SECTION V

AREAS FLOODED, FLOOD DAMAGES, AND FLOOD DAMAGES PREVENTED

A. INTRODUCTION

The Mississippi River floods in April and May 2011 were among the largest and most damaging recorded along the US waterway in the past century with flows and stages that were comparable in magnitude to the major floods of 1927 and 1993.

Large portions of the LMRV are subjected to significant loss and damage when the Mississippi River overflows its banks. During major floods, the region experiences flood damage (economic losses) to unprotected areas between the levees and backwater areas up the tributaries. These damages are associated with farmland, homes, businesses, personal property, roads, and bridges. Additionally, many people are left without shelter, utilities, and food and are inconvenienced by an interruption in daily activities and loss of income. The following section discusses flood damage impacts for the LMRV region in terms of population, number of structures impacted, agricultural acres flooded, flood damages, and flood damages prevented by the MR&T project.

The geographic extent for the MVD Post Flood Report includes the area encompassed by the maximum extent of without project flooding for the Mainline Mississippi River headwater and backwater flooding from the vicinity of Cairo, IL to the Gulf of Mexico, including the Atchafalaya River, as well as the maximum extent of without project flooding below Wappapello Dam. This maximum extent was delineated by completing a hydraulic model of the mainline Mississippi River and the area below Wappapello Dam using without - project flows and without levees to represent natural conditions. The resulting extent was used to establish a comprehensive and consistent geographic boundary on which a repeatable economic analysis could be performed. The economic analysis was performed to estimate the damages prevented by the MR&T system and its operation within the boundaries of the MVD during the 2011 Flood with the intent to:

> (1) not include the Ohio River reservoirs as they are not officially part of the MR&T (recognize they have operation authority to support MR&T), these benefits are being computed by LRD and would be included in more comprehensive Greater Mississippi Basin System Performance Assessment .
>
> (2) include Wappapello Dam in the analysis as this project was authorized by the MR&T project and experienced historical flooding in the 2011 Flood.
>
> (3) not include the Yazoo tributary reservoirs because of the additional modeling effort and time required to capture local headwater flooding that had relatively no impacts or benefit to MR&T during this event.

The economic analyses utilized inundations generated from numerical hydraulic model output and other data to identify types and locations of properties impacted by the 2011 Flood and assess damages associated with these impacts. Three models, Hydrologic Engineering Center's River Analysis System (HEC-RAS) Program, the Flood Event Simulation Model (FESM), and Hydrologic Engineering Center's Flood Impact Analysis (HEC-FIA) Program were utilized in the evaluations. The models were used to generate predicted inundation boundaries for three scenarios to compare to the actual inundation area associated with the 2011 Flood. The actual 2011 Flood (Model Scenario 1) and the three other modeled scenarios are defined in Section V.B.

Two major categories of damages were evaluated based on the availability of flood damage information captured from the flood event. These included flood damages to urban properties, or structures and flood damages to agricultural properties, including crops. It is worth noting that flood impacts occurred to other damage categories, such as roads, bridges, infrastructure, navigation, etc., but, due to time constraints and the availability of information and feedback, these damages are not included in this evaluation. For similar reasons, a comprehensive scenario-based analysis was not done for impacts to the environment. This section later addresses the damages to the environment due to the 2011 Flood as it occurred.

B. MODEL SCENARIO ANALYSIS METHOD

The four scenarios were modeled to allow comparison of actual damage estimates (based on the existing conditions) with damages estimates based on what would have occurred if some FRM features were not present or utilized.

- **Scenario 1 (Existing) -** the existing 2011 scenario as it occurred during the 2011 Flood event (i.e., with levees and flood control reservoirs in place, including deviations to reservoirs' Operation Plans).

  HEC-RAS was used to model this scenario because most flooding is within the levees; therefore, the assumption that the majority of the flow is downstream is accurate and can be captured with a 1D model. The flooding that is not within the levees is backwater flooding at major tributaries which can be accurately modeled with tributary reaches and storage areas within the HEC-RAS program.

- **Scenario 2 (No Levees and Cutoffs) -** the scenario with no levees, but with flood control reservoirs (i.e. without levees and associated cutoffs but assuming all reservoirs are in place). Between 1932 and 1942, the Mississippi River Commission executed 15 artificial cutoffs, or newer and shorter channels in the river that cut across bends in its course, to improve the carrying capacity of the channel and lower the project flood flow line. These artificial cutoffs reduced the length of the river by nearly 170 miles.

  Because of the large amount of levees along the Mississippi River, any scenario without levees would have a large spreading type inundation that cannot be accurately modeled with HEC-RAS. This scenario was modeled using a simplified method developed and used by the MVD to analyze benefits of levees, cutoffs, and floodways (i.e., pre-MR&T conditions). This method uses stage and flow information collected in 1912; therefore this method reflects river conditions that existed before the MR&T project was constructed. While some local levees did exist prior to the MR&T project, they were generally lower and had a smaller cross-section and would have certainly been overtopped by the 2011 Flood. By using this information, an accurate estimate can be made of the 2011 river stages if levees were not present. From the calculated stages, inundation extents and depth grids were produced by MVK's Flood Event Simulation Model. This model is a tool widely used by MVK to produce flood extents from forecasted stages. This simplified method was chosen because of its wide use within MVD and the time frame in which the method could be completed. If the schedule would have allowed for it, this scenario would have been also modeled with FLO-2D. If the modeling effort with FLO-2D was acceptable, the results from the simplified method could be verified and, if necessary, refined.

- **Scenario 3 (No Levees, Cutoffs, and Reservoirs) -** the scenario with no levees and no federal flood control reservoirs. A modification of the MVD simplified method was used to complete this scenario. The flows developed for a No Reservoirs scenario were utilized, which includes no Federal reservoirs on the Missouri and Ohio River basins. The same justification for using the simplified method is applicable for this scenario.

- **Scenario 4 (No Deviations/Directives) -** the existing 2011 scenario without deviations or directives to flood control reservoirs' Operation Plans Discharges without deviations at Corps reservoirs were calculated from the Water Control Section from each District. These discharges will replace the existing conditions discharges, and will be routed through the same HEC-RAS models created for the Existing scenario. For this scenario, an assumption was made that overtopping of levees would not occur; therefore, the assumption that the majority of the flow is downstream is accurate and can be captured with a 1D model. The only flooding not within the levees is backwater flooding at major tributaries, which can be accurately modeled with tributary reaches and storage areas within RAS.

In addition to the four scenarios above, two other scenarios, No Floodways and No Reservoirs, were initially included as part of the modeling effort to determine damages prevented by each of the system components. However, due to the short timeframe to complete modeling, these two scenarios were not analyzed for this Report. However, they may be included in the Greater Mississippi Basin Post-Flood Assessment effort being conducted by HQUSACE.

1. Model Inputs and Assumptions. The UMR contributes flow into the MR&T system that must be included in model study efforts. The upper boundary of the MR&T model on the Mississippi River is at the Chester, Illinois gage site (river mile 109.9 above the mouth of the Ohio River). The drainage area of the Mississippi River at Chester is 708,563 square miles. The six Corps offices providing Water Management within this watershed are Omaha District; Northwest Division-Omaha; Kansas City District; St. Paul District; Rock Island District; and St. Louis District. The first three offices provide Water Management for the Missouri River and tributaries while the latter three support the Mississippi River and tributaries.

2. Analysis, Data Quality, and Uncertainty. When performing the modeling for the four scenarios, it is important to note that two different modeling methods—HEC-RAS and FESM—were used. The HEC-RAS modeling produced inundation depth grids that were mainly inside levees, floodways, or natural backwater areas. Flows were readily available on all major rivers and tributaries; as a result, water surface elevations were produced at numerous points throughout the study area and used to produce the inundation depth grid. The FESM model produced inundation depth grids over very wide flood plains using a limited number of data points to produce the inundation. The methodology used to calculate the water surface elevations for the scenarios that utilized the FESM model is described in the following paragraphs. A more detailed description of the methodology used in Scenarios 2 and 3 can be found in Appendix G, *Economics*.

Due to the two different modeling approaches and extrapolation of existing flows for a scenario based on a set of curves, some uncertainty exists in the modeling results; however, the documented and scientific approach used to calculate the water surface elevations for the various scenarios does produce output that can be used to compare damages and damages prevented.

3. Modeling Environment. The hydraulic modeling of the scenarios was completed using either HEC-RAS, a one-dimensional numerical model, or FESM. HEC-RAS is a very common numerical model applied widely across the Corps. However, FESM is a flood inundation model designed to replace the FEAT Model used by the Corps. The required inputs to the model are the topography in which the simulation will take place in the form of a georeferenced DEM, the path information of river channels, optional path information of sub channels connecting to the main simulation channels, and water elevation information for known points along the simulation channels. FESM differs from most flood inundation models in that it does not considerer either flow or friction, and as a result does not need information about these conditions. Another key difference is that FESM does not directly implement either the Naiver Stocks equations, the de Saint Venant equations (Shallow Water equations), or any obvious approximation, of these equations (any attempt to create a water surface is at some level an approximation of the de Saint Venant equations). Water elevations in channel are determined by the input data and linear interpolation along channels paths if the resolution of the simulation grid is smaller than the spacing between known water elevation points. Lateral propagation of water elevation is done by selecting grid locations adjacent to the expanding flood surface, and determining which adjacent locations are potential sources of inundation. The resulting water level and a grid location depend on the water levels of such sources modified by slope rules.

4. Flood Damages Analysis. The HEC-FIA model is the tool used in this investigation to evaluate flood damages. The HEC-FIA model provides the capability to estimate the impacts associated with flood events and the benefits attributed to flood risk reduction projects. The HEC-FIA is designed to assess disaster impacts after a flood using geo-referenced data grids with inundation, terrain, agricultural, and structural data. The HEC-FIA estimates the area inundated, number of structures inundated, structure damage, agricultural flood damage, and project benefits. The HEC-FIA also has the functionality to estimate life loss during a flooding event; however, life loss will not be addressed in this report.

In FIA, the structure inventory used to calculate structure damages and project benefits can be generated from a HAZUS database, a shapefile, or can be manually entered from an existing source. HAZUS, the chosen source of structure inventories for this report, is a collection of models and databases, including an estimation of the general housing stock, developed by FEMA for estimating the impacts from natural disasters. Crop coverage used to estimate agricultural damages can be generated from the National Agricultural Statistics Service Cropland Data Layer (NASS CDL), a shapefile, or the HAZUS. The NASS CDL, the source of crop coverage for this report, is a geospatial crop-specific digital data layer used in GIS applications provided by the National Agricultural Statistics Service of the United States Department of Agriculture.

C. MODEL RESULTS

Figures V-1 through V-4 illustrate the inundation areas associated with each of the hydraulic numerical modeling scenarios described above. Additional details are provided in Appendix G, *Economics.*

Based on the model outputs alone, it is clear that the MR&T System prevents major damages over a widespread area. Furthermore, when coupling the without levees scenario along with no reservoirs, as expected, even more inundation and subsequently damages would be produced. The ‘reservoir without deviations’ scenario showed some increase in stages in the upper portion of the MR&T system, but those effects diminish as the floodwave progresses downstream.

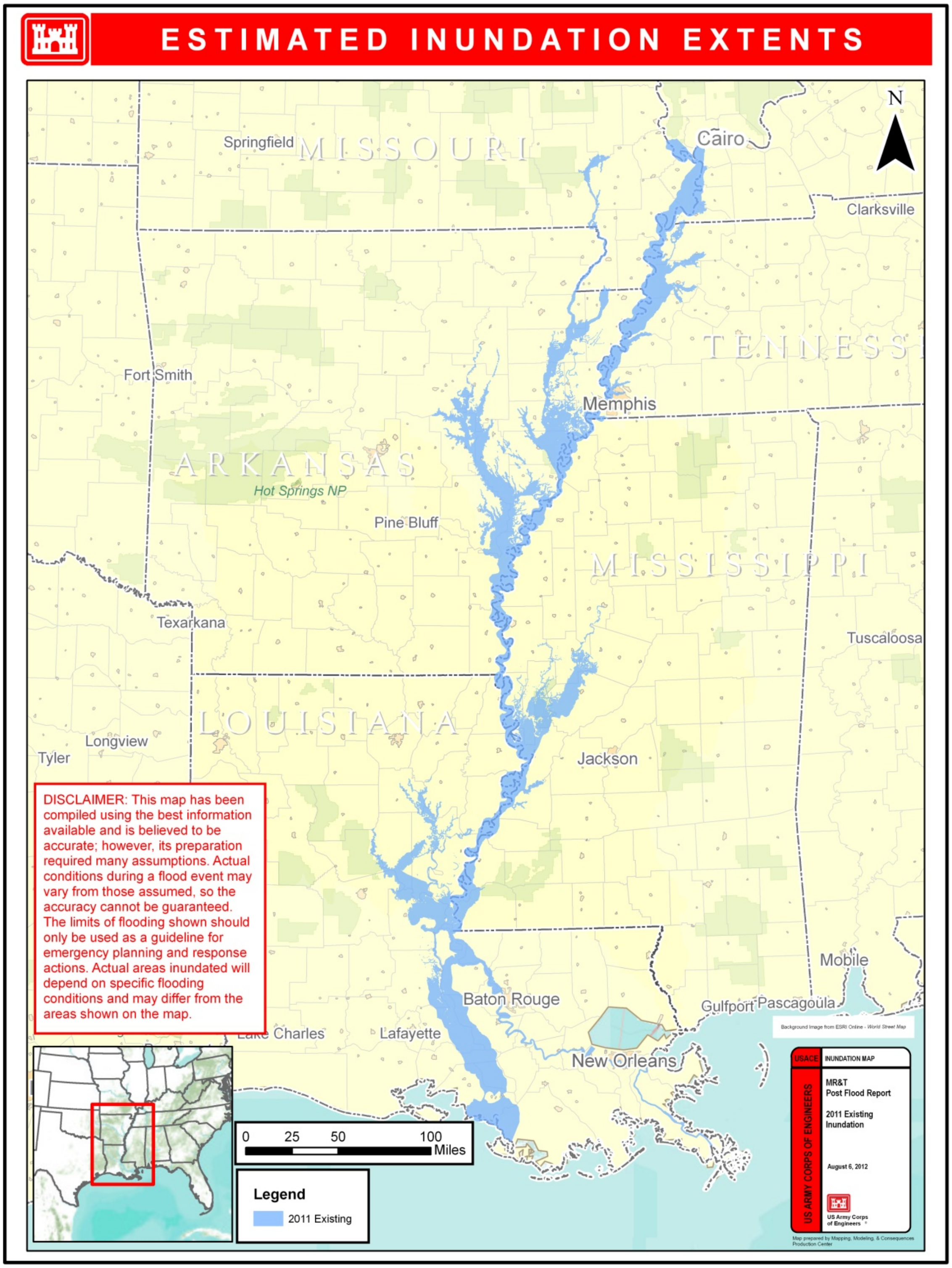


Figure V-1. Scenario 1: 2011 Existing Conditions

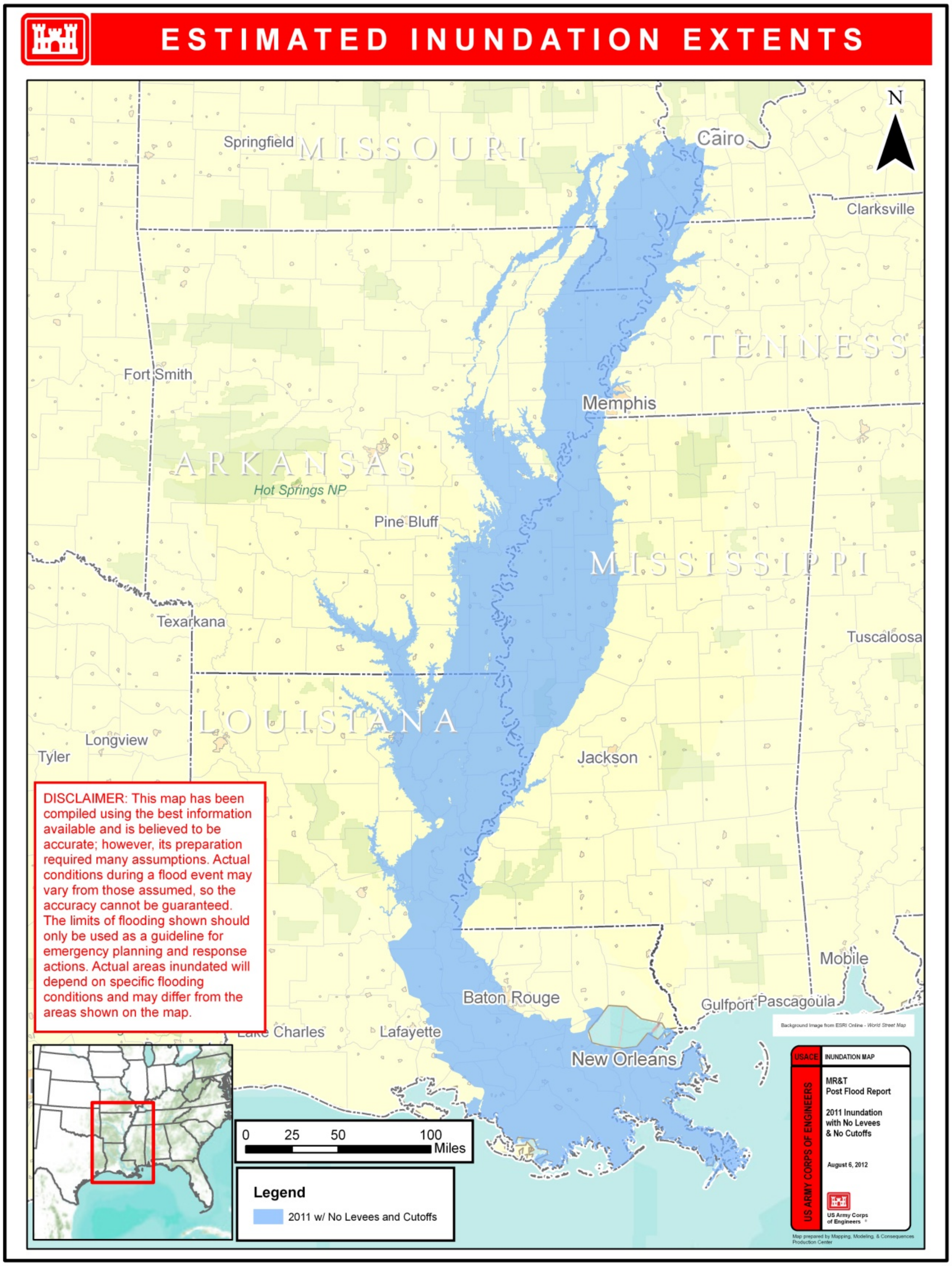


Figure V-2. Scenario 2: 2011 Without Levees and Cutoffs

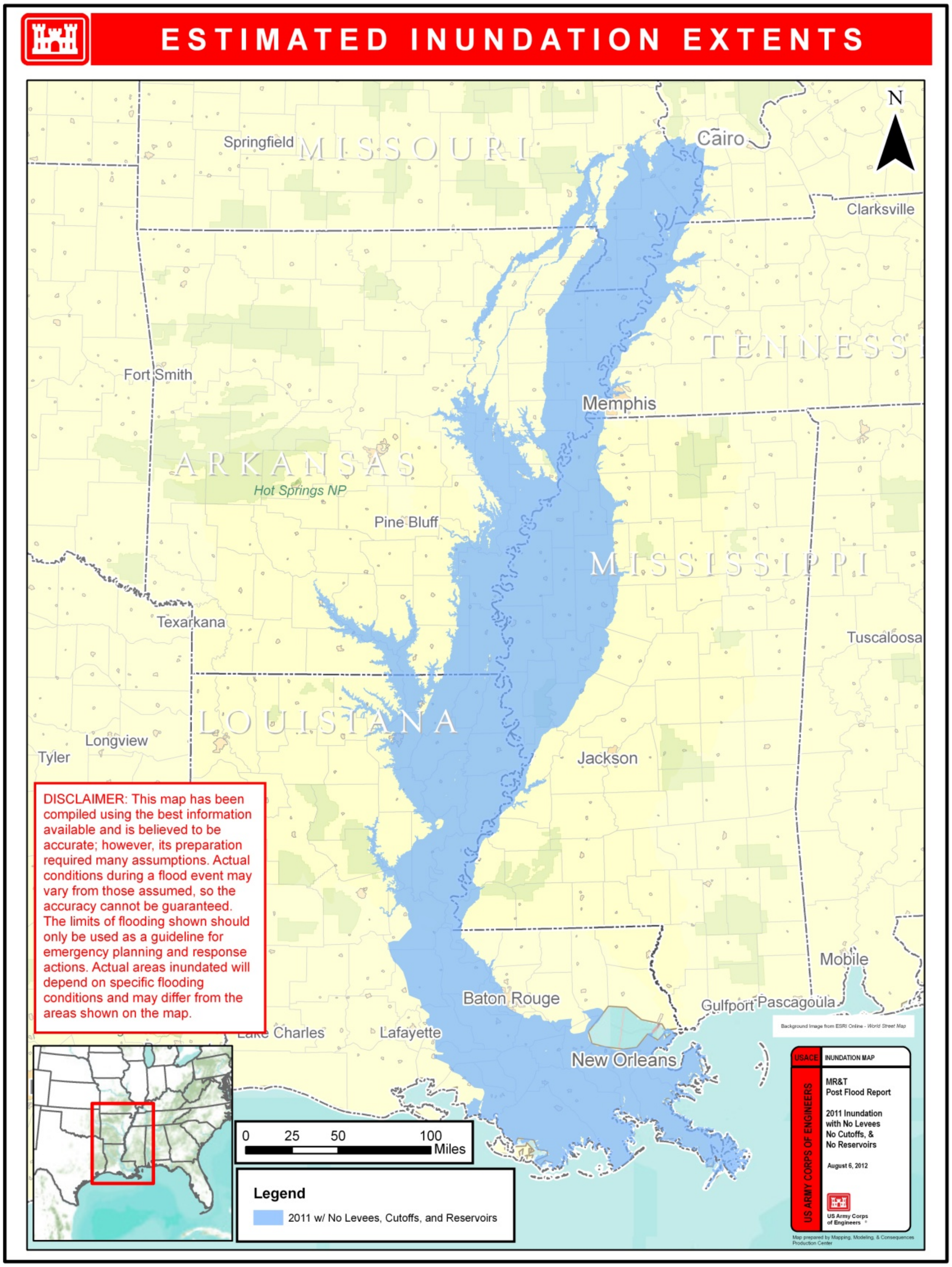


Figure V-3. Scenario 3: 2011 Without Levees, Cutoffs, and Reservoirs

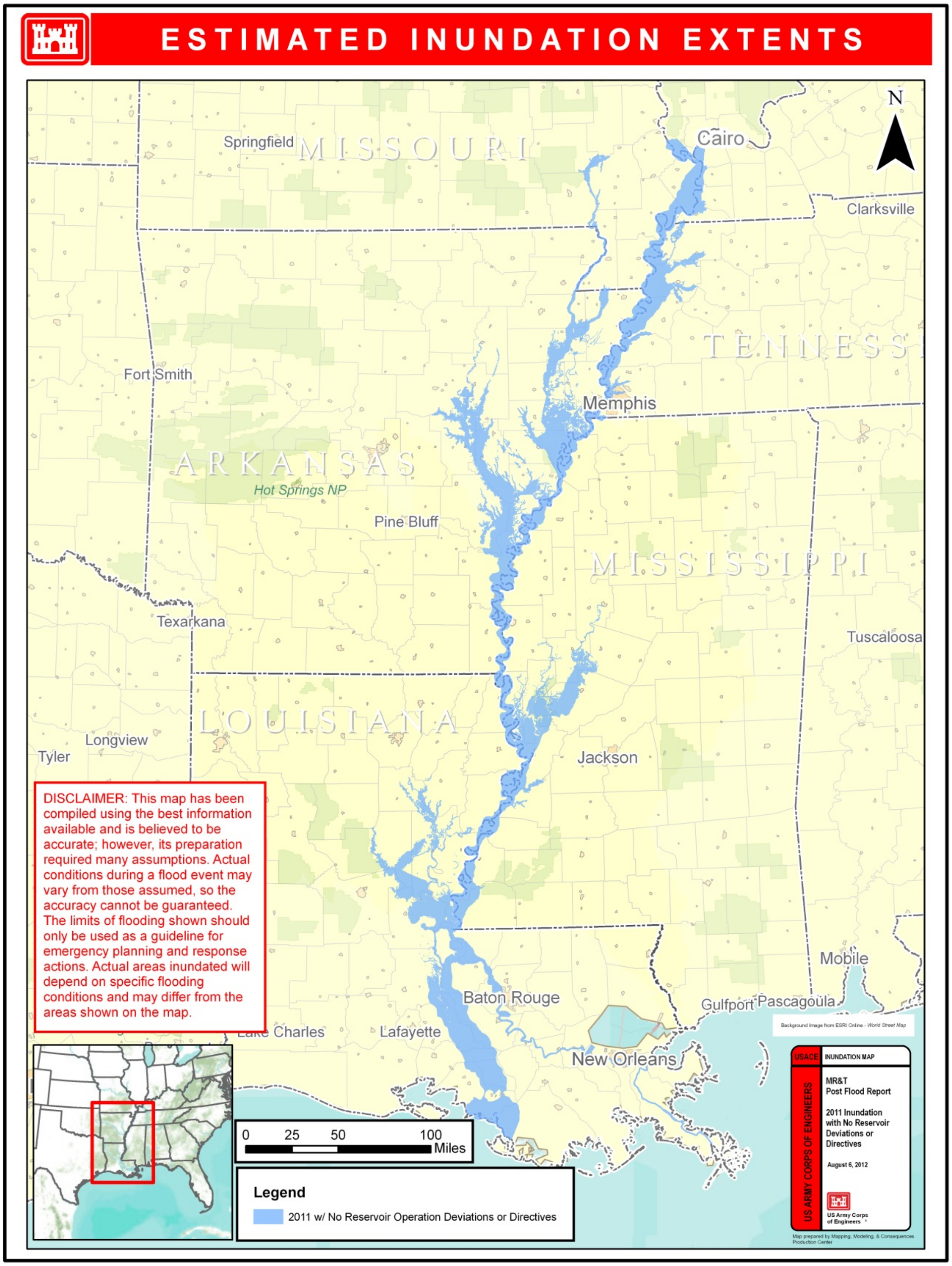


Figure V-4. Scenario 4: 2011 Existing Conditions Without Reservoir Deviations

D. AREAS INUNDATED

Flood damage impacts from the 2011 Flood were determined to impact 119 counties in portions of seven states along the lower Mississippi River—Arkansas, Illinois, Kentucky, Louisiana, Mississippi, Missouri, and Tennessee. These included areas in five US Army Corps of Engineer Districts in the lower MVD—SWL, MVM, MVN, MVS and MVK. Two other districts had potential impacts, LRN and LRL. Population estimates for the 119 counties in these states totaled approximately 6.3 million in 2010, according to the US Census Bureau statistics. Based on results of HEC-FIA, 43,358 people were impacted by the 2011 Flood was. HEC-FIA results account for the exact delineated boundary of the flood, whereas Census estimates account for the entire land area of each impacted county. Census data also includes metropolitan areas which are typically protected from catastrophic flooding from the Mississippi River.

Population impacts by Corps District are presented in table V-1 for the four hydrologic scenarios. Without the MR&T Project in place (i.e., Scenario 3), an estimated 3.6 million people (3,638,005) would be impacted by the 2011 Flood event. This compares to the 43,358 people impacted during 2011 Flood event (Scenario 1). In other words, approximately 3,594,647 people were saved from flood impacts with the MR&T Project in place. Without the MR&T Project in place (i.e., Scenario 3), MVN would comprise about 72 percent of the population impacted, followed by MVK with 19 percent and MVM, 9 percent.

Table V-1. Population Impacted by Scenario and District

District	Scenario 1	Scenario 2	Scenario 3	Scenario 4
SWL	79	3,636	4,041	79
MVM	19,348	312,410	346,253	19,348
MVN	18,281	2,191,303	2,591,972	18,281
MVS	0	0	0	0
MVK	5,650	618,741	695,739	5,650
Total Area	**43,358**	**3,126,091**	**3,638,005**	**43,358**

Source: HEC-FIA output

E. FLOOD DAMAGES

1. Economic Damages. Surveys conducted during and after the 2011 Flood provided a fair insight into the types and number of properties impacted. Discussed below and in greater detail in the Economic Appendix, the two largest categories of flood damage occurred to urban structural and agricultural properties.

a. Damages to Urban Structures. The HEC-FIA software was used to generate a structure inventory for the area inundated downstream of the project during failure and non-failure flood events. US Census data at the census block level and other information from the FEMA Hazard US database (HAZUS-MH) were utilized by HEC-FIA to create the structure inventory. The structures in each census block were evenly distributed over the urbanized area within the block. The urbanized areas were extracted from the 2001 National Land Cover dataset. Structure elevations were based on an elevation grid from the USGS with a ten meter grid size. The inventory created by HEC-FIA was compared with aerial imagery and is considered to be representative of the study area. HAZUS-MH data contains numbers of structures by occupancy type. Some structure characteristics and values are based on regional averages and other assumptions that cause uncertainties in input variables of the damage estimation process.

HEC-FIA was also used for this study in the estimation of damages to property. In the computation of property damages, HEC-FIA assigns each structure a structure point or HAZUS node, a ground elevation based on its location on a digital terrain model. Flooding is computed from depth grids for each failure mode or flood event. Vehicle damages were also calculated using the HAZUS dataset. HAZUS provides estimated day and night vehicle counts and values for both new and used light trucks, heavy trucks, and cars. As with the structure inventory, this data is provided for every census block. The vehicle counts are totaled for every vehicle type and evenly distributed by the HEC-FIA program between every structure in a census block. Estimates of the number of inundated structures, the degree of inundation, and the associated dollar damages, provide a profile of the system-wide impacts associated with a given scenario. While the aggregate system-wide estimates are constructed from estimates at the level of the individual structure, definitive attribution of a specific result to an individual structure in the form of inundation, depth of inundation, or dollar damage is not appropriate.

A more detailed discussion on the parameters and calculation of structural damages is presented in the Economic Appendix (Appendix G, *Economics*).

b. Number of Structures Flooded. Based on HEC-FIA output, the total number of structures affected for the existing 2011 Flood event, as it occurred during the flood (i.e., Scenario 1), resulted in 21,203 structures. This included urban and rural residential, commercial, industrial, and public structures. For the same scenario, an estimated 43,358 people were impacted.

The number of structures flooded by Corps District is presented in table V-2 for the four hydrologic scenarios. Without the MR&T Project in place (i.e., Scenario 3), an estimated 1.45 million structures (1,459,234) would be impacted by the 2011 Flood event. This compares to the 21,203 structures flooded during 2011 Flood event (Scenario 1). In other words, approximately 1,438,031 structures were prevented from flooding with the MR&T Project in place. The MVN contains 68 percent of the structures flooded without the MR&T Project in place (i.e., Scenario 3), followed by MVK with 19 percent and MVM with 12 percent.

c. Agricultural Damages. Agriculture flood damages were evaluated for the 2011 Flood based on the four different hydrologic scenarios, previously defined, for the five Corps Districts determined to potentially be impacted by the flood — SWL, MVM, MVN, MVS and MVK. To develop the database of agricultural acres impacted, state crop data layers were provided by the National Agriculture Statistics Service (NASS) based on the 2010 crop layer. Inundation shape files were reclassified against the land layers in ArcGIS to estimate the total acres of agriculture land impacted. Table V-3 provides the results for the reclassification for each scenario. The existing conditions (Scenario 1, existing MR&T Project as occurred during the 2011 Flood) proved to yield the least amount of land impacted, 1.23 million cleared acres compared to the other scenarios. As expected, Scenario 3 (no levees, no reservoirs) showed the largest total of land inundation (10.2 million acres) when evaluated against the other scenarios.

Table V-2. Number of Structures Flooded By Scenario and District

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	With MR&T Project (as occurred in 2011 event, minor deviations to reservoirs)	**Without MR&T Project** (no levees or cutoffs but w/ reservoirs)	**Without MR&T Project** (no levees, cutoffs or reservoirs)	**With MR&T Project** (as occurred in 2011 event, with no deviations to reservoirs)
SWL	70	3,171	3,507	70
MVM	9,747	155,682	172,130	9,747
MVN	6,799	849,826	999,238	6,799
MVS [1]	0	0	0	0
MVK	4,587	253,667	284,359	4,587
Total	**21,203**	**1,262,346**	**1,459,234**	**21,203**

Source: HEC-FIA output

[1] No site specific survey data on individual structures was available, thus it was difficult to determine damages in these areas with any degree of accuracy. Based on FEMA information, some structures did receive flood damages during the 2011 Flood event but no damage estimates were available.

Table V-3. Total Agriculture Acres Impacted by Scenario and District

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
	With MR&T Project (as occurred in 2011 event, minor deviations to reservoirs)	**Without MR&T Project** (no levees or cutoffs but w/ reservoirs)	**Without MR&T Project** (no levees, cutoffs or reservoirs)	**With MR&T Project** (as occurred in 2011 event, with no deviations to reservoirs)
SWL	34,800	210,500	212,200	34,800
MVM	620,000	2,696,900	2,707,940	620,000
MVN	52,300	1,295,500	1,310,900	52,300
MVS	92,500	675,500	681,860	92,500
MVK	433,500	5,295,200	5,322,800	433,500
Total Area	**1,233,100**	**10,173,600**	**10,235,700**	**1,233,100**

Source: NASS and ArcGIS.

Values indicated are estimated areas of inundation calculated using hydraulic numerical modeling that required assumptions and simplifications.

d. Crop Data. For this study damages were calculated for the following crops: corn, winter wheat, soybeans, grain sorghum, cotton, rice, and sugarcane. These crops constitute the majority of production in the impacted area. Crop budgets used to determine production costs and potential net income from lands in production were taken from budgets prepared by Mississippi State University's Agriculture Extension Service. Crop prices were based on current market prices available in May 2012. Crop yield data was obtained from agronomy experts with Louisiana State and Mississippi State University Extension Services. Damage to farms was evaluated based on three broad categories; production losses, net returns losses, and non-crop damages. All monetary damages were indexed to 2012 dollars.

e. Crop Loss Assumptions. Due to extended duration of the flood of 2011, it was assumed that replanting following the flood was not possible. After the flood started in April, it was assumed that no production costs were expended by farmers. Detailed explanations of the processes utilized to compute agricultural damages are provided in the economic appendix section of the document.

f. Total Economic Damages. The levees along the Mississippi River protect one of the most productive agricultural areas in the world, in addition to many other developments which have occurred over the years. Total flood damage estimates are presented by District in tables V-1, V-2, and V-3 for the four hydrologic scenarios and can be found in Appendix G, *Economics*. Total flood damage estimates from the 2011 Flood, with all current operational features of the MR&T project in place (Scenario 4), totaled over $2.8 billion in urban and agricultural damages. Without a FRM system in place, total flood damages were estimated to exceed $237 billion (Scenario 3). This amounts to $234 billion in savings with the System in place. Total flood damages for Scenarios 2 and 1 were estimated at $225 billion and $2.8 billion, respectively.

Flood damages of these sizes would almost certainly be accompanied by the threat of loss of life and would devastate millions of acres of farmland, numerous communities, homes, and businesses, and disrupt associated infrastructure. The possibility of a flood of this magnitude would be catastrophic to the economy of the region and repercussions would be felt throughout the entire US economy.

- **Scenario 1 - Flood Damages.** Urban flood damages comprise 76 percent of the total flood damages for Scenario 1—the condition as it occurred during the 2011 event. The damages are distributed between in MVN, MVK and MVM (38, 21 and 37 percent, respectively).

- **Scenario 2 - Flood Damages.** With no MR&T levees or cutoffs, but with reservoirs, urban flood damages would consist of 97 percent of the total flood damages. For this scenario, the majority of the total damages would take place in MVN (74 percent), followed by MVK and MVM, with 17 and 8 percent, respectively.

- **Scenario 3 - Flood Damages.** Without the MR&T Project, urban flood damages would account for 98 percent of the total flood damages. The majority of the total damages would happen in MVN (74 percent), followed by MVK (17 percent) and MVM (8 percent).

- **Scenario 4 - Flood Damages.** For Scenario 4—with the MR&T in place, as it was designed—urban flood damages comprise 76 percent of the total flood damages. The total damages are distributed between in MVN and MVM (37 and 38 percent, respectively) with MVK comprising 21 percent.

g. Damages to the MR&T System. The MR&T System consists of levees, drainage structures, pumping plants, channel improvement features, and various other structures. These levee systems are shown in Appendix G, *Economics*. The Immediate Risk Reduction Measures include needs of the MR&T System that were defined as Classification 1 projects in accordance with the Hot Spot Project FRAGO. These projects remediate issues identified during the 2011 event that are likely to cause failure prior to a 25-year flood event. The Long Term needs of the MR&T System are defined as Classification 2 and 3 projects in accordance with the FRAGO. These projects remediate issues identified during the 2011 event that range from unlikely to likely chance of failure due to a 25-year flood event. Further information on damages to MR&T features can be found in *Section VI. C. Damage and Repair Needs* which provides a detailed explanation and results of the MR&T damage assessment conducted by Corps staff.

In addition to levee structures and their features, the Channel Improvement community has identified approximately 240 MR&T channel improvement sites that sustained damage to revetment and/or dikes during the 2011 Flood on the Mississippi and Atchafalaya Rivers, 44 of which could have an impact on system performance if not repaired. Some of the most significant include Cache-Cairo, Third District, Chute of Island 8, Merriwether-Cherokee, President's Island, and Walnut Point/Kentucky Bend. A brief discussion of the each of these can be found in Appendix G, *Economics*. Typical damage is shown in photographs V-1 through V-4.

Photograph V-1. Typical Damage to a Dike

Photograph V-2. Typical Damage to Revetment

Photograph V-3. Location of Critical Scour

Photograph V-4. Example of Overbank Scour

2. Environmental Damages. During the 2011 Mississippi River flood, large reaches of river channel and floodplain experienced high rates of soil/sediment erosion and deposition along with vegetation loss. While these are processes associated with natural river behavior, anthropogenic development has led to an intensification or spatial redistribution of the flooding impacts. For example, many of the major observed environmental impacts occurred in the three large engineered spillway or floodway areas that were activated during the flood: the BPNM Floodway, the Morganza Floodway, and the Bonnet Carré Spillway. Most damage resulted from the force of the initial flood wave as the spillway gates were opened, and the prolonged inundation of the spillway area. Further environmental effects occurred as the large volumes of river water were introduced into coastal estuary locations, which only receive large influxes of fresh water on a periodic basis.

a. Terrestrial Resources

i. Land Resources. During the flood of 2011, the increased river stage caused the rerouting of relatively high velocity flow over many channel bars, islands, and point bars. In the past, the Corps recommended a minimum 'tree screen' of 300 feet perpendicular to the channel bank to inhibit the passage of strong river currents over inundated floodplain areas during floods. Many reaches of the river lack even this screen, and field evidence suggests that such scour damage is more likely with the lack of a tree screen. For example, sites such as the Merriwether-Cherokee Revetment site in Lake County, TN and President's Island in Shelby County, TN (photographs V-5 and V-6 and figureV-5) experienced severe damage that may have been avoided if tree screens were present. Future implementation of tree screens or their beneficial functions should be considered with regard to local bank heights, overbank flow patterns, soil types, and vegetation types to enhance their resiliency and effectiveness. The Thompson Bend Riparian Corridor project, located near the confluence of the Ohio and Mississippi Rivers, has successfully incorporated similar concepts to limit erosion and scour (http://mvs-wc.mvs.usace.army.mil/thompson/projectdescription.htm).

Photograph V-5. Aerial View of Merriwether-Cherokee Revetment Site in Lake County, TN
The photo on the left shows the area before the flood of 2011. Note the narrow band of trees along portions of the Mississippi River bank. The photo on the right is an aerial view of the same revetment site during the flood of 2011. Flow moved across areas with little riparian buffer/tree screen. Improved tree screens may have reduced erosion and flow velocities sufficiently to reduce the damage in the area.

Photograph V-6. Damage Caused by Overbank Flow at Presidents Island

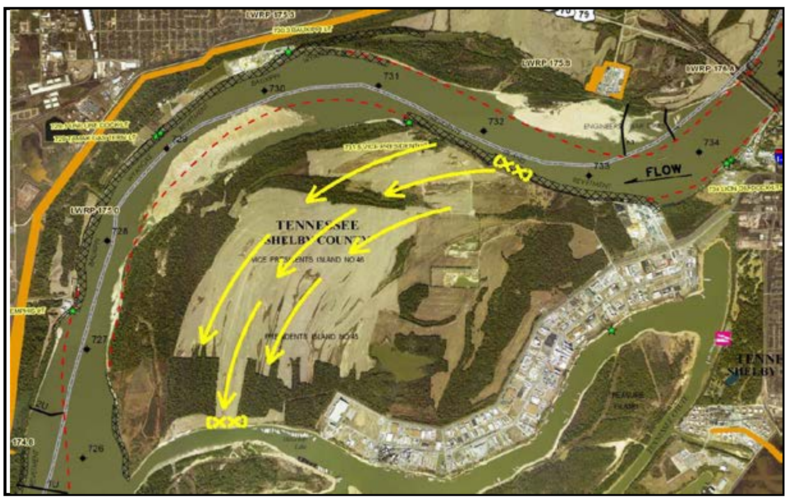


Figure V-5. Annotated Aerial View of the Flow Path of River Water Over President's Island, Shelby County, TN. The flow velocity may have been reduced if a tree screen had been properly installed along the upstream bank of the island.

The introduction of floodwater into the spillway areas caused some mortality to local vegetation. However, the spatial extent of this damage relative to the full vegetated extent in the flooded areas is small, and it is not expected to persist for more than a couple of years. Most terrestrial damage was due to soil scour and the deposition of substantial amounts of sediment along some locations of the floodplain and spillway topographical surface.

While the spillways were engineered for occasional inundation, many contained recreational (e.g., picnic areas, hiking paths, boat launches, and boardwalks) and civil (e.g., roads, culverts, and fences) infrastructure that was damaged by the floodwater during spillway operation. A number of recreational sites have been established within the greater spillway areas or in areas affected by their operation. These sites include approximately 1,093 acres below the BPNM Floodway (e.g., Towosahgy State Park and Big Oak Tree State Park), over 200,000 acres below the Morganza Water Control Structure (e.g. The Atchafalaya Delta Wildlife

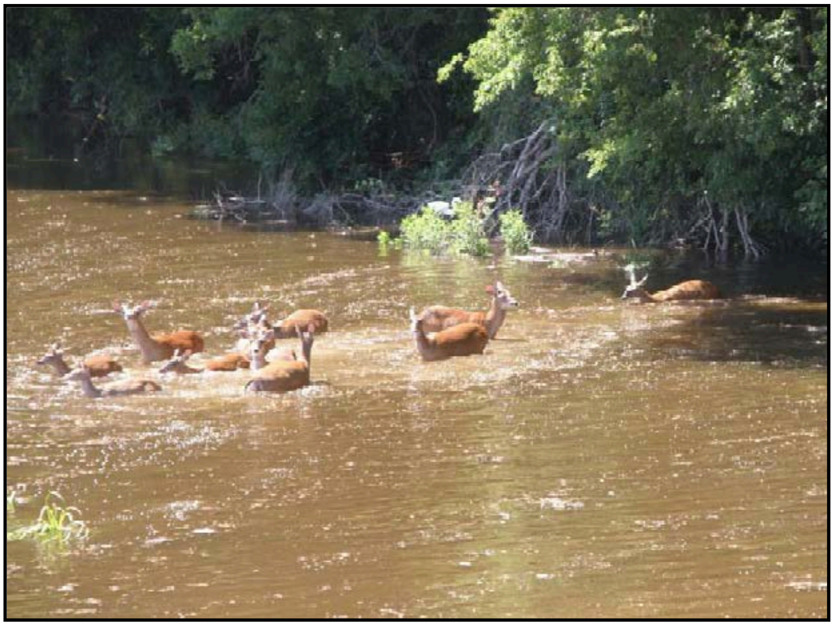
Management Area), and 10 acres below the Bonnet Carré Spillway (e.g. St. Charles Parish Boat Launch and Recreation Area). Large-scale damage to these areas was not reported; however, most of these areas experienced closure or reduced access during and after the flood period. The river discharge introduced to the spillways during their activation did enhance certain recreational activities during and following the flood period, including fishing and crawfish trapping.

ii. Wildlife Resources. When floodwater enters areas unaccustomed to inundation, terrestrial animals flee the area without established escape routes. These fleeing animals run the risk of becoming stranded in areas incapable of supporting their subsistence over the duration of the flood. In general, large-scale flooding promotes crowding or isolating wildlife populations in unflooded regions and may degrade wildlife forage areas until the ecosystem and regional food chains can become re-established. Ground-dwelling animals such as turkey, deer, rabbits, armadillos, feral hogs, and bobcats typically attempt to flee floodwaters while tree-dwelling or semi-aquatic animals often find shelter in trees or slackwater areas with emergent vegetation (photograph V-7).

Photograph V-7. Armadillos Seeking Refuge From Floodwaters

Under non-flash flood, natural flood conditions typical to BLHFs, floodwater rises on the order of inches per day. Under these conditions, animals have the ability to identify the flood risk over time and evacuate to higher ground. While some effort was made to slowly release water into the spillways to minimize its environmental impact, floodwater depths occasionally increased on the order of feet per day, which resulted in observed animal fatalities in a few locations.

Deer fleeing the Morganza Floodway floodwaters were forced to inhabit narrow strips of high ground around levees, emergent trees, and surrounding agricultural fields during the spillway operation (photograph V-8). However, the period of time in which the water control structure was opened was generally not long enough to induce starvation in healthy animals. In the same area, there were some fatalities among interior swamp turkeys. Immediately before the floodway activation, multiple turkeys were fitted with remote tracking devices to record their movement during the floodway operation. Turkeys in areas that experienced rapid flood rise were all observed to methodically search for high ground, traveling along a circular route. Those unable to find high ground died. A concerted effort was made to provide field personnel forms to report black bear sightings. Few bears were seen, but one female bear was killed on the train track running through the Morganza Floodway. There have also been reports that during the spring of 2012, some of the collared and tracked bears are reproducing again this year, suggesting that they lost their cubs last year during the flood, as black bear generally reproduce only after their cubs are 2 years old.



Photograph V-8. Deer Exiting Morganza Floodway During Its Activation

Flooding likely disturbed the nesting activities of the interior least tern, which typically locate their nests on isolated sandbars near the river channel banks, along with other birds that rely on river resources. Flooding inundated nearly all channel bars within the LMR during the flood period. This flooding may have constrained seasonal breeding but did not likely result in large-scale avian fatalities.

b. Aquatic Resources

i. Water Resources. Appendix F, *Environmental and Cultural Resources* of this report contains the results of the water quality sampling conducted by the USGS in coordination with the Corps during the 2011 Flood. Although the sampling occurred at the routine NASQAN sampling sites, in many cases the sampling frequency was increased during the flood. The location of sampling areas is listed in table V-4. The exceptionally high floodwaters of 2011 did not significantly alter the concentration of fluvial sediment, nutrients, and pesticides within the flow of the LMR beyond the mean annual values typical for spring and summer. However, because of the extreme river discharges, the overall mass flux of these constituents did reach record levels. Within the Mississippi River, the transport levels of sediment, nutrients (e.g., nitrogen and phosphorus), and pesticides did not trend with discharge and showed a general tendency to decrease in time within the flood period. Within the spillways, these constituents did display a positive relationship with discharge, but their concentrations were less than that measured in the river at monitoring locations both upstream and downstream of the spillway location. Table V-4 displays averaged and maximum water quality values for four locations along the LMR and the three spillways estimated over the flood period. Also shown are values of the total mass flux for certain contaminants and sediment; however, these flux values were estimated over a shorter time period (as defined in the table legend). The suspended sediment and total nitrogen values shown for the BPNM Floodway were collected during a single time period following the initial activation of the spillway.

Table V-4. Water Quality Values Measured Within the LMR During the 2011 Flood Period

		NUTRIENTS		PESTICIDES
Location	**Suspended Sediment**	**Total Nitrogen**	**Phosphorus**	**Atrazine and Metlachlor**
Mississippi River at MVK, MS	**max -** 164 mg/L **avg -** 126 mg/L 18,800,000[1]	**max -** 2.8 mg/L **avg -** 2.17 mg/L 262,000 [1]	**max** 0.24 mg/L **avg -** 0.19 mg/L 26,200 [1]	**max -** 1.51 µg/L **avg -** 0.88 µg/L
Mississippi River at St. Francisville, LA	**max -** 179 mg/L **avg -** 103 mg/L	**max -** 2.70 mg/L **avg -** 2.07 mg/L	**max -** 0.27 mg/L **avg -** 0.19 mg/L	**max -** 1.43 µg/L **avg -** 0.87 µg/L
Baton Rouge, LA	**max -** 168 mg/L **avg -** 133 mg/L	**max -** 2.8 mg/L **avg -** 2.03 mg/L	**max -** 0.21 mg/L **avg -** 0.17 mg/L	**max -** 1.41 µg/L **avg -** 0.70 µg/L
Mississippi River at Belle Chase, LA	**max -** 206 mg/L **avg -** 149 mg/L	**max -** 2.8 mg/L **avg -** 2.13 mg/L	**max -** 0.27 mg/L **avg -** 0.22 mg/L	**max -** 1.25 µg/L **avg -** 0.83 µg/L
BP NM Floodway	150 mg/L [3]	2.65 mg/L [3]		0.6 µg/L [4]
Morganza Floodway	**max -** 31 mg/L **avg -** 16.5 mg/L 404,000 [1]	9,930 [1]	900 [1]	
Bonnet Carré Spillway	**max -** 177 mg/L **avg -** 105 mg/L 2,307,294 [1, 2]	36,182 [1, 2]	3,342[1, 2]	

[1] values are total estimated flux during the month of May;
[2] during 44 flood days spanning May and June in metric tons;
[3] measured during the initial levee activation;
[4] for Atrazine during the month of May only.

Of some interest are the results of the water quality data for the Atchafalaya Basin. Over 1,000 oil wells were inundated by the floodwaters introduced by the Atchafalaya River and the Morganza Floodway. Samples were collected for gasoline, oil and grease, and petroleum hydrocarbons upstream and downstream from the wells. On May 23, 2011, there was a slightly higher concentration of gasoline detected in the downstream waters, but by the next week, the concentration was higher in the upstream waters. Oil and grease levels were virtually identical upstream and downstream, and there were no detects of petroleum hydrocarbons, indicating that the efforts to shut down and secure the wells prior to inundation were successful. Also, it is interesting to note that during May, 2011, the total load of nitrate plus nitrite decreased slightly between the inflow at the ORCC and the Morganza Floodway, and the outflow at Wax Lake and Morgan City, indicating the possibility of denitrification occurring while the river waters were in contact with the forested wetlands in the Atchafalaya floodway; however, over the same time period, the suspended sediment loads and the total phosphorus loads increased, suggesting that the flood flows caused the resuspension of sediments and adsorbed phosphorus during the flood.

The floodwater released through the Bonnet Carré Spillway entered the coastal waters of southeastern Louisiana and southern Mississippi through Lake Borgne and Lake Pontchartrain. The river water was much colder, much less saline, and contained much higher nutrient loads than the surrounding coastal water, and significantly altered the regional water chemistry in Lake Pontchartrain, and through Mississippi Sound all the way to the area off shore from Biloxi, MS. Coastal waters that typically had salinity levels near 13.0 parts per thousand (ppt) experienced levels as low as 1.0 ppt until mid summer 2011 (figure V-6). The high nutrient loads caused excess phytoplankton (i.e., algae) growth along coastal Louisiana and Mississippi. Freshwater algal species found the Mississippi Department of Marine Resources in Mississippi Sound included *Pediastrum* spp. and *Scenedesmus* spp. and a USGS contractor (The Academy of Natural Sciences of Philadelphia) counted bloom levels of cyanobacteria, likely *Woronichinia.*

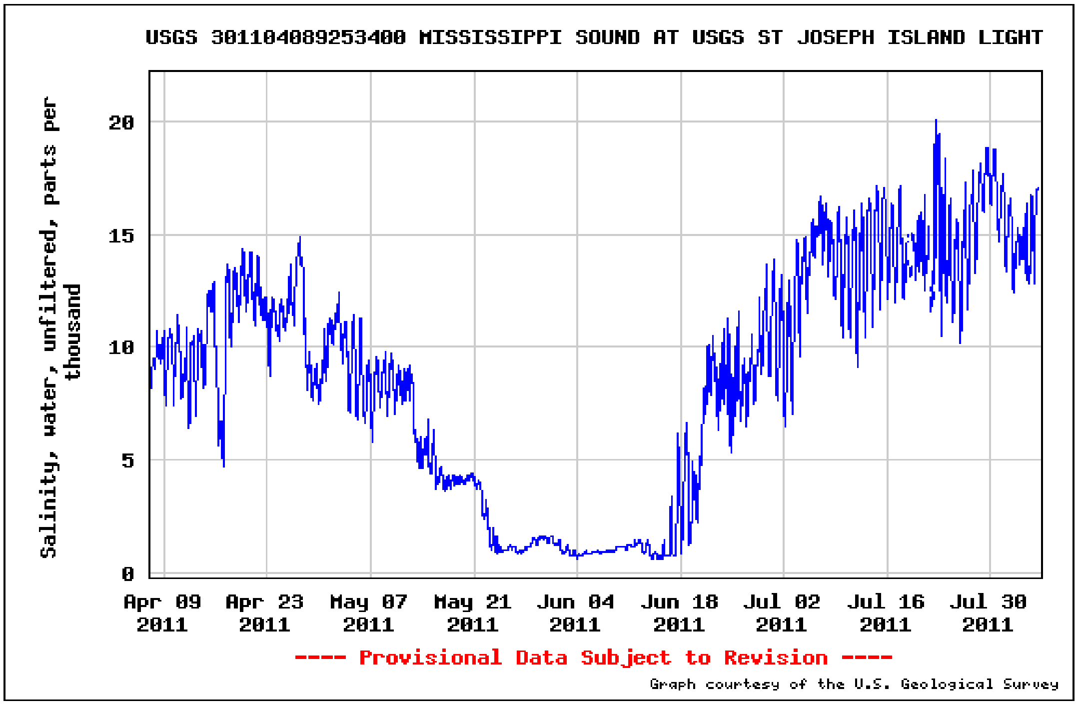


Figure V-6. USGS Plot of Measured Sea Water Salinity at Mississippi Sound During the Flood Period Salinities were in the range of 10 to 15 ppt, dropped to only about 1 ppt during the opening of the Bonnet Carré Spillway (5/9/2011), then recovered back to the 15 ppt after the spillway was closed (6/20/2011). This particular gaging station was nearly 40 miles away from the spillway, providing some sense of the spatial extent of the effects of the 2011 Flood.

The death and decaying process of large volumes of algae depletes the dissolved oxygen in the water in the vicinity of the algae bloom, which leads to hypoxic conditions and sea life mortality. It is hypothesized that the large, continuous discharge of river water into Lake Pontchartrain during the flood period effectively flushed the introduced freshwater and nutrients through the lake into Mississippi Sound (photographs V-9 and V-10 and figure V-7). This may have caused the hypoxic conditions to form in the estuarine areas. Details on this sampling effort, as well as information on phytoplankton community composition and comparisons between the 2008 and 2011 events are presented in the paper in Appendix F.

Photograph V-9. Aerial Photo of Algae Bloom and Mississippi Department of Marine Resources Boat Collecting Phytoplankton Samples on June 27,2011

Photograph V-10. Turbidity off the Coast of Mississippi Believed To Be Due to the Mixing of Fresh and Salt Water, June 22, 2011

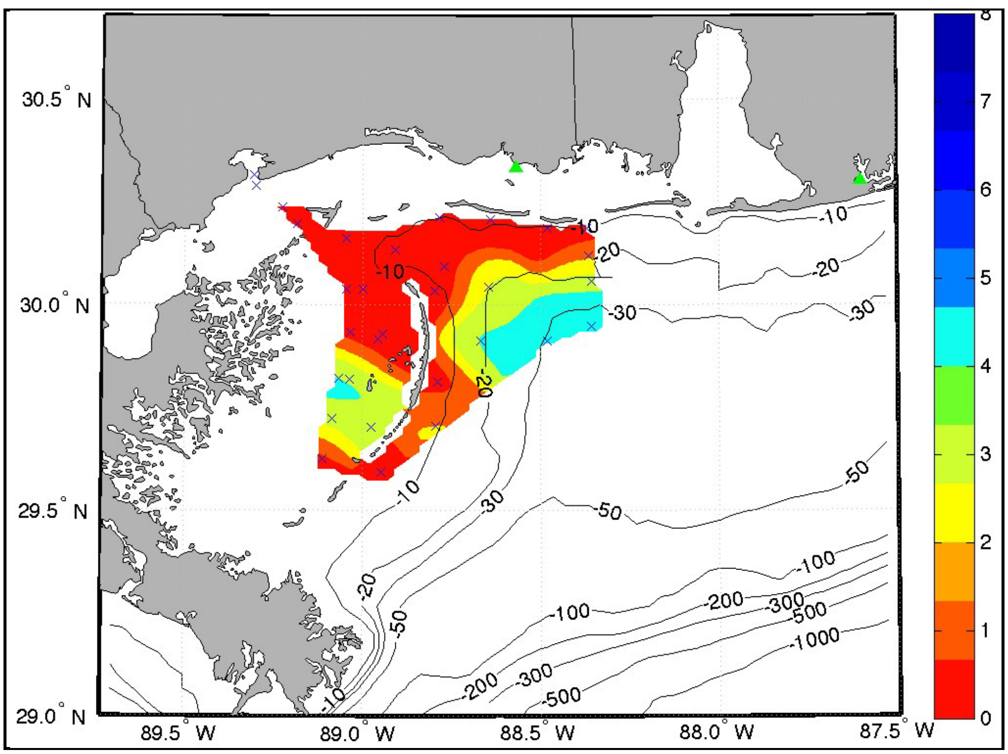


Figure V-7. Survey of Bottom Water Hypoxia in August 2011 in Mississippi Sound (Dr. Steve Howden, Department of Marine Science, University of Southern Mississippi) The scale bar (right hand side) shows bottom water dissolved oxygen concentrations (mg O_2/L). This data would suggest that the nutrient rich freshwater from the river encouraged algal growth and when those algae died, their decomposition exhausted the available dissolved oxygen in the coastal waters.

ii. Fisheries. Most aquatic life along the Mississippi River and side channels has evolved behavior to mitigate the effects of floods (e.g., seeking refuge in side channels and pools). However, some fish fatality occurred due to drastic drops in river water temperature due to very large rainstorms during the flood period. Quick changes in water temperature may inhibit the natural mixing within the water column, which creates temporary zones of low oxygen incapable of supporting life (i.e., hypoxia). The floodwater within the spillway areas disrupted the habitat of some commercially viable species that lived in the area, such as crawfish. However, it is unclear if any of these species' populations were significantly affected.

One of the species of concern in the Mississippi River is the pallid sturgeon. There is little scientific literature describing how pallid sturgeon respond to distributary channel flows (i.e., flow diverted into spillways). For example, it is unknown if secondary channels are actively sought for refuge and increased food sources during main channel floods or if they are avoided (USFWS, 2009). Because of this, it is unknown if the sturgeon observed within the spillway had entered it on purpose or were entrained when swimming nearby. Pallid sturgeon favor turbid water and do consume floodplain food sources, such as macroinvertebrates, as well as invertebrates and small fish living in the main channel (USFWS, 2010). Recent investigations of the BPNM floodway have not identified any topographic or hydrographic features that would appear to attract the sturgeon to the vicinity, other than functioning as a large side channel. Prior floods have shown that pallid sturgeon are entrained by the Bonnet Carré Spillway. Pallids require freshwater, and once the spillway is closed, Lake Pontchartrain returns to a brackish salinity, which would limit pallid sturgeon viability. Therefore, it is necessary to attempt to "rescue" the pallid sturgeon trapped in the Bonnet Carré Spillway and Lake Pontchartain and return them to the Mississippi River. Pallid sturgeon may also be entrained by the ORCC; however, a significant population of pallids lives in a scour hole downstream from the ORCC. It is believed that the length of the freshwater extent of the Atchafalaya River is too short to allow the successful reproduction of pallid sturgeon, thus making the population living downstream of the structure non-viable.

In coastal areas spanning from Lake Pontchartrain and Lake Borgne through Mississippi Sound, and beyond Biloxi, MS, the dissolved oxygen and salinity levels dipped below that required for many aquatic species. Species unable to flee the affected waters, such as sessile animals like oysters, experienced high levels of mortality. For example, mature oysters reefs along Mississippi Sound experienced mortality rates exceeding 85 percent. Preliminary reports estimate that the economic cost of the flood damage (caused by spillway use) to the entire oyster industry as approximately $60 million. The degraded quality of the coastal waters was estimated to have reduced the commercial Mississippi blue crab harvest by approximately 50 percent for 2011 (May to August). The regional brown shrimp population appeared to have been unaffected by the influx of floodwater. Information was requested about the impacts to Louisiana oysters, but the Louisiana state resource agencies declined to comment on their situation.

The Louisiana Department of Wildlife and Fisheries has reported (R.T. Ruth, personal communication) that there was the movement of silver carp from the Mississippi River, through the freshened waters of Lake Pontchartrain, into the Pearl River system. Additional documentation of damages associated with the flood in the Atchafalaya Basin can be found in the report *2011 Atchafalaya Basin Inundation Data Collection and Damage Assessment Project* authored by Carlson, Horn, Van Biersel, and Fruge.

c. Cultural Resources. Damage to archeological sites within the major spillways, during their activation, has largely been limited to the BPNM Floodway. Activation of the BPNM floodway requires detonation of explosives to remove an earthen levee between the floodplain and the spillway entrance. This type of sudden activation creates a near-instantaneous release of a large volume of floodwater into the spillway that has the potential to severely scour soil and sediment along the spillway surface. Scour can destroy archaeological site integrity and expose both Native American and Euro-American historic burials at this site. The activation of the BPNM floodway caused deep scouring around the north end of Birds Point frontline levee. At this location, scouring damaged a previously undetected, late-Mississippian archeological site (National Register site number is 23MI136) (photograph V-11). The flow entrained and transported prehistoric human skeletal remains and related artifacts (e.g., faunal material, pottery pieces) over a seven-acre area. This inadvertent discovery was identified during the immediate post-flood period (June 2011) during the early stages of the "Operation Make Safe" levee restoration.

Photograph V-11. Large Areas of Soil Scour After Spillway Operation at the BPNM Floodway
In this area, soil erosion led to the exposure of a previously unidentified burial site (23MI136).

The Bonnet Carré Spillway contains sections of two cemeteries (i.e., Kugler cemetery and Kenner cemetery) but no scour was observed within their areas. Spillway maintenance activity accidently exposed buried bodies within the Kugler cemetery in 2008. There are no identified archeological sites within the Morganza Spillway.

F. DAMAGES PREVENTED

The existing MR&T Project (whether Scenario 1 or Scenario 4) prevented approximately $234 billion in urban and agricultural flood damages (compared to Scenario 3) during this single event. Without a FRM system in place, approximately 1.45 million residential and commercial structures would have been impacted. With the MR&T System, this decreases to 21,203 structures.

In comparison, the MR&T Project (reservoirs only, Scenario 2) prevented approximately $11.8 billion in urban and agricultural flood damages (compared to Scenario 3) during the 2011 Flood, which results to only a 5 percent reduction in total flood damages. Estimates of flood damages prevented for the four hydrologic scenarios are presented by Corps District in Appendix G, *Economics.* For Scenarios 1 and 4, the flood damage prevented estimates are the same since the hydrographs for these two scenarios were the same. Flood damages prevented for Scenarios 1f and 4 reduced flood damages by approximately 98 percent.

SECTION V
AREAS FLOODED, FLOOD DAMAGES, AND FLOOD DAMAGES PREVENTED

1. Reduced Impact on Population. Estimates on the number of people protected by the MR&T Project during the 2011 Flood are presented in tables in Appendix G, *Economics*. The results of the damage analysis showed that 98 percent of the overall population was spared from the adverse impacts of flooding. The same amount of protection was afforded with Scenario 1 as 4. As shown, the majority of the reduced impacts occurred in MVN, MVK, and MVM.

2. Project Effectiveness. Project effectiveness is measured by the amount of flood risk reduced by the project, or in terms of its percent in flood risk reduction (FRR). This also relates to the degree of protection (DOP) afforded by the project. The results of project effectiveness from flood damages prevented for each scenario are displayed in table V-5. Based on the results of the flood damage evaluation, the FRR for Scenarios 1 and 4 resulted in a 98 percent DOP while Scenario 2 (reservoirs only) provided only minimal protection in terms of FRR with a 5 percent DOP.

3. Overview. Without the MR&T Project in place (i.e., Scenario 3) total flood damages in the seven-state impacted area would have been over $237 billion. Furthermore, the Project provided a 98 percent flood risk reduction. Based on the significant influence of the Mississippi River on surrounding economies, it is not hard to grasp the importance of the main stem levee system to the region. Protecting approximately 53 million acres of land in the States of Arkansas, Illinois, Kentucky, Louisiana, Mississippi, Missouri, and Tennessee of the lower Mississippi River valley, it has the task of trying to contain one of the oldest and most powerful natural resources in the world—the Mississippi River.

Table V-5. Summary of Damages Prevented and Effectiveness of MR&T Project [1]

		Without MR&T Project (Scenario 3) [2]	**With-Project Conditions**		
Scenario	**With-MR&T Project Description**	**Total Damages** (million $)	**Total Residual Damages** (million $)	**Total Damages Prevented Benefits** (million $)	**FRR** [3]
1	**As Occurred 2011** (minor deviations in reservoir operations)	$237,152,397,000	$2,863,843,000	$234,288,554,000	98 %
2	**With Reservoirs, But No Levees**	$237,152,397,000	$225,315,506,000	$11,836,891,000	5%
4	**As Designed 2011** (no deviations in reservoir operations in 2011)	$237,152,397,000	$2,863,843,000	$234,288,554,000	98 %

[1] values expressed in 2012 prices

[2] the without-project condition

[3] percent of FRR from project implementation; also referred to as DOP