# Missouri River Flood 2011
# Vulnerabilities Assessment Report
# Volume I: Summary

## Northwestern Division
## US Army Corps of Engineers

## October 2012

US Army Corps of Engineers®

## Preface

The Corps of Engineers bears a tremendous responsibility to be accountable for and responsive to the lessons we learned during and following the historic Missouri River Basin flood of 2011. There was much information shared and knowledge gained from our collective experience. Indeed, some of the lessons had already been learned from previous floods (e.g., 1881, 1952, 1993) and were reaffirmed during this unprecedented event. This report, the *Missouri River Flood 2011 Vulnerabilities Assessment,* takes a comprehensive, system-wide view of the lessons learned, assessing and beginning to act on those lessons, and documenting them clearly and compellingly for further consideration.

The Missouri River Basin mainstem system is comprised of dams; reservoirs; levees (both federal and non-federal); a 735-mile navigation channel; hydroelectric power plants; habitat for many birds, fish, and plant species; and numerous other components and functions. The Corps is charged with responsibly managing this complex and extensive system for eight congressionally authorized purposes: flood control, navigation, irrigation, hydropower, water quality control, water supply, recreation, and fish and wildlife enhancement. All of the citizens we serve in the Missouri River Basin benefit in one or more ways from this system, and the Corps has a sacred duty to ensure these citizens and other stakeholders know the extent of damages caused to the system by the 2011 flood and what will be done to address those damages as well as what might be done to further reduce flood risks in the future.

In accordance with Public Law (PL) 84-99 and the Disaster Relief Appropriations Act of 2011, assessments of and repairs to the damaged features (e.g., levees, emergency spillways, and river training structures) of the Missouri River Basin mainstem system are progressing rapidly in order to return the system to its pre-2011 flood condition. However, this by itself is not sufficient based on what we learned in 2011. The citizens of the Missouri River Basin, members of Congress, state governors, and others have clearly expressed the view that the *status quo* is not good enough. To reduce the likelihood and consequences of future flood events, a number of improvements are expected, such as better weather forecasting, improved management, timely communication, greater collaboration, and other changes to the way the system is maintained and operated. The Corps is already implementing many actions that will lead to these outcomes. However, we must also conduct a comprehensive evaluation of longer term vulnerabilities and opportunities to improve the system and share those findings with the people we serve.

As we work toward these goals, a framework of "REPAIR-RESTORE-ENHANCE" is useful for characterizing the actions that will return the system to its pre-flood 2011 condition (repair), bring it back to its original design capacity (restore), or take it beyond its original design and construction to increase performance, lower risk, and improve resiliency (enhance). Adoption of this REPAIR-RESTORE-ENHANCE strategy by the citizens and leaders in the basin will be decided over time and with further discourse and deliberation. Each choice and opportunity must have sufficient detail and context to enable thoughtful consideration. Some steps toward improvement are already well underway. Many others—some requiring additional resources, others requiring consensus and basin-wide support—may be decided later but nonetheless are identified now. Such a prioritized set of activities may be undertaken as resources and opportunities become available.

Thus, this *Missouri River Flood 2011 Vulnerabilities Assessment* begins the dialogue about what we will do and what we could do. It serves as an inflection point for us to consider the future of the system, and what might be done to improve it. Changes will require time, commitment, national will, treasure, a lasting vision, and follow-through on the part of the people in the basin, our leaders in Washington, our members of Congress, our governors, our communities, and the Corps. Ultimately, what is done will be our legacy to future generations who live and work in the Missouri River Basin, in part, borne out of what we learned in 2011.

Date: 12 OCT 12

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**Contents**

## 1. INTRODUCTION

The *Missouri River Flood 2011 Vulnerabilities Assessment* report is presented in two volumes. Volume I provides a summary of the flood event, overview of the system and flood damages, description of actions necessary to return the system to pre-flood condition and operability, and recommendations for reducing future flood risks. Volume II contains a detailed technical assessment of the flood risk reduction infrastructure, its performance during the flood event, flood damages and post-flood repairs, and recommendations for mid- and longer-term actions needed to address the remaining vulnerabilities. Volume II also addresses vulnerabilities along tributaries to the mainstem Missouri, which may predate the 2011 flood, in order to give a holistic basin perspective. The technical volume also considers social and economic impacts, water management operations, the ecosystem, Tribal and cultural resources, and communications and outreach. Both the summary report and technical assessment focus on the Corps of Engineers' missions as authorized by Congress, although some non-Corps infrastructure and local policies and regulations are also discussed. These documents were authored by Corps of Engineers' technical experts, who were directly involved with the 2011 flood event.

### a. Missouri River Basin

The Missouri River is the longest river in North America, extending approximately 2,321 miles from the Rocky Mountains in western Montana through the Great Plains to the Central Lowlands of Missouri to its confluence with the Mississippi River just north of St. Louis. With a catchment area spanning roughly 529,000 square miles, the Missouri River Basin encompasses nearly one-sixth of the area of the United States. States in the Missouri River Basin include Colorado, Iowa, Kansas, Missouri, Minnesota, Montana, Nebraska, North Dakota, South Dakota, and Wyoming. (Figure 1)

Cycles of flooding and severe drought have always been a major part of the Missouri River Basin hydrology. In the 1930s and 1940s, devastating floods attracted public and congressional attention, prompting Congress to pass the Flood Control Act of 1944, which authorized the building of numerous dams across the country. The Act authorized the dams in the Missouri River Basin to be operated for eight purposes: flood control, navigation, irrigation, hydropower, water quality control, water supply, recreation, and fish and wildlife enhancement. The Missouri River Basin Development Project, which later became known as the Pick-Sloan Plan, provided for a comprehensive plan for the coordinated development of the basin's water resources.

During the ensuing 60 years, over 50 dams and lakes were constructed by the Corps on the Missouri and the rivers flowing into it. Additional dams were constructed by the U.S. Bureau of Reclamation. Mainstem dams, tributary dams, levees, and hundreds of miles of river channel improvement structures were built in an effort to harness the power and benefits of the "Big Muddy." Six multi-purpose dams and associated infrastructure were designed and constructed by the Corps on the mainstem of the Missouri River, extending from the Fort Peck Dam in northeastern Montana to Gavins Point Dam in southeastern South Dakota and northeastern Nebraska. These operating projects capture and store mountain snowpack, plains snowpack, and rainfall runoff from the upper Missouri River Basin, forming the largest reservoir system in the United States. The system also contains 71 percent of the basin's federal hydropower installed generation capacity, provides almost all of the flow support for the eight authorized purposes on

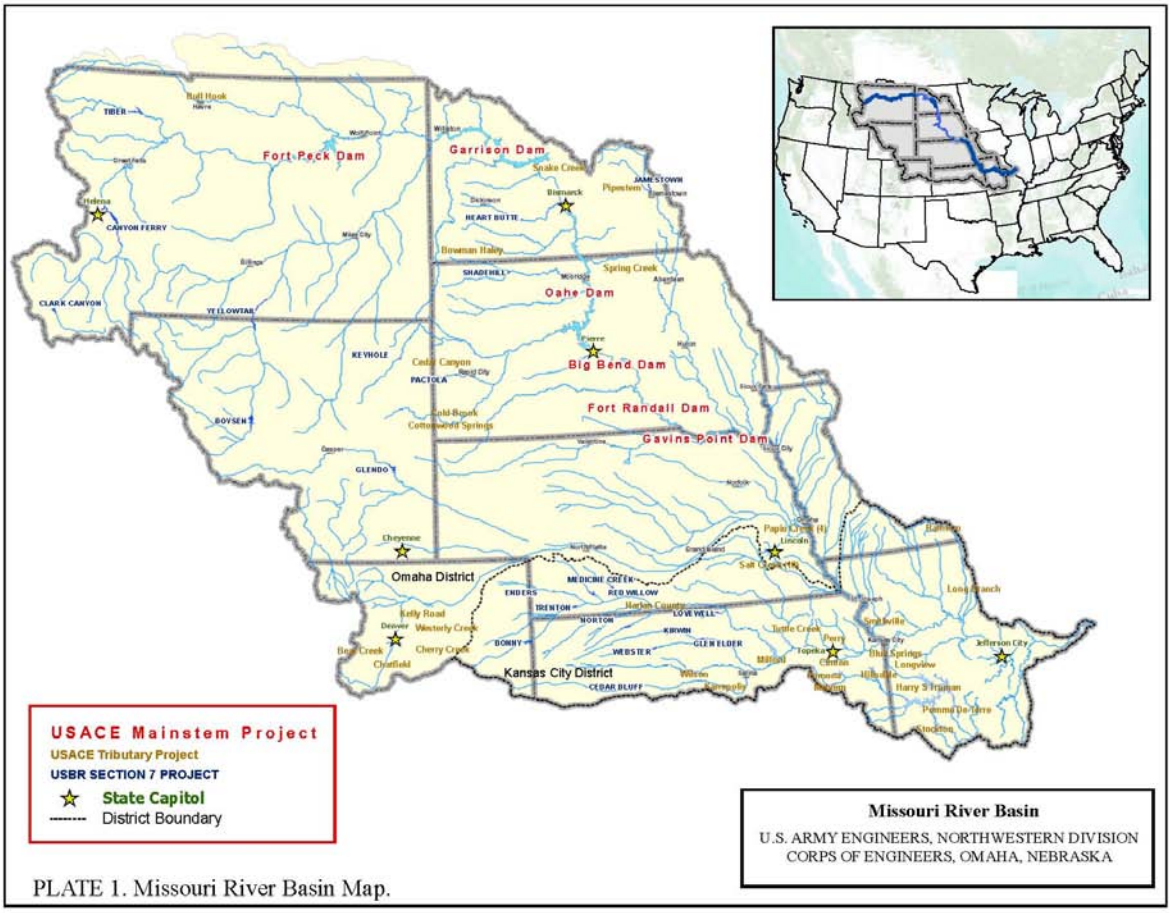


**Figure 1. Map of the Missouri River Basin.**

the Missouri River, and contributes greatly to flood protection for over two million acres of land in the floodplain.

The streambank protection and stabilization structures in the Missouri River from Fort Peck, Montana to Ponca State Park, Nebraska work to prevent bank erosion, while the protection structures downstream of Ponca State Park keep the channel from meandering. In addition, an extensive system of levees has been constructed from Omaha, Nebraska to St. Louis, Missouri, with levees on one or both banks for nearly the entire reach. The levees confine the flow of the river, preventing flooding of the adjoining land and nearby structures, and make the channel more reliable for navigation. (Figure 2)

b. Missouri River Flood of 2011

In 2011, the Missouri River Basin experienced record setting rainfall and snowmelt, resulting in the historic Missouri River flood of 2011. During the five-month period from March 1 to July 1, approximately 49 million acre feet of runoff poured into the system, overwhelming the floodplains and saturating and overtopping levee systems. Despite valiant water regulation and flood fighting efforts, devastation and disruption were massive. Flood waters forced hundreds of

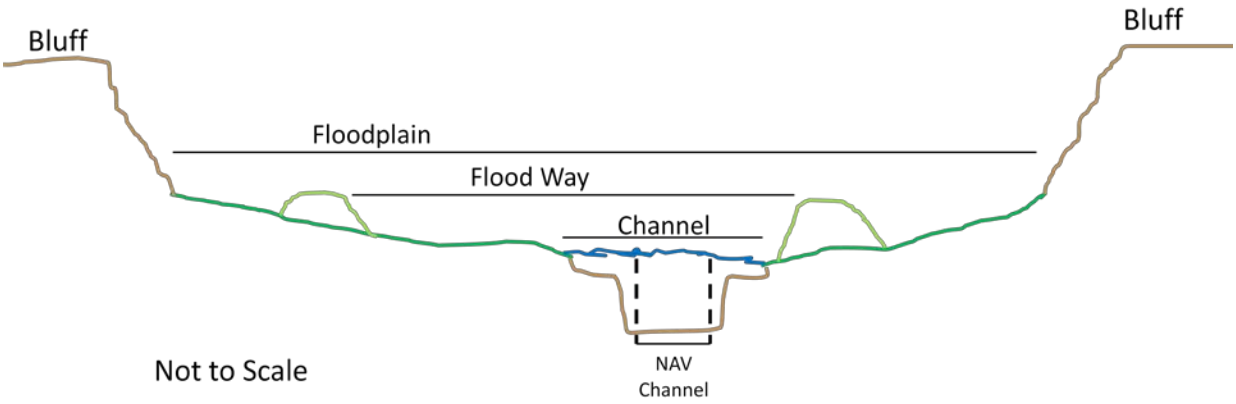


**Figure 2. The floodplain is the relatively flat land bordering a river. When a river overflows, the floodplain is covered with water. The Missouri River floodplain stretches between the bluffs of the enclosing valley walls. The floodway, river channel, and navigation channel are also shown.**

homeowners, farmers, and business owners to evacuate. (Figure 3) Several Missouri River bridges as well as long stretches of interstates, highway, and roads were closed for weeks or months at a time. Approximately 250 miles of railroad tracks were in the flood area, requiring track sections to be raised, temporary berms to be built, and damaged tracks to be repaired. Many road and rail shipments were delayed and rerouted through other states. The upper navigable portion of Missouri River— itself a vital part of the transportation network—was closed to all navigation for several months. All along the river homes were destroyed, agricultural lands were damaged, public and private facilities were impacted, and much pain was suffered. While it is beyond the scope of this report to assess direct or indirect flood damages to non-Corps assets, when computed they are likely to amount to billions of dollars.

The unprecedented volume of runoff during the spring of 2011 led to the following record peak releases (given in cubic feet per second, or cfs) from the Corps' mainstem dams: 65,900 cfs at Fort Peck; 150,000 cfs at Garrison; 160,000 cfs at Oahe; 166,000 cfs at Big Bend; 166,000 cfs at Fort Randall; and 160,000 cfs at Gavins Point. During the prolonged and unparalleled flooding event from May through mid October, impacted Corps-owned infrastructure was stressed as never before. Of particular concern was the condition of emergency and service spillways and tunnels, gate systems, operating controls, embankments, and stilling basins. (Figure 4) Aging infrastructure and prior years of constrained operation and maintenance funding meant that some system components were operating beyond their design life and others were deemed high risk due to known performance deficiencies. Uncontrolled releases pose an unacceptable risk to life and property. Dam condition was constantly monitored and repairs made as necessary and feasible during the heat of operation. Fortunately, the dams and appurtenant structures performed as designed, notwithstanding considerable wear and tear that will require repair prior to the next flood season and beyond. It should also be noted, several flood control components were not used during the flood event to avoid the potential of operating to failure or creating the need for expensive repairs. While preferential uses did not impact flood damages in this case, they did reduce the flexibility and resiliency of the system and do not represent the way the system is intended to be operated and maintained.

**Figure 3. The Missouri River flood of 2011 inundated homes, businesses and agricultural lands. Highways, bridges, railroads, and other infrastructure were also impacted. (Photo taken in June 2011 below Ft. Randall Dam.)**

**Figure 4. In 2011, the flood tunnels at Oahe Dam released a record volume of water. The earthen-channel spillway (not shown) was not used to avoid damages and the need for costly repairs. (Photo taken June 2011.)**

Levees are typically designed and constructed to withstand water loading for a few days or weeks during a year. The 2011 flood subjected the Missouri River levees to months of loading, well beyond the envisioned flood duration. All told, the event caused moderate to extensive damage to roughly 75 federal levees (and many more non-federal levees) within the basin due to overtopping, erosion, and underseepage. (Figure 5) Significant efforts to assess and repair are on-going under the authorities of the Public Law (PL) 84-99 program[1].

Although levees protect property within the floodplain, they also reduce the flow area available for the passage of flood waters, resulting in higher and faster water flow during high water events. In 2011, the flood waters carried excess energy which acted on the river corridor. The extreme high flood flows tended to travel across bends in the most energy efficient manner, severely degrading channel training structures such as dikes and revetments. Sediment traveled with the flood flows, causing both scour and deposition at different locations. Recreation facilities, plant and wildlife habitat, and historic tribal sites[2] along the river channel were also impacted by the force of the flood waters and will require assessment and possibly rehabilitation.

**Figure 5. The levees along the Missouri River were subjected to prolonged water loading. Consequently, many suffered from erosion and underseepage, necessitating extensive repairs. (Photo taken June 2011 of levee L575 near Hamburg, Iowa.)**

[1] PL 84-99, Flood Control and Coastal Emergencies (FCCE) (33 U.S.C. 701n) (69 Stat. 186) authorizes the Chief of the Corps of Engineers, acting for the Secretary of the Army, to undertake activities including disaster preparedness, advance measures, and emergency operations (flood response and post flood response).

[2] The United States has a unique legal and political relationship with Native American tribal governments, established through and confirmed by the Constitution of the United States, treaties, statutes, executive orders, and judicial decisions. Trust responsibility includes a federal obligation to protect, preserve, and perpetuate Native American cultural, subsistence, and religious sites on land managed or held in trust by the federal government.

c. Post-Flood Assessments of Water Management Operations

As the flood waters began to recede in the fall of 2011, the Corps enlisted the assistance of an independent technical review panel comprised of external agency and academic experts in meteorology, hydrology, stream flow forecasting, and reservoir system operations. The panel was charged to objectively assess the operation of the Corps' six mainstem dams prior to and during the flood of 2011 to capture lessons learned and make recommendations to improve future operations.[3]

The panel reviewed and addressed a number of questions related to water management decisions made during the flood, such as whether the Corps could have prevented or reduced the impact of flooding, whether long-term regulation forecasts properly accounted for the runoff into the mainstem system, whether climate change played a role in 2011's record runoff, and the impact of floodplain development. Although the panel concluded that the system had been operated effectively to minimize flood damages, they also recommended six actions to improve system management and performance for the future. All recommendations are currently being implemented in collaboration with other federal, state and local agencies as appropriate.

**Table 1. Recommendations of the Independent Technical Review Panel**

| | Recommendations | Status |
|---|---|---|
| 1. | Support for a program of infrastructure enhancement to ensure all flood release spillways and tunnels are ready for service and that all levees are in good condition | Ongoing |
| 2. | Hydrologic studies to update the design flood with new probabilities | Complete |
| 3. | Review System storage allocations, based on the flood of 2011 | Complete |
| 4. | Improved future cooperation and collaboration with the National Weather Service and US Geologic Survey | Ongoing |
| 5. | Studies to enhance data collection, forecasting, and resulting runoff from plains snow | Ongoing |
| 6. | Decision support system to include real-time status information on tributary reservoirs and inflows and linked to a modern interactive graphic forecast system | Ongoing |

The Corps is also conducting a broader post-flood analysis to examine, assess, and document the performance of the Greater Mississippi River Basin System (including the Missouri River Basin) following the 2011 flooding events on the Mississippi, Missouri, Ohio, and Arkansas rivers.[4] This assessment will incorporate recommendations on how to improve overall system performance by considering local, regional, and national perspectives. This effort will recommend changes and improvements to the operations of the existing systems that can be implemented within existing authorities and policies and further recommend what additional long-term investigation studies, upgrades, and changes currently outside the scope of existing authorities and policies should be pursued.

[3] The report, "Review of the Regulation of the Missouri River Mainstem Reservoir System During the Flood of 2011," is available at http://www.nwd.usace.army.mil/home.asp.

[4] Headquarters US Army Corps of Engineers (HQUSACE) Operation Order (OPORD) 2011-50, Greater Mississippi Basin Flood Repairs and Post-Flood Assessment of Response Operations, dated July 2011.

d. System Flood Storage Vulnerabilities

Based on public input received during the Annual Operating Plan meetings conducted during the fall of 2011, the Corps committed to maintaining a flexible posture in the operation of the system through the fall and winter of 2011-2012. The approach was to evacuate additional water from the system if conditions allowed and to aggressively evacuate water from the system early in the runoff season if it appeared that 2012 would be another high runoff year. As this report is being released in the summer of 2012, current conditions in the basin indicate the risk of snowmelt driven flooding is low for 2012 and the risk of rainfall driven flooding is normal. In fact, almost the entire Missouri River Basin is experiencing "Abnormally Dry" to "Drought" conditions resulting from a persistent pattern of excessive heat and dryness.[5] While the most critical repairs to the Corps' flood control structures and systems were completed prior to the start of the 2012 runoff season, a great deal of work remains. Fortunately, a warm, dry fall and winter in 2011 allowed the evacuation of an additional 700,000 acre-feet of water from the reservoir system prior to the start of the 2012 runoff season. However, in areas with the highest vulnerability, mechanisms to flood fight and monitor will be put into place if conditions change.

While the flood of 2011 was an extreme event, the existing infrastructure functioned as designed and nearly $8.2 billion in damages were prevented through expert management of the flood control system. Nevertheless, numerous individuals, communities, and private and public interests were severely impacted by the flood, and many in the basin have declared that such a flood should never happen again. This mandate for the future is clearly expressed in the following quotes from our elected representatives in the Congress:

> *"After this [2011] year's event, it is obvious that planning must change and management must change to ensure this event is not allowed to happen again."* REP Blaine Luektemeyer, Missouri
>
> *"…compel a reassessment of upstream management for the purpose of preventing catastrophic flooding events…"* REP Jeffrey Fortenberry, Nebraska
>
> *"…this hearing will help the Corps of Engineers consider lessons of this summer and take necessary measures to prevent these types of flood from happening in the future."* REP Lynn Jenkins, Kansas
>
> *"…we have to make it clear once and for all that prevention of flooding has to be the number one priority…"* REP Sam Graves, Missouri
>
> *"Many questions need to be answered. Specifically, what went wrong and what actions need to be taken to prevent a similar flood in the future."* REP Rick Berg, North Dakota
>
> *"We must now figure out what changes should be made to protect farms, their livelihoods, and their homes."* SEN Mike Johanns, Nebraska

[5] U.S. Drought Monitor report, August 7, 2012, http://www.droughtmonitor.unl.edu/

*"I look forward to working with you to better understand the risks and improve flood control…"* SEN Tim Johnson, South Dakota

*"I encourage the committee to very closely examine this year's flooding and to help develop the necessary procedures so that future events will be less destructive."* SEN Ben Nelson, Nebraska

In truth, the Corps cannot attest to the public, stakeholders, and leaders, including Congress that floods such as the 2011 event can be prevented from occurring in the future. The flood of 2011 was an unprecedented 500-year event (based on volume) that surpassed the original system design storm by 20 percent and lasted 5 months. Even if completely repaired, the existing system would still be vulnerable to flooding during extreme events. Nevertheless, the Corps and others can learn from this experience and apply our knowledge and resources toward reducing those vulnerabilities by improving and more effectively managing the system in the years ahead.

e. Repair-Restore-Enhance Framework

The Corps has been working to expeditiously repair the damaged flood reduction system back to pre-flood conditions. However, completing damage assessments and determining required repairs has highlighted vulnerabilities that will remain even after the system has been repaired to pre-flood conditions. Accordingly, as we move to correct flood damages and identify additional opportunities to improve the system structures and their operation, we will use a framework of "REPAIR-RESTORE-ENHANCE" to describe the measures that will return the system to its pre-flood 2011 condition, bring it back to its original design capacity, or take it beyond its original design and construction to increase performance, lower risk, and improve resiliency. Some recommended work presented in this report could involve a combination of repairs, restoration, and enhancement. The recommendations are listed in a single category based on the predominant actions and results.

While there are no formal operating restrictions for the reservoir system in place at this time, there are many operational constraints and/or considerations that water managers incorporate

**Table 2. Definitions of Repair, Restore, and Enhance Actions**

| Action | Objectives | Requirements |
|---|---|---|
| **Repair** | Fix damages caused by 2011 flood, ensuring condition and functionality are re-established. | Use existing authorities and funding. May require additional funding. |
| **Restore** | Renovate system to original design intent and performance criteria to ensure resilience and reliability. | Use existing authorities. May require detailed analyses and studies to justify work. Will require additional appropriations. |
| **Enhance** | Improve system capacity and capability beyond original design to lower risk and improve performance and durability. | May require additional authorities. Will require detailed analyses and studies to justify work. Will require additional appropriations. |

into daily reservoir regulation activities. Excessively high or low Missouri River flows may hamper repair activities. These issues may at times limit operational flexibility and result in the transfer of risk from one area to another. For example, we may operate the system to minimize the requirement to use the Oahe earthen spillway which could suffer significant damages if used. This may involve increasing the use of upstream storage to limit releases at Oahe as well as greater reliance on the Oahe flood tunnels and power house generators.

## 2. REPAIR

The Disaster Relief Appropriations Act (DRAA) 2012[6] provided $1.724 billion to the Corps to repair damages caused by major disasters in the Mississippi River Basin and its tributaries. These funds are being used across the Corps to rebuild infrastructure back to pre-event conditions. Roughly one third of this funding has been allocated to the Missouri River Basin. A primary focus on addressing Missouri River Basin flood vulnerabilities is repairing the levees and operating project infrastructure to pre-flood conditions. The *Missouri River Flood 2011 Vulnerabilities Assessment* Report provides a snapshot in time of the status of repair efforts and where the system would remain vulnerable in the event of a second high-water year. Remaining vulnerabilities in the system were identified if they were unable to be completed in time for the upcoming flood season(s). Some inspections and assessments are still underway on Corps operating project infrastructure, and we are developing updated estimates and designs for required repairs for damages caused by the flood of 2011.

### a. Federal Levees

The 2011 flooding caused moderate-to-extensive damage to levees that are within the basin and currently eligible to participate in the PL 84-99 Levee Rehabilitation and Inspection program. Only those levee systems that have been maintained to an "acceptable" or "minimally acceptable" rating qualify for federal rehabilitation funds. Levee repairs are being completed under the Flood Control and Coastal Emergencies (FCCE) funds provided within the DRAA. We have investigated levee damages, requested funding, and initiated repairs at most damage sites. We expect to have all qualifying levee repair contracts awarded in fiscal year (FY) 12 or early FY13, and all sites completed prior to the 2013 runoff season. For levee sections not repaired to pre-flood condition prior to the 2012 runoff season, the Corps is continuing to use the enhanced regional coordination activities that were developed and refined during the 2011 flood event and have pre-positioned federal and non-federal flood-fighting resources.

### b. Operating Project Infrastructure

For Corps-owned operating projects much of the success of the 2011 infrastructure operation and flood fight can be attributed to historic investments and a commitment to dam safety monitoring, inspection, and maintenance activities. The system performed as designed and prevented significant flood impacts. Although the system did function well, it also suffered significant damages to spillway entrance channels, gates and spillway slabs/structures, flood tunnels, access roads, relief wells and drains, and river training structures. Repairs are required to re-establish

[6] Public Law (PL) 112-77 provided the Army Civil Works program with $1.724 billion of supplemental FY12 funding for disaster recovery for the fiscal year ending September 30, 2012.

system reliability following this unprecedented flood event. Many repair actions have been completed, or are ongoing. Other qualifying repair designs and contract acquisitions are underway using O&M funds appropriated within the DRAA. A predominance of contracts will be awarded in FY12 and completed over the next several years. Initially, it was believed that DRAA O&M funds were sufficient to complete all needed repairs. However, detailed flood damage inspections and assessments were incomplete prior to DRAA enactment due to the extended period of high water. Some assessments are occurring as of this writing, (such as at the Gavins Point spillway) and may lead to future actions. Current repair cost estimates indicate that DRAA O&M funds may not be sufficient for all required repairs. Available funding will be used to repair the most critical work and reduce the greatest flood risks to the basin. The Corps will continue to explore funding options to assure all repairs to pre-flood condition are completed.

c. River Channel

The Bank Stabilization and Navigation Project (BSNP)[7] extends from Sioux City, Iowa to the mouth, and has transformed the free-flowing, winding Missouri River into a self-scouring navigation channel that is prevented from meandering its way across the floodplain The BSNP experienced extensive structural damage during the flood of 2011, but the project performed quite well in preventing meander migrations and channel avulsions, meaning the river returned to its prior alignment when flood waters receded. Preliminary assessments of BSNP structures indicate the 2011 damage is two to ten times greater than the average annual damage depending on the river reach. From Sioux City to Rulo, Nebraska structure damage has led to significant navigation hazards at numerous areas. From Rulo to the mouth, the damages assessed to-date do not materially threaten the function of the navigation project for the upcoming navigation season. However, repair of the damage from the 2011 flood will take two to four years, assuming adequate funding is provided. Extensive degradation to dikes and revetments presents a risk that further damage from normal runoff could lead to navigation problem areas. This risk will remain high until the control structures are repaired. It is important to note that structural integrity failures threaten the sustainability of the navigation channel through shoaling, standouts, reduced depth, and wandering, but also could impact adjacent land and infrastructure.

## 3. RESTORE

Even with the system repairs completed, there will be remaining vulnerabilities where constructed features of the Missouri River system were not specifically damaged by the 2011 flood but are not fully functional due to performance deficiencies or aged infrastructure. In some cases, repairs are being completed to pre-flood condition but additional work is required to restore long-term stability and reliability in design function. The restoration of constructed features will allow for full flexibility in system flood operation and management. These actions are consistent with the independent panel's observation that, "One of the main functions of the Corps is to maintain the water-resources infrastructure that was constructed in the past. The panel would like to emphasize the importance of adequate funding and direction for a program of infrastructure repair and rehabilitation to ensure that all flood-release spillways and tunnels are

[7] The Missouri River Bank Stabilization and Navigation Project was authorized by the River and Harbor Act of 1945. This authorization provides for a continuous 9-foot navigation channel, 300-feet wide from Sioux City, Iowa to the mouth. The Act extended the navigation limits and modified earlier Congressional authorizations in 1912 and 1927 that had provided for a 6-foot deep, 200-foot wide navigation channel.

ready for service as soon as possible." It is anticipated the restoration costs will exceed limited O&M funding. Additional studies will be required to justify work and support budget requests.

a. Federal Levees

For over 20 years, flood events within the lower basin have exposed continuing vulnerabilities in the federal levee system which could impact over $26 billion in economic infrastructure as well as the working environment and residences of nearly 200,000 individuals. For example, four major systems–MRLS L-455 and R460-471 in St. Joseph, Missouri; Kansas City levees; Topeka levees, and Manhattan levees–currently do not meet authorized design protection levels due to aging infrastructure weakness and/or degraded levee heights. These deficiencies could undermine levee integrity through under seepage, flood wall failure, and overtopping during high water events. Restoration of the authorized levels of protection remains a high priority to stakeholders in the basin. Of the four levee systems, two have units in the feasibility study phase (Kansas City's and Manhattan levees) with the others in design or have recently initiated construction contracts. However, concerns still remain due to possible funding shortages for completion of study, design, and construction.

b. Gavins Point Spillway

The Gavins Point spillway has been used on a regular basis to provide controlled water releases. This spillway is extremely important for system operations because there are no flood tunnels at Gavins Point Dam, which has minimal flood storage in comparison to the upper three reservoirs (Fort Peck, Garrison, and Oahe). Without a functional spillway, discharge capacity would be limited to the powerhouse capacity of 36,000 cfs.

The sustained, high-volume releases in 2011caused damages to the spillway slab foundation. DRAA repair funds are currently being used to replace vertical drain covers and patch concrete surfaces. However, recent investigations have revealed additional voids beneath the spillway slab. Testing and analyses are underway to assess the extent of the damages and risk to the structure, and to determine temporary and permanent repairs that may be needed. Due to the extended time required to complete the additional assessment, any final restoration of the spillway function will have to be addressed with future flood repair supplemental funds or budgeted under other appropriations.

c. Fort Peck Outlet Tunnel Ring Gates

Fort Peck has outlet works and flood control tunnels that are designed for releases in excess to power plant capacity (approximately 15,000 cfs) and are regulated by cylindrical ring gates which are not fully functional. Operational problems have been regularly documented and studied since the 1950s. Problems with entrained air, cavitation, gate vibration, violent surging, loud noises, corrosion, and gate icing are prevalent. The gates were last used for flood releases in 1975. All subsequent releases have been through the emergency spillway, which has sufficient capacity. Although no formal operations restrictions have been placed on the ring gates, restoring full use is needed to allow greater flexibility in reservoir management. The importance of such flexibility was demonstrated at Garrison Dam during the 2011 flood. When the emergency spillway gates were initially opened, Garrison project personnel noticed irregular

flow patterns on the spillway slabs. Because the outlet works at Garrison Dam were operational, the project was able to divert the flows from the spillway to the outlet works and inspect and fix the issue in the emergency spillway. We do not have that flexibility at Fort Peck. If project operators observed a problem developing in the Fort Peck spillway, we would have to continue to use the spillway and deal with the damages after the event.

d. Fort Peck Spillway

Prolonged, record-level releases caused significant erosion to the spillway plunge pool and damaged the spillway discharge channel. (Figure 6) Although repairs are being completed with DRAA funds for the most immediate erosion damage, there is concern that future sustained high releases might further erode the earth around the west wing wall or uplift the spillway floor slabs, creating a significant dam safety concern. Restoration to return full design function to the spillway could potentially include armoring the plunge pool, reconstructing/reinforcing the cutoff wall and wing walls, modifying the spillway, adding energy dissipaters, or a combination of these measures.

**Figure 6. Severe erosion along the wing walls of the Fort Peck spillway plunge pool.**

e. Oahe Spillway

At Oahe Dam, discharges have never been allowed to pass through the emergency spillway due to fears of backward erosion of the unlined, earthen channel and the potential for a catastrophic uncontrolled release of the reservoir. At critical times during the 2011 flood, system releases

were within 5,000 to 7,000 cfs of the maximum capacity of all available discharge features and pool elevations were within a few inches from the top of the spillway gates. If a single outlet tunnel or hydropower unit had been unavailable during these times or if inflow spikes had driven the pool higher, it would have been necessary to release through the spillway and possibly incur substantial erosion damage, raising significant dam safety concerns. The Oahe reservoir has been in the exclusive flood control zone (above elevation 1,617 feet) nine times since the system was filled in 1967, or about one of every five years. At such times, there is precious little available storage in the reservoir and inflows must be cautiously managed to prevent overtopping of the spillway gates. During the 2011 flood event, the system was operated to minimize the possibility of using the spillway at Oahe. However, risk was transferred to the upper two projects by going higher into the surcharge pools at Fort Peck and Garrison and possibly having to release larger volumes of water than if we could have used surcharge storage in Oahe. Restoration of the Oahe spillway to the intended design criteria is imperative to ensure operational flexibility during future large flood events.

f. Harlan County Spillway Gates

Harlan County Dam, on the Republican River, has 18 tainter spillway gates, each 40 feet wide by 30 feet high. The gates were designed in the 1940s and have been in service for over 50 years. The Harlan County Dam currently has a pool restriction at elevation 1,962 feet (approximately mid-height on the tainter gates) to prevent buckling during gate operation due to overstress resulting from trunnion bearing friction. The flood control operation plan reduces the maximum allowable load on the gate from 30 feet to only 17.5 feet of water before flood waters are released. This reduced load is intended to minimize the likelihood of gate failure but it also reduces the project's flood control benefits. It is recommended that restoration be done to re-establish the flood control flexibility of the dam.

g. Pipestem Spillway

Pipestem Dam on the James River in North Dakota is operated in conjunction with Jamestown Dam, which is owned by the Bureau of Reclamation and operated by the Corps for flood control. Both reservoirs experienced extreme inflows in 2009, 2010, and 2011. Although the record pool for Pipestem occurred in 2009, the record inflow occurred in 2011. PL 84-99 authorized advanced measures allowed for the installation of temporary levees along the combined downstream channel to protect the City of Jamestown. These emergency measures permitted increasing outlet works discharges sufficiently to prevent use of the uncontrolled emergency spillway at Pipestem. At the time of design, spillway erosion was not considered a major issue because of the long length of the spillway and because the large width of the spillway would produce relatively low velocities in the spillway channel. However, recent evaluations indicate moderate risks associated with the high potential for spillway head cut erosion leading to a potential breach of the spillway crest and near complete loss of pool under extreme magnitude or duration flow conditions. The major concerns are the presence of highly erodible soils, high spillway discharge exit velocities, and updated hydrologic analyses that suggest a more frequent return interval (100-year) for these critical flow conditions to develop. In addition, the presence of large rocks and boulders creates potential for irregular flow patterns which can lead to increased erosion effects. A concrete control sill may be needed at Pipestem to help abate erosion.

h. Information, Analyses, and Plans

In addition to the specific restoration recommendations listed above, there are a number of actions necessary to support improved system operation, flood and impact analyses, and basin planning. These activities are typically funded via the routine O&M program, but under tight federal budgets often do not get priority consideration. These actions include: ***Update Water Control Plans*** - The Missouri River Mainstem Reservoir System is regulated in accordance with the Master Manual. Tributary dams in the system also have water control plans. Outdated water control plans limit operational flexibility during flood events and possibly threaten the infrastructure. Additionally, the Water Control Plan for Rathbun Dam on the Chariton River needs to be updated to mitigate flood risks. ***Update O&M Manuals*** - Post flood repairs to the spillways, outlet works, and other features need to be documented in the project specific O&M manuals. ***Update Hydrologic, Hydraulic, and Flood Impact Assessment Models*** - The independent expert panel recommended hydrologic studies and modeling to update the design flood with new probabilities, re-examining the Missouri River System planning that is based on the entire historical record, and adjusting to the recent decades of varying hydrologic conditions. ***Conduct Periodic Dam Assessments*** - The Corps' periodic assessment process includes visual inspections and risk assessments to facilitate better understanding and management of our dams. Periodic assessments for dams with suspected or confirmed vulnerabilities should be scheduled and budgeted expeditiously. ***Implement Interim Flood Risk Reduction Measures (IRRMs), Surveillance Plans, Emergency Action Plans*** - The Corps must build on the ongoing inspections, assessments, and risk assessments to facilitate risk communication and the development of IRRMs and repair actions, as required. Surveillance and emergency action plans should be updated to better monitor features of concern during future extreme events. ***Resource Levee Safety Program*** - The Levee Safety Program is an effective and established program for identifying and managing vulnerabilities to Missouri River levees. The intent of the program is to regularly assess, communicate, and manage the risks to people, property, and the environment from inundation that may result from breach, overtopping, or malfunction of levee systems. Resources are needed to ensure the program is sufficiently funded on an on-going basis. ***Update Stage Damage Curves*** - Stage-damage curves show the predicted damages that would result from various river stages or flows. These tools help analysts to identify economic vulnerabilities to flooding and evaluate and compare competing water resource investment decisions. ***Collect Current Socioeconomic Data*** - A socioeconomic profile of the floodplain would identify vulnerable populations based on income, age, race, and location at risk from flooding. The ability to accurately estimate socioeconomic impacts from flooding is essential for making optimal and defensible investment decisions about development and commerce along the Missouri River and its tributaries as well as storage allocations for its reservoirs. ***Coordinate Flood Damage Estimates*** - The Corps uses flood damage estimates to identify flood-fighting efforts, operations improvements, and future flood risk management actions that need to be undertaken. Many different federal, state, and local agencies estimate flood damages for their individual needs. It is recommended that a coordinated effort be made to gather estimated flood damages for major flood events. ***Enhance Monitoring and Control of Debris and Sediment*** - Many trees within the 2011 flood inundation zone may not survive the long duration flood event. Fallen trees and other objects will present long-term debris management challenges, especially when reservoir levels increase.

## 4. ENHANCE

Even when fully repaired from damages of the 2011 flood and if restored to full design function, the Missouri River Basin system will still have risk for flood damages in extreme events and in localized events downstream of the mainstem dams or along tributaries. However, there are opportunities that can and should be explored to determine whether damages from future flood events can be reduced. Actions to study, design, and implement comprehensive solutions within the basin will take significant collaboration and tradeoffs among stakeholders and may require additional authority and funding from Congress.

### a. PL 84-99 Expanded Authority

Authority should be provided so that key provisions of Engineer Regulation (ER) 500-1-1 and Engineer Pamphlet (EP) 500-1-1[8] can be revised to allow additional flexibility to the Corps to make smart federal investments using life-cycle analyses, particularly in this increasingly constrained fiscal environment. The current short-term approach of repairing damaged levee systems in-place following a major flood event requires a continuous cycle of federal and local expenditures without the benefit of additional flood protection. Where there are repeated levee failures and economic justification exists, there should be authority to reconstruct using methods or improvements that would limit damages in future flood events.

### b. Low-Profile Levees

Levee design capacity establishes the maximum water level that can be reached without inundating the protected area. Most of the levees that were overtopped in 2011 also ultimately breached because of overtopping. The likelihood of overtopping-induced breaches could be reduced with the addition of special features such as specially designed overtopping reaches, armoring and flattening the landside slopes, or installation of more erosion-resistant levee vegetation.

### c. Floodway Restrictions

Downstream from Omaha, Nebraska, numerous locations exist where levee misalignment, bridge abutments, and railroad and highway embankments constrict the river's flow. A study should be conducted to determine where such constrictions exist and then innovative strategies developed to reduce or eliminate the choke points. Non-structural alternatives, such as acquiring land along the floodway from willing sellers for setback levees as well as opening the natural floodplain by incentivizing home, business, and utility relocation, should be included for consideration.

### d. Flood Risk Reduction Study

Absolute flood protection for the Missouri River Basin is not possible, so the basin needs to plan and prepare for future flooding events. Flood control storage in the reservoir system is just one piece of the solution. Increasing the carrying capacity of the floodway and reducing encroachment in the floodplain are two of many ways to reduce flood risk. Land-use

[8] Army Regulation (AR) 500-60, Disaster Relief, and Engineer Regulation (ER) 1130-2-530, Flood Control Operations and Maintenance Policies. These two documents prescribe policies and procedures for the Corps' civil emergency management program under the authorities of PL 84-99.

management and regulation of development within designated floodplain areas (responsibilities of state and local governments) are also considerations. A Missouri River Watershed Flood Risk Reduction study could be initiated to consider opportunities for additional flood water storage and improved floodway conveyance in the context of all other uses of the river system. The benefit of approaching flood risk reduction in a more holistic manner is that it provides flexibility to respond to a wide range of flooding situations and the resiliency to recover quickly following an event.

## 5. CONCLUSIONS

The Missouri River flood of 2011 was an extreme event which tested the system's ability to handle unprecedented floodwaters as well as our commitment to the current balance of system purposes and benefits. Though the system did function as expected, it sustained extensive damages, which are being repaired in accordance with guidelines and to the extent funding is available. Continued efforts and additional resources will be needed to finalize assessments and complete all needed repairs. This historic event also highlighted remaining vulnerabilities, particularly with respect to levees and project infrastructure, which could be reduced through restoration and enhancement actions. Comprehensive studies are recommended to identify greater flood damage reduction opportunities while recognizing the impact of such measures on the other seven authorized water uses.

The recommendations contained in this report draw attention to how we might reduce residual flood risk; however, it will take cooperation, time, and resources to implement these actions. While it is the role of the Corps is to execute the will of the American people, as expressed by their elected representatives in Congress, as directed by National Command Authorities, and as sanctioned by the Courts, *all of us* bear a shared responsibility for reducing flood risk. We will only achieve success through sustained and united efforts of the various levels of government and the myriad agencies, organizations, and stakeholders involved with the Missouri River Basin.