EFFECTIVENESS OF CHANNEL IMPROVEMENT WORK ON THE MISSISSIPPI RIVER

Richie McComas, Hydraulic Engineer, USACE Vicksburg District, Vicksburg, MS, Richie.McComas@usace.army.mil; and C. Fred Pinkard, Jr., Hydraulic Engineer, USACE, Vicksburg District, Vicksburg, MS, Freddie.Pinkard@usace.army.mil.

Abstract: The Mississippi River has long been a major contributor to the physical and economic development of our nation. However, at the time that the United States was first settled, the Mississippi River was a natural alluvial stream characterized by a wide, shallow channel, numerous shifting sandbars, and large fluctuations in stage. The river was active and freely meandered across its floodplain. In this natural state, the river could not provide a dependable channel to meet the nation's commercial navigation needs nor could it provide for the efficient passing of flood flows.

To meet both navigation and flood control needs, a dependable, low maintenance channel had to be developed. Initially, dredging was conducted to provide adequate depths for navigation and levees were constructed to ease flooding problems. However, these measures alone proved ineffective. Then in 1927, a great flood devastated the entire Mississippi River Valley. As a result of this flood, Congress passed the Flood Control Act of 1928. This legislation authorized the U. S. Army Corps of Engineers to develop a comprehensive system of flood control and navigation improvements for the Lower Mississippi River. To provide an efficient navigation channel and to provide protection for the flood damage reduction levees, the banks of the river had to be locked in place. In response to this need, the Corps of Engineers initiated a comprehensive bank stabilization program. The use of revetment consisting of articulated concrete mattress (ACM) on the lower bank in conjunction with stone paving on the upper bank has proved to be most effective in controlling the erosion of the river's banks. However, revetment alone was not sufficient to provide a low maintenance channel. During low water periods, substantial dredging was required to maintain adequate channel dimensions. As a result of this continued dredging, a system of stone dikes was developed to provide adequate channel dimensions through trouble reaches. Now approximately 85 percent complete, the dike program has greatly reduced the expensive dredging requirements. Dredging within the Vicksburg District is only occasionally required in a limited number of isolated problem reaches.

Even with the proven success of the channel improvement program, additional work is required. With continued construction of the remaining planned channel improvement structures and continued maintenance of existing structures, an efficient navigation channel will continue to be provided on the Lower Mississippi River. During 2001 a paper which summarized the effectiveness of channel improvement work on the Mississippi River was prepared for the 7th Federal Interagency Sedimentation Conference. This current paper provides an update and expands on the information provided in that paper, takes a more detailed look at the project's environmental conservation and enhancement features, and identifies the performance of the channel improvement features during both the historic flood of 2011 and subsequent extreme low water in 2012.

BASIN CHARACTERISTICS

The Mississippi River drainage basin is the third largest in the world, exceeded in size only by the Amazon River in South America and the Congo River in Africa. The Mississippi River drains 41 percent of the lower 48 states, including all or parts of 31 states, extending from New York in the east to Montana in the west. The Ohio, Missouri, Tennessee, Arkansas, and Red River basins are part of the Mississippi River basin. The Mississippi River flows some 2,350 miles from its source at Lake Itasca in Minnesota to the Gulf of Mexico. The Lower Mississippi River Valley extends from just below Cape Girardeau, Missouri for approximately 600 miles to the Gulf of Mexico. The lower valley ranges in width from 30 miles to 125 miles with an average width of 45 miles and includes parts of Missouri, Illinois, Kentucky, Tennessee, Arkansas, Mississippi, and Louisiana. Figure 1 is a map that identifies the boundaries of the Mississippi River basin.

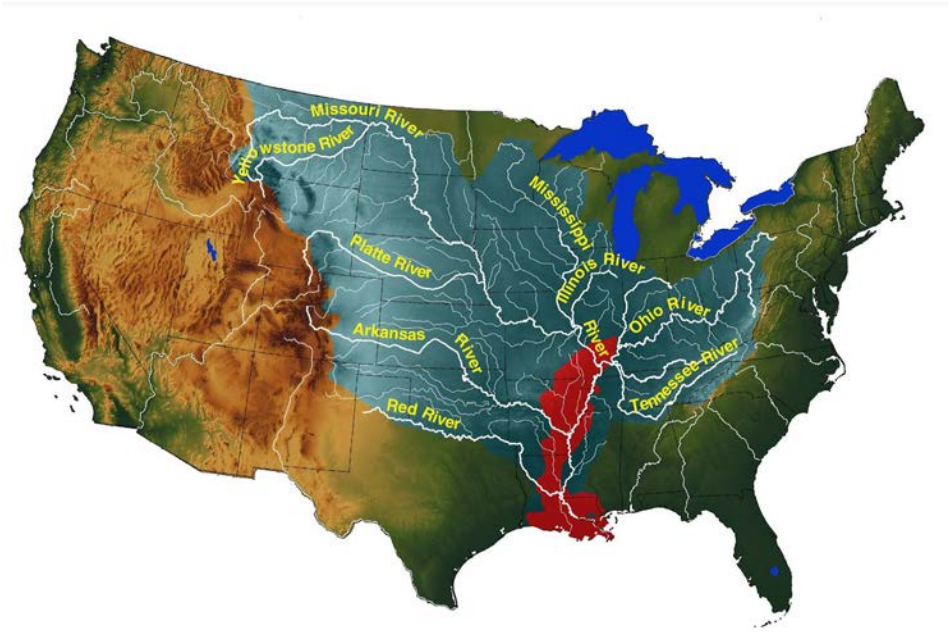

Figure 1. Mississippi River Drainage Basin

On the Mississippi River, flows, stages, and channel velocities vary over a wide range. During the 1943 through 2014 period, the average flow at Vicksburg, Mississippi was 625,000 cubic feet per second (cfs). The minimum recorded flow during this 71-year period was 126,000 cfs during January 1964 while the maximum recorded flow was approximately 2,300,000 during the 2011 flood. During that period, flows ranged on average from a low of around 305,000 cfs to a high of about 1,000,000 cfs. River stages also vary greatly. During the 1943 through 2014 period, the average annual low stage at Vicksburg was 54.1 feet, National Geodetic Vertical Datum (NGVD), the average stage was 66.3 feet, NGVD, and the average annual high stage was 78.4 feet, NGVD. Based on these averages, stages typically varied a little over 24 feet from annual highwater to low water. The lowest stage ever recorded at Vicksburg was 39.2 feet, NGVD during February 1940 while the highest stage recorded was 103.3 feet, NGVD during the 2011

flood. Channel velocities typically range from about 2 to 3 feet per second during low water to over 10 feet per second during highwater.

The Mississippi River is an alluvial river that carries a large and highly variable sediment load. Available data indicates that the annual suspended sediment load at Tarbert Landing, Mississippi (River Mile 306.3) has varied from about 70,000,000 tons to over 575,000,000 tons. Between 1963 and 2005, the average annual measured suspended sediment load was approximately 150,000,000 tons (Thorne et al., 2015). This sediment load equates to 133 tons per square mile of contributing drainage area per year. Sieve analyses indicate that on average, this suspended sediment load consists of about 20 percent sand and 80 percent fine material (silt and clay). Studies have indicated that over time, the measured suspended sediment load on the Mississippi River has significantly decreased primarily due to the construction of the channel improvement features, closure of multipurpose reservoirs, and improved land use management procedures. However, since the measured suspended sediment load is predominantly silt and clay, which are not found in large quantities in the bed, the total measured suspended sediment load could have decreased without any decrease in the bed material load, which is mostly unmeasured. In fact, as pointed out by Biedenharn (1995), the river through much of the Vicksburg and Memphis Districts has a steeper slope and larger stream power (QS) today than it did prior to the 1930's. Therefore, since studies (Nordin and Queen, 1992) show that the bed material size (D50) of the river has not changed significantly since the early 1930's, it is possible that the bed material load in these steeper reaches is higher today than it was prior to that time. This conclusion would suggest that more sediment of the size that deposits in the navigation channel and historically required removal by dredging is carried by the river today.

NAVIGATION DEVELOPMENT HISTORY

The Mississippi River has long been recognized as a valuable transportation benefit. Native Americans traveled the river by canoe for centuries before the European explorers arrived. The Europeans used the river for settlement expansion and small-scale commercial navigation to transport goods such as furs and supplies. The introduction of the steamboat during the early 19th century ignited an explosion of development along the river. However, the river was unpredictable and many steamboats fell victim to hazardous snags, shifting sandbars and high channel velocities. As early as 1820, the Federal Government recognized the importance of improving the Mississippi River for navigation. In that year, Congress appropriated funds for the preparation of a survey, maps, and charts of the Ohio and Mississippi Rivers. In 1824, the Corps of Engineers initiated channel improvement work by removing snags in the Mississippi River below the mouth of the Missouri River. For several years thereafter, channel improvement work was sporadic and limited to localized areas. All channel improvement work halted during the Civil War. As the country began to heal after the war, the need for more substantial Federal involvement in improvements of the river for navigation and flood control was generally recognized. In 1879, Congress established the Mississippi River Commission (MRC) to coordinate engineering operations within the Mississippi River Valley. The MRC was assigned the primary duties "…to take into consideration and mature a plan or plans and estimates as will correct and permanently locate, and deepen the channel and protect the banks of the Mississippi River; improve and give safety and ease to the navigation thereof; prevent destructive floods;

promote and facilitate commerce, trade, and the postal service…". In 1894, dredging began on the river. The success of these dredging operations prompted Congress in 1896 to authorize a 9-foot deep by 250- foot wide navigation channel from Cairo, Illinois to the Gulf of Mexico, to be maintained by dredging alone. However, dredging alone was not entirely effective in providing the required navigation channel and did not provide for the overall development needs of the valley. Then in 1927, the most disastrous flood in the history of the Lower Mississippi River Valley occurred. This flood inundated an area of about 26,000 square miles. During this flood, levees were breached, cities and towns were flooded, industry was paralyzed and crops were destroyed. Over 200 lives were lost and over 600,000 people were displaced. As a result of this flood, Congress passed the Flood Control Act of 1928, the nation's first comprehensive flood control and navigation act. This act increased the authorized navigation channel width to 300 feet and initiated a policy of river improvement and systematic construction of the channel improvement feature. The act also authorized the Mississippi River and Tributaries (MR&T) Project. Every year since the Flood Control Act of 1928 was passed, Congress has appropriated funds for the MR&T Project. The MR&T Project consists of four major components. These components include levees, floodways, tributary basin improvements, and channel improvement. Channel improvement includes stabilization to provide and maintain an efficient navigation alignment, increase the flood carrying capacity of the river, and protect the levee system. To provide for this component, an intense program of revetment and dike construction was initiated and is on-going today. The estimated total construction cost of the Vicksburg District's portion of the MR&T channel improvement program is $1,251,000,000. Through 2014, $1,083,708,129 (87%) has been expended. Maintenance is a critical part of the channel improvement program. Adequate funding must be provided in order to insure the continued functionality of the structures once they are constructed. The Vicksburg District currently receives maintenance funds annually. As more channel improvement works are completed and as existing works continue to age, more maintenance funds are required. However, the availability of funds for maintenance is not increasing resulting in maintenance requirements not being fully met.

Waterborne commerce on the Mississippi River has increased from 30 million tons in 1940 to nearly 500 million tons today. This tonnage includes such commodities as agricultural products including various grains, coal and coke, petroleum products, sand, gravel, and stone, salt, sulphur and other chemicals, among others. Without this valuable transportation system, the railways and highways would have to bear the burden of transporting these commodities. One standard barge that is 35 feet wide and 195 feet long has a capacity of 1,500 tons of cargo. One of these barges has the capacity of 15 railroad cars or 58 18-wheeler trucks. Therefore, it would require approximately 5,000,000 railroad cars or 19,230,000 18-wheeler trucks to transport the tonnage that moves on the Mississippi River today. The Mississippi River also provides an important link in the mobilization of our nation's defense forces. Therefore, the on-going development of the channel improvement program has resulted in the Mississippi River continuing to thrive as a crucial link for the country's economic development.

BANK STABILIAZTION

As is common on natural alluvial rivers, the Mississippi River has historically experienced bankline erosion and resulting migration. As evidenced by the numerous oxbow lakes and meander scars that exist today, the Mississippi River freely meandered across its floodplain. In

this natural state, the river was wide and shallow with numerous shifting sandbars. To provide a dependable navigation channel and to protect the flood damage reduction levees, the banks of the river had to be locked in place along the desired alignment. Therefore, an intense program of bank stabilization was initiated. In the past, several types of revetment have been used including willow, lumber, and asphalt mattresses. While these types of revetment proved somewhat successful, the most economical and effective means of protecting the banks continues to be a revetment composed of articulated concrete mattress (ACM) on the lower bank and stone paving on the upper bank. The current method of ACM placement is unique and is the result of years of research and development.

The use of ACM is restricted to large rivers due to the size of the floating plant required to place the mat. Therefore, in the Vicksburg District, ACM has only been used on the Mississippi River and on the lower Red River below the mouth of the Black River. The mat placement process includes several phases. The first phase involves clearing the bank. Many of the banks on the lower Mississippi River have vegetation that hinders the sinking process. Therefore, a narrow strip is cleared along the top bank to allow anchors to be provided during the sinking process. Caving banks are usually very steep. Therefore, to insure the stability of the revetment, the bank is graded to a flatter stable slope. The banks are graded by a large floating diesel-electric powered dragline. The clearing and grading of the banks are conducted on a schedule so that work is completed as close to the arrival of the mat-sinking unit as possible. This minimizes the potential for erosion of the freshly graded bank, reducing the overall cost of the operation and producing a better product. Natural vegetation re-establishes itself quickly along the stabilized top bank following completion of the revetment construction. Once the banks are graded, ACM is placed (or sunk) by the Mat Sinking Unit. The ACM consist of individual units of mat that are pre-cast and stored at strategically located casting fields along the river. Each unit contains 16 separate concrete blocks that are held together by corrosion-resistant wire embedded in the concrete. Each unit is 25 feet long by 4 feet wide by 3 inches thick and is commonly referred to as a square (100 square feet). Once the revetment season begins, the ACM squares are loaded onto barges and transported to the construction sites. Once on site, the squares are loaded on a specially designed mat-sinking barge. The squares are wired together into a mattress that is 140 feet wide and anchored to the bank with cables. As the mat is assembled, the sinking barge moves out into the river along the mooring barge. As the sinking barge moves, the ACM is launched off the barge and covers the river bottom. Placement of the mat continues to beyond the deepest part of the channel. The mat sinking plant is then moved upstream to lay the next section of mattress. This process continues with each succeeding mattress overlapping the previous mattress in a manner similar to shingles on a roof until the desired length of bank has been revetted. Once the ACM is sunk, placing stone riprap on the graded upper bank completes the revetment process.

ACM is typically placed during the low water season. On the lower Mississippi River, the revetment season usually extends from early September until all scheduled revetment placement is complete, usually in November. The location and amount of revetment placed each year is based on a prioritization of needed stabilization work and available funding. Through 2014, approximately 293 miles of revetment have been placed on the Mississippi River within the Vicksburg District with only 15 miles of revetment remaining to be constructed. Therefore, the revetment construction program is approximately 95 percent complete.

Figure 2. ACM Stacked on the Casting Field

Figure 3. Mat Sinking Unit

During 2011, the flood of record was experienced on much of the Lower Mississippi River with both record stage and discharge set at Vicksburg, Mississippi. During that event, the revetments were severely challenged. While damage did occur to some revetments, no catastrophic failures occurred to any of the revetments within the Vicksburg District. Therefore, during this historic event, the revetments continued to provide protection to the flood damage reduction levees by preventing channel migration due to eroding banks. Congress appropriated supplemental funds after the flood for damage repairs. As of late 2014, the Vicksburg District has completed all flood damage repairs to revetments.

CHANNEL CONTRACTION

The channel improvement feature that has had the greatest impact on dredging is dikes. Dikes are constructed on the Mississippi River to contract the width of the low water channel to provide and maintain adequate channel dimensions for navigation. Historically, dikes have been constructed of timber pile or stone or a combination of the two materials. Since stone is more permanent, this construction material is now used exclusively for dike construction. Dikes on the Mississippi River are constructed to a sufficient height to maintain an efficient low water channel but low enough so as not to hinder the passage of flood flows. Dikes within the

Vicksburg District are typically constructed so as to provide a 2,500-foot width between the riverward end of the dike and the opposite bank of the river. The Vicksburg District has been constructing channel control dikes on the Mississippi River since the early 1960's. As of 2014, 301 dikes totaling approximately 127 miles have been constructed. The dike construction program is approximately 85 percent complete with approximately 23 miles of dikes remaining to be constructed.

As previously mentioned, the Federal Government has been involved in dredging the Mississippi River since the 1890's. As the MR&T bank stabilization and channel control programs progressed, less dredging has been required to provide and maintain an efficient navigation channel. The Mississippi River is dynamic. As river conditions change, dredging is required in trouble reaches. As this occurs, dikes are designed and constructed to greatly reduce or eliminate required dredging.

Figure 4. Mississippi River Dike Field

Records indicate that required dredging within the Vicksburg District often well exceeded 10,000,000 cubic yards per year during the 1960's and the first half of the 1970's. However, during those years, the dike construction program was in its infancy. Figure 5 presents a graphical comparison of the annual dredging conducted on the Mississippi River within the Vicksburg District versus the cumulative amount of completed dike construction. This plot is for channel dredging only and does not include required dredging in the harbors. As the figure shows, in 1970 over 18,000,000 cubic yards were dredged. By that time, a total of less than 35 miles of dikes had been constructed. As the dike construction continued, the amount of dredging required to maintain a dependable low water navigation channel drastically decreased. In 1980, approximately 4,600,000 cubic yards of dredging was required and almost 65 miles of dikes were complete. In 1988, only 4,700,000 cubic yards were dredged even though the basin was experiencing a severe low water with river stages falling lower than had occurred in several decades. At Vicksburg, the low stage recorded in 1988 was the lowest in almost a quarter century. By 1988, just over 75 miles of dikes had been constructed. During the late 1990's and the early 2000's, less than 2,000,000 cubic yards were dredged annually. An increase in dredging was experienced during the later part of the 2000's. This can be primarily attributed to

changing channel conditions at Victoria Bend. The Vicksburg District designed and constructed additional dikes at Victoria Bend during recent years that has lead to a decrease in the need for dredging at this location. In fact, during 2011and 2013, no channel dredging was required in the Vicksburg District and only 282,000 cubic yards were dredged during 2014. Extreme low water occurred during 2012. That year, the lowest stage was recorded at Vicksburg, Mississippi since the extreme low water in 1988. In fact, 86 days with stages below 2 feet were recorded at Vicksburg from July through December 2012. This extreme, long duration low water severely challenged the effectiveness of the channel control dikes especially after many had been damaged during the historic flood experienced the previous year. A combined 6,400,000 cubic yards of channel dredging was required in 2012 at Victoria Bend plus an additional 5 different locations. Since that time, many of the dikes damaged during the 2011 flood have been repaired. However, repair work is still required at approximately 15 dikes. Repairs are being made as funding becomes available. Figure 5 shows the drastic reduction in required dredging as dike construction has progressed. Even during the extreme low water years of 1988 and 2012, channel dredging was limited to manageable amounts. The limited required dredging is a testament to the effectiveness of the channel improvement program.

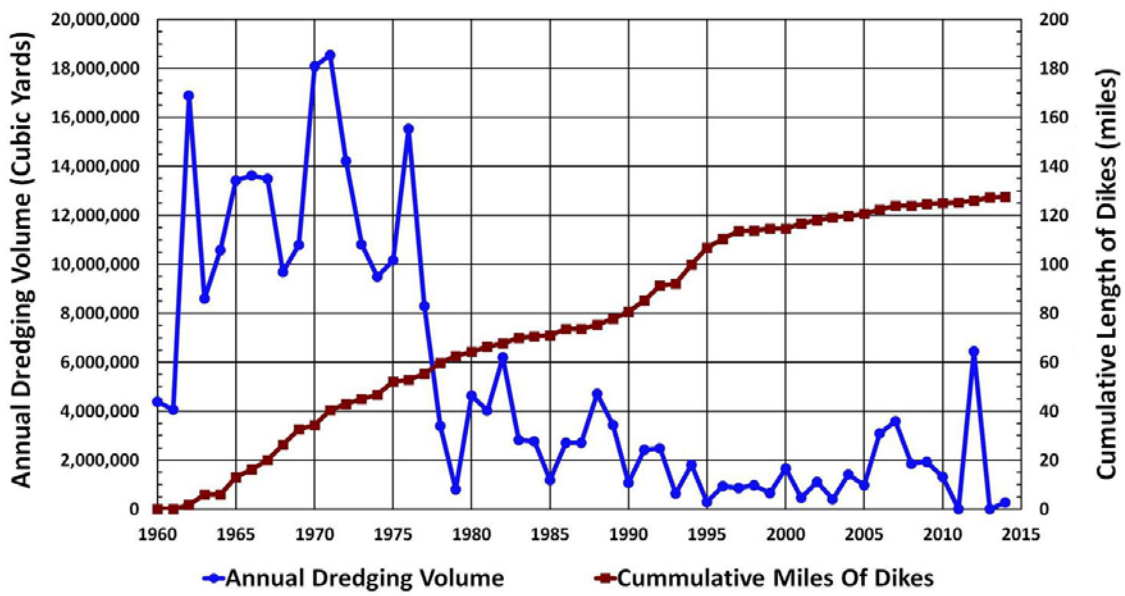

Figure 5. Mississippi River Channel Dredging Versus Cumulative Length of Dikes in Vicksburg District (1960 – 2014)

Environmental Conservation and Enhancement

Since the 1990's, the Vicksburg District has made a concerted effort to provide channel improvement features that not only provide for the authorized missions of flood damage reduction and navigation but also conserve or enhance the environment. For both revetments and dikes, a no work period is provided during April, May, and June for the pallid sturgeon spawning season. Also, restrictions are enforced on both revetment and dike work within set distances from known nesting least terns. Since the mid 1990's, environmental enhancement has

been provided by way of constructing grooves on the surface of the articulated concrete mat. The surface of the mat is grooved during the casting process by dragging a large wire brush type tool over the uncured concrete after it is placed into forms. Use of the grooved mat improves the aquatic habitat provided by the river by increasing the surface area for growth of macro-invertebrates which retain and recycle organic materials that would otherwise be lost from the system. This process provides a food source for fish with recreational, ecological, and economical value.

One of the environmental features currently used by the Corps of Engineers for dikes is the notched concept. By leaving a notch in selected dikes, the navigation channel can be maintained while at the same time provide diverse habitats for a variety of species including fish and the endangered least tern. The intended result is to insure that flow is maintained for longer durations in secondary channels than would otherwise be provided without the notches. The size and location of the notch in dikes is determined by the overall configuration of the river channel at each specific location. The Vicksburg District provides notches with varying widths and bottom elevations of the notch depending on the site. The District's current plan is to notch all future dikes that are constructed across secondary channels. All existing dikes extending across secondary channels that require raising in the future will also be notched at the time they are raised. The Vicksburg District first constructed notched dikes on the Mississippi River during the mid-1980's. Since that time, some 86 notched dikes have been constructed within the District. Figure 6 is an example of a notched dike.

Figure 6. Mississippi River Notched Dike

During 2011 and again in 2013, the Vicksburg District partnered with the U.S. Fish and Wildlife Service, Mississippi River Trust, and the Lower Mississippi River Conservation Committee (LMRCC) to improve habitat for species in the lower Mississippi River without compromising the vital navigation and flood risk reduction systems. The LMRCC is a coalition of 12 state natural resource conservation and environmental quality agencies in Arkansas, Kentucky,

Louisiana, Mississippi, Missouri, and Tennessee. The LMRCC was formed in 1994 and is dedicated to conserving the natural resources of the lower Mississippi River floodplain. This partnership involved the notching of 4 existing dikes at Island 70 and 2 existing dikes at Below Prentiss and another 2 existing dikes at Catfish Point for secondary channel restoration. Each partner agency has a clearly defined role in completing these projects. The Corps of Engineers provides engineering design and construction oversight. The LMRCC secures all necessary permits for regulatory compliance, coordinates all activities and procures the construction contract. Funding for the construction is provided by the USFWS through the Fish Passage Program (Prestwood and Rodgers, 2014). Figure 7 is a photograph of an existing dike at Island 70 being notched.

During July 2013, the Corps of Engineers Mississippi Valley Division in consultation with the U.S. Fish and Wildlife Service (USFWS) developed a conservation plan for three endangered

Figure 7, Dike Notching at Island 70

species on the Lower Mississippi River. Those species include the interior least tern, pallid sturgeon, and the fat pocketbook mussel. Specifically, the conservation plan is a programmatic mechanism by which the channel improvement program of the Mississippi River and Tributaries (MR&T) Project is being utilized to implement conservation measures that maintain and improve habitat values within the Lower Mississippi River for recovery of endangered and other trust species inhabiting the river channel. As a result of the information presented in the conservation plan, the USFWS issued a biological opinion on the channel improvement program on the Lower Mississippi River in December 2013. A biological opinion is required to determine if Federal action (channel improvement program) is likely to jeopardize the existence of a listed (threatened or endangered) species or result in the destruction or adverse modification of critical habitat. The conclusion of the biological opinion was stated by the USFWS as follows: "After reviewing the current status of the interior least tern, pallid sturgeon, and fat pocketbook mussel, the environmental baseline for the action area, the effects of continued operation and maintenance of the channel improvement program, it is the Service's biological opinion that the channel

improvement program is not likely to jeopardize the continued existence of the interior least tern, pallid sturgeon, and fat pocketbook mussel. No critical habitat has been designated for these species; therefore, none will be affected."

CONCLUSIONS

The Mississippi River has been and remains a major contributor to the physical and economic development of the nation. It carries the runoff from rainfall and snow melt for about 41 percent of the contiguous United States plus a small portion of Canada along with about 150,000,000 tons of sediment annually to the Gulf of Mexico. The river also supplies water for millions people and unnumbered industries and power plants. Currently, approximately 500,000,000 tons of commerce are transported on its navigation channel annually. Since their inception, the channel improvement works completed by the Corps of Engineers have contributed significantly to the efficient operation of this mighty river and its service to the nation. More recently, the systematic placement of channel training structures have significantly reduced the need for costly dredging to maintain a dependable navigation channel. The revetment program proved invaluable during the historic 2011 flood in maintaining channel alignment and protecting the flood damage reduction levees from channel migration. Also, the channel improvement program features being utilized to implement conservation measures have proved effective in maintaining and improving habitat values within the Lower Mississippi River for recovery of endangered species that inhabit the river channel.

REFERENCES

Biedenharn, David S., 1995, Lower Mississippi River Channel Response: Past, Present, and Future, Dissertation for Degree of Doctor of Philosophy, Colorado State University, 127.

Nordin, C. F. and Queen, B. S., 1992, Particle Size Distributions of Bed Sediments Along the Thalweg of the Mississippi River, Cairo, Illinois to Head of Passes, Potamology Program (P-1), Report 7, U.S. Army Corps of Engineers, Lower Mississippi Valley Division, Vicksburg, Mississippi.

Prestwood, Deanna. and Rodgers, Angeline, Summer 2014, "Engineering Ecosystem Restoration – A Partnership Approach", Our Mississippi, U.S. Army Corps of Engineers.

Robinson, Michael C., Ethridge, Loyde T., U.S. Army Corps of Engineers, Lower Mississippi Valley Division, Mississippi River Commission August 1984, History of Bank Protection Through The Use Of Revetments.

Thorne, Colin R., Knuuti, Kevin, Harmar, Oliver, Waston, Chester, and Biedenharn, David, April 2015, "Recent and Historical Sediment Loads in the Lower Mississippi River" SEDHYD Proceedings Paper, Reno, Nevada.

U.S. Army Corps of Engineers, Mississippi River Commission, September 1992, Lower Mississippi River Environmental Program, Report 19, Effects of Surface Texture of Articulated Concrete Mattress Blocks on Their Habitat Value.

U.S. Army Corps of Engineers, Mississippi River Commission and Lower Mississippi Valley Division, March 1976, Flood Control In The Lower Mississippi River Valley.

U.S. Army Corps of Engineers, Mississippi Valley Division and Engineer Research and Development Center, July 2013, Conservation Plan for the Interior Least Tern, Pallid Sturgeon, and Fat Pocketbook Mussel in the Lower Mississippi River (Endangered Species Act, Section 7(a)(1)).

U.S. Fish and Wildlife Service, Mississippi Field Office, December 2013, Biological Opinion, Channel Improvement Program, Mississippi River and Tributaries Project, Lower Mississippi River.