities to monitor the water system more closely, improving system reliability. The communications system that controls movement of the captured flood waters could be integrated into lock-and-dam operations and should be easily upgraded as technology improves. Use of smart-grid technology provides energy efficiency by running the pumps only when needed to maximize flood water capture and for ozone injection (water treatment). Sensors and meters can detect the volume of water in storage and in the pipelines and direct the flow along the routes.

House of Representatives (H.R.) Bill 135 (Twenty-First Century Water Commission Act of 2009) would establish the Twenty-First Century Water Commission to study and develop recommendations for a comprehensive water strategy to address future water needs. H.R. 135 was introduced and supported by U.S. Representative John Linder, Georgia's 7th District. A new bill, National Smart Water Grid Act of 2009, could hash out the additional details regarding this proposal. The National Smart Water Grid Commission could be established to manage fresh water in the Midwest and West, implement the ideas in this proposal, and offer new recommendations for better fresh water management in the nation as a whole.

The use of fresh water is of significant importance to National Security, economic security, and the environment and should not be determined solely by those charged with its day-to-day management. As documented in other U.S. governmental studies, fresh water management and use reached parity with other issues of importance to the United States such as National Security. Fresh water use directly affects energy use, and both are interrelated. Thus, it would be appropriate to establish a National Water Commission to provide direction to key decision makers.

National leaders and decision and policy makers in the United States should have reliable information such as that provided by leading universities and national laboratories (e.g., Lawrence Livermore National Laboratory). Once the Commissions are established and armed with data from scientists and engineers, they can proactively address climate change and prepare for the increasing frequency of heavy precipitation events (or proportion of total rainfall from heavy falls) that has and will continue to significantly increase in the Midwestern States.

Water conservation is an important aspect of decreasing demand, but is not the sole solution. Population growth projections provided by the U.S. Census Bureau clearly demonstrate huge increases in Western States. Current water consumption is not sustainable. Demand is projected to increase as competing entities fight for a limited and finite, vital national resource.

Flood waters could be redistributed from flood-stricken areas to drought-prone areas—governments willing. The National Smart Water Grid is similar in magnitude to other large projects such as TVA, the Hoover Dam, Bonneville Power, the Transcontinental Railroad, the interstate highway program, and other innovative infrastructure projects of the past. Building the National Smart Water Grid will require Congressional Appropriations and Presidential approval.

Development of this idea requires preparation of an Environmental Impact Statement (EIS), according to 40 CFR 1502 and requirements in the National Environmental Policy Act (NEPA) Process, including detailed Rights of Way—from origins to destinations. Analytical data input to the NEPA process include details of where the water is captured, the specific routes that the pipelines take, where the water is distributed and in what volume. An important component of an EIS is evaluation of alternatives to the proposed solution.

Help in the obtaining ROWs in the affected corridors is requested. Revenue sharing and fresh water sharing are ways to compensate for ROWs and are considered incentives for governments that enable this project to proceed. The specific routes for the pipelines are proposed but not yet finalized.

The Colorado and Mississippi River systems are politically separated by geographic boundaries, different federal agency jurisdictions, and applicable river water use laws. For this National Smart Water Grid Project to succeed, these separations must be overcome; existing laws could be amended. The National Smart Water Grid will provide overarching prosperity to and commonwealth of the United States.

INTRODUCTION

The author has written this report from the perspective of a citizen engineer looking at potential integrated solutions to an existing national fresh water crisis. He conceived the idea of the National Smart Water Grid (NSWG) through first-hand experience of the effects of flooding and the massive levees and flood walls in cities along the Midwest Rivers, while living in the arid west. He has worked in emergency management assignments post Hurricanes Katrina and Rita in New Orleans and in southern Mississippi and along the Mississippi, Ohio, Illinois, and Arkansas Rivers as well as and other Midwest Rivers from 1981 to 2008. He has driven back and forth across the country and flown over the landscape from northern to southern California and to Las Vegas, Denver, Kansas City, St. Louis, and Paducah seeing the changes to our country, farms, and cities over the last 20 years. The NSWG incorporates a "No Adverse Impact" approach and is an integrated tool for fresh water management. It is not yet in the hands of the U.S. Army Corp of Engineers (USACE) and the U.S. Bureau of Reclamation (USBR), but it could be soon.

Documented in this report are the national problems caused by floods in the Midwest, the droughts in the West, the existence of climate change, increased fresh water demand, population migration and growth, and regional climate changes, and solutions for these fresh water management problems. Also documented are historical floods in the Midwest's large rivers caused by rapid snow melt and excessive precipitation (i.e., heavy rainfall in the river basin). Flood events more than 20 years ago show the effects of high river stages prior to the present infrastructure and recent climate change. Events that occurred in the last 20 years are more representative of what one may expect in the near term (e.g., 10 to 30 years). This discussion is derived from research into the hydrology of the Mississippi River Basin.

Vital statistics of the Missouri and Mississippi Rivers with respect to key water flow data are discussed as well as the defined Action, Flood, Moderate Flood, Major Flood Stages, or water height/level at specific locations. This information is used to determine key locations where flood water may be captured along the Mississippi River Basin.

Locations are shown where water may be delivered to provide the maximum benefit for the most diverse uses. In consideration of environmental concerns, no new dams or reservoirs are proposed west of the Continental Divide; the existing infrastructure is underutilized. New reservoirs are proposed in the Midwest States along the pipeline routes to satisfy increased water demand and to promote development.

Suggestions are given for water treatment within the pipeline system downstream from river drainage and upstream of pipeline discharge. Once the water is delivered from the pipelines to reservoirs, the existing surface water treatment systems/processes should be sufficient to maintain compliance with state and federal water treatment regulations. The two separate collections of pertinent laws that govern present regulation and use of the river water in the Midwest Rivers and the Colorado River are discussed, including federal laws pertaining to government-sponsored interstate or interagency projects.

An analogy of a famous pipeline for simple comparison (i.e., the Alaska Pipeline) is presented. Although the Alaska Pipeline is used to transport oil, it is a long-distance (800 miles) pipeline built at a time of great National Security crisis caused by the Arab Oil Embargo of the 1970s. The Alaska Pipeline statistics provide an order of magnitude cost and time estimates for the permitting, construction, operation, and maintenance of the National Smart Water Grid™ pipelines.

Rivers and lakes have many uses, including transportation corridors for barges and other large vessels. Inland waterways can efficiently convey large volumes of bulk commodities over long distances. On the Mississippi River, convoys of 30 barges (equivalent to 30 jumbo rail cars or 110 normal trucks) are common unless the river is at flood stage. A flood can force suppression of river barge traffic and nearby railroad and highway traffic.

Recreational uses of rivers and lakes include boating, water-skiing, swimming, hiking, camping, fishing, and tourism among many other uses. Recreation is severely impacted by floods and droughts.

Fresh water consumption includes drinking water, agricultural irrigation, industrial use, and power plant cooling to name a few examples. Hydro-electric power production, electricity generation uses much water, but does not fully consume it.

Water conservation is an important aspect of decreasing demand, but it is not the sole solution. Population growth projections provided by the U.S. Census Bureau clearly demonstrate huge increases in Western States. The logical conclusion arises that current consumption is not sustainable, let alone increased demand, as competing entities fight for a limited and finite, vital national resource.

Demand for fresh water continues to increase. 70 percent of the fresh water the world uses is for agriculture, while industry uses 20 percent. Fresh water is becoming scarcer, raising a concern that so-far manageable price increases could spike. Careful land use management would help decrease waste, but increased economic growth and other factors will lead to demand outpacing supply.

This report shows that an infrastructure construction of magnitude of the National Smart Water Grid will have a net positive impact on Gross Domestic Product and a potential reduction in the government's budget deficits as water sales exceed cost. The benefit of the sale of captured water and a reduction in costs from flood and drought damage will be more than sufficient to build the National Smart Water Grid. Flood waters could be redistributed from the flood-stricken areas to drought-prone areas—governments willing. However, the National Smart Water Grid will require Congressional Appropriations and Presidential approval.

FLOODS IN THE MIDWEST

Midwest River Floods Historical Information

According to the USACE web site, the volume of water flowing through the Mississippi River during the GREAT flood was 2,500 thousand cubic-feet per second (kcfs) in 1927 while the 1993 flood was 1,000 kcfs. The cost of damages was $4.4B and $7.5B for the 1927 and 1993 floods, respectively, expressed in 1993 dollars. Any single major flood event that tops the levees could cost $30B or more in current dollars in damages alone. The USACE estimated the 2008 flood could have had $27B in damages. Lost productivity and loss of human life (52 dead and 75,000 displaced in 1993) are not even included in these estimates. Whenever the rivers are at or above flood stage, transportation of river traffic, such as barges and tugboat, must be suspended or numerous boating accidents could occur. Alternate and more expensive transportation, primarily by railroad, is used instead of river traffic. These costs of alternate transportation are not included in the above damage estimates.

Garciliaso de la Vega, in his history of the expedition begun by DeSoto, described the first recorded flood of the Mississippi as severe and of prolonged duration, beginning about March 10, 1543, and cresting about 40 days later. By the end of May, the river had returned to its banks, having been in flood for about 80 days. The floods of 1849 and 1850, which caused widespread damage in the Mississippi River Valley, revealed the national interest in controlling the mighty river.

In 1882, one of the most disastrous floods ever known devastated the entire delta area. The losses were appalling. During that flood there were hundreds of carcasses, and the outlook for a permanent solution to flooding in the Mississippi Valley was disheartening.

Major floods again occurred in 1912, 1913, and 1927. The flood of 1927 was the most disastrous in the history of the Lower Mississippi Valley. An area of about 26,000 square miles was inundated. Levees were breached, and cities, towns, and farms were laid waste. Crops were destroyed, and industries and transportation paralyzed.

Property damage amounted to about $15 billion at today's prices. Over 200 lives were lost and over 600,000 people displaced. Out of it grew the Flood Control Act of 1928, which committed the federal government to a definite program of flood control and authorized the Mississippi River and Tributaries Project, the nation's first comprehensive flood control and navigation act.

Other severe flooding events occurred in 1937, 1965, 1973, 1982, 1993, and 2008. The severe flooding in 1993 is considered to be the most devastating in recorded U.S. history. It affected the upper and middle Mississippi Valley from late June until mid-August 1993 with record levels on the Mississippi River and most of its tributaries from Minnesota to Missouri. At St. Louis, the river remained above flood stage for over two months and crested at 49.6 feet (19 feet above flood stage). Industry and transportation along the Mississippi were virtually at a standstill during the summer months of 1993. In all, over 1,000 of the 1,300 levees in the Mississippi River system failed, over 70,000 people were displaced, nearly 50,000 homes were either destroyed or damaged, 12,000 square miles of agricultural land was unable to be farmed, and 52 people died. Fortunately, larger cities along the Mississippi remained protected by floodwalls. The cost of the flood was enormous. Most estimates of total flood damage run to nearly $20 billion in today's dollars. Data of Mississippi River Basin floods include:

Mississippi River

January and February 1937
Death Toll: 1,100
Heavy rains flooded 12,700 square miles, destroying 75,000 homes, and leaving 600,000 refugees.

April – May 1912
Death Toll: 200
The Mississippi River overflows its banks.

April 22, 2008
The flow measured 1.8 million cfs, which is more than 500 kcfs above Action Stage. The flood was caused by intense rainfall throughout the central plains and Ohio River valley in March and April that had by April 22 reached the Vicksburg, Mississippi in the Lower Mississippi River Basin. Flood mitigation by USACE included:

- 701 USACE employees responded (does not include National Guard in the hundreds)
- Sandbags provided: 14 million
- Pumps provided: 130
- Plastic sheeting provided: 3,744 rolls
- Water provided: 450,000 gallons
- Flood damages prevented: $27 billion

Missouri River at Kansas City, Missouri

May 16 - June 1, 1903
Death Toll: 200
Heavy rains brought flooding that raised the level of the Missouri River 35 feet.

Ohio River

March, 1913
Death Toll: 700
Heavy rains brought severe flooding. The disaster led to the nation's first flood control board and programs.

Arkansas River

Mother's Day 1970; June 8, 1974; and Memorial Day 1976.

Memorial Day weekend, 1984
Death Toll: 14
Heavy rains brought severe flooding especially in 1984; 3,500 families were forced out of their homes, damaged 7,000 houses and businesses and cost Tulsa, OK between $150 million and $180 million, depending on the source. Overall, Michael. (2009).

One can draw a reasonable conclusion using historical data combined with hydrology data that most flooding occurs due to heavy precipitation from February to October depending on where the precipitation falls and how the hydrology in the river basin channels the water. Historical flood data for the Mississippi River at Cape Girardeau is shown in Table 1, which documents the top 10 historical crests. Eight crests were greater than 42 ft (Major Flood Stage) that caused extensive damage to Cape Girardeau and over 100,000 acres were flooded in each event. The data is typical of each city along the river.

Table 1. Historical Flood Crest Data for the Mississippi River at Cape Girardeau.

#	Top Ten Historical Crests	Ft	Flood Impacts
1	48.49 ft on 08/08/1993	48.5	This flood will exceed the highest stage on record by just 0.01 in.
2	47.00 ft on 05/24/1995		
3	46.90 ft on 08/03/1993		
4	45.70 ft on 05/18/2002		
5	45.50 ft on 05/01/1973		
6	44.10 ft on 04/17/1979		
7	42.40 ft on 05/27/1943	43.0	The flood gate on North Main Street closes.
8	42.35 ft on 07/03/2008	42.0	**Major Flood Stage**—many homes in the Cape Girardeau area are affected and evacuations may be required. Over 100,000 acres is flooded. Numerous roads are closed.
9	41.90 ft on 07/05/1947		
10	41.37 ft on 06/24/2008		
	Six of ten historical crests occurred in the last 20 years.	38.0	The flood gate at Broadway closes.
		36.0	The flood gate on Themis Street closes.
		32.0	**Flood Stage**—minor flooding occurs. The Mississippi River backs into several creeks producing flooding.
		29.0	**Action Stage**—the area north of the Little River Diversion Channel begins to flood.

Cape Girardeau, Missouri is located along the Upper Mississippi River and can be seen in Map No. 113 of the Upper Mississippi River Navigation Charts (USACE 2001). The data in Table 1 were extracted from the NOAA Hydrograph taken from gage CPGM7 just north of river mile 52. Of the most severe flood events, two historical crests occurred in 1940s, two occurred in the 1970s, while the remaining six crests occurred in the 1990s and 2000s. The majority of the crests occurred in the last 20 years and demonstrates the increased rate of severe floods.

The USACE has placed water gages along the rivers that indicate the river depth and corresponding calculated flow (kcfs). Many of the gages are monitored in real time by the NOAA, who provides Advanced Hydrologic Prediction Service available on the internet. When one combines data of the Mississippi River Navigation Charts that document the river features showing location of the gages and the Advanced Hydrologic Prediction Service, one can accurately document historical floods and calculate the probability of future floods at specific locations. Since the floods are anticipated events, one can use predictive modeling to determine when and how much water can be captured from the river at specific locations during flood events and transported away from the river to mitigate the flood consequences.

Appendix 1 lists the river water gages located along the Missouri and Mississippi Rivers and the corresponding key features of the river at each location. The data collected include the river surface elevation above mean sea level (amsl) and the river stage data for each gage location. Of particular value is the calculation for flow of water (kcfs) available to drain above the Action Stage. The Action Stage corresponds to the regulated water surface profile below which the river cannot be touched according to the Anti-drawdown Law and general existing river uses. However, the water level above the Action Flood, Moderate Flood, and Major Flood Stages are above where the Anti-drawdown law applies. (See discussion of Mississippi River Law.) The water level above the Action Stage documented in the NOAA Advanced Hydrologic Prediction Service is the flood water available for capture and transport via pipelines. Two examples are provided in Appendix 2.

Midwest River Information

The longest river in the USA is the Missouri River (it is a tributary of the Mississippi River and is 2,540 miles long), but the biggest in terms of water volume is the deeper Mississippi River. The Midwest Rivers are separated from the Colorado River by the Continental Divide. The two river systems are also politically separated by different federal agency jurisdictions and applicable river water use laws. For this National Smart Water Grid project to succeed, both separations must be overcome.

Midwest River Water/Land Use

Agriculture

For nearly 200 years agriculture has been the primary user of the basin lands, continually altering the hydrologic cycle and energy budget of the region. The value of the agricultural products and the huge agribusiness industry that has developed in the basin produces 92% of the nation's agricultural exports, 78% of the world's exports in feed grains and soybeans, and most of the livestock and hogs produced nationally. Sixty percent of all grain exported from the U.S. is shipped via the Mississippi River through the Port of New Orleans and the Port of South Louisiana.

Transportation

The Mississippi, Missouri, and Ohio Rivers form navigation arteries of great importance to the nation's transportation system, carrying an ever-growing commerce and is vital to industry. This heavy commercial traffic includes grains, coal and coke, petroleum products, sand and gravel, salt, sulphur and chemicals, and building materials among others. More than 500 million tons of domestic cargo moves along the Mississippi River system each year. The lower river, which has a relatively narrow but deep channel, is navigable for oceangoing ships upstream to Baton Rouge, La. From there to Cairo a 12 ft deep channel is maintained. From Cairo to Minneapolis and on the other navigable streams (the Cumberland, Ohio, Tennessee, Illinois, Arkansas, and Missouri rivers), a 9 ft deep channel is maintained in most places. About 24,150 km (15,000 mi) of the system are presently navigable, and river traffic has experienced significant growth in recent years. The cargoes transported on more than 8,000 towboats consist mainly of petrochemicals from the Gulf of Mexico and grain from the Midwest. In measure of tonnage, the largest port in the world is located on the Mississippi River at LaPlace, La. Between the two of them, the Ports of New Orleans and South Louisiana shipped more than 243 million tons of goods in 1999.

Industry

The amount of industry and commerce along the Mississippi River Basin is immense and growing. Industry provides jobs, general wealth, tax revenue and contributes substantially to our national security. Industry is a significant user (approximately 20%) of our fresh water.

Recreation/Tourism on the Midwest Rivers

Recreation opportunities on the Upper Mississippi River System are as varied as the river itself. Millions of people visit the area every year to participate in water activities, including boating, hunting and fishing, swimming, or simply enjoying the river's beauty. Annual recreational expenditures on the Upper Mississippi River System exceed $1.2 billion. 2 million acres (land and water) in the Mississippi River Basin including the following amenities:

- 7 national parks
- 444 recreation areas
- 9,526 camp sites
- 33 lakes
- 14 visitor centers
- 329 boat ramps
- 6,074 miles of lake shoreline
- 1,360 shoreline management permits
- $3.3 million annual value of volunteer labor
- 92 concessionaires
- $3 billion annual cumulative value to local economies
- $6.6 million annual user fees

Drinking Water Supply

Communities up and down the river use the Mississippi to obtain fresh water. A January, 2000 study published by the Upper Mississippi River Conservation Committee states that close to 15 million people rely on the Mississippi River or its tributaries in just the upper half of the basin (from Cairo, IL to Minneapolis, MN). The Environmental Protection Agency indicates that more than 50 cities and more than 25 million people rely on the Mississippi River Watershed for daily water supply.

The average American consumes approximately 160 gallons per day.

River Stages

The Corps of Engineers furnishes data on river stages and flows to the National Weather Service (NWS) forecast office in Minneapolis, Minnesota, which has the sole responsibility for issuing public warnings, watches, and statements on current river levels, as well as forecasts of expected flood crests. Daily river stages and flood forecasts are disseminated through the local media as well as the NOAA weather radio, weather wire, and internet. The NOAA weather wire is used by many local civil defense and police agencies.

The flood forecasts issued by the NWS are referenced to elevation in feet above mean sea level (amsl) or to stage, which is measured as the height in feet of the river level above an arbitrary reference point known as the gage datum. Appendix 1 lists the data for the Mississippi and Missouri Rivers.

Since the elevation of the gage datum (zero of the gage) is known, forecasts referenced to stage may be converted to elevation by simply adding the datum elevation to the stage reading. The normal reference used for this purpose is the NWS flood stage at each location or the project pool elevation for each lock and dam pool. With these known reference points, river interests can use the current and forecasted river stages to determine how the forecasted river level relates to local topography. NOAA uses the following terminology when describing floods:

Action Stage — water level above which flooding begins.
Minor flooding — minimal or no property damage, but possibly some public threat or inconvenience.
Moderate Flooding — some inundation of structures and roads near stream. Some evacuations of people and/or transfer of property to higher elevations are necessary.
Major Flooding — extensive inundation of structures and roads. Significant evacuations of people and/or transfer of property to higher elevations are necessary.

Mississippi River

The Mississippi River is the major river of North America and the United States at 2,339 miles (3,765 km) in length and flows from northwestern Minnesota south to the Gulf of Mexico, just below the city of New Orleans. When combined with its major tributaries (the Missouri and Ohio Rivers) it becomes the third largest river system in the world at 3,877 miles (6,236 km) in length. The five largest tributaries of the Mississippi River are the Arkansas, Illinois, Missouri, Ohio, and Red Rivers.

The Mississippi River has the third largest drainage basin in the world, exceeded in size only by the watersheds of the Amazon and Congo Rivers. It drains 41 percent of the 48 contiguous states of the United States. The basin covers more than 1,245,000 square miles, includes all or parts of 31 states and two Canadian provinces, and roughly resembles a funnel which has its spout at the Gulf of Mexico. Waters from as far east as New York and as far west as Montana contribute to flows in the lower river.

Figure 1. Mississippi River and its Cities.

Figure 2. Mississippi River Basin and USACE Tributaries Project Area (Lower Mississippi).

The Upper Mississippi River has a series of 27 locks and dams along its course from Minneapolis/St. Paul, Minnesota to Cairo, IL that are used by the USACE to manage and control the flow of water. The Upper Mississippi River Navigation Charts (USACE 2001) prepared under the direction of the USACE document the navigation regulations for the Mississippi River above Cairo, IL. The Lower Mississippi River Navigation Charts (USACE 2007) document the Mississippi River from the Ohio River tributary (south of Cairo, IL) to the Gulf of Mexico. The navigation charts document the location of gage stations, navigation aids, transportation routes within and alongside the rivers, and significant navigation facilities including the river mile and cities along the river.

The lower alluvial valley of the Mississippi River is a relatively flat plain of about 35,000 square miles bordering on the river which would be overflowed during time of high water if it were not for man-made protective works. Even with the man-made protective works, severe flooding occurs. This valley begins just below Cape Girardeau, Missouri, is roughly 600 miles in length, varies in width from 25 to 125 miles, and includes parts of seven states—Missouri, Illinois, Tennessee, Kentucky, Arkansas, Mississippi, and Louisiana.

The Mississippi carries an average of 436,000 tons of sediment each day. Over the course of a year, it moves an average of 159 million tons of sediment.

Hydrology of Mississippi River Basin

The hydrology of the Mississippi River Basin is well documented in several sources. The Times Atlas (Bartholomew, John 1958) depicts the mean annual precipitation in the Upper Mississippi River in the range of 20-40 inches per year. The Middle Mississippi River and the Ohio River receive 40 or more inches per year precipitation. The Lower Mississippi River above New Orleans receives 40 or more inches per year precipitation, and from New Orleans to the Gulf of Mexico receives 60 or more inches per year precipitation.

The Lower Missouri River to the confluence of the Mississippi River receives 20 to 40 inches per year precipitation with the range increasing as the Missouri River approaches the Mississippi River. From the head of the Arkansas River to the confluence of the Mississippi River the precipitation ranges from 16 to 40 inches per year increasing as the Arkansas River approaches the Mississippi River. The Mississippi River Basin (Lower Mississippi River, Lower Arkansas River, and entire Ohio River) receives more than 40 in. mean annual precipitation.

The mean annual precipitation increases from 40 to 60 inches per year approaching the Gulf of Mexico. The precipitation is at a maximum during the three months of June, July and August and at a minimum during December and January.

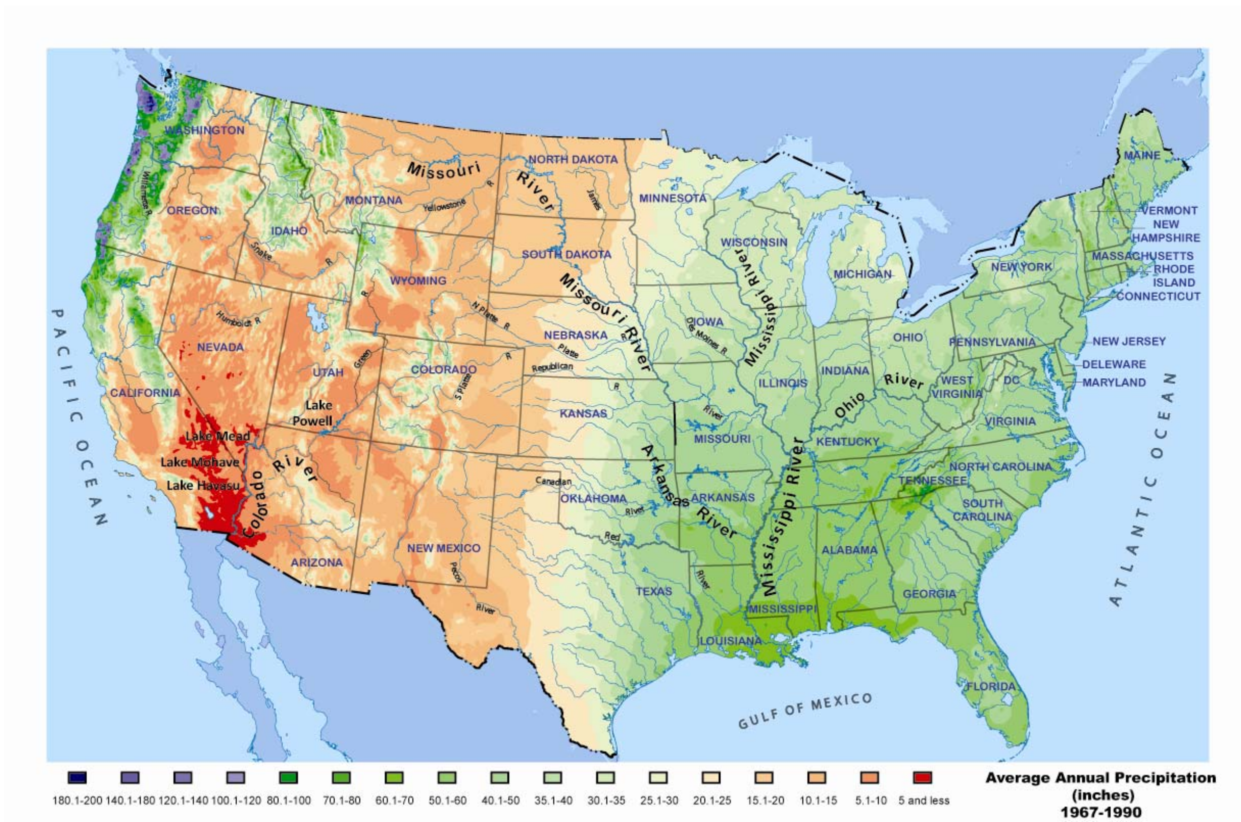


Figure 3. Annual Precipitation

Increases in precipitation were substantially higher than increases in runoff, suggesting that during the 20th century evapotranspiration had increased in the Mississippi River basin. According to the USACE, a majority of river gages analyzed show worsening flood trends that are at the 90% confidence level or higher in the Upper Mississippi River and the data provide very strong evidence that flood risk has increased in the lower part of the Missouri basin, on the Mississippi near Hannibal, on the Illinois River, and at St. Louis below the juncture of the two rivers.

The Lower Missouri and Arkansas Rivers to the Middle Mississippi River including much of the Ohio River have climate classification of Midlatitude Continental (Strahler and Strahler, 1992). Midlatitude climates are in a zone of intense interaction between unlike air masses: the polar air front zone. Tropical air masses moving poleward and polar air masses moving equatorward are in conflict in this zone, which contains a procession of eastward-moving wave cyclones. Locally and seasonally, either tropical or polar air masses dominate in these regions, but neither has exclusive control.

Mississippi River Use Governing Law and Key Definitions[1]

Historical Background

Federal improvements in the interest of navigation on the Mississippi River began as early as 1824. In 1878, the U.S. Congress authorized the first comprehensive project on the upper river: a 4 1/2-foot channel. This was followed by authorizations for a 6-foot channel in 1907 and a 9-foot channel in 1928, the depth that is presently maintained.

To achieve a 9-foot channel in the upper Mississippi, the construction of a system of navigation locks and dams was authorized in 1930 and expanded in 1932, 1935, 1937, 1945 and 1958. The St. Paul District of the USACE has jurisdiction over the thirteen uppermost structures—No. 10 at Guttenberg, Iowa, to Upper St. Anthony Falls Lock and Dam in Minneapolis, Minnesota. These locks and dams, supplemented by dredging, maintain the 9-foot depth during the navigation season (average is 1 April to 1 December).

The river ecosystem is home to a diverse array of fish and wildlife that find habitat in its channels, backwaters, sloughs, wetlands, and adjacent uplands. The Mississippi Flyway is the migration corridor for 40% of North America's waterfowl and shorebirds. A 40-mile reach of the Upper Mississippi River has been characterized as the single most important inland area for migrating diving ducks in the United States. The Flyway is also an important migration corridor for raptors and neotropical songbirds. Portions of the River provide habitat for breeding and wintering birds, including the bald eagle. A total of 154 species of fish and 50 species of freshwater mussels have been recorded in the river system.

The Mississippi River and its floodplain are home to a diverse population of living things:

- At least 260 species of fishes, 25% of all fish species in North America
- 40% of the nation's migratory waterfowl use the river corridor during their Spring and Fall migration
- 60% of all North American birds (326 species) use the Mississippi River Basin as their migratory flyway
- From Cairo, IL, upstream to Lake Itasca, there are 38 documented species of mussel. On the Lower Mississippi, there may be as many as 60 separate species of mussels
- The Upper Mississippi is host to more than 50 species of mammals
- At least 145 species of amphibians and reptiles inhabit the Upper Mississippi River environs.

1 http://www.mvp-wc.usace.army.mil/projects/general/ld_brochure.html

Navigation Pools

The dams create slack-water pools for navigation during periods of low and medium flows. The locks pass river traffic from one pool to another, like a stairway of water.

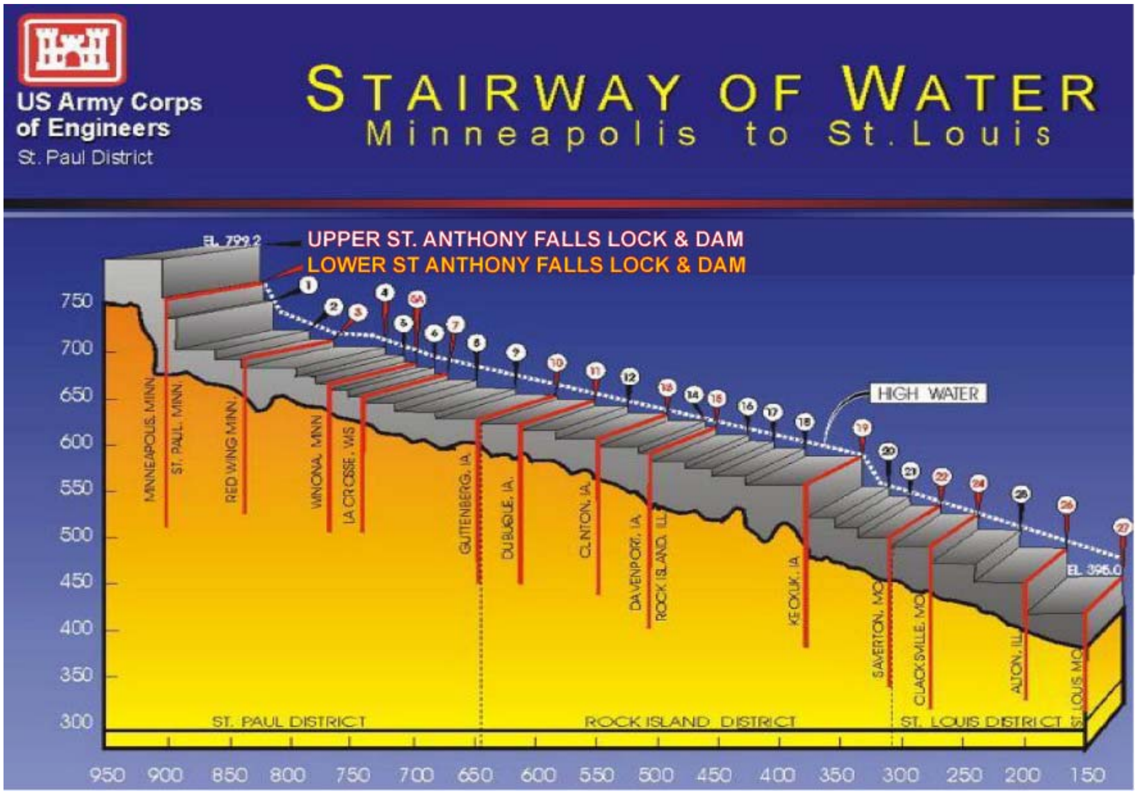


Figure 4. Upper Mississippi River Stairway of Water[2].

Slack-Water Pool System

Navigation dams, like those on the upper Mississippi are unusually different from a typical first impression of a dam. These dams are not solid but are a series of concrete piers across the river with movable gates between the piers. A dam is formed when the gates are lowered, causing the water level upstream of the dam to rise and form a slack-water pool deep enough for navigation.

In order to operate the slack-water pool system, it was necessary for the federal government to acquire interest in all real estate that would be subject to flooding caused by the use of the dams. Much of this land is now serving the public for recreational purposes and as wildlife refuges. Some land is owned outright and some is covered by "flowage easements" allowing artificial flooding of privately-owned land, if necessary.

2 Credit for this USACE image http://www.mvp.usace.army.mil/docs/StairwayofWater.pdf

Open River

There are times, usually in spring, when the natural flow provides a channel deep enough for navigation without the use of the dams. When this occurs, the gates between the piers are raised completely out of the water so that the river flows free, as an open river. Many people believe that the navigation pools should be drawn down before periods of high water are expected, to provide storage capacity for incoming flows. In this context, the term drawdown means to allow the water from an upper step on the stairway of water to flow to a lower step via the open dam gate. However, this drawdown cannot be performed for both physical and legal reasons.

The physical reason is that the pools do not contain sufficient storage capacity to accommodate flooding events. Even if each pool was completely emptied prior to an anticipated heavy runoff period, it would take only a matter of hours to refill them and this would not appreciably lower the peak river stages reached by the flood. This is because the amount of storage that could be made available by pool drawdowns is so very small in comparison with flood volumes. The legal reason for not drawing down pools is the "Anti-Drawdown Law." This act of Congress, dated March 10, 1934, is entitled, "An act to promote the conservation of wildlife, fish, and game, and for other purposes," as amended by Public Law 732 on August 14, 1946, and again by Public Law 697 on June 19, 1948.

The "Anti-drawdown Law" directs that in the management of facilities (including locks, dams and pools) on the Mississippi River between Rock Island, Illinois, and Minneapolis, Minnesota, administered by the USACE, full consideration and recognition is to be given to the needs of fish and other wildlife resources, including habitat. To the maximum extent possible, the law directs that the Corps regulation of the navigation pools take the needs of these natural resources into account, while maintaining navigation, without causing damage to property, and without creating additional liability to the government. The law also directs that the Corps shall generally operate and maintain pool levels as though navigation were carried on throughout the year.

Dam Operations

Each dam is operated to accommodate river flow conditions. In normal operation, all gates are partially open, to allow water to flow through. As the river flow increases or decreases, the gate openings are increased or decreased accordingly.

If a pool contained by an upper and lower dam had no flow, the water surface of the pool would be level throughout its entire length. However, if flow occurs through the pool, a slope must exist to the water surface; the upstream end of the pool will rise as the discharge of the upper dam increases, and the downstream end of the pool will fall as the discharge of the lower dam increases, resulting in a drawdown at the lower dam. The water surface profile of the pool will tend to pivot about a point somewhere between the two dams. The pivot point is called the "primary control point," and its location is found to be at or near the point of intersection of the "project pool" elevation and the "ordinary high water profile." Court decisions have defined ordinary high water profile as follows: "where the banks of a body of water are relatively steep, ordinary high water mark is coordinate with the limit of the bed of the water; and that, only, is to be considered the bed which the water occupies sufficiently long and continuously to wrest it from vegetation and destroy its value for agricultural purposes."

When the banks are low and flat, ordinary high water mark is considered as "the point up to which the presence and action of the water is so continuous as to destroy the value of the land for agricultural purposes by preventing the growth of vegetation, constituting what may be termed any ordinary agricultural crop." On navigable lakes and rivers the Government of the United States holds an easement to use the riparian lands up to ordinary high water mark, in the public interest.

The primary purpose of the dams in the St. Paul District is to maintain a minimum channel depth of nine feet for navigation, and to accomplish this purpose, project pool elevations must be maintained at the primary control points. The operation of the dams is required at low and moderate flows in the Mississippi River, but the dams are not needed during high flows, and the movable dams must be removed from the water before flood stages are reached. The Action Stage is the level where the movable gates are removed. Except for the water that goes into valley storage as the inflows increase, all inflow must be discharged.

In each pool, field surveys have established the ordinary high water profile, and the location of the primary control point has been determined. Project pool elevation is maintained at the primary control point, and the pool elevation at the dam is allowed to fall as the discharge is increased. However, the drawdown at the dam must be limited so that navigation and conservation interests in the area, from the primary control point to the dam, will not be damaged by extremely low water. The maximum allowable drawdown from an upper step to a lower step varies from 0 to 1 foot in the various pools, depending on local conditions. By using this method of operation, the inundated area for many smaller flood events is reduced, thereby greatly reducing the cost to the Government of acquiring flowage rights.

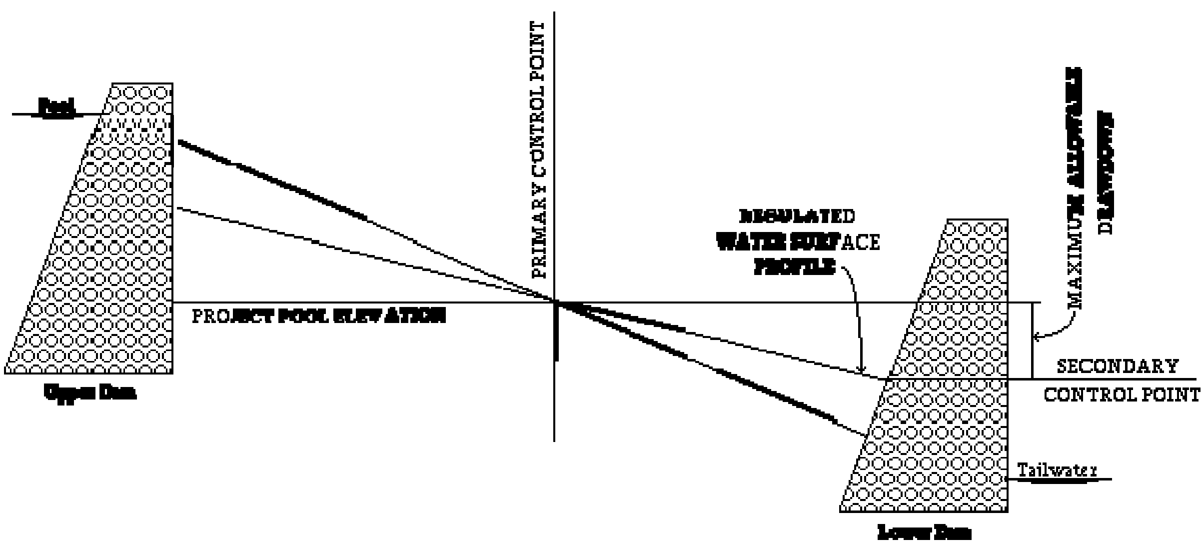


Figure 5. Mississippi River Lock and Dam Plan of Operation.

The regulated water surface profile has a continuous slope along the river. When the maximum allowable drawdown from an upper step to a lower step has been reached at the dam, control of the pool is shifted from the primary control point to the dam, and the pool is then said to be in secondary control. If, while the pool is in secondary control, the inflow continues to increase, the maximum allowable drawdown is maintained at the dam by increasing the discharge to the lower step, and the stage at the primary control point and at all other points in the pool is allowed to rise.

The proposal is to integrate the National Smart Water Grid into the existing infrastructure. Flood water will be captured at or above Action stage during flood events. New drains built into the levee walls (slotted drains over arch pipes parallel with the levee) will send water to interim storage tanks located on the river bank adjacent to the levee. Pumps will transport water from the tanks via interstate pipelines.

As the dam discharge is increased, the head at the dam will be decreased; and when the head has been reduced to less than one foot, the dam gates shall be raised out of the water, and open river flow will be in effect.

When the river has been in open river flow condition and the pool elevation at the dam falls to the secondary control elevation, the gates are returned to operation and secondary control elevation is maintained at the dam until the stage at the primary control point has fallen to project pool elevation. Then, control of the pool is returned to the primary control point, and project pool elevation is again maintained at the primary control point.

This plan of operation, combined with the natural variation of flows, results in fluctuations of pool levels, which may at times cause adverse flood effects. However, compensation has been paid to those affected by project operations, as authorized by Congress. By pumping the excess water, this compensation for flood damages will significantly decrease. Consistent with the basic purpose of the navigation project, which was authorized for and designed to make safe navigation of the Upper Mississippi River possible, every effort is made to cooperate with other activities, such as small-boat docks and harbors, farming, trapping, fishing, and other pursuits within the area of the pools.

Missouri River

The Missouri River begins in southwestern Montana in the Rocky Mountains, first flowing north then generally southeast across the heart of the United States, ending at the Mississippi River, just north of St. Louis as shown in Figures 6 and 7. It is the longest river in the United States at 2,500 miles (4,023 km). The Missouri River Navigation Charts prepared under the direction of the USACE document the Missouri River from Sioux City, Iowa to Kansas City, Missouri and from Kansas City, Missouri to the mouth at the Mississippi River approximately 15 miles upstream from St. Louis.

According to the USACE, analysis of flows on tributaries of the Missouri River adds to evidence of a significant increase in flood risk with time over the last century.

Figure 6. Missouri River and its Cities.

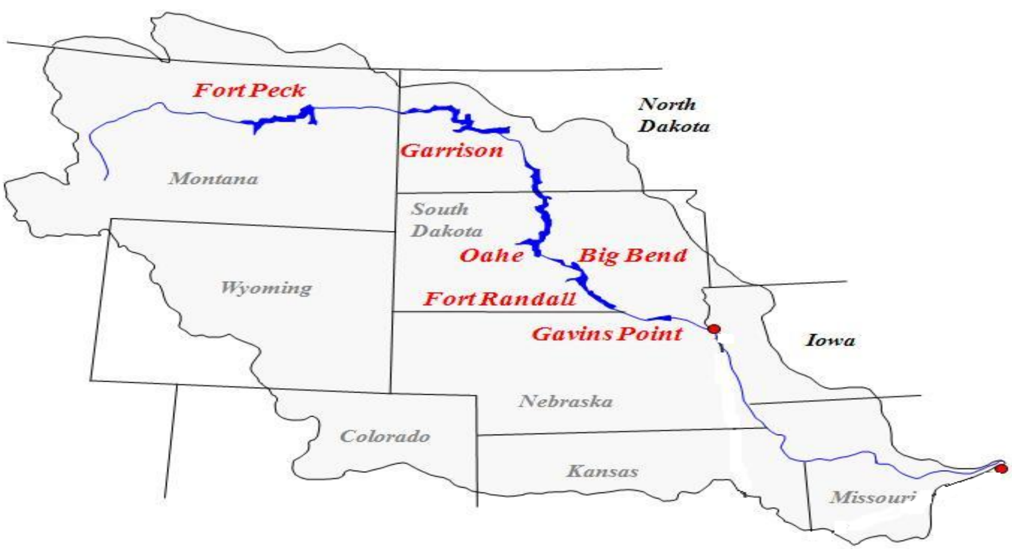


Figure 7. Missouri River and its Reservoirs/Lakes.

The commercial navigation season is normally from latter March to latter November at Sioux City, and from the first of April to the first of December at the mouth. Ice conditions preclude navigation during the rest of the year. Specific minimum flow rates are required during the navigation season to provide adequate depths and width. To meet the flow requirements, insufficient natural flows are augmented by releases from upstream reservoirs, as shown in Figure 7. A flow of 30 to 35 kcfs is generally maintained at Sioux City and Omaha, and 35 to 40 kcfs is maintained at Kansas City.

Arkansas River

The Arkansas River is a large tributary of the Mississippi River, rising in the Sawatch Range of the Rocky Mountains near Leadville in central Colorado, and flowing generally east-southeastward for 1,460 miles (2,350 km) through Kansas, Oklahoma, and Arkansas before entering the Mississippi River 40 miles (64 km) northeast of Arkansas City, Arkansas. The Arkansas River has a total fall of 11,400 feet (3,475 m), and its drainage basin covers 161,000 square miles (417,000 square km).

From Leadville the Arkansas River flows southeast for about 100 miles (160 km) to Canon City, Colorado, falling 6,750 feet (2,060 m). It leaves the mountains near Canon City through the Royal Gorge, a narrow canyon cut into solid granite with vertical walls more than 1,000 feet (300 m) high. Between Canon City and Great Bend, Kansas, the Arkansas River’s channel is wide and shallow and meanders through a dry area that is extensively irrigated. Heavy rainfalls upstream will occasionally cause floods.

Southeastward from Great Bend the river flows through a more humid area and is frequently more than 0.5 mile (0.8 km) wide with a deep channel. The river receives its main tributaries in the Oklahoma portion: the Salt Fork, Cimarron, Verdigris, Grand, and Canadian rivers. The Arkansas River Navigation System enters the river 5 miles (8 km) northeast of Muskogee, Oklahoma, at the mouth of the Verdigris River, and continues through Arkansas to the Mississippi River. Many water-control projects have been established in the Arkansas River basin, including a multiple-purpose reservoir at Eufaula on the Canadian River near McAlester, Oklahoma. Principal river cities are Pueblo, Colorado; Wichita, Kansas; Tulsa, Oklahoma; and Fort Smith and Little Rock, Arkansas.

Red River

The Red River rises in two branches in the Texas Panhandle and flows east forming the border between Texas and Oklahoma, and briefly between Texas and Arkansas. At Fulton, Arkansas, the river turns south into Louisiana to empty into the Atchafalaya and Mississippi Rivers. The total length is 1,360 miles (2,190 km). Since 1943 the Red River has been dammed by Denison Dam to form Lake Texoma, a large reservoir of 89,000 acres (360 km^2), some 70 miles (110 km) north of Dallas. Other reservoirs serve as flood control on the river's tributaries. The Red has a mean flow of over 7,000 cfs. A lock system allows navigation of barge traffic as far north as Shreveport, Louisiana.

Ohio River

The Ohio River flows generally southwest, formed by the confluence of the Allegheny and Monongahela Rivers in Pittsburgh, Pennsylvania. It forms the natural borders of Ohio and West Virginia, Ohio and Kentucky, as well as parts of the borders of Indiana, Illinois and Kentucky. It empties into the Mississippi River at the Illinois border near Cairo, IL and is 975 miles (1,569 km) long.

Figure 8. Ohio River and its Cities.

DROUGHTS IN THE WESTERN STATES

Droughts in the Western states have caused farmlands to dry up putting tens of thousands of workers out of work. The California Central Valley is more than 400 miles long, comprised of the water-rich Sacramento Valley in the north and the drier San Joaquin Valley in the south. One of the nations most productive agricultural regions, has suffered as the state faces its third year of below-average precipitation, groundwater supplies are under increasing pressure, according to data gathered since 2003. Landowners are drilling more and deeper wells, and underground water levels are starting to drop once again as they did during previous droughts in the 1970s and 1980s. (Faunt 2009)

California's Central Valley covers about 20,000 square miles and is one of the most productive agricultural regions in the world. More than 250 different crops are grown in the Central Valley with an estimated value of $17 billion per year. This irrigated agriculture relies heavily on surface-water diversions and groundwater pumpage. Approximately one-sixth of the Nation's irrigated land is in the Central Valley, and about one-fifth of the Nation's groundwater demand is supplied from its aquifers.

California's continuing population increase has heightened competition for water within the Central Valley and statewide. That competition is likely to be exacerbated by reduced deliveries of Colorado River water to Southern California. As water resources become more valuable, a number of issues have gained prominence, including how to conserve agricultural land; the conjunctive use of surface and groundwater supplies; changing land-surface elevation in response to groundwater pumping; aquifer storage and recovery; the effect of land-use changes on water supplies, and climate change.

Droughts have caused forests to become significantly stressed and the potential for forest fires increase proportionally. Forest fires in Colorado, Nevada, Arizona, Utah, Wyoming, and California have devastated huge tracts of land and have costs millions of dollars to fight—money hard to find in these state budgets. The U.S. Drought Monitor is shown is Figures 9 and 10.

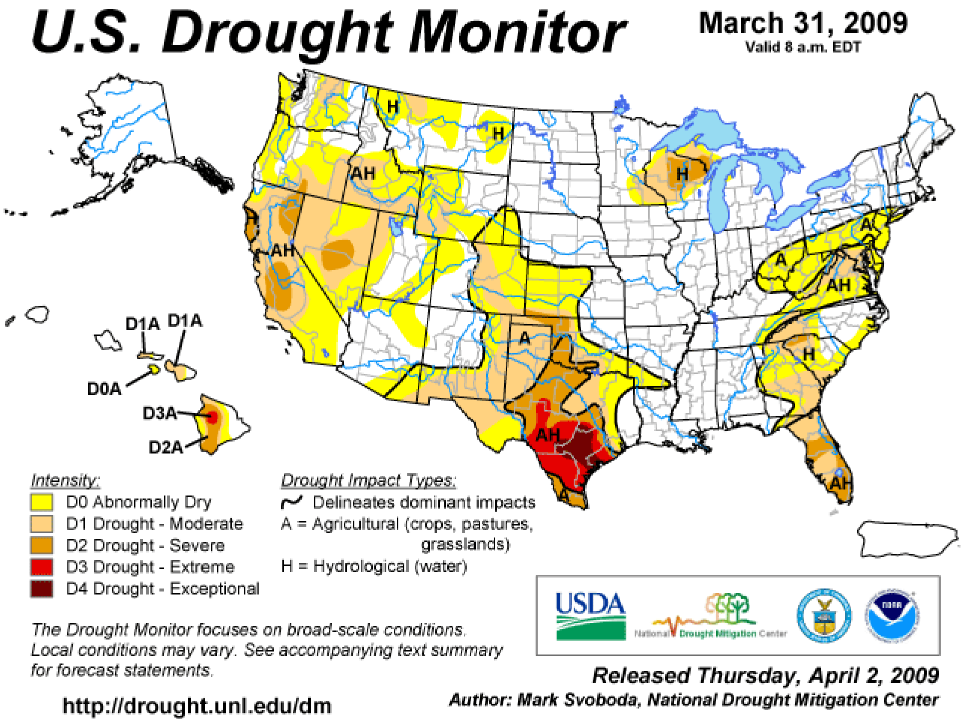
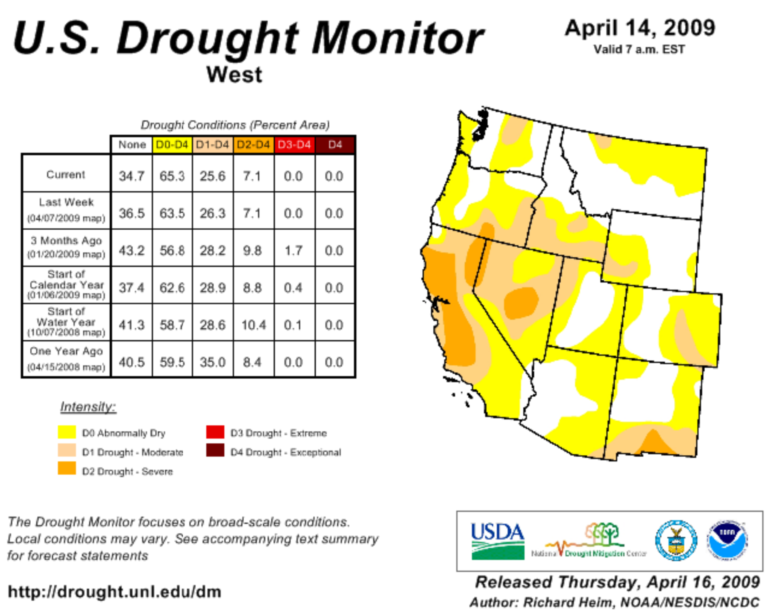


Figure 9. U.S. Drought Monitor Map[3].



Drought Conditions (Percent Area)

	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	34.7	65.3	25.6	7.1	0.0	0.0
Last Week (04/07/2009 map)	36.5	63.5	26.3	7.1	0.0	0.0
3 Months Ago (01/20/2009 map)	43.2	56.8	28.2	9.8	1.7	0.0
Start of Calendar Year (01/06/2009 map)	37.4	62.6	28.9	8.8	0.4	0.0
Start of Water Year (10/07/2008 map)	41.3	58.7	28.6	10.4	0.1	0.0
One Year Ago (04/15/2008 map)	40.5	59.5	35.0	8.4	0.0	0.0

Figure 10. Western States Drought Monitor Map.

3 U.S. Drought Monitor website is: http://drought.unl.edu/dm/monitor.html

Colorado River

Beginning in the Rocky Mountains of northern Colorado, the Colorado River moves southwest, ending in the Gulf of California. It is 1,450 miles (2,333 km) in length and over the centuries formed numerous canyons along its winding path. The most famous of these is the Grand Canyon in northern Arizona. The river has more than 30 electric power plants along its run. The river has 83 reservoirs in the upper basin and 10 reservoirs in the lower basin. The Colorado River drains about 250,000 square miles. The Colorado River provides 30 million people with drinking water and also provides enough water to keep 3.5 million acres of farmland in production. The Colorado River Basin is shown in figures 11, 12, and 13.

The 30-year (1971-2000) average unregulated inflow to Lake Powell is 12.06 maf (14,876 mcm)[4]. Unregulated inflow adjusts for the effects of operations at upstream reservoirs. It is computed by adding the change in storage and the evaporation losses from upstream reservoirs to the observed inflow. Unregulated inflow is used because it provides an inflow time series that is not biased by upstream reservoir operations. At the beginning of water year 2008 (October 1, 2007), Colorado River total system storage was 54 percent of capacity. The amount of water stored in the country's two largest reservoirs, Lake Powell and Lake Mead are graphically depicted in Figures 16 and 18.

According to the Colorado Water Conservation Board, the Colorado River Basin is expected to have an additional 61,900 AF of demand by 2030.

Figure 11. Colorado River.

4 US Bureau of Reclamation, Annual Operating Plan for Colorado River Reservoirs, 2009.

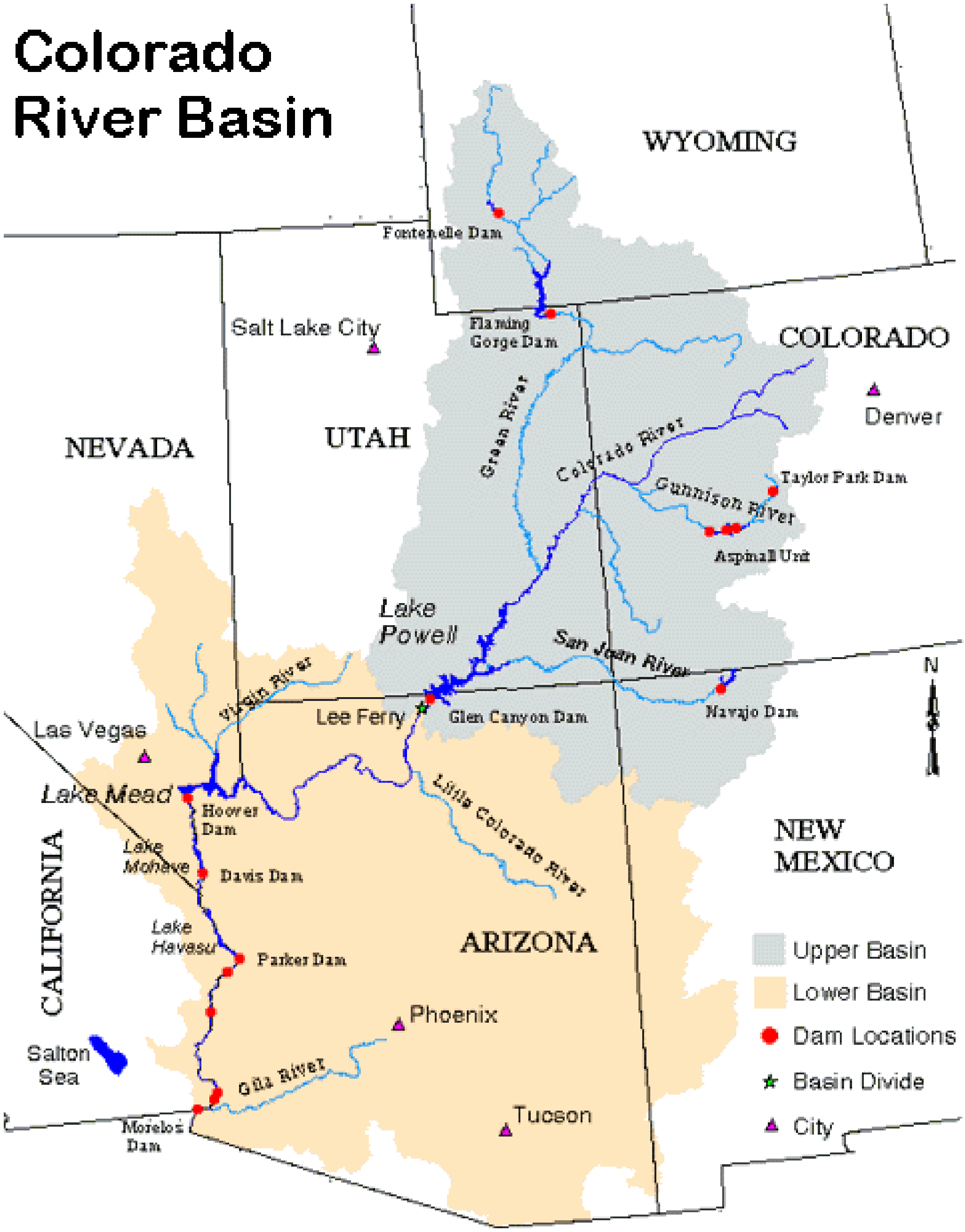


Figure 12. Colorado River Basin[5].

5 Credit for this image: http://crc.nv.gov/images/colorado_river_basin.gif

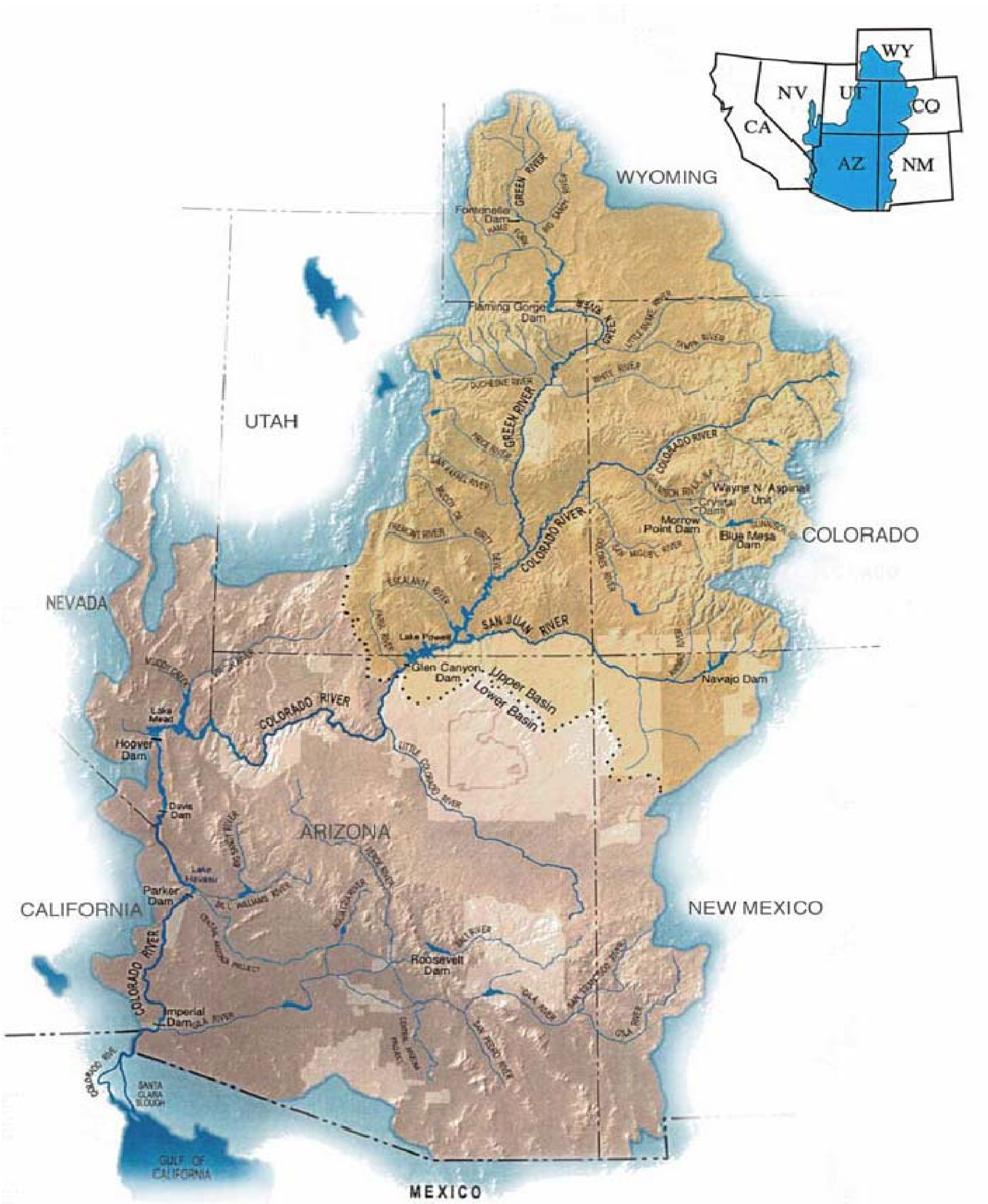


Figure 13. Colorado River Basin.

Lake Powell

Lake Powell, created by the Glen Canyon Dam, is 186 miles long with more than 1,986 miles of shoreline. By the time the dam was completed in 1963, it took another 14 years to fill Lake Powell. Since then, Lake Powell has proven to be a premier attraction for millions of visitors from all over the world. Notice the watermark on the canyon wall on the left, which indicates the lake is less than full capacity. Lake Powell and the surrounding Glen Canyon National Recreation Area are located in the southwestern United States, spanning some 1932 square miles of high desert landscape in southern Utah and northern Arizona. The waters of Lake Powell cover 13% of the existing Glen Canyon Recreational Area.

Figure 14. Natural Beauty of Western Canyons at Lake Powell.

The Glen Canyon Dam was completed in 1963 and provides critical water storage for the Upper Basin states. Glen Canyon Power plant has eight generators with a maximum combined capacity of close to 1,300 megawatts. Today, Lake Powell winds its way through this desert paradise with excellent views of balancing rocks, pinnacles, buttes, arches and amphitheaters. The combination of clear skies, crystal clear water and red sandstone rock formations makes this national recreation area an ideal place for the outdoor enthusiast.

Lake Powell is more than just a fantastic recreation area. Lake Powell has a capacity of 27 maf and is second only to Lake Mead for stored water capacity.

Figure 15. Glen Canyon Dam and Lake Powell.

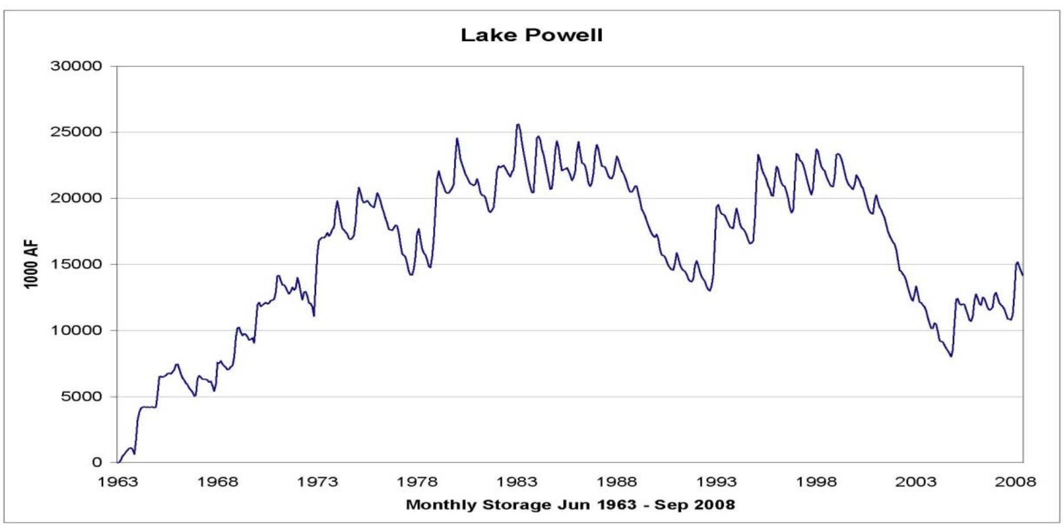


Figure 16. Lake Powell Monthly Storage Volume from 1963 to 2008[6].

6 US Bureau of Reclamation, Annual Operating Plan for Colorado River Reservoirs, 2009.

Lake Mead

The western half of the United States has received far less rain and snow in the past several years than normal. This sustained drought has caused many changes easily detected by NASA's Earth-observation satellites: dramatic decreases in soil moisture, shrinking snow pack in the Rockies, withering vegetation, more frequent and severe forest fires, and falling water levels in major reservoirs throughout the West.

Figure 17. Lake Mead, Western States Most Valuable Water Source.

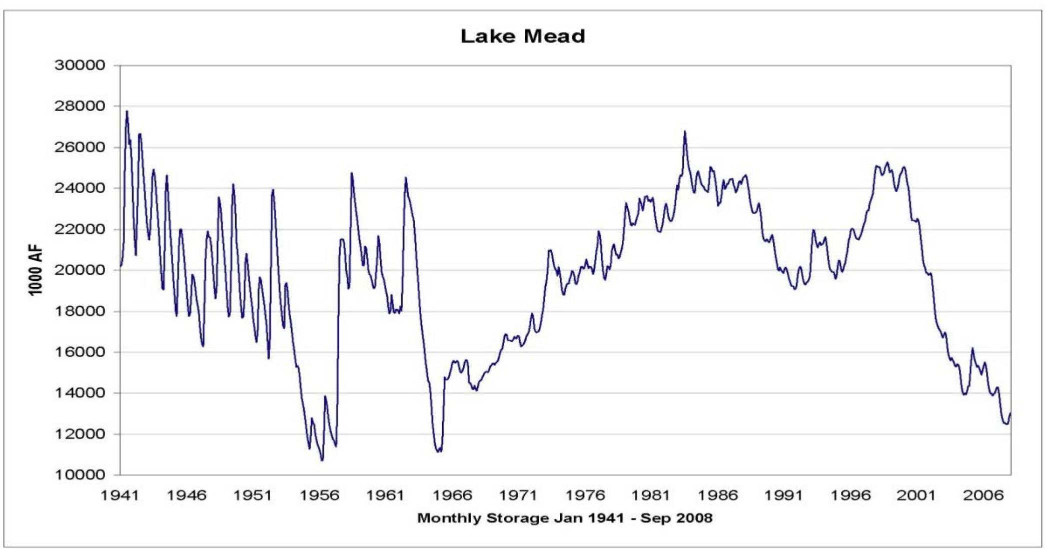


Figure 18. Lake Mead Monthly Storage Volume from 1941 to 2008[7].

7 US Bureau of Reclamation, Annual Operating Plan for Colorado River Reservoirs, 2009.

Lake Mead is one of the most important water resources in the West. Created in the 1930s, it ensures a steady water supply for Arizona, Nevada, California, and northern Mexico by holding back the flow of the Colorado River behind the Hoover Dam. It is one of the largest water reservoirs in the world. When full, the lake contains roughly the same amount of water as would have otherwise flowed through the Colorado River over a two-year period, roughly 28.5 maf. As of May 2003, Lake Mead was at roughly two-thirds of this capacity and falling. Reservoir storage in Lake Mead declined during water year 2008 by 0.492 maf. As of March 2009, Lake Mead was only 45% full. Water supplies, water quality, and power supplies already have been affected throughout the Colorado River Basin.

Lake Mead is divided into four major basins: (from west to east) the Boulder, Virgin, and Gregg Basins, plus the Overton Arm which extends northward from the Virgin Basin to the confluence of the lake with the Virgin and Muddy Rivers. Each of these basins shows signs of the water level changes in the reservoir. At the northern end of the Overton Arm the Muddy and Virgin Rivers flow into the lake. Water level changes in this area have brought back to view the foundations and road grid of the flooded town of St. Thomas, left when the town was demolished to make way for the new lake. At the southern end of the lake, where the Hoover Dam holds back the Colorado River, water level drops have changed the shoreline. The Boulder Basin now has a series of islands that were beneath the water in 2000, including a pair adding to the cluster of Boulder, Little Boulder, and Rock Islands. Black Island has become a part of the northern shoreline. Saddle Island was formerly only connected to the shore by the water pipes which are fed by the water intakes on the island; now the shoreline extends well beyond the peninsula under the pipes. Figures 19 and 20 show a dramatic change in visible shoreline, caused by protracted droughts in the Colorado River Basin.

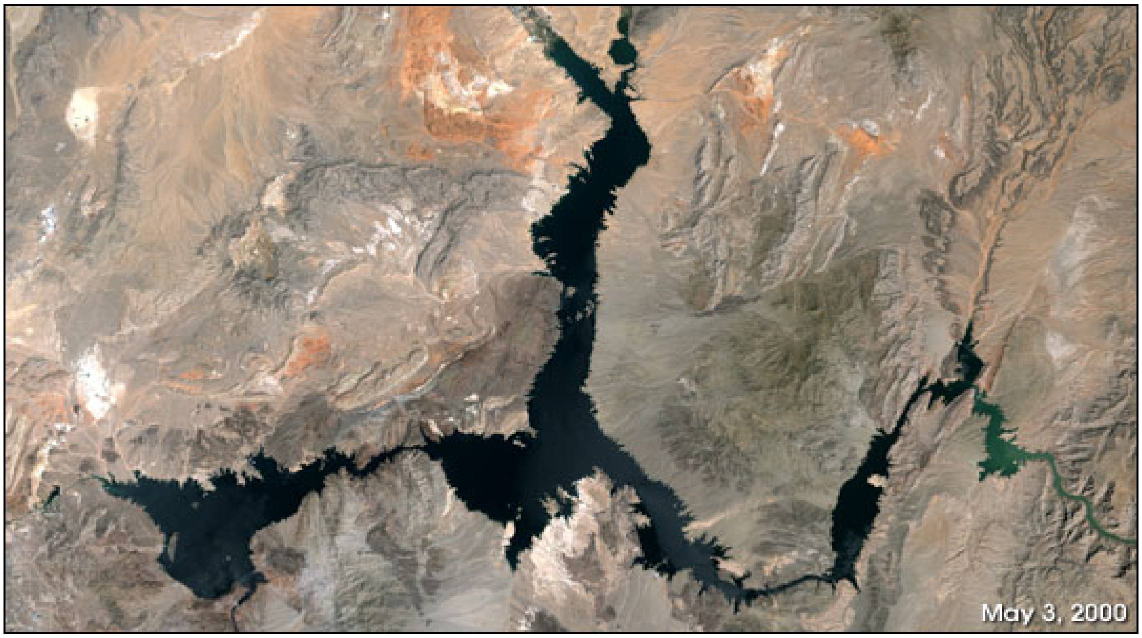


Figure 19. Lake Mead Shoreline May 3, 2000[8].

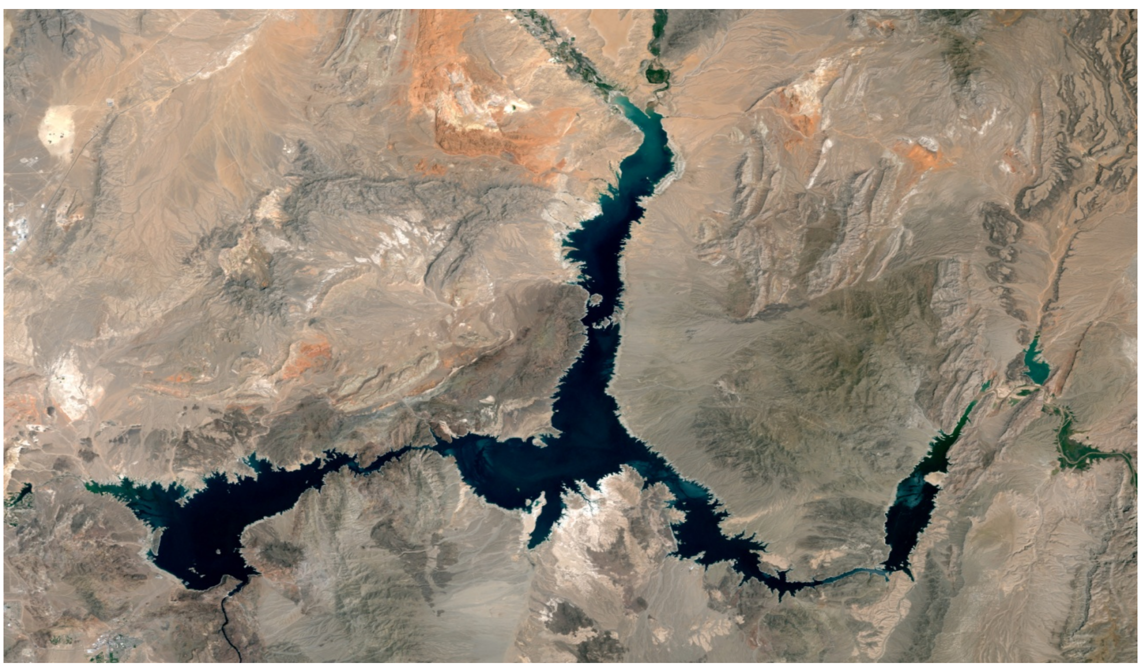


Figure 20. Lake Mead Shoreline May 2003

8 (Images by Jesse Allen, based on data provided by the Landsat 7 Science Team) http://earthobservatory.nasa.gov/Features/LakeMead/

The top image above was acquired by the Landsat satellite and shows the shoreline of Lake Mead in May 2000. Compared to the image below that shows the shoreline in May 2003, dramatic changes are quite evident in the three-year span between these images. In the space of just three years, water levels in Lake Mead have fallen more than 60 feet due to sustained drought. Water levels in the lake dropped 60 ft between 2000 and 2003, and have dropped 100 ft from 2000 to 2009. Water management officials predict a further drop of between 15-20 ft this year, if weather and water use predictions are correct.

In the Boulder Basin of Lake Mead, the lower water level has connected former islands like Saddle Island to the shoreline. The National Park Service has also moved marinas to the new shoreline or new sites, such as moving Las Vegas Bay marina to Hemenway Harbor.

Colorado River Use Governing Law

The web site9 posted by the US Bureau of Reclamation (USBR) describes how the Colorado River water use must be parsed out among its many users. Salient portions of laws are augmented with other information and summarized below.

Law of the [Colorado] River

The Colorado River is managed and operated under numerous compacts, federal laws, court decisions and decrees, contracts, and regulatory guidelines collectively known as the "Law of the River." This collection of documents apportions the water and regulates the use and management of the Colorado River among the seven basin states and Mexico. Following is a synopsis of the most significant documents.

1. **The Colorado River Compact of 1922** (45 Stat. 1057) — The cornerstone of the "Law of the River", this Compact was negotiated by the seven Colorado River Basin states and the federal government in 1922. It defined the relationship between the upper basin states, where most of the river's water supply originates, and the lower basin states, where most of the water demands were developing. At the time, the upper basin states were concerned that plans for Hoover Dam and other water development projects in the lower basin would, under the Western water law doctrine of prior appropriation, deprive them of their ability to use the river's flows in the future.

   The states could not agree on how the waters of the Colorado River Basin should be allocated among them, so the Secretary of Commerce Herbert Hoover suggested the basin be divided into an upper and lower half, with each basin having the right to develop and use 7.5 maf of river water annually. This approach reserved water for future upper basin development and allowed planning and development in the lower basin to proceed.

2. **The Boulder Canyon Project Act of 1928** (45 Stat. 1057) — This act: (1) ratified the 1922 Compact; (2) authorized the construction of Hoover Dam and related irrigation facilities in the lower Basin; (3) apportioned the lower basin's 7.5 maf among the states of Arizona (2.8 maf), California (4.4 maf) and Nevada (0.3 maf); and (4) authorized and directed the Secretary of the Interior to function as the sole contracting authority for Colorado River water use in the lower basin.

9 http://www.usbr.gov/lc/region/pao/lawofrvr.html

3. **California Seven Party Agreement of 1931** — This agreement helped settle the long-standing conflict between California agricultural and municipal interests over Colorado River water priorities. The seven principal claimants - Palo Verde Irrigation District, Yuma Project, Imperial Irrigation District, Coachella Valley Irrigation District, Metropolitan Water District, and the City and County of San Diego - reached consensus in the amounts of water to be allocated on an annual basis to each entity. Although the agreement did not resolve all priority issues, these regulations were also incorporated in the major California water delivery contracts.

4. **The Mexican Water Treaty of 1944** — Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande, Treaty Between the United States of America and Mexico (Treaty Series 994, 59 Stat. 1219); Committed 1.5 maf of the river's annual flow to Mexico.

5. **Upper Colorado River Basin Compact of 1948** (63 Stat. 31) — Created the Upper Colorado River Commission and apportioned the Upper Basin's 7.5 maf among Colorado (51.75 percent), New Mexico (11.25 percent), Utah (23 percent), and Wyoming (14 percent); the portion of Arizona that lies within the Upper Colorado Basin was also apportioned 50,000 acre-feet annually.

6. **Colorado River Storage Project Act of 1956** — Provided a comprehensive Upper Basin-wide water resource development plan and authorized the construction of Glen Canyon, Flaming Gorge, Navajo and Curecanti dams for river regulation and power production, as well as several projects for irrigation and other uses.

7. **The Arizona v. California U.S. Supreme Court Decision of 1964** — In 1963, the Supreme Court issued a decision settling a 25-year-old dispute between Arizona and California. The dispute stemmed from Arizona's desire to build the Central Arizona Project so it could use its full Colorado River apportionment. California objected and argued that Arizona's use of water from the Gila River, a Colorado River tributary, constituted use of its Colorado River apportionment, and that it had developed a historical use of some of Arizona's apportionment, which, under the doctrine of prior appropriation, precluded Arizona from developing the project.

   The Supreme Court rejected California's arguments, ruling that lower basin states have a right to appropriate and use tributary flows before the tributary co-mingles with the Colorado River, and that the doctrine of prior appropriation did not apply to apportionments in the lower basin.

   In 1964, the Court issued its decree. This decree enjoined the Secretary of the Interior from delivering water outside the framework of apportionments defined by the law and mandated the preparation of annual reports documenting the uses of water in the three lower basin states.

   In 1979, the Supreme Court issued a Supplemental Decree which addressed present perfected rights referred to in the Colorado River Compact and in the Boulder Canyon Project Act. These rights are entitlements essentially established under state law, and have priority over later contract entitlements.

   On March 27, 2006, the Supreme Court issued a Consolidated Decree to provide a single reference to the provisions of the original 1964 decrees and several subsequent decrees (1966, 1979, 1984, and 2000) that stemmed from the original ruling. This decree also reflects the settlements of the federal reserved water rights claim for the Fort Yuma Indian Reservation.

8. **Minute 242 of the U.S.-Mexico International Boundary and Water Commission of 1973** — United States/Mexico agreement in Minute No. 242 of August 30, 1973, (Treaty Series 7708; 24 UST 1968) - Required the U.S. to take actions to reduce the salinity of water being delivered to Mexico at Morelos Dam.

9. **The Colorado River Basin Salinity Control Act of 1974** — Authorized desalting and salinity control projects, including the Yuma Desalting Plant, to improve Colorado River quality.

10. **Other Pertinent Law**

Consolidated Decree entered by the Supreme Court of the United States in Arizona v. California (547 U.S. 150 (2006));

Boulder Canyon Project Act (45 Stat. 1057);

Boulder Canyon Project Adjustment Act (54 Stat. 774; 43 U.S.C. 618a);

Colorado River Storage Project Act (70 Stat. 105; 43 U.S.C. 620);

Colorado River Basin Project Act (82 Stat. 885; 43 U.S.C. 1501);

Colorado River Basin Salinity Control Act (88 Stat. 266; 43 U.S.C. 1951);

Hoover Power Plant Act of 1984 (98 Stat. 1333);

Colorado River Floodway Protection Act (100 Stat. 1129; 43 U.S.C. 1600);

Grand Canyon Protection Act of 1992 (Title XVIII of Public Law 102-575, 106 Stat. 4669).

Off-stream Storage of Colorado River Water; Development and Release of Intentionally Created Unused Apportionment in the Lower Division States: Final Rule (43 CFR Part 414; 64 *Federal Register* 59006, November 1, 1999).

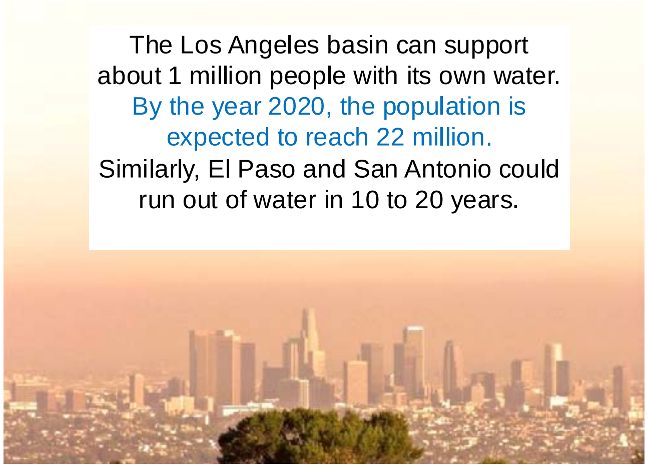
Amendatory Agreement to Agreement between the Central Arizona Water Conservation District and the Metropolitan Water District of Southern California for a Demonstration Project on Underground Storage of Colorado River Water, December 1, 1994.

Storage and Interstate Release Agreement among The United States of America, acting through the Secretary of the Interior; The Metropolitan Water District of Southern California; the Southern Nevada Water Authority; and the Colorado River Commission of Nevada, October 21, 2004.

Federal Law

National Environmental Policy Act (**NEPA**) is United States environmental law signed in 1970 and amended in 1977 (40 CFR Parts 1500 to 1508). Title 40, Protection of the Environment, Part 1502 requires an Environmental Impact Statement that is analytical. The information in this report could be used.

Population Profile and Projections of the United States



The U.S. population currently exceeds 300 million people. Census Bureau projections estimate a 7 percent increase with the national population reaching 350 million by 2025 and 420 million by 2050. The highest rates of population are projected to occur in the Southwest.

States in the South and West are expected to show big gains between 1993 and 2020 Campbell (2008) U.S. Census Bureau[10]. The South should remain the most populous region, with the West recently passing the Midwest in second place. Out of the 16 States that should gain at least a million persons, only 1 is located in the Northeast (New Jersey) and 1 in the Midwest (Illinois).

California, the most populous State during the 1993-2020 period, alone should add over 16 million persons. This would boost its share of the Nation's population from 12 to 15 percent. Texas and Florida are expected to be the next biggest gainers. In 1994, Texas replaced New York as the second most populous State. Florida should succeed New York as the third largest State after 2015.

The most rapid rates of growth during the 1993 to 2020 period should occur in Nevada (2.1 percent per year), Hawaii (2.0 percent), California (2.0 percent), and Washington (1.9 percent). The slowest growth rate over this period should belong to West Virginia (with less than 0.1 percent annually).

The components of population growth, namely, births, deaths, internal migration (State-to-State moves), and international migration (immigration) affect each State differently. For example, between 1990 and 2020:

> California is projected to sustain a net loss of 4 million internal migrants to other States. (New York, Illinois, and Michigan should also each lose at least 1 million.) But this huge loss would be more than compensated for by projections that show California will add 10 million international migrants (39 percent of the Nation's total) and have more than twice as many births as deaths (20 million versus 8 million).
>
> Florida is projected to add 2 million immigrants, joining California, New York, Texas, New Jersey, and Illinois in adding at least 1 million each. Counter to California trends, Florida should see a net gain of nearly 4 million from other States; only Washington, North Carolina, and Georgia are also expected to add over a million through net internal migration. During the projection period, about as many Floridians should die as would be born (6 million each).

10 Results are from Series A, the preferred series, which is a time-series model and uses State-to-State migration observed from 1975-76 through 1991-92.

California Population and Household Projections

California's population will likely reach 40 million by 2010, and 45.5 million by 2020 (California Department of Finance, 1998). On a yearly basis, California's population is expected to grow at a rate of 1.6 percent per year in 2010, and 1.3 percent per year between 2010 and 2020. The Census Bureau projects that the California Central Valley's population will increase to 6 million people by 2020.

Regional Population Projections

Population growth will vary from one part of California to another. Comparing different urban regions:

- **Greater Los Angeles:** The six-county Greater Los Angeles Metropolitan Region include Los Angeles, Orange, Riverside, San Bernardino, Ventura, and Imperial counties. Altogether, the Greater Los Angeles region is projected to grow to 19.2 million persons in 2010, to 21.8 million persons in 2020.
  Among individual counties, Los Angeles County alone is projected to add two million more residents by 2020. Further to the east, Riverside and San Bernardino counties will likely add 1.1 million new residents by 2020. Orange County is projected to add 458,000 new residents by 2010 and 726,000 by 2020. Projected growth increments in Ventura and Imperial counties will be considerably smaller.
- **San Francisco Bay Area:** California's second-largest metropolitan region, the nine-county San Francisco Bay Area, will, it is projected, add 600,000 residents by 2020.
  More than half of the Bay Area's population growth will occur in just two counties: Santa Clara and Alameda. Santa Clara County's population is projected to grow by 525,000 persons between 1997 and 2020, while Alameda County's population will likely grow by 395,000. Elsewhere in the Bay Area, projected 1997-2020 population growth will exceed 200,000 persons in Contra Costa County, and 140,000 in each of San Mateo, Solano, and Sonoma counties. San Francisco is projected to grow by 5,000 residents between now and 2010. Napa and Marin counties are expected to grow by 37,000 and 25,000 persons, respectively.
- **The San Joaquin Valley:** The eight-county San Joaquin Valley Metropolitan Region (consisting of Fresno, Kern, Kings, Madera, Merced, San Joaquin, Stanislaus, and Tulare counties) was home to just under ten percent of California's population in 1997. By 2020, that share is projected to have increased to 11.2 percent. According to the California Department of Finance, the San Joaquin Valley Metropolitan Region will likely grow by 900,000 residents between 2010 and 2020.
  Within the San Joaquin Valley region, population growth will be fairly evenly distributed. Kern and San Joaquin counties are projected to add the most new population; and Madera, Merced, and Kings Counties, the least. Projected population growth rates in the San Joaquin Valley will vary from a low of 43 percent in Fresno County to a high of 98 percent in Madera County.
- **San Diego County:** California's fourth largest metropolitan region is projected to grow by 476,000 residents between 2010 and 2020. San Diego County will account for 9.2 percent of projected state population growth by 2020.
- **The Sacramento Metropolitan Region:** Consisting of El Dorado, Placer, Sacramento, Sutter, Yuba, and Yolo counties—is currently home to 1.8 million people, or 5.6 percent of the state's population. DOF projections suggest that this region will add another 544,000 residents by 2010, and another 923,000 residents by 2020.

- **The Central Coast Metropolitan Region** is less an identifiable urban region than a combination of several small and mid-sized cities strung along Highways 1 and 101. From north to south, it includes Santa Cruz, San Benito, Monterey, San Luis Obispo, and Santa Barbara counties. Its northern portion, including Santa Cruz and San Benito counties, borders on and is sometimes considered to be part of the San Francisco Bay Area. Its southern county, Santa Barbara, is sometimes considered part of Southern California.
  By 2020, this amalgam of coastal counties population will be just under two million. Population growth will be evenly distributed throughout the region, with Monterey County likely to add the most additional population (+197,000), and San Benito likely to add the least (+36,000). Altogether, the Central Coast Metropolitan Region will account for 5.3 percent of the state's 1997-2020 population growth.
- **The Northern California Non-metropolitan Region** consists of five mostly rural counties (Butte, Colusa, Glenn, Shasta, and Tehama), each having one or two small cities. The population of this region is expected to grow to 612,000 in 2010, and to 722,000 in 2020. The Northern California Metropolitan Region will account for 2.1 percent of the state's 1997-2020 projected population growth. Nearly three-quarters of this region's projected population growth will occur in just two counties: Butte and Shasta. The populations of California's 21 non-metropolitan counties will, DOF projects, grow to 1.7 million in 2020. The non-metropolitan counties projected to grow the most during this period are Imperial (+156,026), Kings (+68,864), Nevada (+48,037), Lake (+38,024), San Benito (+36,125), Mendocino (+32,848), Tuolumne (+25,199), and Calaveras (+24,794).

High Growth in Cities, Southern California: Following past trends, almost all of the State's population and household growth will occur in metropolitan areas; and more than half of it will occur in Southern California. Those counties that now have the lion's share of population—Los Angeles, Orange, San Diego, San Bernardino, Santa Clara, and Alameda—will also experience the lion's share of population growth. Thirteen of California's 58 counties are projected to add 100,000 or more new households by 2020. Los Angeles County alone is projected to add more than two million people and one million households by 2020.

Some Rural Growth: Although not the focal points of California's growth, some rural counties (e.g., Calaveras, Lake, and Nevada) will see their populations increase by 50 percent or more by 2020.

Randy Pellatz, assistant director of utilities for the city of Flagstaff says that eight years of drought and a growing population is causing serious water supply problems (June 23, 2007). Since 1990 the population has grown from 45,000 to 62,000 and the reservoir that provides 40% of the city’s water is down to 18 percent of normal levels. Although water for human use is a priority concern, the most serious threat that they face is wildfire. And, since Arizona is the US state with the fastest growing population the water supply problem will likely remain even if the rains return.

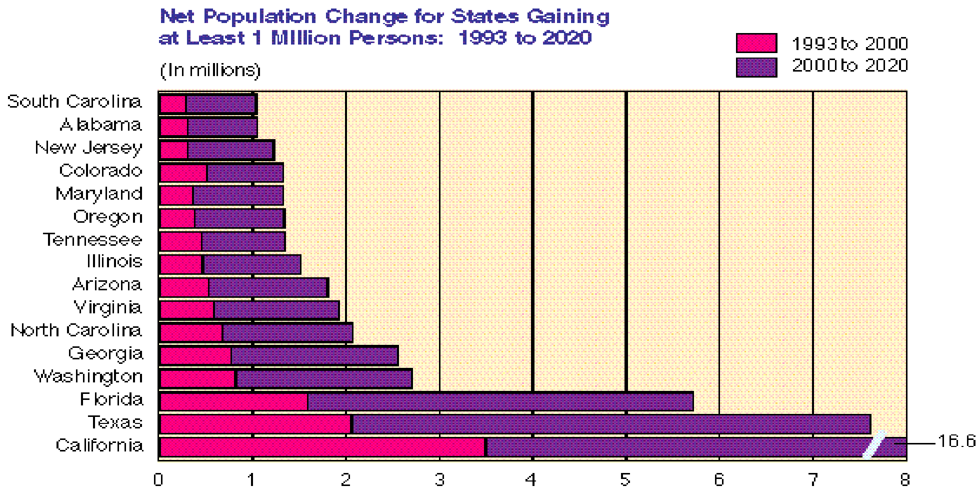


Figure 21. Net Population Change 1993 to 2020

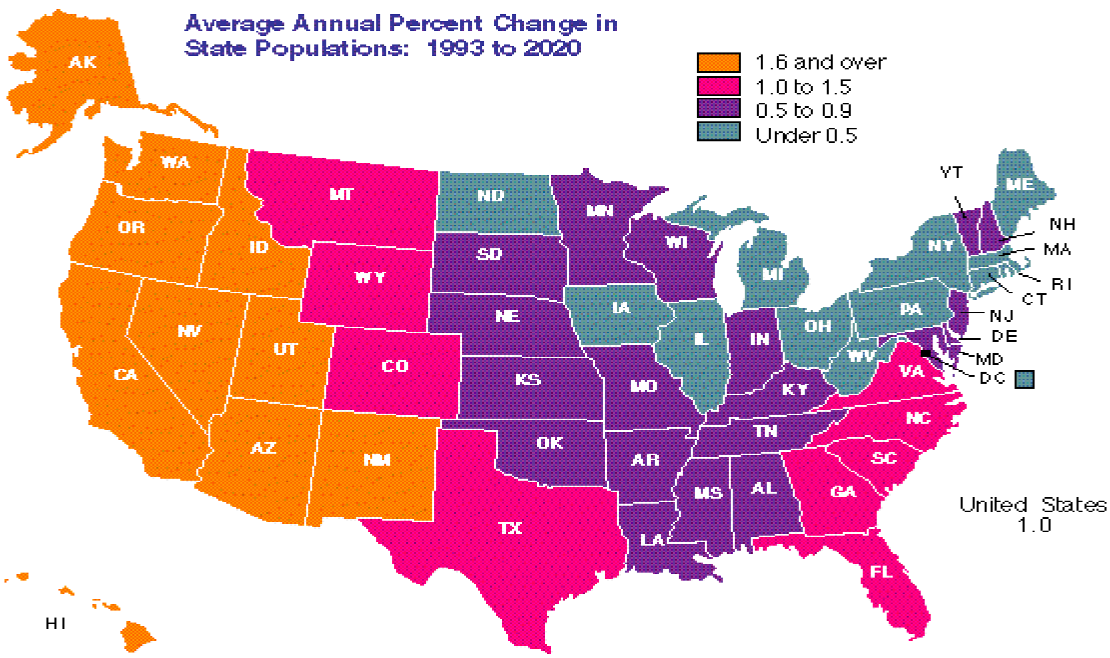


Figure 22. Average Annual Percent Change in State Populations.

Global Warming and Regional Climate Change

A report on Global Climate Change Impacts (Karl, 2009) listed national climate change key messages:

- U.S. average temperature has risen more than 2°F over the past 50 years and is projected to rise more in the future; how much more depends primarily on the amount of heat-trapping gases emitted globally and how sensitive the climate is to those emissions.
- Precipitation has increased an average of about 5 percent over the past 50 years.
- Projections of future precipitation generally indicate that northern areas will become wetter, and southern areas, particularly in the West, will become drier.
- The amount of rain falling in the heaviest downpours has increased approximately 20 percent on average in the past century, and this trend is very likely to continue, with the largest increases in the wettest places.
- Many types of extreme weather events, such as heat waves and regional droughts, have become more frequent and intense during the past 40 to 50 years.

The United States and Mexico consume 100% of the Colorado River water (per the existing law specified consumption rate) prior to the water reaching the Gulf of California and the Pacific Ocean. Even if the volume of water is greatly increased, as a result of this NSWG, all of the water would still be used versus flowing to the Pacific Ocean. Thus, the water captured from the Midwest's Rivers and diverted to the Colorado River would be consumed on land.

The diverted water could be used for many purposes. Agriculture is a primary user. A substantial portion of diverted water used in agriculture will get captured in plants on a huge scale. (Growing more plants will also provide significant increased carbon capture.) Evaporation and transpiration would still occur and some diverted water would return to the atmosphere and still get to the ocean per the hydrologic cycle. What amount of water could be diverted from the ocean in 10, 50 or 100 years? Before this thought is summarily dismissed as just a drop in the bucket, consider that a fraction of a meter in ocean level may matter when the ocean is projected to rise by a meter or more over the next 50–100 years without this NSWG plan. Diverting river water from the ocean at a rate of several maf per flood over 50–100 years could provide mitigation to rising sea level. The effect of water diversion, carbon capture, and regional climate change could be modeled by the national laboratory supercomputers.

Diverting Mississippi River Basin water to the Colorado River Basin will cause a regional climate change that adds humidity to the Colorado River Basin. The change will be immediate and lasting for as long as the diversion continues. The addition of water to the Colorado River via National Smart Water Grid will help mitigate the global climate change impact on the shift in amplitude and timing of this snowmelt-fed river.

Climate, freshwater, biophysical and socio-economic systems are interconnected in complex ways where a change in any one of these variables can induce change in another. Freshwater related issues are critical in determining key regional and continental vulnerabilities. Thus, the relationship between freshwater resources is of primary concern to our society and has significant implications for all living organisms.

Mitigation of Non-point Source Pollution Focuses on the Source

Net increases in nutrient loads (particularly nitrogen and phosphorus) have resulted in the eutrophication (excessive plant growth and decay) of lakes, rivers and receiving coastal waters and subsequent degradation of ecosystems, fisheries and human health. One of the world's largest dead zones has appeared off the mouth of the Mississippi River in the Gulf of Mexico, attributed to excessive nitrogen loads from the river, with harmful impacts on biodiversity and fisheries. This dead zone left unchecked will adversely affect the United States. Diverting water from the Mississippi River to the Colorado River will decrease the size of this dead zone.

Over the past 50 years, farming has altered the hydrology and chemistry of the Mississippi River, injecting more carbon dioxide into the river and raising river discharge, finds a study by researchers at Louisiana State and Yale universities. LSU Professor R. Eugene Turner and graduate student Whitney Broussard, along with their colleagues at Yale, tracked changes in the discharge of water and the concentration of bicarbonate, which forms when carbon dioxide in soil water dissolves rock minerals. Researchers concluded that liming and farming practices, such as changes in tile drainage, tillage practices and crop type, are most likely responsible for the majority of the increase in water and carbon in the Mississippi River. The additional water in the Mississippi River is altering the chemistry of the Gulf of Mexico as by increasing the amount of nutrients and pollution the river transports to the Gulf, Raymond, et al (2008).

The USGS also monitors the water quality of the Mississippi River and determines the amounts of nutrients, such as nitrogen and phosphorus, being transported to the Gulf of Mexico. Analysis of a pre-peak flow sample collected at St. Francisville, LA on April 8, 2008 (during the most recent major flood event) indicates that the daily loads of nitrogen and phosphorus in the Mississippi River were 15 million pounds and 2 million pounds, respectively. These loads are about twice as high as the long-term averages of 8.2 million and 760,000 pounds per day of nitrogen and phosphorus, but only about half as high as the maximum loads measured over the last 34 years.

Daily loads of nutrients will vary with flow, and estimated total loads for the flood will be available after more water-quality samples are collected and analyzed through late May. In July, the USGS will provide preliminary loads for April through June. Both current and historical data about nutrient loads in the Mississippi River basin can be found at http://toxics.usgs.gov/hypoxia/mississippi/index.html.

Floods are important to water quality in the Gulf of Mexico because they carry large amounts of nutrients (scoured from the farm lands), which cause excess algal growth and hypoxia. Hypoxia, a zone of low dissolved oxygen which can stress and kill bottom-dwelling organisms, has been measured annually in the northern Gulf of Mexico since 1985. The timing and volume of freshwater inputs and the spring load of nitrogen and phosphorus contributed from the Mississippi River Basin to the continental shelf are important factors in determining the size of the hypoxia zone. Nutrients in the Mississippi River Basin come from a variety of sources, including soils, agricultural cropping, application of fertilizers and manure, urban sources, and atmospheric deposition. Monitoring and reporting of both streamflow and water quality are crucial to understanding and resolving the Gulf hypoxia issue[11]. Diverting Mississippi River water from the Gulf could mitigate this effect and should be evaluated.

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11 http://toxics.usgs.gov/hypoxia/index.html.

NATIONAL SMART WATER GRID™

The National Smart Water Grid initial proposal could start with pipelines strategically located at key intervals along the Mississippi River Basin to capture the majority of flood waters. The first phase could provide the most flood relief and deliver water to the most impacted drought area. Figure 23 shows the National Smart Water Grid, Initial Proposal of Pipelines. Subsequent proposals could include a pipeline from the Mississippi River to points east, for example Florida. The attached map USACE Civil Works Activities (Appendix 3) shows all the USACE projects in the United States, the river systems, state and agency boundaries, as well as the proposed pipeline routes for consideration. The development of the National Smart Water Grid project will take many years and could be built in phases.

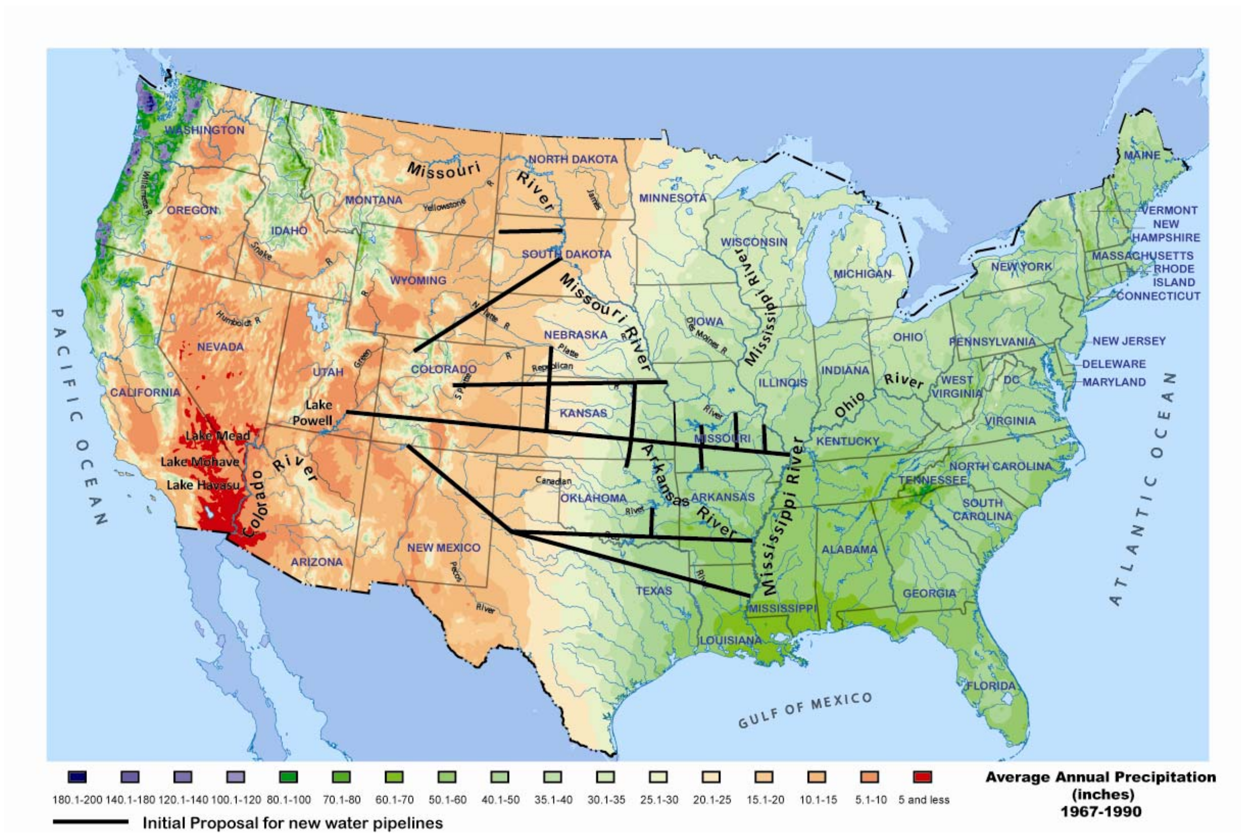

Figure 23a. National Smart Water Grid, Initial Proposal of Pipelines, Precipitation.

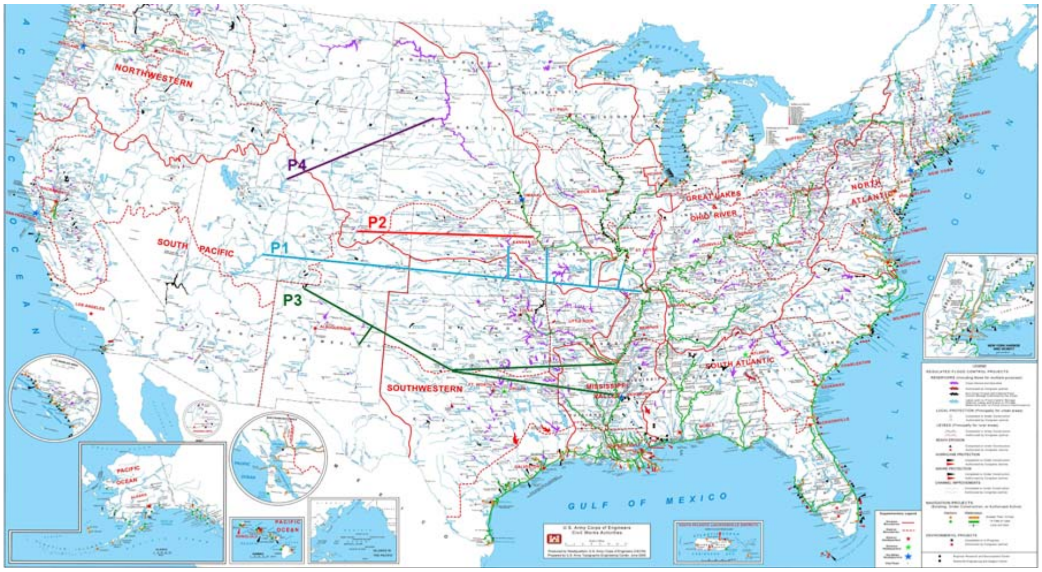

Figure 23b. Initial Proposal of Pipelines, Integration with Existing Infrastructure.

The first pipeline (P 1, blue) could be from the confluence of the Ohio and Mississippi Rivers along the Illinois and Missouri state borders (e.g. near Cairo, IL) to its destination on the Colorado River upstream of Lake Powell, Utah. The distance from the primary draw point to its destination is approximately 1,140 miles. When compared to the 800 mile long Alaska Pipeline, which is a good example of long distance pipeline application used for national resources, the length is just 340 miles more. A review of highway maps shows this initial pipeline route is north of US highway 40 and south of US highway 70. This pipeline would be the workhorse and the primary leg and consist of four 8-ft diameter parallel pipes.

A second pipeline (P 2, red) could be between the Kansas Cities and the Chatfield Reservoir near Denver, Colorado and could travel along the US Interstate Highway 70 corridor. The second pipeline could provide water for agricultural irrigation to Kansas and Colorado, and potable fresh water for the greater Denver metropolitan area. This pipeline could consist of two 8-ft diameter parallel pipes. The estimated distance is approximately 620 miles.

A third pipeline (P 3, green) could draw water from the Arkansas River and the confluence of the Arkansas and Mississippi Rivers to the Navajo Reservoir on the San Juan River in Northern New Mexico. The San Juan River is a tributary to the Colorado River and connects at Lake Powell. The pipeline could provide agricultural irrigation to states along the route and fresh water to western Texan cities. This east-west pipeline could consist of two 8-ft diameter parallel pipes. The estimated distance is approximately 970 miles.

A fourth pipeline (P 4, purple) could be from the Upper Missouri River (Oahe Reservoir) to the Green River above Flaming Gorge. This pipeline could consist of one 4-ft diameter pipe. The estimated distance is approximately 470 miles.

Additional pipelines and the resulting grid could be developed based on results of the first pipelines and developing needs of the country. Key assumptions for the National Smart Water Grid are listed below.

- The National Smart Water Grid is designed and constructed to move flood water from the Midwest's rivers to the Western states.
- Length: ranges from 470 to 1140 miles depending on pipeline routes.
- Pipe diameter: 48, 96, and 144 inches depending on location and application.
- Volume: transport ~1-2 maf/month in each set of parallel pipeline routes.
- Pipe design and material along the river banks integrated into the levees: arch pipe design corrugated steel with slotted drain top inlets.
- Steel pipe from the interim storage tanks to first pump (~ 1200 psig, > 50 kcfs) and destination.
- Pipelines above ground or buried depending on locations.
- Pumping stations located at approximately 100 mile intervals or as required for elevation change.
- Operating season projected from February to October during flood events.
- P1, P3, & P4 cross continental divide through mountain passes.
- Pipelines cross over 800 rivers and streams.
- Cost to build: $82 billion estimated in 2009.
- Spread work among different contractors.
- Workforce to exceed 100,000 employees over life of construction and over 4,000 during operations and maintenance.
- Slotted drains at Action Stage elevation over arch-pipes (AISI Handbook, 1994) constructed into river levees with gravity feed to first interim storage tanks.
- Ozone injection at the pumping stations.

Government oversight

Permits estimated, number

- Federal — 900
- State — 1250

Notices to Proceed estimated, number

- Federal — 650
- State — 500
- Indian Tribes permission — 20

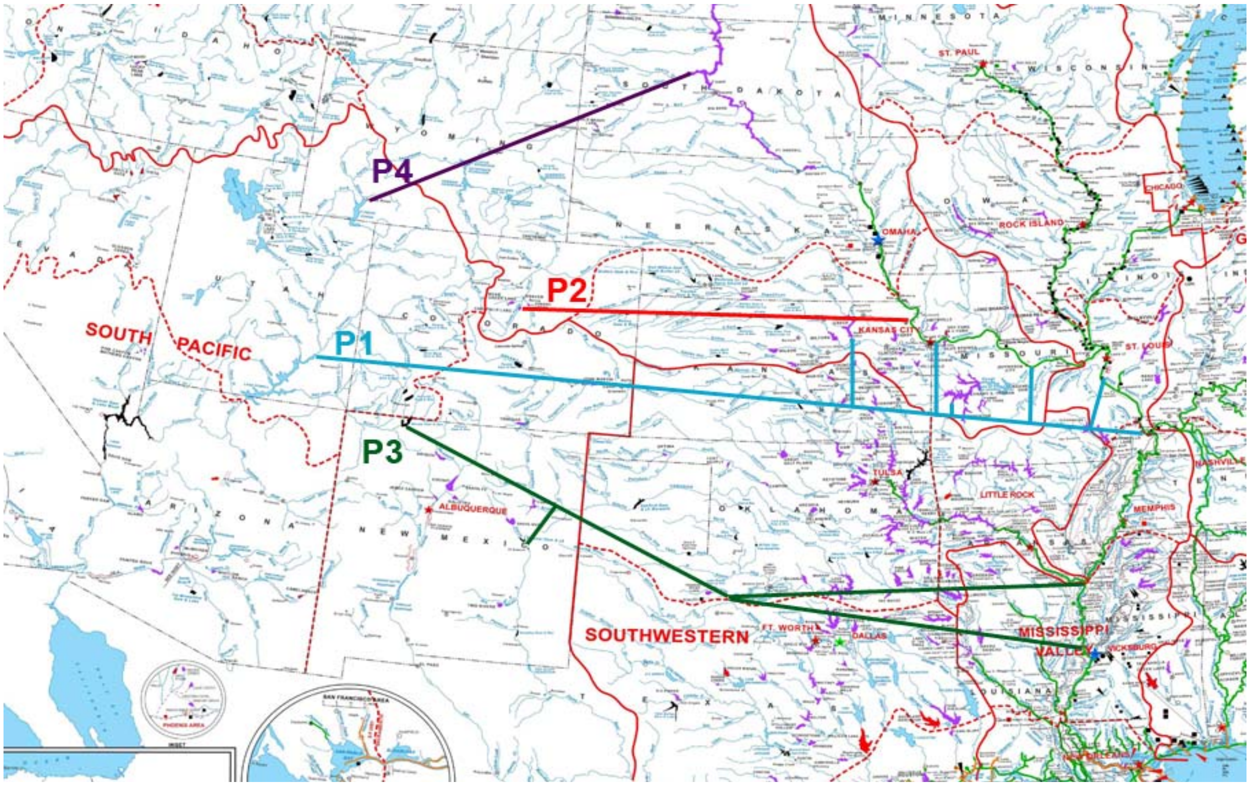

Figure 23c. Initial Proposal of Pipelines, Integration with Existing Infrastructure, Zoom

National Smart Water Grid Preliminary Conceptual Design

Water can be captured along a river bank by using a continuous slotted steel drain into a pipe-arched corrugated steel buried in the river bank. The opening of the slotted drain should have grating to prevent most debris larger than 2 inches from entering the capture pipe. The capture pipe could have a span of 16 ft or more using a pipe-arch depending on location and amount of water available to capture. The elevation of the slotted drain should be at the Action Stage elevation for the primary capture pipe. A secondary or tertiary capture pipe could run parallel to the primary capture pipe with a slotted drain entrance at the Flood Stage elevation to capture more water during the flood event, and the diameter could be matched to correspond to the volume of water desired for capture at a given location. The primary drain at Action Stage and secondary drain at Flood Stage and tertiary drain at Moderate Flood Stage provide a set of steps integrated into the river levee wall.

The use of corrugated steel pipe (CSP) buried in the river bank contour allows the water to flow downstream in the capture pipe to a designated location where the captured water could be collected into large tanks located adjacent to the river bank. A pipe arch design has hydraulic advantages at low flow and should accommodate this application. The river surface elevation over Action Stage or Flood Stage or Moderate Flood should provide ample head to move the water from the river to the collection tank. The use of concrete lined CSP should be considered for their strength and low hydraulic resistance, especially between the river bank capture pipes and the tanks.

The size of the interim storage tanks (that feeds the primary pumps and pipelines) could be large enough to hold significant flood water for uniform continuous pump operation. A parametric study could determine the optimum size at a given capture location considering the various input and output rates to/from the tank. A suggested size for initial consideration would be 5 to 10 million gallon capacity. It should be located below the arch-pipe elevation to enable gravity feed from the capture pipes into the tank. A tank of this structure could have a slightly pitched roof and vents that allow precipitation to enter directly into the tank and venting to prevent overpressure during filling.

The capture pipes and the tanks are expected for use seasonally estimated during February to October. The pipes and tanks should have man-way access to enable entry for maintenance and for debris/sediment removal during the off-season.

Large pumps capable of moving 50,000 cfs or more are expected to drain the interim storage tanks and feed the pipelines. The pumps should auto-actuate above a specified water level in the interim storage tank. A parametric study considering volume, displacement, suction head or lift to next pump or storage location, efficiency, and energy use will determine the optimum size(s) and type. The number of pipes from the interim storage tank to destination will vary depending of the volume and rate of water captured and moved. The data in the Appendix 1 spreadsheet gives the elevation above mean sea level for each river gage location and could be used to provide an approximate elevation of the first storage tanks and pumps. Valves should be appropriated located having remote control connected to water level in the collection tanks and destination data.

Right of Way

Right of Ways (ROW) acquisition will require assistance from state and local governments. The idea of water sharing and revenue sharing from the sale of water provides incentives to the governments where the ROW is needed.

The ROW from capture point on the river could be alongside the river in the river bank itself up to the first interim storage tank, and use the highways and the railroads that are affected by the flood events. Maybe working with the railroads this projects funding could help to upgrade our rail system while piggy-backing on whatever is left of the railroad existing ROWs. ROWs could be alongside electrical transmission lines or new utility corridors between cities.

The proposed pipeline from Kansas City to Denver could travel along the Interstate 70 corridor traveling on one side or the other of the highway and in some locations along the median. The pipeline could be buried to minimize impact.

National Smart Water Grid Destination Points

Several destination points could be utilized for storage of this vital national resource. The primary and largest reservoir is the Colorado River, with a primary pipeline destination point above Lake Powell, Utah. Another destination points could be the upper west branch of the Colorado River above Flaming Gorge reservoir and the Navajo Reservoir on the San Juan River. Other destinations points could include the Chatfield and Cherry Creek Reservoirs or a new reservoir near Denver, Colorado.

Chatfield Reservoir

Chatfield Reservoir is a flood-control reservoir on the South Platte River owned and operated by the U.S. Army Corps of Engineers. It was built in response to the devastating floods of 1965 that caused millions of dollars of damage in Denver. The reservoir has the ability to store more than 300,000 acre-feet of flood waters from the South Platte River and Plum Creek. Denver Water can use about 27,400 acre-feet of space in Chatfield, and uses its own water rights to fill and maintain water in the reservoir. Pursuant to an agreement with the State of Colorado, Denver Water manages its water for municipal supply, while also maintaining water levels for recreation. The land at Chatfield is leased to the State of Colorado, which operates Chatfield State Park.

Upper Colorado River Basin Reservoirs

- Fontenelle Reservoir
- Flaming Gorge Reservoir
- Blue Mesa, Morrow Point, and Crystal Reservoirs
- Navajo Reservoir

The Flaming George and Navajo Reservoirs are proposed as destination points for this project.

Lower Colorado River Basin Reservoirs

- Lake Powell
- Lake Mead
- Lakes Mohave and Havasu
- Bill Williams River
- Senator Wash and Laguna Reservoirs
- Imperial Dam

Lake Powell is proposed as a destination point for this project.

Safe Drinking Water

The overall cost of the Smart Water Grid™ is influenced by the quality of water transported. Irrigation water is not as valuable as potable drinking water. A key concept of the Smart Water Grid™ is the cost efficiencies that may be obtained by first killing harmful species in the water prior to transport, rather than at the destination points. This section discusses harmful species in the Mississippi River and water treatment with respect to the Safe Water Act. Part of the Smart Water Grid™ conceptual design is to skim off the top water during a flood, it is not taking high turbidity water from the bottom of the river. This reduces transmission of debris, disease and parasites.

Harmful Species in the Mississippi River Basin

The Mississippi River contains some harmful species (e.g., Zebra Mussel, notable parasites, and biological organisms). The Safe Water Drinking Act considers the control of biological organisms (pathogens) such as cryptosporidium (a protozoan parasite), Giardia lamblia (a flagellated protozoan parasite), Escherichia coli, and total coliform bacteria. Water treatment is necessary for the inactivation of cryptosporidium by ozone, ultraviolet (UV) light, or chlorine dioxide. Ozone and/or chlorine dioxide could be added to the water while in transit inside the pipelines. Ozone does not form organochlorine compounds, nor does it remain in the water after treatment. Ozone is a cost-effective method of treating water, since it is produced on demand and does not require transportation and storage of hazardous chemicals. Once ozone has decayed to oxygen, it leaves no taste or odor in drinking water. Water treatment is suggested by adding ozone at the first pumping station and at designated pumping stations, as necessary to kill harmful biological organisms, prior to discharge to a reservoir.

Work performed in the development of an environmental impact statement would identify different aquatic species between the river systems and evaluate the potential effects.

Water Treatment

Water treatment within the pipelines is suggested such as ozone injection, chlorination and algaecide additives to prohibit species propagation (e.g., Zebra Mussel) from source to destination. During the design, the engineers should evaluate organic and inorganic chemistry effects in the pumps, pipelines storage tanks, rivers and reservoirs, sediment removal or filtering, and implement requirements from the Safe Drinking Water Act. For example, the Safe Drinking Water Act mandates that above ground drinking water supply systems introduce an amount of chlorine to maintain a minimum of 0.2 ppm residual Free Chlorine in the drinking water supply pipes, based on results of regular testing. Drawing water directly from the host river surface during flood events will provide water with low turbidity. The existing water treatment facilities in the Colorado River system should provide ample water treatment, however their expansion may be necessary to support the increased flow volume. Sand Filters and other water treatment systems could be added as necessary to accommodate the increased supply of water from the pipeline.

Cost Benefit Analysis

Capturing, treating, transporting, and using water require large amounts of energy. This is particularly true in the West, where water supplies and population centers are often separated by hundreds of miles, requiring a tremendous amount of infrastructure to move water from where it is available to where it is needed. ***The Smart Water Grid™ will pay for itself in a single major flood event.***

Where will the money come from? Sale of Water.

Irrigation Water. Freshwater for irrigation can be sold in the range of $100 to $500 per acre ft plus the cost of transporting the water, meaning 1 maf can be sold for between $100M to $500M (Downing 2009).

Potable Fresh Water. Residential/commercial use freshwater is sold from western city utilities[12] at a range from $1.16 to $4.58 per 1,000 gallons in Las Vegas, NV; $1.99 to $4.74 per 748 gallons (HCF) in Phoenix, Arizona; $2.92 to $5.48 per HCF in Los Angeles, CA; $1.91 to $7.64 per 1,000 gallons in Denver, CO (not including service, commodity, environmental, meter, or other charges). Since the pipe from the utility to the residence/commercial user delivers the water directly to the user, the cost of transportation is included in the base fees plus the other named fees. The retail value of 1 maf can be sold for between $356M to $2,344M as listed in Table 2.

12 Data obtained from each city's respective water utility web site in July 2009.

Table 2. Sales Prices of Fresh Water in Western Cities

Cost per unit measure	1,000,000 gal	1 acre ft 325,900 gal	1 maf
$1.16/ k gal	$1,160	$356	$356M
$1.91/ k gal	$1,910	$586	$586M
$4.58/ k gal	$4,580	$1,405	$1,405M
$7.64/ k gal (highest cost)	$7,640	$2,344	**$2,344M**
$1.99/748 gal	$2,660	$816	$816M
$2.92/748 gal	$3,904	$1,198	$1,198M
$4.74/748 gal	$6,337	$1,945	$1,945M
$5. 48/748 gal	$7,329	$2,248	$2,248M

Conversions: 100 cubic ft (one HCF) = 748 gallons
1 acre ft = 325,900 gallons
1 million acre feet (maf) = 325,900,000,000 gallons

Thus, 60 maf of fresh water could produce revenue from $22B to $140B depending on the buyers. An $82B construction cost could be recovered over a single major flood event.

Where will the savings come from? Decreased costs associated with floods damage and droughts. Recent congressional testimony indicates that the current situation of floods and droughts cost more than $11 B annually (Pope 2008).

> "Direct economic losses from floods and droughts are high, averaging US $11.5 billion annually in direct losses…"
>
> Pope (2008)

Compare the cost of water with alternatives such as desalination plants that provide fresh water at costs from $100 to $4000 per acre foot (California Coastal Commission 2009).

Consider the length of proposed pipeline is approximately 3200 miles. The estimated cost to build the pipeline could range from $1B to $4B per hundred miles with a total cost for the four pipelines of approximately $82B as listed in Table 3. The cost benefit analysis is listed in Table 4.

Table 3. Cost Estimate to Build Initial Proposal of Pipelines

Leg	Distance (miles)	Design	Cost per pipeline leg
P 1 Blue	1140	4 x 8 ft dia pipes	$45.6B
P 2 Red	620	2 x 8 ft dia pipes	$12.4B
P 3 Green	970	2 x 8 ft dia pipes	$19.4B
P 4 Purple	470	1 x 4 ft dia pipe	$4.7B
Totals	3200		$82.1B (total)

Table 4. Cost/Benefit Analysis for Single Major Flood Event

Cost/Benefit Input Parameter	Cost or Benefit
Drought Consequence in West	$7B
Flood Consequence in Midwest	$27B
Misery Index (Drought + Floods)	$34B
Smart Water Grid Construction	$82B
Estimated Volume of Captured Fresh Water from 2008 Major Flood	60 maf
Average total sales Captured Fresh Water	$81B
Net Benefit = Water Sales + Misery Index – Construction Costs	+ $33B

The National Smart Water Grid™ will pay for itself in a single major flood event.

Alaska Pipeline Analogy

Some salient facts about the Alaska pipeline were obtained from multiple sources:

- The Trans Alaska Pipeline System was designed and constructed to move oil from the North Slope of Alaska to the northern most ice-free port in Valdez, Alaska.
- Length: 800 miles.
- Diameter: 48 inches—single pipe.
- Pipe material: steel
- Crosses three mountain ranges and over 800 rivers and streams.
- Cost to build: $8 billion in 1977, largest privately funded construction project at that time.

Alaska Pipeline Construction

Construction began on March 27, 1975 and was completed on May 31, 1977; 2 years, 2 months.

Design, route survey and selection

Archaeological survey

Contractors — University of Alaska, Alaska Methodist University

- Cost, total — $2.2 million approx.
- Sites excavated, total — 330 approx.

Soils survey

- Bore holes — 3,500 approx.
- Soil samples — 15,000 approx.
- Time devoted to preconstruction effort — 6 years approx.

Alaska Pipeline Government oversight

Permits required, number

- Federal — 515
- State — 832

Notices to Proceed required, number

- Federal — 465
- State — 403

Construction Contractors, by pipeline segment

- Section 1 (145 miles) Valdez to Gulkana River-Morrison-Knudson-Rivers
- Section 2 (157 miles) Gulkana River to Salcha River-Perini Arctic Associates
- Section 3 (144 miles) Salcha River to Yukon River-H.C. Price
- Section 4 (127 miles) Yukon River to Midnight Dome-Associated Green
- Section 5 (98 miles) Midnight Dome to Kuparuk River-Arctic Constructors
- Section 6 (125 miles) Kuparuk River to Pump Station 1-Arctic Constructors

Contractors and subcontractors, total number — 2,000 approx.

Materials

- Shipped to Alaska, total weight — 3 million tons approx.
- Gravel used for entire project, total — 73 million cu. yds.
- Gravel used for workpad — 32 million cu. yds.

Testing, hydrostatic pressure —

- Maximum, equivalent to 96% of specified minimum yield strength.
- Minimum, 125% of operating pressure or 750 psi, whichever was greater.

Welding

- Double joints, number — 42,000
- Field girth welds, number — 66,000
- Passes for field girth welds, number
  - .562 in. pipe — 7
  - .462 in. pipe — 6

Design modes

Selection — Soil sampling and other means were used to determine soil types along the route. Where stable soils were found, the pipeline was buried in the conventional manner.

- Above-ground — 420 mi.
- Conventional below-ground — 376 mi.

Alaska Pipeline Workforce

- Peak — 28,072, Oct. 1975 (includes Alyeska employees and contractors)
- Peak, contractor only — 21,600
- Total over life of construction project (1969-1977) — 70,000 approx.
- Minority hire, percentage — ranged from 14% to 19%
- Women, percentage — ranged from 5% to 10%

Alaska Pipeline Operations Basic Information

- Maximum daily throughput — 2.136 million bbl., avg.
  (With 11 pump stations operating). Rates exceeding 1,440,000 bbl./day assume drag reduction agent (DRA) injection.
- Maximum daily throughput — 2000 (with 7 pump stations operating) — .99 million bbl., avg. Rates exceeding 1,000,000 bbl./day assume DRA injection
- Fuel required for all operations (fuel oil equivalent) — 210,000 gal/day.
- Pressure —
  Design, maximum — 1,180 psi
  Operating, maximum — 1,180 psi

- Pump Station facilities in original design — 12 pump stations with 4 pumps each.

Alaska Pipeline Control System

- Basic function — Provides instantaneous monitoring, control of all significant aspects of operation, and pipeline leak detection. Operators in the Operations Control Center at the Marine Terminal monitor the system 24 hours a day and control oil movement through the pipeline and loading of tankers.
- Computer type — Data general MV/20000 and various PCs
- Location — Computer hardware and controllers' consoles are located in the Operations Control Center at the destination.

- Points monitored —
  - Pipeline —
    - 3,047 Input points
    - 352 Control points
- Remote data acquisition units —
  - Pipeline — 14 (each Pump Station, plus the beginning and end)
  - Metering — 14
- Software programming functions —
  - Data acquisition and control
  - Alarm and data processing and display
  - Hydraulic modeling
  - Leak detection
  - Historical archiving and reporting
  - Seismic evaluation

Key Fresh Water Management Organizations and People

The Corps of Engineers/Bureau of Reclamation have studied, planned and engineered the waterways being proposed for flood mitigation for years. They will have to be brought on board and included in the entire review and planning process. The same is true of state/local governments. The rivers identified in this report are critical lifelines for many communities and a large rural population. Good reasons were used for settlements on key waterways and most of them remain viable and critical to economic survival today. Furthermore, a group of what could be called water wizards exists in the U.S. Most of them are leaders and key members in the Association of State Floodplain Managers. They have tremendous influence on national water policy and legislation regarding flooding and related watershed management around the country. Lists of the key organizations and a few key contacts follow.

Key Organizations

Association of State Floodplain Managers
Western Governor's Association (WGA)
National Governor's Association
National Emergency Management Association
FEMA, Hazard Mitigation Department
US Army Corps of Engineers
US Bureau of Reclamation
NOAA
EPA
Colorado Water Research Institute
National Drought Mitigation Center
National Flood Plain Manager Association
National Water Resources Council
Natural hazards Observer (Natural Hazards Center CU boulder)
Colorado Water Council
Denver Water Department (as well as other large cities water dept.)

Figure 24. Federal Agencies Associated with Water Use Management.

Key Individuals

Larry Larson — Executive Director of the Association of State Floodplain Managers and founding member since 1977

Gerry Galloway — A nationally recognized expert in water resources management

Glen L. Martin — Professor of Engineering at the University of Maryland and visiting scholar at the U.S. Army Corps of Engineers Institute for Water Resources

Paul Conrad — Water resources specialist at the National Wildlife Federation

Dave Sprynczynatyk — North Dakota Adjutant General and former Director of Transportation as well as State Engineer for the North Dakota State Water Commission

Don Barnett — Mayor of Rapid City, North Dakota when catastrophic disaster occurred in 1972 and currently still active in floodplain management and mitigation. Currently works in the marketing department of THK Associates, Aurora, Colorado

Tony Willardson — Deputy Director of Western States Water Council

Pam Inmann is Executive Secretary of Western Governors Association, headquartered in Denver, Colorado. Jack Truby, Ron Cattany-from Department of Natural Resources, Larry Lang- Colorado Water Conservation Board, Hal Simpson, Office of the State Engineer Colorado Department of Natural Resources, Sandy White a Colorado Water Law Attorney.

These organizations and individuals are not the only keys to gaining success, but they do know the territory and have been difference makers nationally in water resources management for years. Their views count and their experiences are invaluable. Furthermore, federal, state and local politicians will have to be briefed and lobbied on the nature and magnitude of the project.

This National Smart Water Grid concept is all the more significant as the West is getting drier and more residents are (nervously) dependent on underground aquifers. Colorado has major problems with that dependency as population continues to grow over the Denver Aquifer. No one truly knows how much accessible water (groundwater) is in the aquifers; how many wells are drawing water from that source or how much water they are drawing, nor do they know how long that resource will serve even the current private well owners. A 100 year supply is required by the State for a building permit to be issued. Some well permits issued by the Sate Engineer for residential use, include a note "no guarantee that there is a 100-year supply".

Governments

United States of America, Canada, and Mexico

States involved

Arizona	Louisiana	Oklahoma
Arkansas	Minnesota	South Dakota
California	Mississippi	Tennessee
Colorado	Missouri	Texas
Illinois	Nebraska	Utah
Iowa	Nevada	Wisconsin
Kansas	New Mexico	Wyoming
Kentucky	North Dakota	

SUMMARY

Water is captured only during flood events from a source river level above the regulated surface elevation defined as Action Stage. A large portion of the proposed initial proposal for four main pipelines is necessary for the overall concept to achieve maximum positive impact. Existing engineering and technology would use pipelines to transport the captured fresh water to locations of significant demand. Substantial work is needed to negotiate the many Right of Ways, the fresh water sharing, and revenue sharing with the affected state, federal, and tribal governments. The implementation of the National Smart Water Grid would help mitigate several specific problems on a national scale:

1. Flood mitigation
2. Drought mitigation
3. Significant sustainable job creation
4. Decreased eutrophication in the Gulf of Mexico
5. Regional climate change and global warming mitigation
6. Significant increased gross domestic product
7. Improved National Security
8. Contribution to federal and state budgets deficit reduction
9. Improved national fresh water management
10. Increased agricultural productivity
11. Improved transportation on the Midwest's rivers, and adjacent railroads and highways
12. Improved fishery and wildlife habitats
13. Increased recreation and tourism
14. Decreased salinity in Colorado River water crossing the U.S.—Mexico border

Pros:

- Save lives; thousands of lives would be saved by decreased flooding impacts over 50–100 years;
- Would be a national mitigation action of extraordinary measure and would make a huge difference in watershed management;
- Would provide substantial sustainable economic stimulus;
- Would decrease/eliminate flood risk and save costs for disaster relief;
- Would balance the cycle of excess water supply versus drought across the Midwestern and Western U.S.;
- Impact on National Flood insurance program;
- Positive environmental impact;
- Revenue from sale of water.

Cons:

- Interstate issues and legal constraints;
- Water rights related issues;
- Costs;
- Environmental impact issues;
- Overall system management;
- Impact on National Flood insurance program;
- Political impacts.

REFERENCES

AISI (1994 Ed.). American Iron and Steel Institute, *Handbook of Steel Drainage & Highway Construction Products*, Washington, D.C.

AwwaRF (2006). American Water Works Association Research Foundation and University Corporation for Atmospheric Research, Climate Change and Water Resources: A Primer for Municipal Water Providers

Badt, Karin (1994). *The Mississippi Flood of 1993.* Chicago: Children's Press.

Bartholomew, John. (1958). Plate 3, World Climatology, Volume I, *The Times Atlas*, the Times Publishing Company, Ltd. London.

Bates, B.C., Z.W. Kunderdzewicz, S. Wu and J.P. Palutikof, Eds. (2008): Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva

California Coastal Commission (2009). http://www.coastal.ca.gov/desalrpt/dchap1.html

Campbell, Paul R. (2008). *State Population Projections,* U.S. Census Bureau, Population Profile of the United States http://www.census.gov/population/www/pop-profile/stproj.html

CDHCD http://www.hcd.ca.gov/hpd/hrc/rtr/chp2r.htm

Chatfield Reservoir http://www.denverwater.org/waterquality/chatfield.html

Colorado River "Law of the River," http://www.usbr.gov/lc/region/pao/lawofrvr.html

Deadliest U.S. Floods: http://www.epicdisasters.com/index.php/site/comments/the_deadliest_us_floods/

Downing, Jim. (2009). Economic, environmental hurdles block critical California water transfers. Sacramento Bee: http://www.sacbee.com/ourregion/story/1853186.html

Faunt, Claudia. C., Ed. (2009) Groundwater Availability of the Central Valley Aquifer, California: U.S. Geological Survey Professional Paper 1766

GAO/RCED-95-125: (1995). *Midwest Flood: Information on the Performance, Effects, and Control of Levees.* http://www.gao.gov/archive/1995/rc95125.pdf

Karl, Thomas R., Jerry M. Melillo, and Thomas C. Peterson, (eds.). (2009). *Global Climate Change Impacts in the United States*, Cambridge University Press. http://www.globalchange.gov/usimpacts http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf

NOAA (2009). National Oceanic and Atmospheric Administration, Office of Hydrologic Development, Advanced Hydrologic Prediction Services, http://www.nws.noaa.gov/oh/ahps/

Overall, Michael. (2009). *25 Years Ago Flood Buried Tulsa*. Tulsa World: http://www.tulsaworld.com/news/article.aspx?subjectid=11&articleid=20090524_11_A13_Thepow525438

Pearson, W. L. (2009). *Floods to Droughts*. NOAA PowerPoint Presentation: http://www.nationalpress.org/usr_doc/NPFNorman042109v1.ppt

Perry, Charles A. (2000). Significant Floods in the United States during the 20th Century: USGS: http://ks.water.usgs.gov/pubs/fact-sheets/fs.024-00.html

Pope, C. T. (2008). Global Warming to Increase Unpredictable Weather: Impacts on Water, Cooley says in Congressional Testimony. http://www.circleofblue.org/waternews/world/north-america/global-warming-to-increase-unpredictable-weather-pacific-institutes-heather-s-cooley-testifies-before-congress/

Raymond, et al (January 24, 2008). "*Anthropogenically Enhanced Fluxes of Water and Carbon from the Mississippi River*," Neung-Hwan Oh, R. Eugene Turner, Whitney Broussard, Peter A. Raymond Nature 451, 449-452

Safe Drinking Water Act

http://www.e-laws.gov.on.ca/html/statutes/english/elaws_statutes_02s32_e.htm

USACE (2001). *Upper Mississippi River Navigation Charts*, U.S. Army Corp of Engineers

USACE (2007). *2007 Mississippi River Navigation Flood Control and Navigation Book*, U.S. Army Corp of Engineers

USBR (2008). *Annual Operating Plan for Colorado River Reservoirs*, U.S. Bureau of Reclamation http://www.usbr.gov/lc/region/pao/lawofrvr.html

Appendix 1

Water Gages Data Along the Missouri and Mississippi Rivers

The following spreadsheets gather data using the NOAA water gages located at specified locations along the Missouri and Mississippi Rivers and the corresponding key features of the river at each location. The data collected include the river surface elevation above mean seal level and the river stage data for each gage location. Of particular value is the calculation for flow of water (kcfs) available to capture above the Action Stage. The Action Stage corresponds to the water surface profile below which the river cannot be touched. However, the water level above the Action Flood, Moderate Flood, and Major Flood Stages are above where the Anti-drawdown law protects. (See discussion of Mississippi River Law.) The water level above the Action Stage documented in the NOAA Advanced Hydrologic Prediction Service is the flood water available for capture and transport via pipelines. The yellow highlighted columns list the flow rate of flood water available for capture at each gage location.

Mississippi River Gage Information

NOAA		River	Datum Elev.	Stage at LOL	LOL Elev.	Action Stage	Action Stage	Flood Stage	Flood Stage	Mod Flood Stage	Mod Flood Stage	Major Flood Stage	Major Flood Stage	Flood-Action	Mod Flood-Action	Major flood-Action	Record	Record	Record
Gage Number	Location / Description	Mile	ft	(Flat Pool) ft	(Flat Pool) ft	ft	kcfs	ft	kcfs	ft	kcfs	ft	kcfs	kcfs	kcfs	kcfs	ft	kcfs	Date
	Lock 10, (UPPER) Guttenberg	615.1	600.00			13	123	15	157	18	208	21	262	34	85	139	23.7	305	
	Lock 10, Tail (LOWER) Guttenberg	615.1	600.00	3.0	603.0									0	0	0			
	Rock Island District																		
	Cassville, WI Left Bank, Dairyland Power, staff + wire weight	606.7	596.30	6.7	603.0									0	0	0			
	Waupeton, Right Bank, staff at bridge	599.9	593.30	9.7	603.0									0	0	0			
	Specht's Ferry, IA Right Bank, staff on rock wall	592.3	590.60	12.4	603.0									0	0	0			
	Lock 11, Pool (UPPER) Dubuque	583.0	588.20	14.8	603.0	15.0	145	16.0	157	17.0	169	20.5	210	12	24	65	25.7	>300	
	Lock 11, Tail (LOWER) Dubuque	583.0	588.20	3.8	592.0									0	0	0			
	Dubuque, IA, Right Bank, staff + satellite at RR Bridge	579.9	585.39	6.6	592.0	15.0	124	17.0	146	18.0	158	21.5	203	22	34	79	26.8	300	
	Nitaho Valley, IA Right Bank, staff at ramp & bridge	567.1	581.80	10.2	592.0									0	0	0			
	Gordon's Ferry, Right Bank, staff at RR Bridge	566.2	582.10	9.9	592.0									0	0	0			
	Lock 12, Pool (UPPER) Bellevue	556.7	580.20	11.8	592.0	16.0	151	17.0	162	18.0	183	20.0	225	11	32	74	23.5	>310	
	Lock 12, Tail (LOWER) Bellevue	556.7	580.20	2.8	583.0									0	0	0			
	Pleasant Creek, IA Right Bank, staff on sheet piling upstream of ramp	553.0	579.09	3.9	583.0									0	0	0			
	Maquoketa River, IA	547.4	583.00	0.0	583.0									0	0	0			
	Savanna Bay, Left Bank, "X" corner of concrete of sign at ramp	541.0			583.0									0	0	0			
	Sabula, IA, Right Bank, staff at RR Bridge (channel 13)	535.0	572.27	10.7	583.0									0	0	0			
	Lock 13, Pool (UPPER) Fulton	522.5	568.70	14.3	583.0	15.0	142	16.0	154	18.0	182	20.0	211	12	40	69	25	>300	

NOAA		River	Datum Elev.	Stage at LOL	LOL Elev.	Action Stage	Action Stage	Flood Stage	Flood Stage	Mod Flood Stage	Mod Flood Stage	Major Flood Stage	Major Flood Stage	Flood-Action	Mod Flood-Action	Major flood-Action	Record	Record	Record
Gage Number	Location / Description	Mile	ft	(Flat Pool) ft	(Flat Pool) ft	ft	kcfs	ft	kcfs	ft	kcfs	ft	kcfs	kcfs	kcfs	kcfs	ft	kcfs	Date
	Lock 13, Tail (LOWER) Fulton	522.5	568.70	3.3	572.0									0	0	0			
	Clinton, IA, Right Bank, RR Bridge, staff downstream of pivot	518.0	566.30	5.7	572.0									0	0	0			
	Comanche, IA Right Bank, staff + tape inside satellite shed foot 8th Ave.	511.8	563.20	8.8	572.0									0	0	0			
	Princeton, IA Right Bank, staff	502.1	563.56	8.5	572.0									0	0	0			
	LeClaire, IA Right Bank, in shed 400 ft downstream of museum	497.0	563.20	8.8	572.0									0	0	0			
	Lock 14, Pool (UPPER) Le Claire	493.3	557.08	14.9	572.0	10.0	149	11.0	172	12.0	191	13.5	220	23	42	71	17.8	300	
	Lock 14, Tail (LOWER) Le Claire	493.3	557.08	3.9	561.0									0	0	0			
	Bettendorf, IA Right Bank, **Phillip's oil dock**, staff at cell	487.2	551.54	9.6	561.0									0	0	0			
	Lock 15, Pool (UPPER) Rock Island	482.9	542.50	18.5	561.0	13.0	136	15.0	161	16.0	175	18.0	215	25	39	79	22.6	305	
	Lock 15, Tail (LOWER) Rock Island	482.9	542.50	2.5	545.0									0	0	0			
	Sunset Marina, Left Bank, wire weight at hoist	479.7	534.10	10.9	545.0									0	0	0			
	Linwood, IA Right Bank, staff at Amoco dock	475.5	534.20	10.8	545.0									0	0	0			
	Eastern Iowa Power, Right Bank, staff at intake	468.0	540.00	5.0	545.0									0	0	0			
	Fairport, IA Right Bank, in pump house at hatchery (call lock 16)	463.5	535.16	9.8	545.0									0	0	0			
	Lock 16, Pool (UPPER) WNW, IL	457.2	533.80	11.4	545.0	14.0	161	15.0	172	16.0	185	18.0	212	11	24	51	24.1	330	
	Lock 16, IA Tail (LOWER) WNW, IL	457.2	533.79	2.4	536.0									0	0	0			
	Muscatine, IA, Right Bank, tape at power plant (call lock 16)	453.1	530.47	5.3	536.0	15.0	149	16.0	161	18.0	186	20.0	222	12	37	73	25.6	340	
	Farmland Dock, IA, Right Bank, staff at dock	450.2	528.20	7.8	536.0									0	0	0			
	Lock 17, Pool (UPPER) New Boston	437.1	526.57	9.3	536.0	14.0	139	15.0	149	16.5	165	18.5	200	10	26	61	25.9	>350	
	Lock 17, Tail (LOWER) New Boston	437.1	526.57	1.3	528.0									0	0	0			
	Keithsburg, IL Left Bank, staff + wire weight at grain elevator	427.7	523.19	4.8	528.0	13.0	156	14.0	176	15.5	210	17.0	241	20	54	85	24.5	450	
	Oquawka, IL Left Bank, staff at downstream end Marina	415.2	513.24	14.8	528.0									0	0	0			
	Lock 18, Pool (UPPER) Gladstone	410.5	518.50	9.5	528.0	9.0	142	10.0	160	12.0	198	14.0	238	18	56	96	22.5	450	6/17/2008
	Lock 18, Tail (LOWER) Gladstone	410.5	518.50	-0.3	518.2									0	0	0			
BRL14	**Burlington, IA** Right Bank, **RR Bridge** staff + satellite in shed on bank	403.1	511.45	6.8	518.2	14.0	152	15.0	176	16.5	205	18.0	242	24	53	90	25.7	>450	
	I S U Power Plant, IA, Right Bank, staff at intake	399.0	498.20	20.0	518.2									0	0	0			

NOAA		River	Datum Elev.	Stage at LOL	LOL Elev.	Action Stage	Action Stage	Flood Stage	Flood Stage	Mod Flood Stage	Mod Flood Stage	Major Flood Stage	Major Flood Stage	Flood-Action	Mod Flood-Action	Major flood-Action	Record	Record	Record
Gage Number	Location / Description	Mile	ft	(Flat Pool) ft	(Flat Pool) ft	ft	kcfs	ft	kcfs	ft	kcfs	ft	kcfs	kcfs	kcfs	kcfs	ft	kcfs	Date
	Ft Madison, IA, Right Bank, RR Bridge staff + satellite in shed on bank	383.9	518.20	0.0	518.2									0	0	0			
	Ft Madison, IA, Right Bank, harbor, top of wall at ramp = 522.79	383.8	500.00	18.2	518.2									0	0	0			
EOK14	**Lock 19, Pool (UPPER) Keokuk**	364.3	518.20	0.0	518.2	14.0	192	16.0	226	17.5	250	19.0	280	34	58	88	27.6	>500	7/10/1993
	Lock 19, Tail (LOWER) Keokuk	364.3	477.83	2.2	480.0									0	0	0			
	Warsaw, Left Bank, staff on sheet pile upstream of elevator	359.9	472.90	5.8	478.7									0	0	0			
GGYM7	**Gregory Landing, IA**, Right Bank, tape + satellite in shed at elevator	352.9	472.71	5.5	478.2	14.0	185	15.0	202	18.0	257	25.0	416	17	72	231	28.5	>550	7/9/1993
	Lock 20, Pool (UPPER) Canton	343.2	468.50	7.0	475.5									0	0	0			
CANM7	**Lock 20, Tail (LOWER) Canton**	343.2	468.50	1.5	470.0	12.0	165	14.0	195	20.0	310	25.0	460	30	145	295	27.9	>500	7/9/1993
	LaGrange, IA, Right Bank, staff on cell + wire weight at elevator	336.0	464.60	5.4	470.0									0	0	0			
UIN12	**Quincy, IL**, Left Bank, staff + satellite at water plant	327.0	458.60	11.4	470.0	15.0	167	17.0	199	18.0	215	22.5	295	32	48	128	32.1	>550	7/10/1993
	Lock 21, Pool (UPPER) Quincy	324.9	457.80	12.2	470.0									0	0	0			
QLD12	**Lock 21, Tail (LOWER) Quincy**	324.9	457.80	1.7	459.5	15.0	191	17.0	224	18.0	241	22.0	302	33	50	111	31.3	>500	7/13/1993
	N E Mo Power, MO, Right Bank, staff at intake	320.0	454.60	4.9	459.5									0	0	0			
	Hannibal, MO, Right Bank, staff at **RR Bridge**, satellite in bldg upstream harbor	309.8	449.50	10.0	459.5									0	0	0			
HNNM7	**Hannibal Water Works**	309.0	449.50	10.0	459.5	14.0	154	16.0	201	18.0	241	22.0	319	47	87	165	31.8	>510	7/15/1993
	Lock 22, Pool (UPPER) Saverton	301.2	446.10	13.4	459.5									0	0	0			
	St Louis District																		
SVRM7	**Lock 22, Tail (LOWER) Saverton**	301.2	446.10	2.9	449.0	14.0	178	16.0	212	20.0	280	22.0	317	34	102	139	29.6	520	7/25/1993
	Mundy's Landing, MO	293.0	441.85											0	0	0			
LVSM7	**Louisiana, MO**	282.9	437.33			13	156	15	200	20	298	25	417	44	142	261	28.4	530	7/25/1993
	Lock & Dam No. 24 (UPPER) Clarksville	273.5	421.81											0	0	0			
CLKM7	**Lock & Dam No. 24 (LOWER) Clarksville**	273.2	421.81			23	158	25	188	31	277	33	332	30	119	174	37.5	487	7/29/1993
	Rip Rap Landing, IL	265.0	426.03											0	0	0			
	Mosier Landing	260.3	400.00											0	0	0			
	Sterling Landing	250.8	420.48											0	0	0			
	Lock & Dam No. 25 (UPPER) Winfield	241.5	407.00											0	0	0			
CAGM7	**Lock & Dam No. 25 (LOWER) Winfield**	241.2	407.00			24	162	26	198	30	258	34	358	36	96	196	39.6	560	8/1/1993
	Dixon Landing, IL	228.3	410.62											0	0	0			
GRF12	**Grafton, IL**	218.0	403.79			17	225	18	242	24	332	29	430	17	107	205	38.2	>750	8/1/1993
	Alton, IL	203.0	400.00											0	0	0			
	Mel Price Lock & Dam (UPPER) Alton	201.0	395.48											0	0	0			

NOAA		River	Datum Elev.	Stage at LOL	LOL Elev.	Action Stage	Action Stage	Flood Stage	Flood Stage	Mod Flood Stage	Mod Flood Stage	Major Flood Stage	Major Flood Stage	Flood-Action	Mod Flood-Action	Major flood-Action	Record	Record	Record
Gage Number	Location / Description	Mile	ft	(Flat Pool) ft	(Flat Pool) ft	ft	kcfs	ft	kcfs	ft	kcfs	ft	kcfs	kcfs	kcfs	kcfs	ft	kcfs	Date
ALN12	**Mel Price Lock & Dam (LOWER) Alton**	200.5	395.48			19	303	21	344	29	543	34	697	41	240	394	42.7	>800	8/1/1993
	Hartford, IL	196.8	350.00											0	0	0			
	Chain of Rocks	190.4	313.91											0	0	0			
	Lock & Dam No. 27 (UPPER)	185.3	350.00											0	0	0			
	Lock & Dam No. 27 (LOWER)	185.1	350.00											0	0	0			
EADM7	**St. Louis, MO**	179.6	379.94			28	463	30	504	35	618	40	759	41	155	296	49.6	1080	8/1/1993
	Engineers Depot, MO	176.8	379.58											0	0	0			
	Jefferson Barracks, MO	168.7	377.69											0	0	0			
	Waters Point, MO	158.5	370.39											0	0	0			
	Selma, MO	145.8	0.00											0	0	0			
	Brickeys, MO	136.0	357.78											0	0	0			
	Little Rock Landing, MO	125.5	213.79											0	0	0			
CHS12	**Chester, IL**	109.9	341.05			25	385	27	422	30	480	38	660	37	95	275	49.7	1000	8/7/1993
	Bishop Landing, MO	100.8	334.11											0	0	0			
	Red Rock Landing, MO	94.1	328.92											0	0	0			
	Grand Tower, IL	81.9	321.93											0	0	0			
	Moccasin Springs, MO	66.3	313.89											0	0	0			
CPGM7	**Cape Girardeau, MO**	52.1	304.65			29	315	32	373	37	501	42	657	58	186	342	48.5	>900	8/8/1993
	Grays Point, MO	46.3	301.83											0	0	0			
THB12	**Thebes, IL**	43.7	300.00			30	403	33	473	37	594	42	791	70	191	388	45.9	1000	5/23/1995
	Commerce, MO	39.5	301.83											0	0	0			
	Price Landing, MO	28.2	299.75											0	0	0			
	Thompson Landing, MO	20.2	280.00											0	0	0			
	Birds Point, MO	2.0	274.53											0	0	0			
	Cairo, IL, Mouth of Ohio River	2.0	270.47											0	0	0			
	ABOVE HEAD OF PASSES																		
	Cairo, IL, Ohio River	953.8	270.47			32		40	864	47	1130	53	1365	864	1130	1365	59.5	1700	
	Wickliffe, KY (gage established 1932)	951.5	269.12											0	0	0			
	Columbus, KY	937.2	266.38											0	0	0			
	Hickman, KY (gage established 1929)	922.0	264.73											0	0	0			
NMDM7	**New Madrid, MO**	889.0	255.48			30	924	34	1090	40	1350	44	1550	166	426	626	48	1770	2/3/1937
TPTT1	**Tiptonville, IL**	872.2	245.14			34	1030	37	1200	45	1790	47	2000	170	760	970	47.8	>1900	2/6/1937
CRTM7	**Caruthersville, MO**	846.4	235.49			29	833	32	948	41	1480	43	1650	115	647	817	46	2000	2/5/1937
	Cottonwood Point, MO	832.7	230.18											0	0	0			
OSGA4	**Osceola, AR**	783.4	209.43											0	0	0	50.9		2/7/1937
	Fulton, TN	778.2	208.61											0	0	0			
	Memphis, TN	734.7	183.91			28	1020	34	1280	40	1580	46	1890	260	560	870	48.7		
	Mhoon Landing, MS	687.5	161.22											0	0	0			
HEEA4	**Helena, AR**	663.0	141.70			40	1200	44	1450	50	1990	55		250	790		60.2	>2400	
	Fair Landing, AR	632.5	132.20											0	0	0			
	Rosedale, MS	592.2	108.73											0	0	0			
	Arkansas City, AR	554.1	96.66			36	1360	37	1400	40	1600	44	1960	40	240	600	59.2	>3000	
	Greenville (Bridge), MS (gage established 1940)	531.5	74.92			36	1400	48	1470	52	1690	57	1890	70	290	490	58.2	>1900	
	Lake Providence, LA	487.2	69.71											0	0	0			

NOAA		River	Datum Elev.	Stage at LOL	LOL Elev.	Action Stage	Action Stage	Flood Stage	Flood Stage	Mod Flood Stage	Mod Flood Stage	Major Flood Stage	Major Flood Stage	Flood-Action	Mod Flood-Action	Major flood-Action	Record	Record	Record
Gage Number	**Location / Description**	**Mile**	**ft**	**(Flat Pool) ft**	**(Flat Pool) ft**	**ft**	**kcfs**	**ft**	**kcfs**	**ft**	**kcfs**	**ft**	**kcfs**	**kcfs**	**kcfs**	**kcfs**	**ft**	**kcfs**	**Date**
	Vicksburg (Canal), MS	437.6	46.25											0	0	0			
	Vicksburg, MS	435.7	46.23											0	0	0			
	St. Joseph, LA	396.4	33.12											0	0	0			
	Natchez, MS	363.3	17.28											0	0	0			

Missouri River Gage Information

NOAA		River	Datum Elev.	Stage at LOL	LOL Elev.	Action Stage	Action Stage	Flood Stage	Flood Stage	Mod Flood Stage	Mod Flood Stage	Major Flood Stage	Major Flood Stage	Flood-Action	Mod Flood-Action	Major flood-Action	Record	Record	Record
Number	**Location / Description**	**Mile**	**ft**	**(Flat Pool) ft**	**(Flat Pool) ft**	**ft**	**kcfs**	**ft**	**kcfs**	**ft**	**kcfs**	**ft**	**kcfs**	**kcfs**	**kcfs**	**kcfs**	**ft**	**kcfs**	**Date**
RULN1	2 NW Rulo		837.23			15	70.7	17	85	21	120	25.6	200	14.2	49.3	129.3	25.60	200	
SJSM7	St Joseph		788.19			14	66.9	17	87	21	126	27	214	20.1	59.1	147.1	32.10	321	
ATCK1	Atchison		762.20			19	83	22	114	27	193	30	271	31	110	188	31.63	340	
LEVK1	Leavenworth		742.21			17	92	20	119	24	166	30	253	27	74	161	35.30	>330	
KCDM7	Kansas City	366.2	706.40			29	200	32	230	35	280	49	520	30	80	320	48.87	500	7/27/1993
SBEM7	1 E Sibley		683.92			19	100	22	124	29	220	31	260	24	120	160	35.9	>380	
NAPM7	Napoleon		680.24			14	89.5	17	115	25	109	30	408	25.5	19.5	318.5	28.86	290	
WVYM7	Waverly		646.00			17	87	20	119	29	275	31	340	32	188	253	31.15	340	
MIAM7	Miami		621.35			15	80	18	104	28	258	29	295	24	178	215	32.6	>510	
GLZM7	Glasgow	226.3	586.49			22	130	25	170	27	196	32	284	40	66	154	39.5	>300	
BOZM7	Boonville		565.42			18	130	21	168	35	500	36	596	38	370	466	37.1	>600	
JFFM7	Jefferson City	143.9	520.08			21	170	23	200	25	226	30	327	30	56	157	38.3	>500	
CMSM7	1 E Chamois	116.6	502.50			15	160	17	183	28	394	31	500	23	234	340	33.3	610	
GSCM7	1 NE Gasconade	104.7	484.80			20	151	22	170	34	500	37	600	19	349	449	39.6	>600	
HRNM7	Hermann		481.56			19	165	21	192	26	269	33	455	27	104	290	37	660	
WHGM7	Washington	67.6	457.56			18	204	20	236	28	373	31	438	32	169	234	35.4	>660	
SCLM7	1 E St. Charles	28.2	413.59			23	193	25	230	30	313	36	420	37	120	227	40.1	715	

Appendix 2

Calculate the Amount of Water Available for Capture During Flood Events

Purpose and Objective

The purpose of this analysis is to estimate the amount of water that can be captured from the Mississippi River at a specified location using advanced hydrographs provided by National Oceanic and Atmospheric Administration (NOAA). Suppose we were able to capture a fraction of the flood waters and transport this water westward versus watching it expand into a flood plain or race to the Gulf of Mexico to join the oceans. Capture 10% of a 1,000 kcfs flood flow.

Example: Capture 10% of 1,000 kcfs per month
= 60s/min x 60 min/hr x 24 hr/day x 30 days x 10% x 1,000 kcfs
= 259,200,000 kcf

Conversion: 1,000 cubic ft = 0.022 956 840 808 acre ft
= 5,950,413 acre ft
= 5.95 maf

During a single major flood event, approximately 6 to 60 maf (10 to 100% of a major flood volume) are available for drainage from the Mississippi River basin. The annual average flow of the Colorado River into Lake Powell is 12 maf. Approximately five times that amount is available for capture during a single major flood event.

This example illustrates the volume of water that could be captured during a flood event. The actual amount of water captured depends on the engineering design of the capture system, its specific capacity for drainage, interim storage, size of the pipelines and pumps, and number of capture points. The size of the system should be designed to capture a significant volume of water to mitigate the flood event and to send the water to where it is needed; this amount may be 50%-90% of a major flood event captured at different locations along the Mississippi River Basin. Thus, the need for multiple pipelines.

Assumptions and Input

A. Water cannot be captured when river level is below Action Stage.
B. Water can be captured when river level is at or above Action Stage.
C. The NOAA Advanced Hydrologic Prediction Service hydrographs provide accurate information based on river gage data as shown in Figures 25 and 26.

Analytical Methods and Computations

The amount of water that can be drawn from the Mississippi River is equal to the area under the curve of the hydrograph that depicts the water level data points above the Action Stage. The Area is calculated by multiplying the right vertical axis [flow (kcfs)] by the horizontal axis (time increment), where each box on the horizontal access equals 12 hours or 43,200 seconds.

Results

Example 1:

Review the advanced hydrograph for the Mississippi River at Thebes on April 14, 2009. Calculate the amount of water available to be drawn above the Action Stage during mid April 2009.

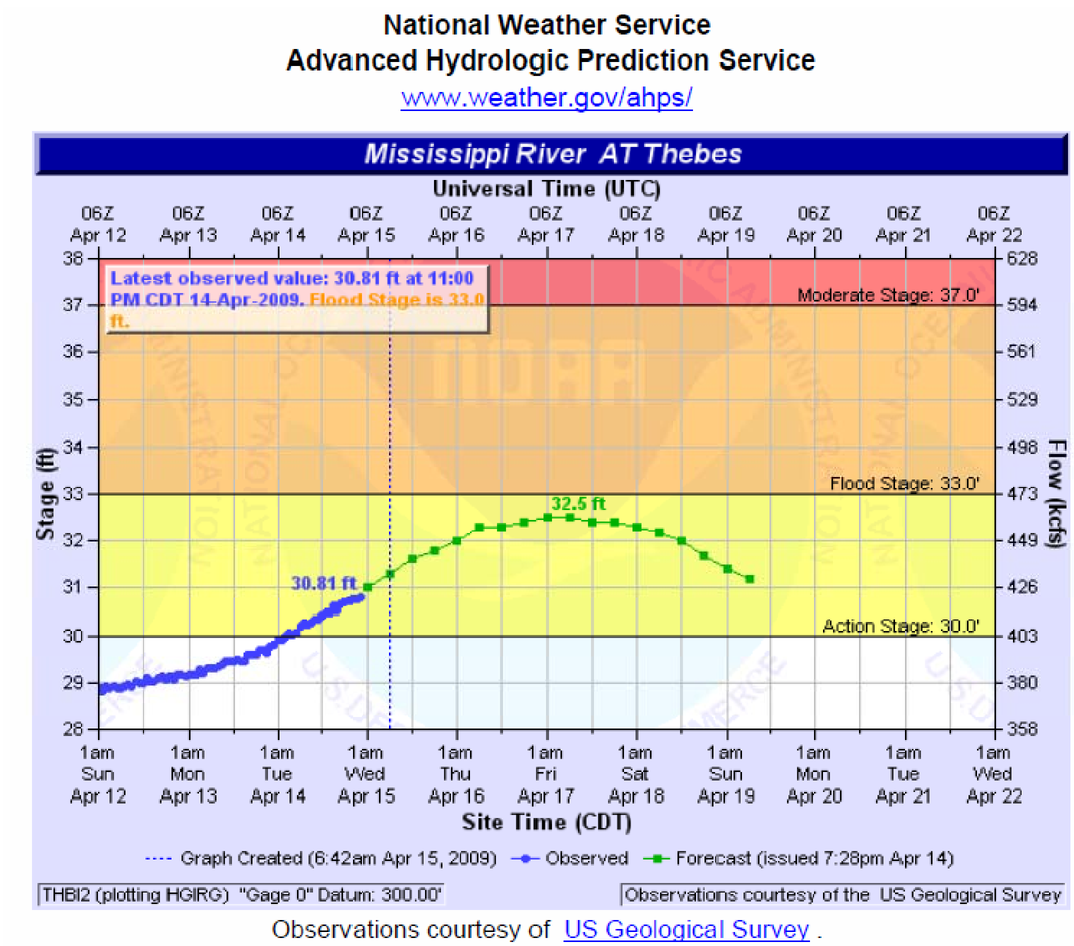

Figure 25. Advanced Hydrograph of Mississippi River at Thebes April 14, 2009[13].

The right vertical axis shows the Action Stage of 30.0 ft equals 403 kcfs. The Mississippi River water surface stage is measured by gage THB12 and is plotted on the hydrograph by the observed (blue) and the forecast (green) data points. Each vertical box is approximately 23 kcfs. The water level is forecast to crest at 32.5 ft (~461 kcfs) on Apr 17, 2009.

The observed water level crossed above the Action Stage 30.0 ft after 1 am Tue Apr 14. The water is forecast above the Action stage until approximately 1 pm Sun Apr 19, when the green line crosses back below the Action Stage. The time that the river is at or above Action Stage is approximately 13 horizontal boxes that are 12 hours duration each for a total of 156 hours or 56,160 seconds.

13 http://www.crh.noaa.gov/ahps2/print_image.php?wfo=pah&gage=thbi2&type=0

The area of each box is equal to the flow of 23 kcfs times 12 hours or 43,200 seconds and can be expressed by the following equation:

$Q\ (flow)_{box} = 23\ kcfs \times 43{,}200\ s$
$Q\ (flow)_{box} = 993{,}600\ kcf$

The quantity of whole boxes (B) is estimated at 19, which is approximate. The total volume of water is equal to the flow per box times the number of boxes and can be expressed by the following equation:

$V = Q_{box} \times B$
$V = 993{,}600\ kcf \times 19\ boxes$
$V = 18{,}878{,}400\ kcf$
$V = 435{,}400$ acre ft or 0.4 maf

Example 2:

Review the advanced hydrograph for the Mississippi River at Grafton on April 15, 2009. Calculate the amount of water available to be drawn above the Action Stage during April 10 to 20, 2009.

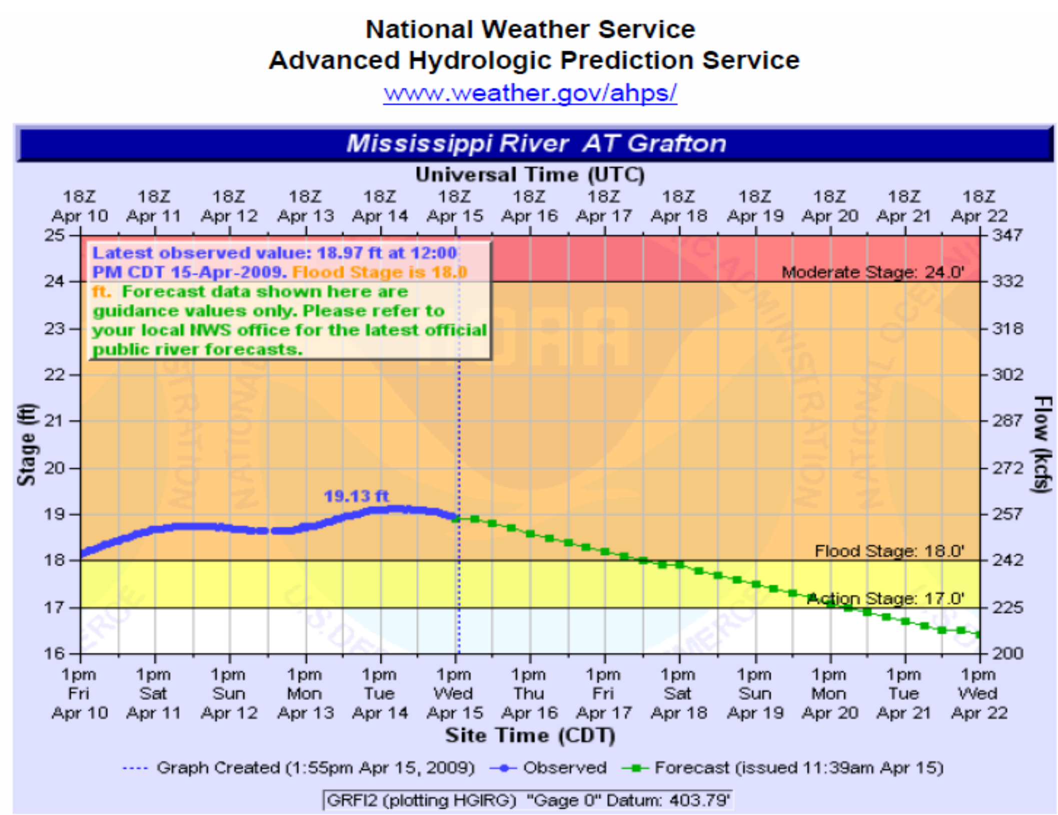

Figure 26. Advanced Hydrograph of Mississippi River at Graton April 14, 2009[14].

14 http://www.crh.noaa.gov/ahps2/hydrograph.php?wfo=lsx&gage=grfi2&view=1,1,1,1,1,1,1

The right vertical axis shows the Action Stage of 17.0 ft equals 225 kcfs. The Mississippi River water surface stage is measured by gage GRF12 and is plotted on the hydrograph by the observed (blue) and the forecast (green) data points. Each yellow vertical box is approximately 17 kcfs and each orange vertical box is approximately 15 kcfs. The water level crested at 19.13 ft on Apr 14, 2009.

The observed water level was above the Flood Stage of 18.0 ft at 1 pm Fri Apr 10. The water is forecast above the Action stage until approximately 1 pm Mon Apr 20, when the green line crosses back below the Action Stage. The time that the river is at or above Action Stage is approximately 20 horizontal boxes that are 12 hours duration each for a total of 240 hours or 86,400 seconds.

The area of each yellow box is equal to the flow of 17 kcfs times 12 hours or 43,200 seconds and can be expressed by the following equation:

$Q\ (flow)_{yellow\ box}$ = 17 kcfs x 43,200 s
$Q\ (flow)_{yellow\ box}$ = 734,400 kcf

The area of each orange box is equal to the flow of 15 kcfs times 12 hours or 43,200 seconds and can be expressed by the following equation:

$Q\ (flow)_{orange\ box}$ = 15 kcfs x 43,200 s
$Q\ (flow)_{orange\ box}$ = 648,000 kcf

The quantity of whole yellow boxes (By) is estimated at 17 and the whole orange boxes at 10, which are approximate. The total volume of water is equal to the flow per box times the number of boxes and can be expressed by the following equation:

$V = Q_{yellow\ box} \times By + Q_{orange\ box} \times Bo$
V = 734,400 kcf x 17 boxes + 648,000 x 10 boxes
V = 12,484,800 kcf + 6,480,000 kcf = 18,964,800 kcf
V = 435,400 acre ft

Conclusions

The water volume above Action Stage can be calculated at a gage location along the Mississippi River. Example 1 documents that the amount of water above Action Stage at Thebes between April 14 and 17, 2009 is approximately 18,878,400 kcf.

Example 2 documents that the amount of water above Action Stage at Thebes between April 10 and 20, 2009 is approximately 18,964,800 kcf.

Appendix 3

U.S. Army Corp of Engineers Civil Works Activities

The following map is issued by the USACE and documents all the Civil Works Activities effective June 2005 and documents most water management projects in the United States. The map shows the regulated flood control projects, navigation projects and environmental projects. The red lines are for the different jurisdictions boundaries. The green lines document where navigation projects maintain the water depth to 14 ft or less.

The National Smart Water Grid, shown as pipeline routes P1 through P4, would be integrated into the USACE current projects and become a new tool for flood control and fresh water management.

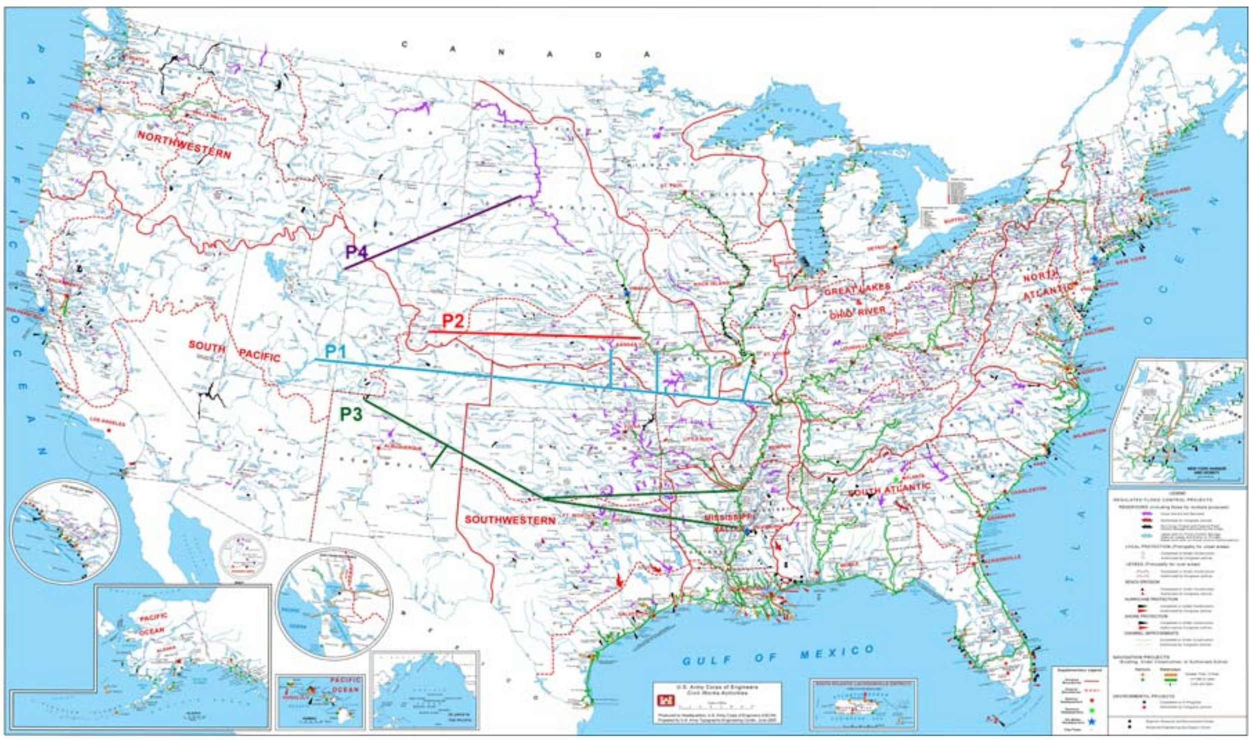

Figure 27. Initial Proposal of Pipelines, Integration with Existing Infrastructure