Mississippi Valley Division,
Regional Planning and Environment Division South

Hatchie/Loosahatchie, Mississippi River Mile 775-736, TN and AR Final Integrated Feasibility Report and Environmental Assessment

Appendix 5 – Ecological Models

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Habitat Benefits Analysis for the Lower Mississippi Resources Assessment Hatchie to Loosahatchie Reach

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1.1 SUMMARY

The Hatchie to Loosahatchie reach stretches from approximately river miles 735 – 774 and includes Mississippi, and Crittenden Co., AR, and Tipton and Shelby Co., TN. The project area was divided up into eleven geomorphic complexes (areas of shared floodplain hydrology) to simplify project planning. To evaluate existing conditions, develop habitat acres, and determine connection frequency for habitat benefits analysis, project area waterbodies, and the channels that connect the waterbodies to the river were identified. Additionally, areas of high elevation within the connecting channels (obstructions/connection thresholds) were identified as points of potential project measures. The project team then reviewed the project area identifying measures that met project objectives and could benefit priority species focusing on Alligator Gar, Pallid Sturgeon, Bottomland hardwoods (BLH), and rivercane. Measures were then reviewed for feasibility and 84 were carried forward for habitat benefits analysis and incremental cost analysis. These measures created a variety of conditions and could be grouped by their effects. Six effects groups were determined: 1. alter connectivity, 2. waterbody enhancement, 3. aquatic channel enhancement, 4. water management, 5. enhance and restore natural vegetation, and 6. sediment control. Two existing regionally certified and six new habitat benefit models were used to model the benefits of project measure effects. Benefits of the 83 ecological measures varied from 0.02 net average annual habitat units to 1,614 net average functional capacity units. These benefits were carried forward to the incremental cost analysis.

1.2 INTRODUCTION

The U.S. Army Corps of Engineers (USACE) is preparing a feasibility report to determine feasible and cost-effective measures to increase the quality or quantity of large river habitats, floodplain waterbodies, and vegetative mosaic. The area studied stretches between the Hatchie and Loosahatchie Rivers across the active floodplain of the Lower Mississippi River. This report summarizes the habitat benefits analysis of the feasible restoration measures. The habitat benefits analysis calculates a number (Net AAHU – average annualized habitat units) which is used to represent the benefit of a restoration measure. Measure's costs and benefits can then be compared to determine cost effectiveness. The following sections document the analysis. Supporting data were developed to assist in measure development and calculating model inputs. The habitat benefits analysis evaluated the effects of the different measure groups using benefit models and affected acreage determined over a period of target years. This resulted in Net AAHUs. In conducting the habitat benefits analysis, management measure descriptions were developed for retained and screened out measures. These descriptions are included in Appendix 1.

The purpose and need for the proposed action is to restore habitat and ecosystem function along an approximate 39-mile reach of the LMR and its floodplain in harmony with the existing USACE mission areas of ensuring navigation and flood risk reduction.

Section 402 of the Water Resources Development Act (WRDA) of 2000 authorized the assessment of information needed for river related management, natural resource habitat needs, and river related recreation and access in the LMR, along the main channel and adjacent floodplains. The Lower Mississippi River Resource Assessment (LMRRA) included recommendations for: (1) the collection, availability, and use of data needed for river management; (2) the implementation of measures to restore, protect, and enhance habitat; and (3) potential projects for river recreation and access. LMRRA recommended eight priority conservation reach habitat restoration studies on the LMR to examine the Mississippi River batture for ecosystem restoration features. Section 1202(a) of WRDA 2018, Public Law 115-270 authorized this study to determine feasibility of habitat restoration for each of the eight identified priority reaches. This study effort is the first feasibility study being conducted on one of these eight identified priority reaches.

1.3 SUPPORTING DATA

1.3.1 Identifying Waterbodies

A method to identify and develop comparable acreage for project area waterbodies was needed to address the LMRRA project objective 3 “increase the quality of floodplain waterbodies”. Within a single year, waterbodies within the active floodplain (batture) fluctuate with river stage, sometimes going dry and vegetating during extreme low water. Over longer time periods, waterbodies also form and fill, converting to wetland as sediment fills them or developing as sediment is scoured. This leads to a mosaic of ephemeral, temporary and permanent waterbodies. The team chose to focus on permanent waterbodies, which are those that retain water year-round, to focus efforts and maximize benefits to aquatic species. Identifying permanent waterbodies within the active floodplain involved a consideration of the river’s stage or discharge utilizing data that reflected recent conditions.

The existence and size of floodplain waterbodies can be determined from elevation data or imagery. Waterbodies within the LMRRA floodplain have not been surveyed, thus there is no information for their submerged bed. The USGS 3D elevation program (3DEP) has collected terrestrial LiDAR. These data were collected at moderate river stages so any area below a moderate river stage would be classified as a waterbody. Additionally, classification using LiDAR is time consuming: it takes 19 files to cover the project area, each file is 300 MB, and valley slope must be removed for waterbody size to be comparable. Waterbodies could be digitized from aerial imagery collected at a known discharge, but this is also a time-consuming process. Therefore, the team chose to use remote classification of satellite imagery collected at a known discharge.

Satellite imagery classification: Following the methods of Allen (2015), the available Sentinel-2 satellite imagery (2017 – current) was reviewed to select cloud free images which captured the largest extent of the project area on a single date. Landsat imagery (2005 – current) was not used because older imagery may not capture waterbody scour and fill, and Landsat's coarser resolution, 30m, may miss smaller waterbodies. The available imagery dates were compared to the river's discharge at the Memphis gage (USGS 07032000) to establish a set of imagery collected at or below the target discharge. The extent of inundation is not necessarily consistent at a single river stage or discharge. For example, Hopefield Chute is connected to the river through a small channel. The water surface within the river's main channel falls and rises faster than Hopefield rises and falls because of the small connecting channel. Thus, a waterbody's area may be higher on a falling hydrograph and lower on a rising hydrograph. The composite approach (using multiple images) helps to average this variation improving classification.

Three methods to identify a target discharge were investigated. Waterbody presence was investigated at bank full discharge, an analyst selected discharge, and a discharge exceeded 75% of the time (Q25) discharge. The LMR's discharge variability has not changed much since the construction of the major watershed reservoirs, thus discharge rates were determined from a cumulative frequency analysis of 1962 – 2019 discharge at the Memphis gage. The Allen (2015) method was used to identify waterbodies at these three discharges but expanded to include growing season imagery to capture low water. The Q25 method was selected, and the discharge exceeded 75% of the time at the Memphis gage was determined to be 301,430 cfs (Table 5-1). Three Sentinel-2 images met the criteria.

23Aug2020: 312,000 cfs 7Oct2020: 257,000 cfs 17Oct2020: 237,000 cfs

These images were used to produce a raster file where any pixel with a value of 1 represented a permanent waterbody (Allen 2015). The imagery resolution was 20m so any waterbody with visible water area less 1/10th of an acre or narrower than 20 m may not be included. This file was edited to remove misclassifications, separate tributaries, and floodplain waterbodies from the main channel, classify waterbodies, and assign names when known. The analyst selected discharge was later used to represent the permanent waterbody acreage. The bank full, analyst selected discharge and Q25 investigations are described in more detail below.

Bank full (Q95): The project's hydraulic engineer determined bank full as 1.13 mcfs (million cubic feet/second) or 214.0 feet NAVD88 at the Memphis gage using an existing 1D/2D Hydraulic Engineering Center – River Analysis System (HEC-RAS) model. Bank full was chosen because it would represent batture waterbodies at their largest before overbank flooding. Approximately 70% of the cloud free leaf off images were at this discharge or lower. Using bank full, the areas of the active floodplain classified as a waterbody included large areas of woody wetland (Figure 5-1). In other words, areas with elevations ≤ 214 feet would be classified as waterbodies. This water surface elevation occurs approximately 5% of the time on the Memphis gage from 1962 to 2019. Utilizing bank full, inundated areas could be classified as waterbodies even though they were inundated only 5% of the year. This method was discarded.

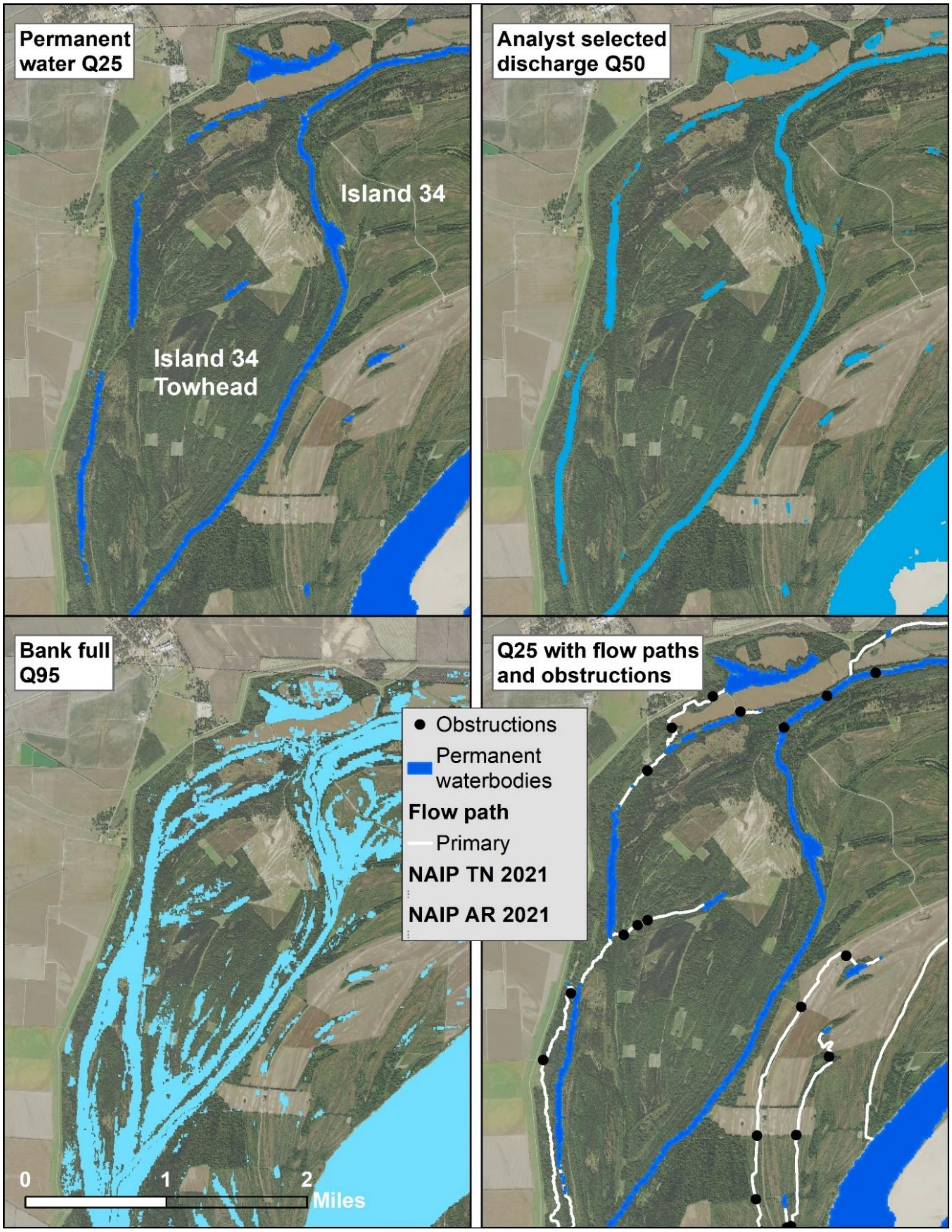

Figure 5-1. Illustration of the Various Waterbody Classifications using Satellite Imagery Taken at or below a Known Discharge

Elevation data were used to identify the lowest elevation (primary) flow path between permanent waterbodies and the river. Obstructions blocking these paths were then identified.

Analyst selected discharge (Q50)**:** Because bank full classified inundated wetlands as waterbody, the imagery was visually investigated for the highest discharge image that showed named waterbodies within their banks. Imagery at or below 600 thousand cubic feet per second (kcfs) appeared to capture the Hatchie to Loosahatchie waterbodies without additional flooding (Figure 5-1). This discharge is near the average stage at Memphis of 14.1 feet or 585 kcfs. Waterbodies classified with this method could have a bed elevations of ≤ 14.1 feet and thus will be dry up to 50% of the year. This method was discarded.

Q25 (selected method): With the prior investigations it became clear that an ideal method of identifying permanent and temporary waterbodies might be to identify areas that are inundated for the entire year (permanent) and a percentage of the year (temporary). In other words, choose imagery that was taken at the average minimum yearly discharge (permanent waterbodies) and a discharge that is exceeded for a certain percentage of the year. However, there was no Sentinel-2 cloud free imagery at an average minimum yearly discharge because this discharge occurs for a short period. The cloud free imagery dates for low water and leaf off and corresponding discharges were investigated (Table 5-1). In consideration of repeating this method for other LMRRA reaches, it was felt that there was sufficient imagery using a Q25 discharge; a discharge exceeded 75% of the time using daily discharge from 1962 to 2019. This dataset will identify waterbodies that are inundated 75% of the year or more which the project team considered permanent waterbodies.

Table 5-1. Percent Exceedance Calculated from Daily Discharge Data Collected from 1962 to 2019 after the Installation of Major Mississippi River Watershed Reservoirs

Percent Exceedance	1962-2019		Percent Exceedance	1962-2019
	Flow (cfs)			Flow (cfs)
5 (Q95)	1,149,000		55	428,000
10	987,000		60	396,000
15	878,000		65	362,000
20	797,194		70	334,000
25	719,000		75 (Q25)	301,430
30	653,000		80	272,000
35	602,000		85	244,825
40	554,000		90	219,000
45	511,000		95	189,000
50 (Q50)	466,000			

1.3.2 Waterbody File Editing and Attribution

Once waterbodies were identified from the Sentinnel-2 imagery, they were investigated to determine if the waterbody polygons should be removed, separated, or merged. Each polygon was also attributed with name, when known, and classified into types. Areas of satellite imagery misclassified as waterbodies were identified by viewing national agriculture imagery program (NAIP) 2010 – 2021 imagery. Waterbodies were considered misclassifications and were removed if there was no water at that location in any of the imagery. Waterbodies were separated at the point where one waterbody connected to another. For example, the lower end of Brandywine Chute flows into Poker Point secondary channel. The waterbodies were separated using the ArcGIS cut polygon tool. A cut line was digitized through the apex of the angle where the two waterbodies connect following the bank line of the waterbody. Separate polygons that made up one waterbody were merged, using NAIP imagery to determine polygons that made up each single waterbody. For example, Brandywine Chute is a long narrow scarp. Because Brandywine is narrow with a forested riparian zone, it shows up as a series of separate waterbodies in the satellite imagery. These separate waterbody polygons were merged. Waterbodies were assigned names from topographic maps, the MVM environmental master plan and local information from individuals familiar with the site. All floodplain waterbodies were classified by assigning a type to the attribute table (Figure 5-2); in part to assist the project development team (PDT) with identifying scare habitats. A "?" after the classification was used to indicate uncertainty in the classification.

Waterbody types:

- Borrow area – Waterbody that appears manmade. Generally, with straight or consistently curved sides, often rectangular. Banks are typically consistently sloping. This type of waterbody is often near a levee or other anthropogenically elevated ground. Borrow areas are more easily determined from elevation data as forest and scrub/shrub can obscure the shape and banks in imagery.
- Channel - Mississippi River main and secondary channels.
- Creek - Linear waterbody with primarily unidirectional flow. Differs from tributaries as it does not flow into the Mississippi River but rather other channels or waterbodies. Creek or bayou are typically the names on USGS topographic maps or national hydrography dataset files.
- Crevasse - large levee blow out. Appears in imagery as a relatively large irregular lake in the floodplain near a levee with no visible dam.
- Impoundment – waterbody upstream of a dam such as a reservoir.
- Oxbow – lake generally in a horseshoe shape (Centennial Bend is a combined horseshoe) that was formerly the main channel of the Mississippi River abandoned through a neck cutoff as reported in Winkley 1977, illustrated in Fisk 1944, Harmar and Clifford 2006, or aerial imagery. Unlike meander scarps, oxbows experience primarily bidirectional flow with a low elevation downstream tie channel connection and a high elevation upstream connection.

- Meander scarp (chute) – A relatively narrow long primarily unidirectionally flowing channel with portions of the channel at steeper angles to the main channel than secondary channels. For example, parts of Brandywine Chute are perpendicular to the main channel. Scarps differ from oxbows because they retain unidirectional flowing conditions rather than bidirectional.
- Tie channel - self-adjusting (when no manmade structures are present) channel that connects a large floodplain lake to the main channel. These channels are maintained by the head differential that occurs when river levels rise/drop faster than lake levels.
- Tributary – flowing waterway that flows into the Mississippi River.
- Secondary Channel – Unvegetated channel connected to the Mississippi main channel at both ends and generally wider, closer, and more parallel to the main channel than a meander scarp.
- Scour Hole (blue hole) – a relatively deep waterbody formed by a levee blow out, road erosion etc. Scour holes differ from Crevasse because they are generally circular and small.
- Slough - catch all for any floodplain waterbody that looks like it could have been an old river channel. These waterbodies are generally linear in shape with shallowly sloping sides.
- Unk (unknown) - waterbody made in several ways such as a borrow area in a historic slough or a waterbody whose formation cannot be determined.

1.3.3 Obstructions and Connectivity

Part of LMRRA objective 3 is to optimize the aquatic connectivity of floodplain waterbodies. To address this component of the objective, the path that permanent waterbodies connected to the Mississippi River and any obstruction in this path were digitized into a line and point ArcGIS file respectively. The USGS 3DEP elevation data were used for this process. The most current 1m digital elevation model (DEM) when available or LiDAR elevation files (downloaded as LAS files) were downloaded from https://apps.nationalmap.gov/downloader/#/ in November 2021. When a 1m DEM was unavailable, a terrain (ArcGIS 10.7.1) was created from the bare earth LiDAR returns. For the most part, the elevation data were collected from 29 – 30 Jan 2014 when the river's water surface at RM 750 was approximately 197.3 and 195.5 on the falling limb of the hydrograph. This means that water would have inundated higher areas of the floodplain and was in the process of draining out when the Lidar data were acquired. Some areas of the floodplain with elevations higher than 197.3 feet could be inundated and thus have no ground elevation.

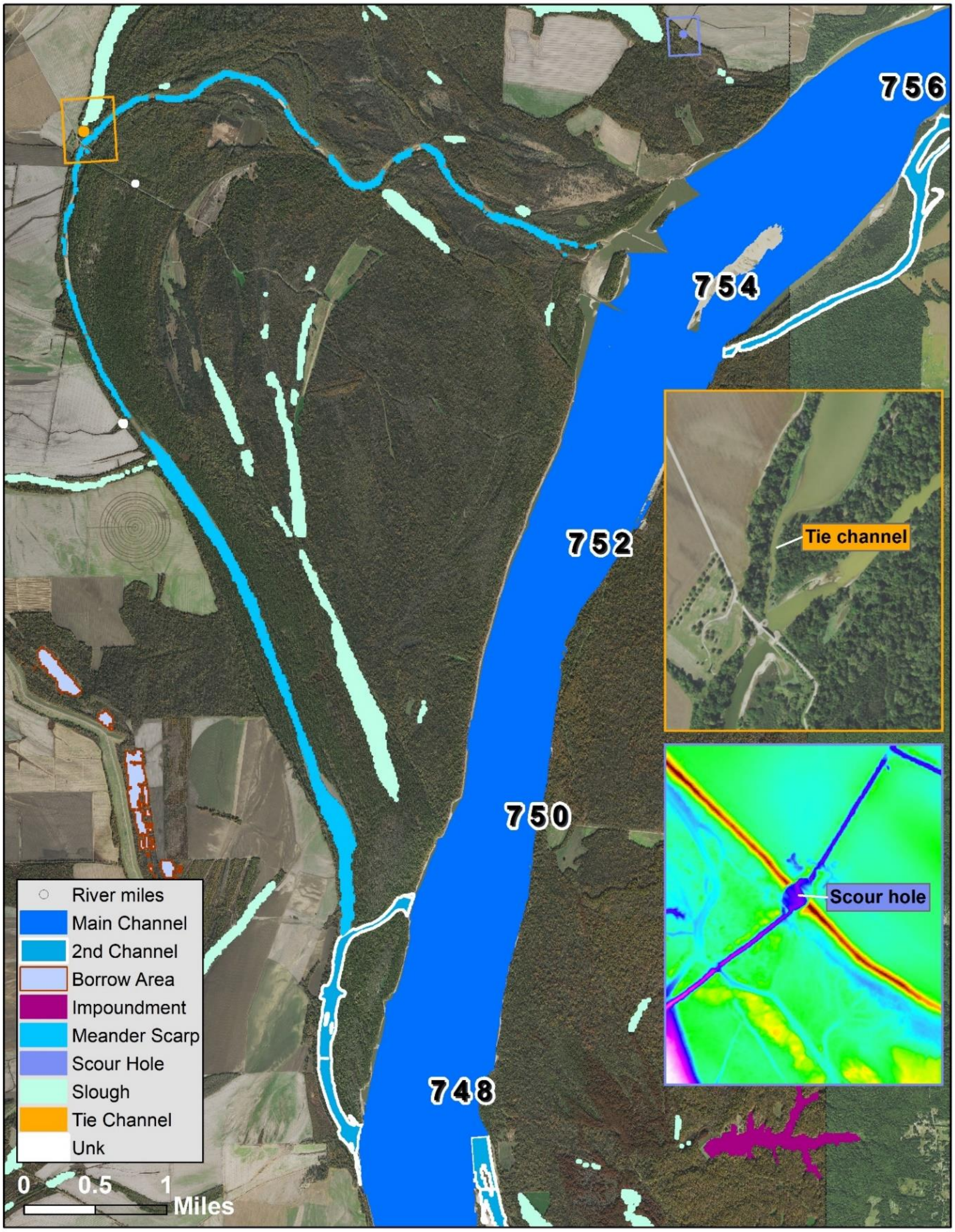

Figure 5-2. Waterbody Types Found Around Brandywine Chute (a Meander Scarp) within the Hatchie to Loosahatchie Project Area

The lack of ground elevation in low lying areas led to multiple flow paths being digitized for most waterbodies. Once identified these paths were compared in imagery and elevation datasets to determine the lowest elevation "primary" path. This was added to the type column of the flow path table as well as secondary (second lowest) and so on. As flow paths were identified, obstructions in the channels, (such as road crossings, berms, culverts, natural levee) were also identified. These obstructions and their identification are described below.

<u>Obstructions (type):</u>

- Bridge – A bridge visible in NAIP 2010 - 2021 or in Google Earth imagery.
- Culvert – If elevation data indicated a berm or imagery showed a road and there was a consistent deeper channel on each side, it was assumed a culvert was present.
- Low water crossing – Appears as a berm generally perpendicular to the long axis of the waterbody with a decreasing crest elevation from the waterbody's edge to the center. The banks of the berm have a gradual slope to the channel bed with no defined channel which would indicate a culvert. Imagery shows a road.
- Berm – Similar to a low water crossing but without a gradual decrease in crest elevation making a berm similar in appearance to a small earthen dam. There may be changes in crest elevation due to erosion, but eroded areas have variable slopes. The berm may be used as a road crossing. An obstruction was considered a berm if the berm's elevation was similar to the prevailing ground elevation, sides had consistent and generally equal slopes, one side showed evidence of ponded water (area of relatively consistent elevation or ponded water visible in imagery), and there was no to minimal channel on either side. Ponded water and a channel would suggest an undersized culvert or water control structure.
- Natural levee – A natural levee is a high elevation depositional area along the channel bank that slopes downward toward the floodplain. A natural levee obstruction is the point of highest elevation in a channel where it cuts through the levee.
- Water control structure – Determining the difference between a water control structure (e.g., flashboard risers, flap gates) and culvert is difficult. A water control structure can be visible in imagery. Location may be provided by onsite personnel. Occasionally a structure can be determined in elevation data because there is a channel on one/both sides of a high elevation area (berm, road crossing) and directly adjacent a sump (relatively circular area with deeper elevation than adjacent channel).
- Ground – Area of higher elevation in a floodplain channel that does not match the prevailing elevation of surrounding channel bed and does not have sides with nearly matching or consistent slopes (which would suggest a manmade berm).
- Channel bed – Same as ground except occurs within a channel connected at both ends where flow is almost always upstream to downstream. This term applies to chutes, meander scarps, secondary channels, etc.

- Dike – A rock or wood manmade structure visible in imagery and/or documented in the USACE river training structures GIS file.
- Beaver dam – An area of wood visible in imagery that spans the entire channel. Because wood can build up along the upstream side of pile dikes, areas of wood spanning the channels that were not documented as dikes in the USACE river training structures GIS file were called beaver dams. Thus, beaver dams are likely undocumented pile dikes.

As the PDT investigated the project reach, they used the permanent waterbody, flow path, and obstruction GIS files to identify potential project actions that would address project objectives. These actions became known as project measures. Each measure could require one or more items to achieve the objective. This resulted in a GIS point file "Complexname"_Measures documenting the general location for each item. This file incorporated information from the obstructions file and became the system by which the project team tracked management measure status and refined items. Important attributes within the "Complexname"_Measures file are explained in Table 5-2.

Table 5-2. The Attributes for the GIS file ("Complexname_Measures") Documenting the Location of the Proposed Management Measures

Attribute	Definition
Creator	The three initials of the person that created the GIS feature
Type	The type of feature (see information on obstructions)
Notes	Notes by the Creator generally providing more information about the obstruction
Item	A unique number letter combination assigned to track each item. Generally, the Measr_Nmber with a letter added.
Measr_Nmber	The management measure identified represented by the first letter(s) of the complex name, an underscore, and a number (D_1). The first measure identified for a complex was assigned a 1 and so on.
MeasrScale	Potential option for grouping items to form scales for different management measures where completion of all items was not required to achieve the project objective.
LongNotes	Project development team/program manager description of the item
Objective	The Lower Mississippi River Resource Assessment objective(s) addressed by the item
Creators	The three initials of the person(s) who created the item specific attributes
CplxName	The name of the complex assigned by the project development team and representing named geomorphic or political features contained within the area.
Screened	Out/In indicating if a measure was removed from further evaluation in the planning process
Scrn_Notes	PDT notes explaining why a measure was removed from further planning consideration
RMConn	The river mile where, when following the channel network, the channel containing the obstruction would first connect to the main channel. As the river rises at this point, water would flow up the channel toward the obstruction. When the main channel water surface elevation exceeds the obstruction's elevation water should flow past the obstruction.
Elev_m	The elevation of each obstruction determined from the digital elevation model, or Lidar terrain. For culvert and water control structure type obstructions, the elevation was the nearby prevailing channel invert. This is an attempt to estimate the culvert or structure invert without a field survey. For berms and other solid features, elevation is the lowest point in the top of the berm where the berm blocks the channel.
ElevSource	The source of the elevation data. The USGS 3DEP digital elevation model, Lidar tile name, image from which the water surface elevation was determined, or engineering data.
Elev_ft	Same as Elev_m except sourced from engineering data or water surface interpolated elevations from imagery and gage data because these were in feet.
PropElev	Proposed new elevation for the channel or invert in meters (<80) or in feet (>100). This elevation is typically based off the predominant elevation of the adjacent channel downstream and at times upstream of the point. For isolation measures, this elev. is based on the prevailing elevation of the surrounding ground. Elev. is determined from the same ElevSource as Elev_m.

Without Project Elevation: Once management measures were determined, elevations, channel profiles, and connectivity were determined where needed/possible for project measures. Elevation and channel profiles were developed from the terrain and DEM models. For culverts, the existing invert was estimated as the prevailing elevation of the nearby channel bed outside of scour and deposition areas that were directly adjacent to the culvert. If a scour or deposition area was visible in the elevation data, then the culvert was noted as undersized. For other obstructions, the elevation was determined as the elevation of the location where water would first flow over the obstruction (notch in a dike, low spot in a berm etc.). These existing elevations were recorded in Elev_m or Elev_ft columns in the GIS attribute table and were used for the without project elevations (converted using the MS Excel convert function when necessary).

With Project Elevation: The GIS data and imagery were used to propose a future elevation. These proposed elevations were based off the predominant elevation of the adjacent channel downstream and at times upstream or calculated based on the desired percent connection. For isolation measures, proposed elevation was based on the prevailing elevation of the surrounding ground in consideration of BLH and agriculture inundation. In some cases, the GIS proposed elevation became the with project elevation. When further investigation was needed, the GIS proposed elevations, elevation data, and channel profiles were used by the PDT, geotechnical, and engineering to determine the with project elevation. When elevation data and aerial imagery did not provide sufficient information to propose an elevation, a 1-foot lower elevation was assumed. The project team considered this a very conservative assumption for the future with project.

Connectivity: The design and placement of many project measures required a knowledge of the duration and sometimes frequency of connection (when river water flowed into/out of the waterbody). The project elevations, or connection elevation provided by those with local knowledge were compared to the 2017 gage data or the water surface elevation for the location extrapolated from upstream and downstream 2017 gage data (Oliver et al. 2022) to determine connection. 2017 was considered an average water year and was used because taking the average over multiple years removes hydraulic variability (Figure 5-3). See Appendix A1: Island 35 management measure I35_2, I35_5c, and I35_12a for examples where connection frequency was used.

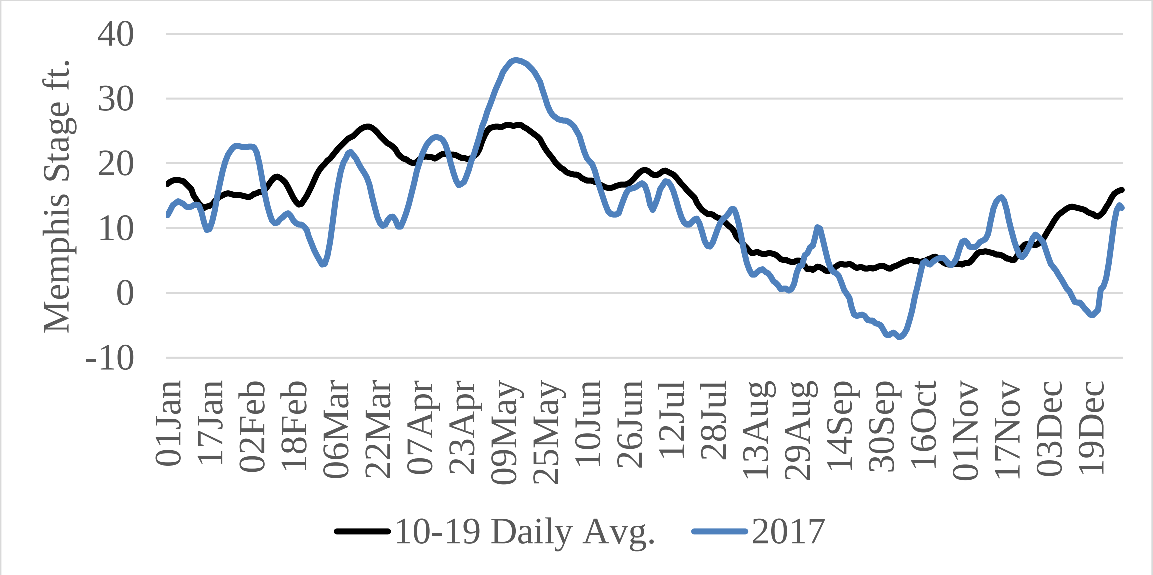

Figure 5-3. Memphis Gage Daily 8:00 am Stage for 2017 Compared to the Daily Stage Averaged from 2010 to 2019.

Note: The 2010-to-19-time frame was chosen to reduce effects of the changing stage discharge relationship occurring near Memphis.

For project planning prior to model development, connectivity was also measured as the percent of days from 2010 – 2019 that the adjacent main channel water surface elevation exceeded the channel invert. The USGS 3DEP elevation data used to determine most channel inverts were from 2014. Thus 2010 – 2019 reduces effects of changing stage and contains a range of high to low water years. The water surface elevation was calculated for the adjacent river mile using 2010 – 2019 Osceola and Memphis gage water surface elevation and the equation for slope (Oliver et al. 2022). For channels primarily connected at both ends (unidirectional), like Island 35 Chute, the adjacent river mile was determined by drawing a perpendicular line from the river miles to the obstruction. For channels connected predominantly at one end (bidirectional), a line was drawn from the point where the bidirectional channel connected to a unidirectional channel to determine river mile. Thus, all obstructions along a bidirectional channel have the same river mile.

SECTION 2
Habitat Benefits Analysis

As the project measures were developed, the PDT began to discuss how the benefits of the measures could be evaluated. The USACE planning process requires a numeric accounting of project benefits and costs. This section documents the process and information utilized for calculating project measure benefits, the habitat benefits analysis.

2.1 MANAGEMENT MEASURE GROUPS

As the project developed, the PDT realized that measures could be grouped by the benefits they created for aquatic and floodplain organisms and habitat. These groups included alter connectivity, waterbody enhancement, aquatic channel enhancement, water management, enhance and restore natural vegetation, and sediment control.

Alter connectivity: All waterbodies within the active floodplain experience a variety of flow regimes. For this study, regimes were characterized by the primary direction of flow: upstream to downstream flow (unidirectional), bidirectional (backwater) flow where river water flows into and out of the same channel, and minimal flow (isolation). Secondary channels and meander scarps flow from upstream to downstream at most river stages. As the river level drops, these channels can experience bidirectional flow as obstructions (sand, bedrock, clay deposits, rock, pile, and road crossings) become exposed and block unidirectional flow. When this occurs, groundwater and connected lakes can feed water into the channel. This water can then flow out the upstream and/or downstream ends to the main channel. Alternatively, river water can flow in and back up to the obstruction creating connected backwaters. If there are multiple obstructions, isolated pools may occur.

It is likely that secondary channels and meander scarps experienced all these conditions with fluctuating river levels prior to European colonization. Maintaining channels in a variety of conditions will likely lead to greater system biodiversity. It is also likely that manmade obstructions (rock dikes, pile dikes, and road crossings) have skewed the system wide connectivity of primarily unidirectional waterbodies towards a less connected system. Additionally, increasing the time period, quantity, and velocity of unidirectional flow can increase sediment removal. In other words, sediment deposits in secondary channels and meander scarps as flow decreases. With enough time this sediment may vegetate leading to these habitats transitioning to isolated floodplain sloughs and eventually wetlands. In addition to improving waterbody longevity, increasing unidirectional flow ensures aquatic species access to these channels and the habitats that connect to them, and promotes persistence of species that require flowing water away from navigation disturbances.

Flood plain borrow areas, crevasses, sloughs, scour holes, and oxbow lakes predominantly connect to the river through bidirectional flow. During moderate stages typically from late winter to early summer, the main channel rises enough for river water to flow up small natural and manmade floodplain channels and into floodplain waterbodies. When the river drops, the direction of flow reverses and water flows from the waterbodies back into the river. The water brought in during these backwater events carries minimal sediment because it is low velocity water from the top of the water column. During larger more infrequent floods, the Mississippi flows across the floodplain resulting in floodplain waterbodies experiencing unidirectional flows which can scour/deposit sediment and flush organisms, organic matter, and nutrients into the main channel. In some instances, large floods can create new floodplain waterbodies or completely fill existing waterbodies. Improving bidirectional connectivity allows aquatic organisms to access waterbodies through lower velocity backwater flows. Measures seek to restore bidirectional connectivity to a more natural state removing or altering man-made obstructions and alterations. This often includes removing or replacing culverts, berms and crossings and removing sediment from agricultural runoff. Because access to the active floodplain's private lands had to be maintained, fish friendly structures were proposed incorporating minimal vertical drop, maximizing the amount of time at least 1 foot of water was present and considering the need for baffles to provide velocity refugia for upstream passage.

Low uni- and bidirectional connectivity creates isolated aquatic habitats which promote unique backwater and wetland species. Prior to levee construction, isolated waterbodies were likely widespread on the edges of the LMR floodplain. During infrequent large floods, these waterbodies were connected to the river. When connected the rare fish community was picked up in flood waters and spread. These fish sometimes perished, but sometimes settled in new suitable habitats, preserving, and increasing system species diversity.

Today every year or every other year, floodwaters spread across the great majority of the active floodplain because it is constrained by the levees. This connects all but the most elevated waterbodies. With this connection, competitive riverine fish move in and dominate most communities until water quality or predation diminish their numbers. This decreases the prevalence of wetland fishes including Flier, Taillight Shiner, Pirate Perch, Banded Pygmy Sunfish, Bantam Sunfish, several species of darters and others. Isolated waterbodies may also have lower turbidity as bottom sediments are less frequently mobilized with inflowing water. Lower turbidity and compacted bed sediment promotes aquatic and wetland plant species, further increasing habitat value. Finally, decreased connectivity may decrease abundance of invasive species. Invasive carp utilize flow paths to move into floodplain waterbodies to feed on the abundant plankton depleting the food supply at the base of the food chain. They can also disrupt native fish nest building and guarding (most sunfishes), and eventually become the dominant biomass. Reducing connectivity may reduce carp recruitment and will provide better management options.

Waterbody enhancement**:** For this LMRRA reach, waterbody enhancement involved increasing bathymetric complexity by deepening and creating bed elevation/shoreline diversity in sloughs and borrow areas. This was based off of the environmental guidelines developed from the extensive biological studies completed by the Corps on borrow areas along the Lower Mississippi River. Biologists have studied the use of borrow areas by fish, birds, turtles, frogs, and other wildlife and how wildlife use changes with the shape, depth, water quality, and degree of river flooding. Incorporating environmental design features in borrow areas can greatly enhance the diversity of fish and other wildlife that inhabit them.

Environmental design features include making them mostly bowl-shaped, with deeper areas of up to 10 feet and shallower areas of less than 5 feet; creating sinuous, or curved, shorelines; planting native trees along shorelines; and creating islands.

Floodplain waterbodies form from the scour and migration of river channels (Winkley 1977) and when material is excavated to elevate surrounding ground (borrow areas). After initial formation, these waterbodies may be maintained for many decades to over a century by periodic scouring floods. However, the predominant trend is for waterbodies to slowly fill with sediment and transition to wetlands and eventually forest. As sedimentation occurs, the waterbodies also become shorter, narrower, and develop gently sloping beds of fine sediment. Agriculture can increase sedimentation and speed up this transition. Alternatively, tiling and drainage canals can drain floodplain waterbodies. If temporary, this drying process can be both harmful and beneficial to aquatic organisms. Harmful because organisms must leave or die as the waterbody dries. Beneficial because as the waterbody dries the bed sediment compacts, consolidates, and may grow wetland plants. When the waterbody refills, it will be deeper, less turbid and may have plants which aquatic organisms can use for shelter and food. With the managed river and privately owned and managed floodplain, fewer floodplain waterbodies form.

<u>Aquatic channel enhancement:</u> Aquatic enhancement includes measures that 1) modify or build rock structures or 2) install wood debris traps. Unlike unidirectional and bidirectional measures, the primary purpose of these measures does not involve connectivity but rather diversifying the hydraulic environment and promoting more structural diversity.

Rock structures are proposed to alter the flow of water creating diverse flow patterns which in turn alter sediment distribution and create a riverbed with varying substrate and elevation. Measures propose to enlarge or add to existing dike notches which would divert more water into the downstream secondary channel but not alter connectivity. Hard points are proposed along bank lines to create bathymetric diversity and protect adjacent floodplain. Eddies form around hard points which benefit numerous species that feed on the small-bodied organisms trapped in the swirling currents. The final type of rock structure proposed in this study are chevrons. Chevrons look like a horseshoe pointed upstream and have scouring flows along the legs that can clear fine sediment off gravel, and/or protect valuable floodplain habitat and recreational infrastructure.

Wood debris traps are proposed to add additional woody debris to the Lower Mississippi River. Bank stabilization and floodplain forest management has likely led to a decrease in the amount of woody debris within the river affecting nutrient dynamics and the species that utilize woody habitat. Secondary channels are an ideal location to add woody debris. Secondary channel velocities are generally lower so the wood will not be washed away, the habitat is accessible to main channel species, and the wood will not impact navigation.

<u>Water management</u>: The pre-European Lower Mississippi River floodplain was likely a matrix of aquatic, herbaceous, and forested habitat. Today, there is minimal herbaceous habitat and species that rely on this habitat, like alligator gar, are in decline. Management agencies maintain open moist soil management areas to address this need. To prevent

invasive species colonization and woody encroachment, these areas are typically maintained as food plots, planted with row crops to feed resident and migratory wildlife. Determining moist soil management unit location based upon soils and hydrology would result in an ideal scenario. However, unit location is often based upon societal factors: access, land use, and farmer proximity. Thus, the hydrology may be sub-optimal for target species. In addition, the hydrology of the floodplain has been extensively altered by roads, agriculture, hunting camps, and other uses. Providing water management on existing moist soil management units allows managers to control the hydrology to benefit the widest range of species and/or those species most in need.

Enhance and restore natural vegetation: This group includes floodplain measures that enhance or restore natural vegetation by changing inundation, managing undesirable species, or planting including:

- Floodplain reforestation
- Bankline reforestation
- Forest enhancement
- Forest inundation management
- Herbaceous wetland planting

Reforestation is proposed through replanting or natural succession in the floodplain and along bank lines. Bankline reforestation always involves converting agriculture or relatively bare ground adjacent to waterbodies and channels to forest. Floodplain reforestation always involves planting either Cypress/Tupelo or bottomland hardwood to reintroduce these rare forest types. Bankline reforestation can be through natural succession allowing trees to fill in with time or through planting.

Floodplain reforestation targeted areas of migratory bird priority to address goals of the Lower Mississippi Valley Joint Venture for reforestation to benefit breeding birds (https://www.lmvjv.org/), areas on public land, and frequently inundated agriculture. Floodplain reforestation introduces rare forest types back into the local ecosystem. These trees will provide unique habitat and benefit the species that utilize the surrounding forest. Enlarging contiguous tracts of forest (to create forest core areas with > 1 km of forest in all directions) will benefit declining populations of birds that rely on forest interior (Twedt et al. 2006). Finally, the seeds produced could result in further increases of these forest types.

Reforesting bank line results in numerous additional benefits. Bank stability is increased. The forest creates a wind break reducing sediment mobilization and wind fetch on the adjacent water body improving waterbody clarity and longevity. The trees provide shade reducing the adjacent water temperature and daily dissolved oxygen fluctuation. Leaves and branches that fall from the trees increase invertebrate abundance and diversity leading to larger and more numerous fish populations.

Forest enhancement involved improving existing areas of forest. These areas were generally identified by PDT members with local site knowledge. Tree girdling with trees left in place was the primary method chosen to improve forest stands. During plans and specifications, property or personal safety concerns may modify this approach. Tree girdling creates standing dead trees which are eaten by insects that then feed birds, and other wildlife. Additionally, many birds, including the Prothonotary warbler, and mammals create and use nest cavities in dead trees. Eventually when the trees fall, they provide a source of floodplain and aquatic dead wood benefiting numerous additional insect and fungus species.

Forest inundation management proposed to change how water moved from the river onto and off the floodplain. The natural levees along the Mississippi River can be 10 – 15 feet higher than interior floodplain lowlands. Overtopping floods, natural levees, and historic channel paths create complex lowland floodplain hydrology. Extensive alteration of LMR floodplain channels has occurred changing hydrology for access and use (agriculture, hunting, fishing, forestry, and others). In some cases, channel alteration has led to increased flood frequency and decreased flood duration. River water frequently backs up the deep channels cut to drain overtopping floods. This floods forests 4 – 5 times per year that would have historically flooded once in the spring. As the water drops, these channels quickly drain low areas that would have historically held water. Roads that cut across the floodplain can also cause water to pond on floodplain forests. Because of the complex hydrology, forest inundation management measures were designed to address the site-specific hydrology issues as determined by elevation data and information from site managers.

Herbaceous wetland planting proposed to plant wetland species on suitable wet agricultural ground. The distribution of emergent, floating, and submersed aquatic vegetation is dependent on flow regime and elevation relative to the river. River flows scour many aquatic habitats preventing aquatic vegetation establishment. With increased disconnection from the Mississippi River’s turbid and scouring flows and protection from agricultural runoff, floodplain waterbodies (borrow areas, sloughs, crevasses) can develop a variety of vegetation types. As water clarity improves, the most protected lakes can support submersed aquatic plants such as pondweeds. Due to extensive floodplain agriculture, floodplain channelization, and invasive species, aquatic vegetation has likely declined.

Sediment Control: Many LMR waterways including large tributaries have been straightened. This increases channel slope and thus stream power. In an alluvial system like the LMR, this leads to a period of increased erosion and bank caving until the channel readjusts. Often this adjustment is prevented by manmade features due to societal concerns. Sediment control measures, e.g., drop pipes, weirs, bank protection, were discussed where geomorphic channel adjustment was occurring due to channelization where continued erosion endangered high quality unique habitat and recreation infrastructure.

2.1 HABITAT BENEFITS MODEL

Because each management measure group created different benefits, the PDT determined different models were needed to estimate project benefits. Models required different inputs reflecting the different effects of the various management measures and output habitat suitability indices (HSI) or functional capacity units (FCU). Inputs and outputs were determined for a set of target years because measure effects may change with time e.g., planted seedlings mature into full sized trees. Indices or units were then multiplied by acreage and divided by the 50-year project life to generate Average Annual Habitat Units (AAHU) or Estimated Average Annual Functional Capacity Units (AAFCU). The difference between with project and without project AAHU/AAFCUs, represents the ecosystem benefit or eco-lift of the project measure.

Models:

Aquatic measures that alter connectivity:

- LMR Waterbody Bidirectional Connectivity Model (bidirectional) - increase bidirectional connectivity of plesiopotamal, parapotamal, and eupotamal waterbodies (Ward and Standford 1995)
- LMR Floodplain Waterbody Wetland Isolation Model (isolation) - decrease connectivity to plesiopotamal floodplain waterbodies
- LMR unidirectional Channel Connectivity Model (unidirectional) - increase unidirectional flow frequency in eupotamal secondary channels and meander scarps

Aquatic measures that enhance waterbodies or channels:

- Borrow Area Fish Diversity Model (Borrow) – waterbody changes in depth or turbidity
- LMR River Training Structure Eddy Model (Eddy) – aquatic measures that create eddies, scour holes, or bank scallops
- LMR Aquatic Invertebrate Substrate Model (Substrate) – aquatic measures that change substrates (e.g., gravel, large woody debris).
- LMR Wood Traps Model (Wood Trap) – aquatic measures that add wood traps for invertebrate colonization and structural diversity.

Floodplain measures that enhance or restore natural vegetation by changing inundation, managing undesirable species, planting, or control sediment:

- HGM for Mississippi Alluvial Valley (HGM) – vegetated wetland measures

Model Inputs: For bidirectional, isolation, and unidirectional models, each measure could have numerous items with different without and with project connection elevations. To ensure computational time and complexity did not exceed project deadlines, the item with the greatest difference between with and without connection elevation was used for model input. This is further justified because these models and their benefit acreage do not capture the full impact of these connectivity measures. Benefits of connectivity measures flow throughout the system.

Bidirectional and Isolation models: Fisheries data collected from 2014 – 2016 for the Island 63 ecohydrology study were used to develop these models. The Island 63 study collected fish, invertebrate and water quality data from different waterbodies throughout a 22 mile stretch of river from RM 642 – 620. Waterbodies sampled included secondary channels, oxbow lakes, borrow areas, sloughs, scour holes, and a crevasse with different connectivity to the main channel. One group of LMRRA management measures proposes to alter permanent waterbody connectivity. For management measures proposing to alter bidirectional connectivity, the catch per unit effort (CPUE) of silversides (*Menidia beryllina* and *Labidesthes sicculus)* from the Island 63 study were related to the frequency of bidirectional connection. Silversides were chosen because they represent species that would utilize bidirectional connectivity to move into and out of the floodplain. For management measures proposing to isolate floodplain waterbodies, the catch per unit effort of a guild of wetland fish species was related to the frequency of bidirectional connectivity.

The final equations for the models were:

Bidirectional	Isolation
$\frac{(21.86+1.438x)}{150 \max \mathrm{CPUE}}$	$\frac{(19.29-0.183x)}{25 \max \mathrm{CPUE}}$

2000-2015 cumulative connection frequency (x): The models have one input, percentage of days from 2000 to 2015 that the adjacent main channel water surface elevation exceeded the measure’s elevation (see Without Project Elevation and With Project Elevation section above for more detail). This input was calculated similarly to the connection percentage that was used to inform project planning. Without project elevation was the elevation of the channel blockage. With project elevation was the new elevation proposed by the PDT in consideration of navigation, geotechnical and societal concerns. If no new elevation was proposed, the predominant elevation outside of the blockage area was used. The water surface elevation was calculated using the Osceola and Memphis gage daily water surface elevation and the equation for slope (Draft Oliver et al. 2023). To determine river mile, a line perpendicular to the LMR river miles was drawn to the point where the bidirectional channel connected to a unidirectional channel. Thus, all obstructions along a bidirectional channel have the same river mile.

<u>Unidirectional model</u>: ERDC-EL (Engineer Research and Development Center – Environmental Laboratory) scientists have studied the invertebrate composition of meander scarps and secondary channels with different levels of unidirectional flow frequency. The results relating invertebrate richness to the stage when the river begins flowing through a secondary channel have been published in Harrison et al. (2017) and Harrison (2018). Additionally, this study has a larger sample size of these channel types than the Island 63 study. Therefore, the published relationship (Harrison et al. 2017) between species richness and Helena stage was modified for the Unidirectional model.

Unidirectional

$$\frac{(23.288-0.78x)}{27 \ \max \mathrm{richness}}$$

Flow thru stage (ft LWRP Low Water Reference Plane) (x): The model has one input, the flow thru stage in feet low water reference plane (LWRP). The flow thru stage is the low water reference plane stage that river water must reach to begin flowing through the unidirectional waterbody e.g., secondary channel or meander scarp. For example, the invert of a dike notch. The LWRP is equivalent to the river's water surface elevation at a set discharge typically recorded in 10th of a river mile increments. New LWRP values are determine on a regular basis. Therefore, the LWRP values closest to the year the elevation data used to determine the notch invert should be used. For example, the low spot in a dike is determined from a 2009 multibeam bathymetric survey. The 2007 LWRP should be used to convert this elevation. If the bathymetric survey had been completed in 2020, the 2021 LWRP should be used. The without and with project elevations were converted to 2007 LWRP (MVM 2008) by subtracting the 0 LWRP elevation at the measure’s river mile from the project elevation.

Borrow model: The Borrow model was developed from two datasets of repeat sampling of borrow area fish, water quality and morphometric characteristics. The first dataset was collected in the early 1980’s and published by Cobb et al (1984). Rotenone samples were collected from twenty-five borrow areas along the batture of the Lower Mississippi River from New Madrid, MO to near Lutcher, LA. Data on fishes, macrobenthos, water quality, and sediments were collected. Topographic surveys of each area were conducted to derive habitat variables. As part of the 1998 Mississippi River Levees Environmental Impact Statement, eight riverside borrow areas, seven of which were previously sampled by Cobb et al. (1984), and four landside borrow areas were sampled in 1996/97. Sampling occurred during mid- to late summer when the borrow areas were isolated from the Mississippi River (Killgore et al. 1998). The same hydrologic, morphometric, and water quality variables measured by Cobb et al. (1984) were obtained, and fish were collected using rotenone, seining and gillnets. The rotenone fish data, water quality and morphometric datasets were used to develop the Borrow model. The five borrow areas that were sampled with seine and gillnets in 96/97 were resampled in 2019 and Modoc borrow area near Island 63 was also sampled. All of the 1980’s, 1996/97, and 2019 data were used to inform input values for the model. The model equation is:

$$\frac{(31.2*VDI+2.2*Max.depth\ ft-0.2*\%\ Area>5ft-0.1*Turbidity\ NTU-24.3)}{43\ \text{max richness}}$$

VDI: Volume development index calculated by 3x (mean depth/maximum depth). VDI < 1 indicates a slender steep sided borrow area while VDI > 1 indicates a more bowl-shaped basin. Although assumptions were made for maximum depth, the PDT felt there were too many unknowns to determine an average depth. The average VDI from the dataset was 1.2. This value was used for with and without project. Project monitoring of borrow area bathymetry before and after construction will allow calculation of with and without project VDI for future LMRRA reaches.

Maximum depth: Because of the trend for floodplain waterbodies to fill with time and that project borrow areas have been present since 1985 - 2001 (visible in G. Earth imagery), the project team assumed a without project value of 3 feet when other information was not available. The environmental design for borrow areas recommends 75% of the borrow area be 5 feet or greater. Thus, engineering planned for depth increases of 5 feet making the maximum with project depth 8 feet.

% Area > 5 feet: The percent of the waterbody that is greater than 5 feet deep was 0 for without project and 75% per environmental design of borrow areas guidelines unless otherwise noted.

Turbidity: Deeper water is less turbid than shallow water (Robel 1961). Using the database borrow areas, the average turbidity value for borrow areas with an average depth of 2.5 – 3.5 feet was 23 NTU. This value was used for the without project value. Since there were no borrow areas with an average 8 feet depth, a line fitted through the turbidity and depth values was used to predict the with project turbidity of 10.9 NTU.

Eddy model: Eddies form when water flows past a rock structure or fallen tree and reverses direction to flow into the space behind and downriver. These swirling currents carry and disorient small-bodied organisms attracting predators like blue catfish and freshwater drum and filter feeders like paddlefish. Data on the numbers of these individuals captured in the main channel compared to eddies formed below point bars were used to determine that eddies increase habitat value from 0.1 to 1.0 for paddlefish. The project team chose to use paddlefish because they are a priority species under objective 3, and an uncommon species whose population has declined unlike the abundant blue catfish and freshwater drum.

Substrate and Wood Trap models: In 2014, ERDC began collecting macroinvertebrates with a benthic sled within the LMR (Harrison et al. 2018). In addition to the invertebrates, substrate was also noted. These data were used to develop the substrate model. Benthic sled studies led to additional questions about the invertebrates that utilized the difficult to sample substrates present within the river. The colonization study was initiated placing leaf packs, gravel, wood, stone, and articulated concrete mattress in submerged retrievable baskets to study colonization of these difficult to sample substrates. These baskets were periodically retrieved, and invertebrate colonization studied. From these two data sets, the increase in richness when a wood trap is added to various existing substrates was determined. Richness values were then converted to a 0 to 1 scale. For example, a wood trap constructed on sand substrate would have a without project score of 0.2 and a with project score of 0.86.

Hydrogeomorphic Wetland Functional Assessment: HGM is a method for developing and applying indices for the site-specific assessment of wetland functions. HGM, which included the functional assessment models and associated variables, was certified for regional use in the Mississippi Alluvial Valley by the National Ecosystem Restoration Planning Center of Expertise (ECO-PCX) (USACE 2019). The HGM models were formulated, tested, and certified specifically for the forested alluvial systems of the Mississippi River valley. The HGM Approach was initially designed to be used in the context of the Clean Water Act Section 404 Regulatory Program permit review process to analyze project alternatives, minimize impacts, assess unavoidable impacts, determine mitigation requirements, and monitor the success of compensatory mitigation. A variety of other potential uses has since been identified, including the design of wetland restoration projects, and management of wetlands (Murray and Klimas 2013). It has been used previously in the project area to assess wetlands for the Mississippi River Levees Supplemental Environmental Impact Statement (Murray and Klimas 2013). HGM is composed of six functions (Equations 1 - 6) which are formulated with a suite of 13 variables selected specifically for each function (Table 5-3). During plan formulation, field surveys of representative sites were conducted to determine variable values.

Function 1: Detain Floodwater

$$FCI = V_{FREQ} \times \left[\frac{(V_{DWD\&S} + V_{STRATA} + V_{TBA})}{3} \right]$$

Function 2: Detain Precipitation:

$$FCI = \frac{\left[V_{POND} + \frac{(V_{SOIL} + V_{LITTER})}{2} \right]}{2}$$

Function 3. Cycle Nutrients:

$$FCI = \frac{\left[\frac{(V_{TBA} + V_{STRATA} + V_{TREESIZE})}{3} + \frac{(V_{SOIL} + V_{DWD\&S})}{2} \right]}{2}$$

Function 4. Export Organic Matter:

$$FCI = V_{FREQ} \times \frac{\left[\frac{(V_{TBA} + V_{STRATA})}{2} + \frac{(V_{LITTER} + V_{DWD\&S})}{2} \right]}{2}$$

Function 5. Maintain Plant Communities:

$$FCI = \left(\left\{ \frac{\left[\frac{(V_{TBA} + V_{TREESIZE})}{2} + V_{COMP} \right]}{2} \right\} \times \left[\frac{(V_{SOIL} + V_{DUR} + V_{POND})}{3} \right] \right)^{1/2}$$

Function 6: Provide Habitat for Fish and Wildlife.

$$FCI = \left(\left[\frac{\left(V_{FREQ} + V_{DUR} + V_{POND}\right)}{3} \right] \times \left[\frac{\left(V_{COMP} + V_{STRATA} + V_{DWD\&S} + V_{TBA}\right)}{4} \right] \times \left[\frac{\left(V_{TRACT} + V_{CONNECT} + V_{CORE}\right)}{3} \right] \right)^{1/3}$$

Table 5-3. HGM Variables per Function

Variable	Description	Function
V_{TRACT}	Tract size	1, 6
$V_{CONNECT}$	Percent connectivity	6
V_{CORE}	Percent core	6
V_{FREQ}	Change in flood return interval	4, 6
V_{POND}	Percent area subject to ponding	2, 5, 6
V_{DUR}	Change in growing season flood duration	5, 6
V_{SOIL}	Soil integrity	2, 3, 5
$V_{DWD\&S}$	Down woody debris and snags	1, 3, 4, 6
V_{LITTER}	Percent cover of the litter layer	2, 4
V_{STRATA}	Number and top strata present	1, 3, 4, 6
$V_{TREESIZE}$	Number and top tree size present	3, 5
V_{COMP}	Composition of tallest woody stratum	5, 6
V_{TBA}	Tree basal area	1, 3, 4, 5, 6

A set of assumptions are provided with the assessment to support the predicted future with and future without project conditions.

General Assumptions:

1. Sum of wetland cover types has a cumulative impact on core area that surrounds the wetland assessment area.
2. Restoration measures that include surface water connection improvements have a positive effect on flood frequency (VFREQ).
3. Flood duration (VDUR) is adequate to maintain wetland hydrology, thus moderately impacted flood duration can be improved by establishing connection.
4. From a remote sensing scale, soil integrity (VSOIL) has not been adversely affected such that the model would be sensitive to the change.
5. Some restoration measures may result in moderate impacts to woody debris and snags in forested wetlands, but recovery is anticipated.
6. No group 1 species in VCOMP; dominance by group 2 and 3 species.

7. Chinese privet, Japanese honeysuckle, and reed canary grass are assumed to be present on most complexes.
8. Establishment of reed canary grass (FACW+) can be reduced by an increase in VDUR to a minimum of 14 consecutive days of inundation. However, dense stands may require mechanical removal and/or an EPA labeled herbicide.
9. Tree counting (density), and basal area assumed to use a #10 prism is 1-6 (VTBA).
10. Once functions based on trajectories are fully realized, increases in variable scores were not included beyond 20 years.

Variable Specific Assumptions:

1. VDWD&S: Future without project (FWOP) forested wetlands have a natural amount of snags and down coarse woody debris.
2. VLITTER: FWOP forested wetlands have a natural amount of leaf litter.
3. VTREESIZE: Medium tree size (> 6 inches DBH) are considered mature.
4. VCOMP: Mast production trees are currently limited in distribution and maturity.

Limitations with HGM Models:

1. Models and associated variables were formulated to assess functions of “forested” wetlands. Consequently, assumptions were made for application to creation of emergent wetland systems.
2. Models were not sensitive to existing conditions and FWOP on intensive agricultural plowed areas. Consequently, restoration measures (Future With Project FWP) that result in a fully functional forested or emergent wetland were considered 100% eco-lift.
3. Model was not sensitive to assessing eco-lift on lotic systems. Other models were used.

2.2 ACREAGE

For all management measures, acreage was determined as follows unless otherwise noted in the write up for the specific measure (Appendix 1).

Aquatic waterbodies**:** A combination of the satellite imagery and HEC-RAS waterbody outlines were used to calculate aquatic waterbody habitat acres. Both sets of waterbody outlines were developed to illustrate aquatic acreage when the river was at a 50% discharge. A 50% discharge was chosen because it represents a midpoint condition. A combination of sources was used to mitigate method limitations thus improving accuracy and reducing uncertainty. Satellite imagery does not capture aquatic area obscured by forest canopy and intermittently captures narrow waterbodies such as Island 35 Chute. The HEC-RAS model over and underestimates intermittently connected floodplain waterbodies. The model’s elevation data does not include the narrow floodplain channels that first drain/fill floodplain waterbodies. Therefore HEC-RAS outlines were used for channels connected at both ends (main channel, secondary channel, and meander scarps). Satellite imagery waterbody outlines were used for floodplain waterbodies and waterbodies predominantly connected at one end.

Aquatic waterbody project area acreage:

Applicable models: Bidirectional, Isolation, Unidirectional, Wood Trap and Borrow

Waterbodies where project actions would occur (e.g., borrow areas to be deepened) represented the management measure project area. For bidirectional measures, waterbodies upstream of obstructions to be modified and downstream of the next obstruction were used as the project area. For unidirectional measures proposing to modify all obstructions or increase flow, the project area was the entire waterbody from upstream to downstream end. The entire secondary channel was used as the acreage for measures adding wood traps evaluated with the wood trap model. Wood traps would increase invertebrate abundance providing forage for all species within the secondary channel. The traps would also provide additional places for fish to shelter.

Aquatic waterbody supplemental acreage:

Applicable models: Bidirectional, Isolation, Unidirectional

Measures that modify connectivity benefit the Mississippi River's migratory and non-migratory species pool. Improved floodplain access benefits aquatic migratory species which utilize the littoral zone (Gutreuter et al. 1999). Paddlefish, a species of concern throughout the LMR, utilize off-main channel, slow velocity aquatic areas as nursery areas, for feeding, and overwintering (Tripp et al. 2020). This species and numerous others travel many miles during their yearly activities (Ickes et al. 2005; Tripp et al. 2020).

Non-migratory species benefit from the additional habitat heterogeneity. For example, pockets of isolated habitat create unique species pools which can restock the system during extreme floods maintaining LMR systemwide biodiversity. Thus, benefits accrue beyond the acreage considered for the project area. To conservatively estimate these benefits, downstream waterbodies with primary flow channels connecting between connectivity management measure project area, secondary channels and main channels (thalweg to bank within the complex boundary that the waterbody connects to) were evaluated as supplemental acreage (Figure 5-4).

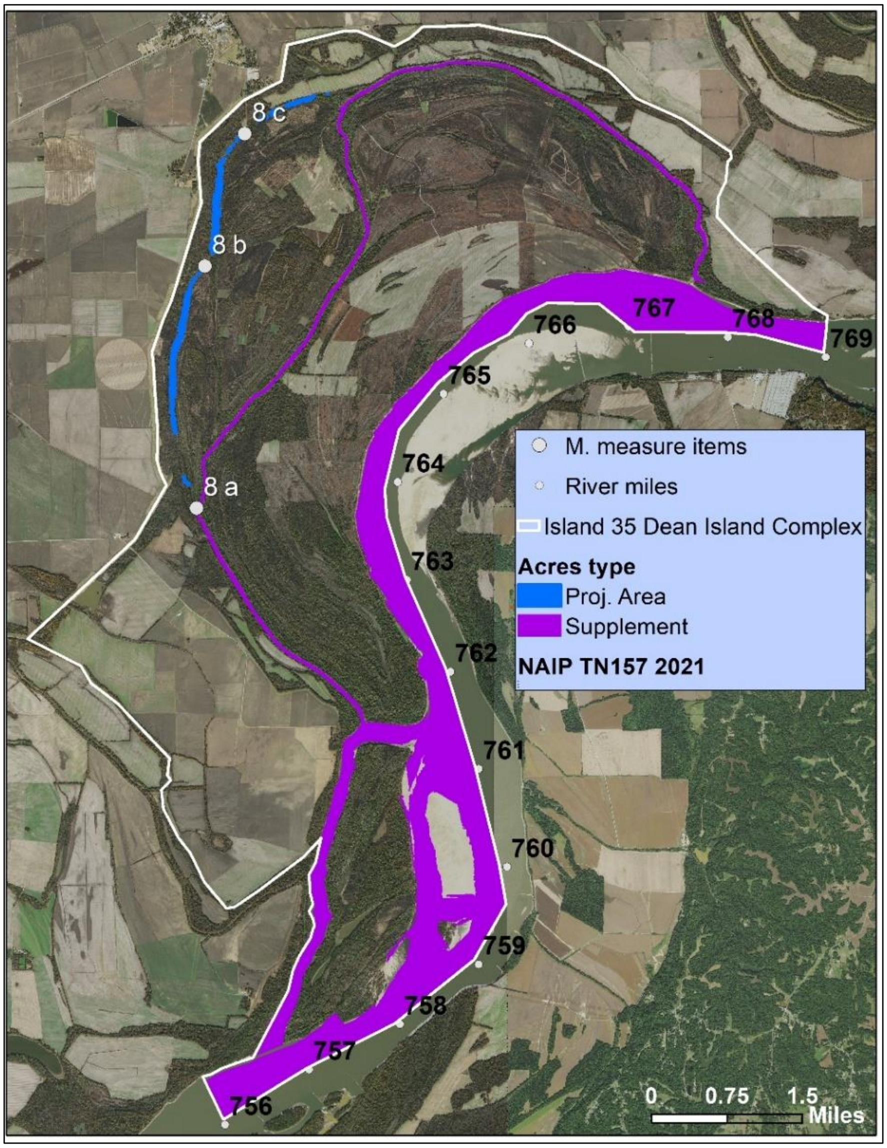

Figure 5-4. Example of Project Area and Supplemental Acreage of Waterbodies Representing Island 35 Dean Island Management Measures 8_a Evaluated with the Bidirectional Model

Rock structures project area acreage:

Applicable models: Eddy, Substrate

Rock structures are extremely common within the Lower Mississippi River. The project team felt that their effect would not reach beyond the immediate area of the structure and the change in the riverbed (bathymetric diversity) created by the structure. Therefore, contour lines created from multibeam bathymetric surveys of structures similar to those proposed were used to determine the structure's area of effect (Figure 5-5). For structures which varied greatly in size, like hardpoints, these effect areas were scaled to the size of the structure. Calculation of this acreage is discussed further in the applicable management measure descriptions (Br_5, HT_2, I35_7g and M_1; Appendix 1).

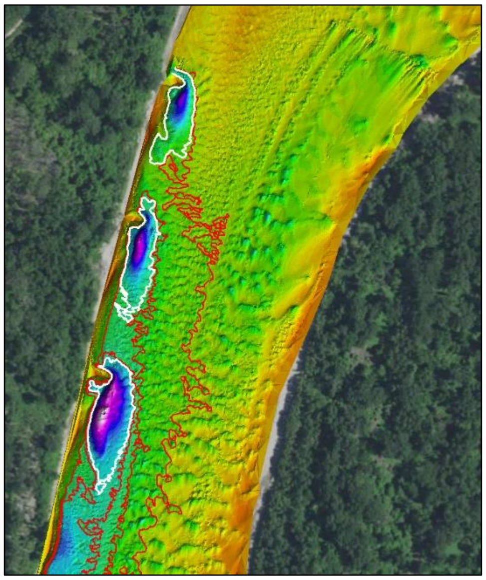

Figure 5-5. The Area of Effect of Hardpoints Shown by the White Contour Line. The White Contour Encompassed the Change in Bathymetry Above and Below the Hardpoint While the Next Contour (Red, 1 ft Greater) Expanded Beyond the Hardpoint's Effect

Floodplain plant communities**:** Floodplain acres for measures altering the plant community were provided by engineers, the sponsor, and land managers, created from elevation data, digitized from NAIP 2019/2021 imagery, or clipped from the 2017 Mississippi River levees land cover dataset. When reforestation efforts were targeting a particular inundation rate, the 2017 Osceola and Memphis gage data were used to determine a corresponding elevation for this inundation rate. The 2014 USGS 3D elevation program 1m digital elevation models were used to create a contour at this elevation. The elevation contour was modified using 2019/2021 imagery to exclude homesteads and, in some cases, use existing roads as boundaries.

Floodplain project area acreage:

Applicable model: HGM

Project acreage for these measures was the footprint of the project action such as the replanting area or area whose inundation would change.

Floodplain supplemental acreage:

Applicable model: HGM

Floodplain species utilizing existing habitat also benefit from improvements to connected habitats. Therefore, supplemental acres included acres of contiguous similarly classified habitat to the management measure (forest adjacent to proposed reforestation area). Adjacent forest was defined as forest or scrub/shrub in the 2017 Mississippi River Levees (MRL) land cover file sharing an edge with the reforestation area. Roads and water channels visible in 2019/2021 NAIP were used to determine non-contiguous habitat. In some cases, the 2017 MRL landcover was incorrect over large areas when compared to 2021 NAIP (Figure 5-6). In these cases, forest/scrub/shrub was digitized from 2021 NAIP imagery.

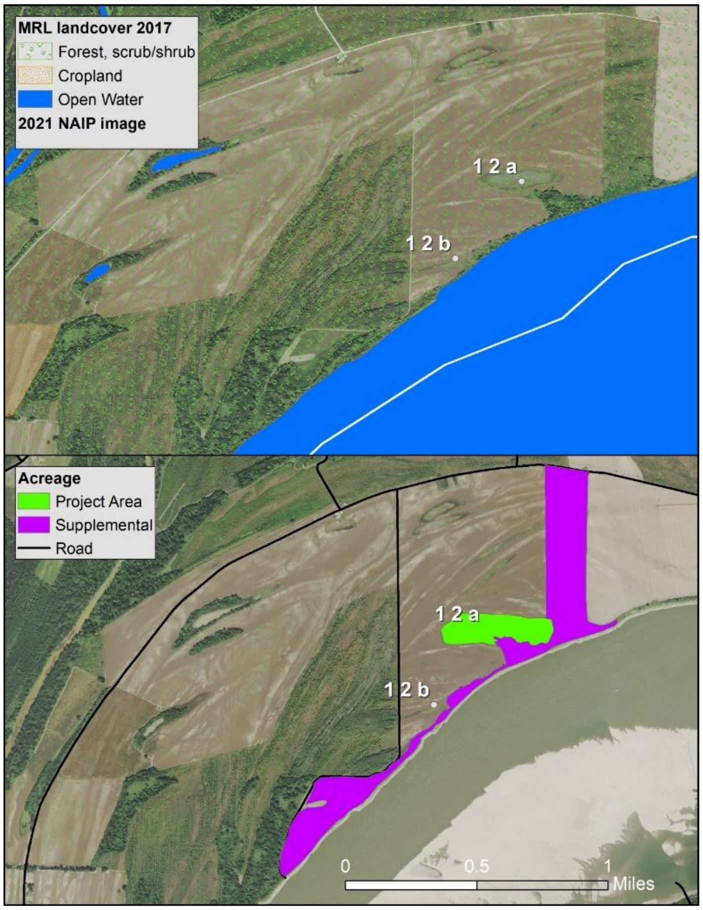

Figure 5-6. Example of Project Area and Supplemental Forest Acreage for Island 35 Dean Island Management Measures 12a and 12b Evaluated with the HGM Model

The acreage for 12b was calculated from the engineering specifications (reforest 8,000-ft x 300-ft) thus the acreage did not need to be digitized. Supplemental and 12a acreage was digitized from National Agricultural Imagery Program 2021 aerial image because the 2017 Mississippi River Levees landcover did not capture existing conditions in the area. Roads and agriculture created non-contiguous habitat and the boundaries for the acreage.

2.3 TARGET YEARS

Federal projects, their costs, and benefits, are typically evaluated over a 50-year planning horizon (USACE 2000). It is always the goal that management measures be self-sustaining. However, economic, environmental, and societal considerations prevent many management measures from reaching self-sustainability. Even self-sustaining measures like reforestation might need assistance. The 50-year project life allows for an accounting of the costs and/or benefits that reflect changes over time. Operations, maintenance, monitoring and adaptive management may be required for measures that cannot sustain themselves. For example, in the case of the forest, beaver and deer may remove planted saplings requiring replanting. Alternatively, the project team could exclude replanting costs and reflect the risk as a reduction in reforestation benefits with time.

For measures that were self-sustaining or would receive operations and maintenance, target years were 0 to capture without project conditions, 1 to capture with project benefits and 50 the final year of the period of analysis. For other aquatic and wetland measures, benefits would change with time. For aquatic measures, the rate of change was determined to be relatively consistent and thus target years were 0, 1, 10, 20, 30, 40, and 50. For wetland measures, target years captured the development and maturation to tree basal area, woody debris volume, litter cover, and vertical forest strata for floodplain forests evaluating benefits annually from years 0 – 20 when the forest reached maturity and then cumulatively from years 21 to 50. Target years for each model are discussed in further detail below.

<u>Bidirectional, Isolation and Unidirectional target years</u>: Measure change with time: The functions created by measures evaluated by the connectivity models would be preserved by resilient project design and operations and maintenance (O&M) if necessary. O&M would maintain structures (culverts and weirs) and remove sedimentation to ensure connectivity of secondary channels and floodplain waterbodies. Even without O&M, research and site manager local knowledge suggest there would be little change in benefits. Most connectivity measures do not connect at low stages. Thus, water from the middle to top of the water column would flow into these channels. There would be no bedload transport. Mississippi River suspended sediment loads have decreased with reservoir formation, river stabilization works, and large-scale erosion control efforts resulting in a sediment starved system (Meade and Moody 2009). These two factors combine to indicate sedimentation rates from bidirectional connectivity in channels buffered by vegetation would be minimal over the 50-year project life. Weirs and culverts constructed within the floodplain are buffered from the full force of the LMR by floodplain vegetation. Meeman-Shelby Forest State Park and Eagle Lake Refuge WMA managers have found that culverts and berms (less resilient than weirs) have a very long-life span. Additionally, USACE engineers design project measures for a 50-year project life using stronger materials and rigorous designs. With this information, the

PDT concluded measure benefits would not change with time due to declining function or sedimentation.

System changes affecting measure benefits: In some cases, LMR system change would affect the benefits of connectivity measures. The channel bed of connectivity measures, where manmade obstructions remain, cannot adjust with time. Therefore, a change in river level will affect these measures. In a large-scale analysis, Biedenharn et al. 2017 found that river levels around Memphis are changing with time. The stage discharge analysis found that Mississippi River water surface elevations for low to mid-level river discharges were falling at the Memphis gage (Biedenharn et al. 2017). This study also found that when the river is at higher discharge, the water surface elevation has not changed (Figure 5-7). These changes are projected to continue in the future. Therefore, as the river's water surface elevation decreases, floodplain channels that cannot adjust will become less connected.

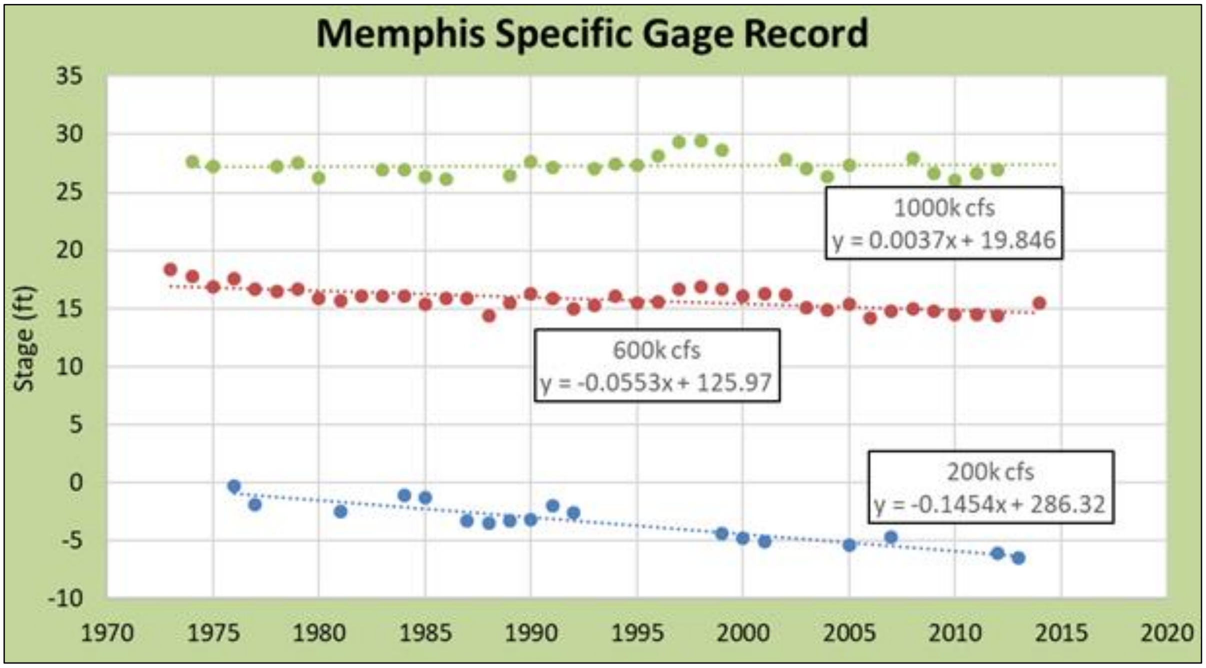

Figure 5-7. The Stage (a way of measuring the Lower Mississippi River water surface elevation) at the Memphis Gage when the River is Carrying a Set Amount of Water (discharge). Stages at Low and Moderate Discharge are Decreasing while High Discharge Shows No Change

The annual rate of change in water surface elevation was determined from the equation of a line fit through the stage discharge analysis data (Table 5-4). To determine HSI values for the target years, the rate of change was applied to the measures without project and with project elevations increasing the elevation with time (equivalent to decreasing the water surface elevation), thus decreasing connectivity variables. To determine the applicable rate of change for the measure, three groups were determined from the stage discharge analysis (Table 5-4). The measures without and with project elevations were converted to a stage at Memphis. The 2007 low water reference plane (07 LWRP) zero elevation at the management measure's river mile was subtracted from the zero 07 LWRP elevation at the Memphis gage. The resulting value was then subtracted from the measure's elevation representing the measure's Memphis equivalent elevation (removing the change in elevation due to valley slope). This elevation was then converted to stage by subtracting the Memphis gage's zero stage elevation. The measure's stage discharge group for the measure's without and with Memphis stage was then determined. In some cases, the stage discharge group differed between with and without project or changed with time. For example, if the without project equivalent Memphis stage at year 0 is 6.95 then at year 1 it would be 7.1 (e.g., 6.95 + 0.15). At this point the 0.06 rate would apply and thus at year 10 the elevation would be 7.64 (e.g., 7.1 + 0.06 * 9).

Table 5-4. The Linear Equations Fit to the Water Surface Elevation (ft) Per Year from 1970 to 2014 at the Memphis Gage for Three River Discharges. These Equations were used to Calculate the Rate of Change in Feet Per Year and Group into Three Stage Ranges

Discharge	Stage range	Rate ft/year
1,000,000 cfs	> 23 ft	0.00
600,000 cfs	> 7 ft and < 23 ft	0.06
200,000 cfs	< 7 ft	0.15

Aquatic connectivity measures that removed all man-made obstructions were considered to be relatively self-sustaining. These measures include HT_1, HT_7, HT_10, I35_7a, I40_4. The Mississippi River Valley is composed of alluvial soils (relatively fine with variable cohesion) that are generally easily moved by scouring flows. Therefore, the bed of channels with no compacted berms, culverts, water control structures, dikes or other manmade obstructions can adjust. This adjustment is evident in the unobstructed tie channels of oxbow lakes. The PDT assumed that the channel bed of these measures would adjust with the predicted changes in water surface elevation.

Borrow model target years**:** Management measures evaluated by this model propose to deepen borrow areas and floodplain waterbodies. Like floodplain waterbodies, borrow area channels connect to the river's main channel at mid to high stages bringing minor quantities of suspended sediment. Unlike floodplain waterbodies, borrow areas are generally adjacent to mowed and maintained levees and roads. Additionally borrow areas are generally in higher elevation areas of the floodplain. These high elevation areas are more suitable farm ground and thus there is a higher density of farming on the surrounding land. Therefore, runoff may create measurable sedimentation in the borrow areas. The repeat sampling of borrow areas and collection of depth information in 1981, 1996, and 2019 provided information on sedimentation. Borrow areas on average lost 17% of their depth over the 38-year period. From this an annual rate of 0.004474 was calculated and applied to the max depth variable within the Borrow model to calculate target year HSI.

Eddy, Substrate, and Wood Trap model target years: The functions created by measures evaluated by these models would be preserved by resilient project design and O&M if necessary. The measures evaluated by the eddy and sometimes substrate models are rock river training structures with a non-navigation focus. The structures are proposed for areas not subjected to the full force of the main channel, yet they are designed to the same rigorous standards. Within the Memphis District, the height of main channel dikes is slowly reduced by overtopping (erosion) and scouring (subsidence). O&M rebuilds the structure to the planned height to ensure water is maintained within the navigation channel. The proposed measures resilient design and lower impact placement would reduce erosion and subsidence. Additionally minor changes in structure height would not impact measure function. Therefore, eddy and substrate model target years were 0, 1, and 50.

The Wood Trap model is also used to evaluate wood trap measures. These measures are designed similarly to historic pile dikes with additional revetment at the base. Within the Memphis District, there are numerous secondary channel pile dikes which were decommissioned in the 1950s. These dikes are present and functioning today. Project measures (Br_1, I35_3, I35_7a, S_4, and S_6) propose to notch these dikes because they remain functional, blocking flow in secondary channels. This evidence suggests it is unlikely that wood trap function will decline over the project life and target years were 0, 1, and 50.

<u>HGM target years</u>: The first 20 years following measure construction represents the most important period to determined successful wetland restoration and thus future conditions were evaluated annually for years 0 – 20 and cumulatively from years 21 to 50. Projection of future conditions in response to restoration measures were approximated using recovery trajectories from Klimas et al. (2004). Because of the remote nature of the functional assessment, four measures were selected to determine restoration success: tree basal area to represent mature forest stands and the critical variables mature forest stands support: woody debris volume, litter cover, and vertical forest strata. The following recovery trajectories for forested wetlands represent anticipated rates of restoration success and full realization of wetland functions over time.

Based on prior studies (Klimas et al. 2004), a minimum of 12 years is required to begin to realize full functionality based on tree basal area alone (Figure 5-8). The recovery and realization of five HGM functions are dependent on mature forest stands including: detain floodwater, cycle nutrients, export organic matter, maintain plant communities, and provide habitat for fish and wildlife (Table 5-3).

A minimum of 16 years is required to fully realize the ecological benefits of downed woody debris and snags (Figure 5-9). The occurrence of down woody debris and snags is expressed in four functions: detain floodwater, cycle nutrients, export organic matter, and provide habitat for fish and wildlife (Table 5-3).

A minimum of 8 years is required to fully realize the ecological benefits of leaf litter on the forest floor (Figure 5-10). The occurrence of leaf litter is expressed in two functions: detain precipitation and export organic matter (Table 5-3). The role leaf litter plays in carbon export and food chain support cannot be over emphasized.

A minimum of 20 years is required to produce three vertical plant strata in a mature forest unless understory and groundcover species are planted or naturally recruited (Figure 5-11).

Vertical plant strata are expressed in four functions: detain floodwater, cycle nutrients, export organic matter, and provide habitat for fish and wildlife (Table 5-3).

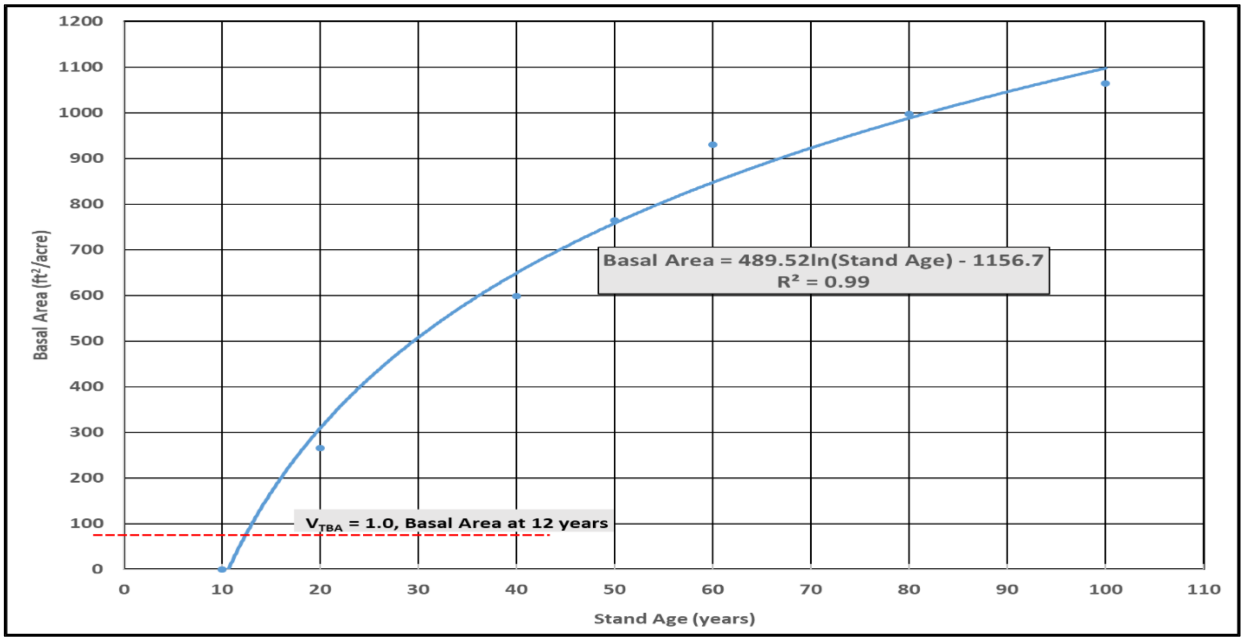

Figure 5-8. Recovery Trajectory for Restored Forested Wetlands Depicted by Tree Basal Area Per Acre

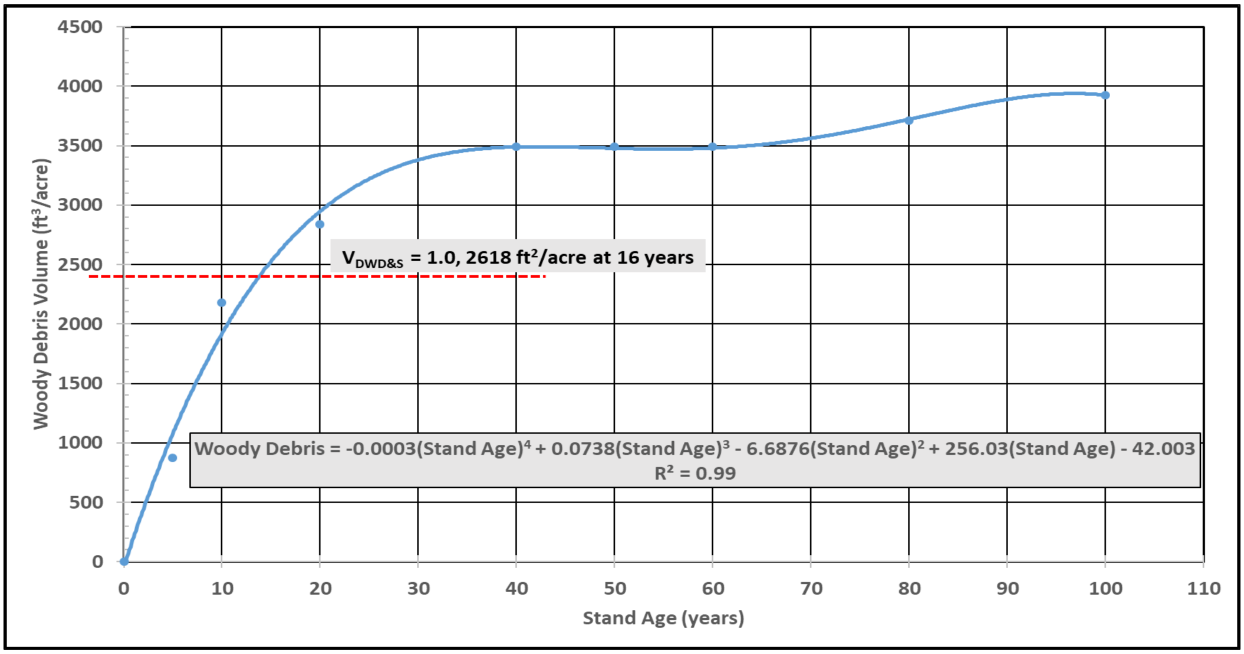

Figure 5-9. Recovery Trajectory for Restored Forested Wetlands Depicted by Woody Debris Volume

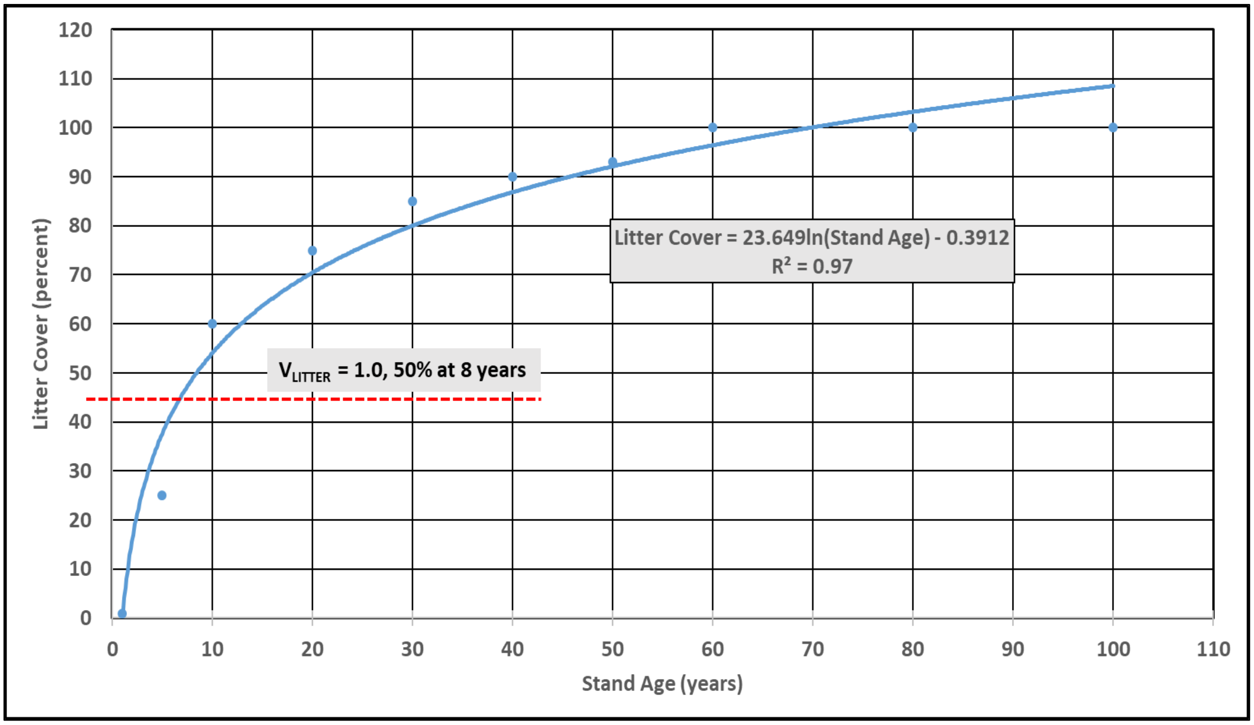

Figure 5-10. Recovery Trajectory for Restored Forested Wetlands Depicted by Litter Coverage

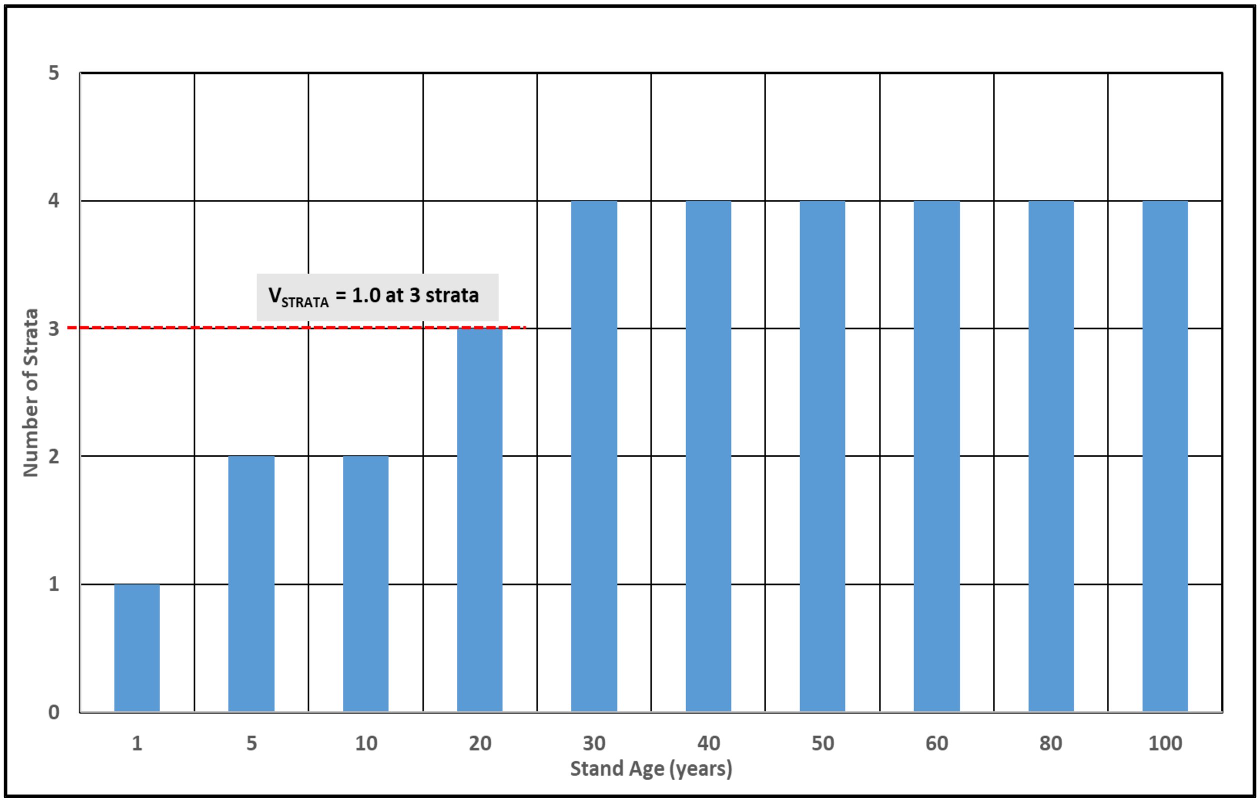

Figure 5- 11. Recovery Trajectory for Forest Vertical Strata

2.4 RESULTS

Bidirectional: The Bidirectional model was used to evaluate 22 measures that increased the connection frequency of sloughs, a borrow area, and secondary channels in 8 complexes. Connection frequency ranged from 1 – 58% without project and 2 – 100% with project with an average increase of 8%. Net AAHU ranged from 0.02 to 46 with low values due to the minor increases in connectivity (< 10%) and/or the small acreage of many sloughs (Table 5-5).

Table 5-5. Measure, Acres, Year 1 Connection Frequency, Year 1 Habitat Suitability Index (HSI), and Net Average Annual Habitat Units (Net AAHU) for Measures Evaluated with the Bidirectional Model

Short Description	Measure code	Acres	Without	With	Without	With	Net AAHU
			00-15 Conn. Freq. %		HSI		
Slough connectivity	Br_10	2	8	13	0.22	0.27	0.06
Slough connectivity	Br_12	25	33	45	0.46	0.58	3.01
Slough connectivity	Br_13	80	5	15	0.20	0.28	4.83
Thweatt Chute connectivity	D_1	84	22	26	0.35	0.40	3.89
Slough connectivity	HT_1	9	25	30	0.38	0.44	0.47
Slough connectivity to Ballard Slough	HT_4	54	25	35	0.38	0.48	4.75
Ag field connectivity	HT_7	21	11	15	0.25	0.29	0.27
Food plot connectivity	HT_10	16	11	13	0.25	0.27	0.17
Swale connectivity to slough	HB_2ab	8	14	24	0.28	0.38	0.56
Borrow pit connection	I35_6c	22	2	3	0.17	0.17	0.11
I35 Towhead Chute connectivity	I35_8_a	70	17	30	0.31	0.43	7.73
Slough connectivity	I35_10a	4	1	2	0.16	0.16	0.02
Slough connectivity	I35_11	17	7	12	0.21	0.26	0.77
Danner Lake upstream connectivity	I40_1b	161	8	9	0.22	0.23	2.47
I40/41 Chute upstream connectivity	I40_2b	5	14	35	0.28	0.48	0.90
Slough connectivity	I40_4	5	26	31	0.39	0.44	0.22
Slough connectivity	I40_5	17	11	22	0.25	0.35	1.19
Redman Point Bar 2nd channel downstream connectivity	RL_3	4	29	41	0.42	0.54	0.42
Mound City Chute connectivity	RL_7	100	20	25	0.34	0.39	4.72
Slough connectivity	S_1	21	22	27	0.36	0.40	0.93
Slough connectivity	S_2	2	21	27	0.35	0.41	0.12
Lookout Bar downstream connectivity	S_6	127	58	100	0.70	1.00	46.38

Isolation: Four measures were evaluated with the Isolation model. Elevated ground around these three borrow areas and a crevasse would have led to infrequent connection if manmade channels had not been created. Connectivity ranged from 6 – 21% and project measures proposed to reduce this connectivity to 3 – 10%. The relatively small acreage of the waterbodies and less than 15% reduction in connectivity led to low AAHUs (Table 5-6).

Table 5-6. Measure, Acres, Year 1 Connection Frequency, Year 1 Habitat Suitability Index (HSI), and Net Average Annual Habitat Units (Net AAHU) for Measures Evaluated with the Isolation Model

Short Description	Measure code	Acres	Without	With	Without	With	Net AAHU
			00-15 Conn. Freq. %		HSI		
Isolate borrow area	HB_10	12	21	10	0.62	0.70	0.61
Isolate borrow area	I35_4b	5	6	3	0.73	0.75	0.11
Isolate Golden Lake Crevasse	I35_5c	41	6	5	0.73	0.74	0.33
Isolate borrow area	I40_6	29	14	5	0.67	0.74	1.50

Unidirectional: Five measures were evaluated with the unidirectional model. Dikes, road bridges and vegetated sediment deposits increased the bed elevation of these secondary channels and meander scarps. This elevated ground reduces the frequency of flowing conditions. The Helena stage that channels began to flow currently ranges from 1–8 feet and project measures proposed to decrease the elevation to -2 to-7 feet. The large acreage of these measures combined with modest improvements in HSI resulted in AAHUs ranging from 23 – 275 (Table 5-7).

Table 5-7. Measure, Acres, Year 1 Flow thru Frequency (Stage 07LWRP), Year 1 Habitat Suitability Index (HSI), and Net Average Annual Habitat Units (Net AAHU) for Measures Evaluated with the Unidirectional Model

Short Description	Measure code	Acres	Without	With	Without	With	Net AAHU
			Stage 07LWRP ft.		HSI		
Notch Poker Point pile dikes	Br_1	106	8.2	0.2	0.63	0.86	24
Flow thru Brandywine Chute	Br_4	499	4.1	-4.5	0.74	0.99	122
Flow thru I35 Chute	I35_3	240	4.3	-2.7	0.74	0.94	48
Notch Dean 2nd channel dikes	I35_7a	341	3.3	-3.4	0.77	0.96	64
Flow thru Island 34 & Sunrise Towhead Chute	S_4	705	10.1	-5.3	0.57	1.00	300

Borrow: The Borrow model was used to evaluate 11 measures that proposed to increase depth in borrow areas and one slough. The moderate acreage and changes in HSI between without and with project produced moderate net AAHUs (Table 5-8).

Table 5-8. Measure, Acres, Year 1 Habitat Suitability Index (HSI), and Net Average Annual Habitat Units (Net AAHU) for Measures Evaluated with the Borrow Model

Short Description	Measure code	Acres	Without	With	Net AAHU
			HSI		
Deepen borrow area	Br_14	47	0.40	0.53	4.41
Deepen borrow areas	Br_16	54	0.40	0.50	3.76
Deepen Thweatt Chute	D_2	84	0.40	0.49	5.27
Deepen borrow area	HB_3	6	0.51	0.77	1.41
Deepen borrow area	HB_4	7	0.51	0.77	1.63
Deepen borrow area	HB_5	6	0.51	0.77	1.41
Deepen borrow area	HB_6	13	0.51	0.75	2.75
Deepen borrow area	HB_7	8	0.51	0.76	1.83
Deepen borrow area	HB_8	16	0.51	0.74	3.22
Deepen borrow area	HB_9	12	0.51	0.75	2.58
Deepen borrow areas	I40_7a	29	0.40	0.59	4.52

Eddy: Three measures, each in a different complex, were evaluated with the eddy model. These measures created large benefits as captured by the difference between without and with project HSI and AAHUs varied depending on the acreage effected by the measure (Table 5-9).

Table 5-9. Measure, Acres, Habitat Suitability Index (HSI), and Net Average Annual Habitat Units (Net AAHU) for Measures Evaluated with the Eddy Model

Short Description	Measure code	Acres	Without	With	Net AAHU
			HSI		
Brandywine Chute hardpoints	Br_5	499	0.10	1.00	445
Dean 2nd Channel hardpoints	I35_7g	3	0.10	1.00	2.67
Main channel bank hardpoints	M_1	6	0.10	1.00	5.35

Substrate: Five measures proposed adding wood traps to five different secondary channels and were evaluated with the wood trap model. One measure proposed to add a river training structure to prevent fine sediment deposition on gravel. This measure was evaluated by the substrate model. These six measures affected larger acreages with large differences between without and with HSI resulting in high Net AAHUs (Table 5-10).

Table 5-10. Measure, Acres, Habitat Suitability Index (HSI), and Net Average Annual Habitat Units (Net AAHU) for Measures Evaluated with the Substrate or Wood Trap Model

Short Description	Measure code	Acres	Without HSI	With HSI	Net AAHU
Wood traps Poker Point	Br_2	106	0.19	0.86	70
Wood traps Densford	D_3	125	0.19	0.86	83
River structure clean gravel	HT_2	45	0.51	1.00	22
Wood traps Hickman Bar 2nd channel	M_14	740	0.19	0.86	491
Wood traps Loosahatchie	RL_6	790	0.19	0.86	524
Wood traps Lookout Bar 2nd channel	S_7	127	0.19	0.86	84

HGM: HGM was applied to 32 restoration measures across nine complexes totaling over 4,600 acres (Table 5-11). The HGM evaluation provided a particularly compelling opportunity to visualize the temporal response for each complex (Figures 5-12 through 5-16). In general, the following conclusions can be made:

- Approximately 10 years are required before most functions are expressed. Afterward, functional capacity increases substantially over time.
- Functions that are driven by hydrologic restoration and connectivity (detain floodwater, detain precipitation, cycle nutrients, and export organic matter) respond rapidly as compared to functions relying predominantly on plant maturation (maintain plant communities and provide habitat for fish and wildlife).
- Restoration of slough systems and existing agricultural lands results in the most benefit (eco-lift) in net AFCUs.

Table 5-11. Application of HGM to Island Complexes

Short Description	Measure code	Acres	Net AAFCU
Deans island reforestation	I35_2	42	65
Riparian buffer	I35_6b	11	25
Reforest bankline	I35_7h	8	18
Forested buffer	I35_9b	12	27
Cypress/tupelo swamp	I35_12a	14	32
Slough reforestation	I35_12b	55	126
Canopy gaps	Br_6a	78	66
Canopy gaps	Br_7a	196	48
Increase flow/reduce ponding	Br_8b	207	133
Increase flow/reduce ponding	Br_9a	15	31
Reduce inundation frequency	Br_11a	600	627
Restore Willow Lake	Br_15a	583	203
Reforest LMR high bank	HT_6	52	26
Prevent gully head cut, install grade control structure	HT_8	18	3
Emergents for waterfowl	HB_1	39	9
Reestablish flow, plant emergents	HB_2c	22	39
Reforestation	I40_1a	37	46
Reforestation	I40_2a	29	36
Reforest high bank	I40_3	59	102
Reforest wet agricultural land	I40_7b	44	116
Weir for cypress	M_5	6	8
Emergents for waterfowl	M_6	30	14
Emergents for waterfowl	M_11	52	24
BLH enhancement	M_13	54	29
BLH enhance forest	RL_4	1049	676
Reforest cypress/tupelo	RCP_1	8	19
Connectivity, emergent veg.	RCP_2	110	177
Bear creek	RCP_3	87	177
Bear creek	RCP_4	11	69
Reforest cypress/tupelo	S_8_1	19	30
Restore I34	S_9	1167	1,614
Buffer I34 riparian	S_10	21	36

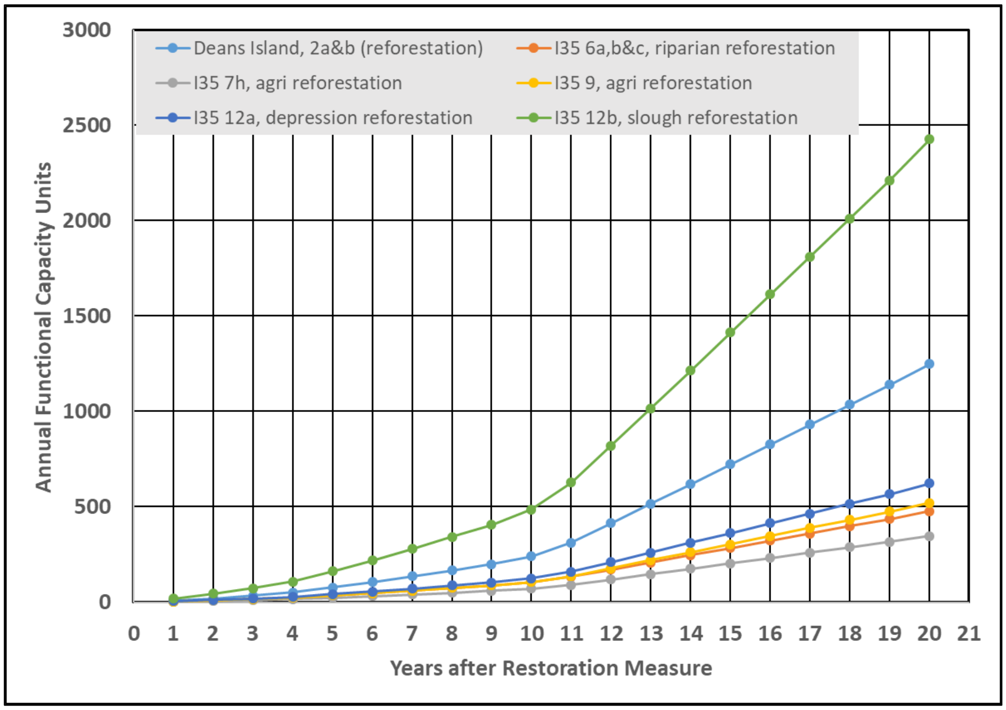

Figure 5-12. Average Functional Capacity Units Over 20-year Period Following Restoration Actions on Deans Island and Island 35

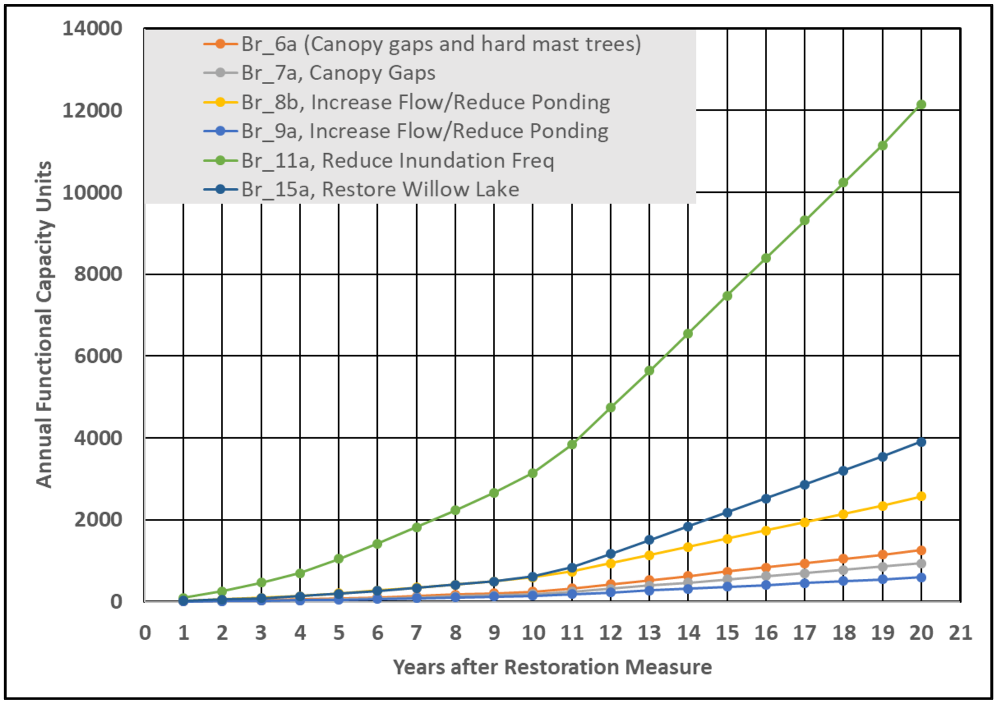

Figure 5-13. Average Functional Capacity Units Over 20-year Period Following Restoration Actions on Brandywine Island (Br)

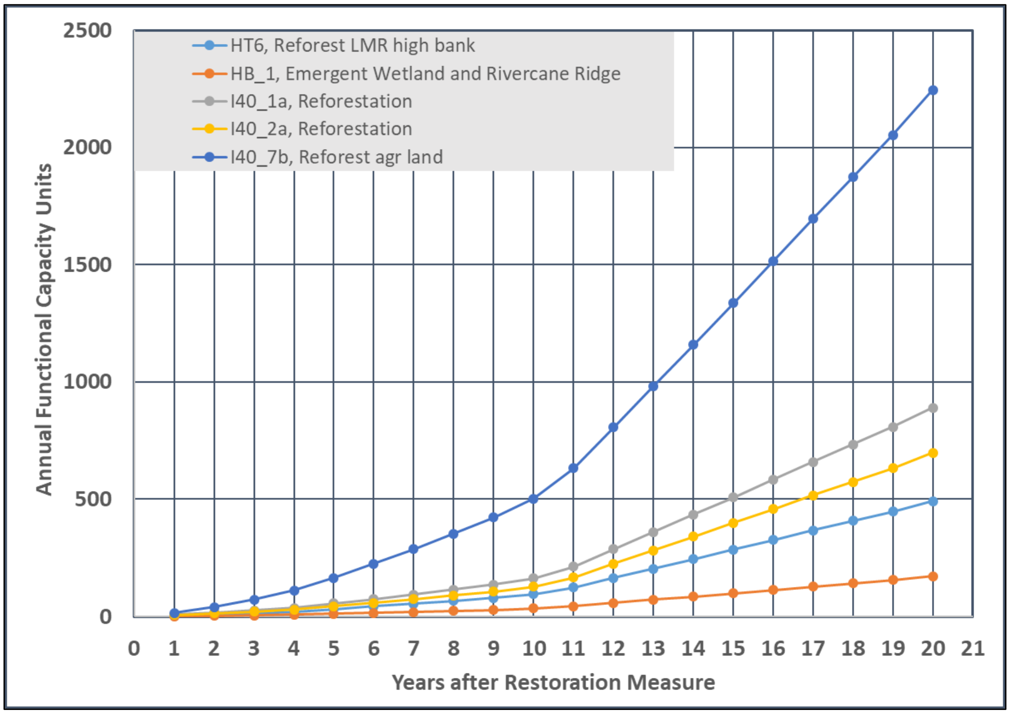

Figure 5-14. Average Functional Capacity Units Over 20-year Period Following Restoration Actions on Hatchie-Towhead (HT), Hopefield Point (HB), and Island 40 (I40)

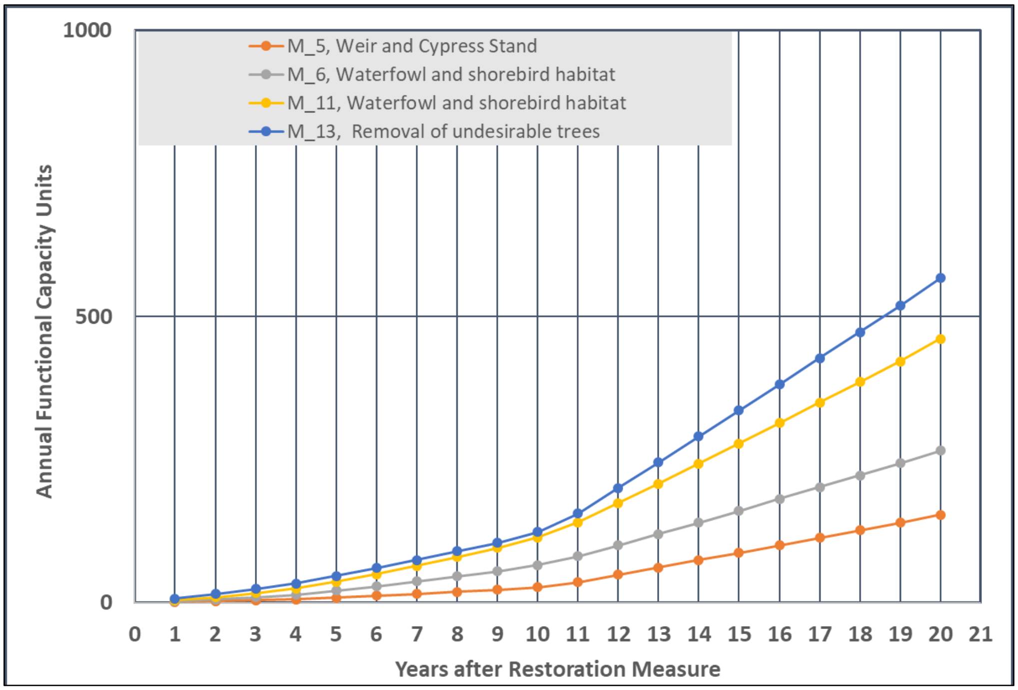

Figure 5-15. Average Functional Capacity Units Over 20-year Period Following Restoration Actions on Meeman-Shelby (M)

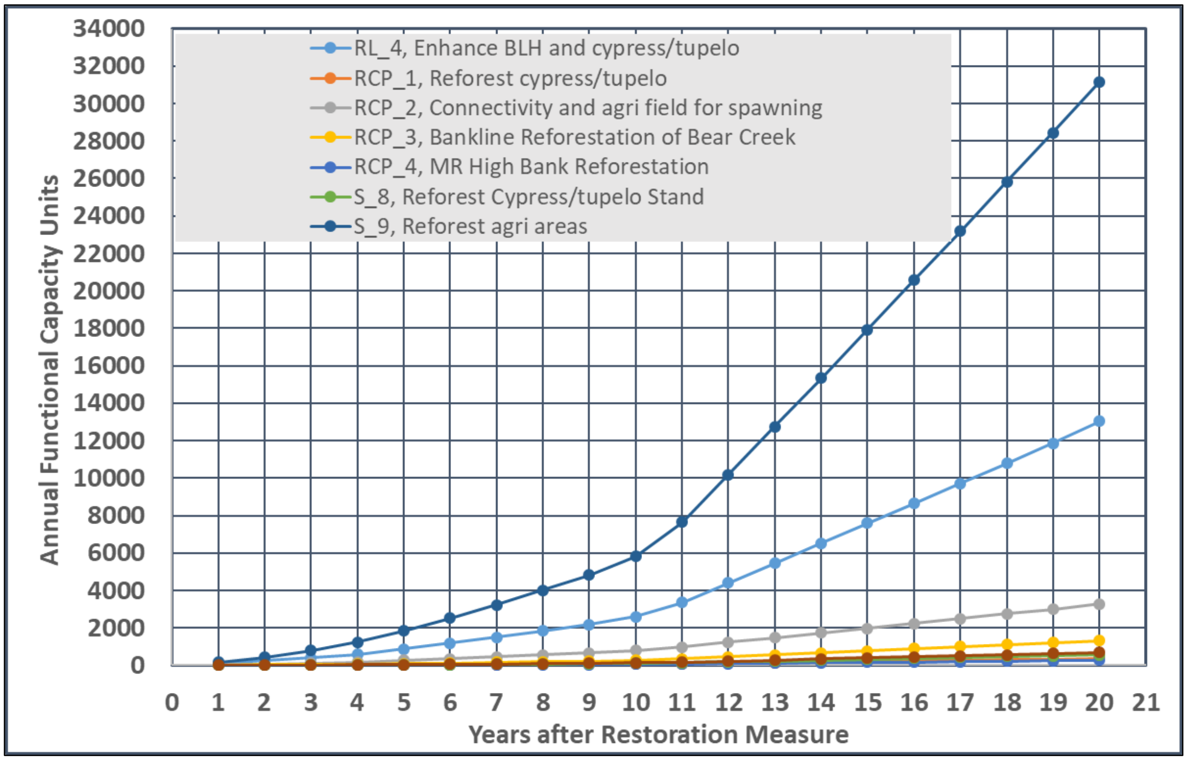

Figure 5-16. Average Functional Capacity Units Over 20-year Period Following Restoration Actions on Redman Point (RL), Richardson Cedar Point (RCP), and Sunrise Towhead (S)

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List of Acronyms and Abbreviations

3DEP	3D elevation program
AAFCU	Average Annual Functional Capacity Unit
AAHU	Average Annual Habitat Unit
BLH	Bottomland Hardwood
CPUE	Catch Per Unit Effort
ERDC	Engineer Research and Development Center
ESA	Endangered Species Act
ECO-PCX	Ecosystem Planning Center of Expertise
FCU	Functional Capacity Unit
HEC-RAS	Hydraulic Engineering Center – River Analysis System
HGM	Hydrogeomorphic
HSI	Habitat Suitability Index
LMR	Lower Mississippi River
LMRRA	Lower Mississippi River Resource Assessment
LMRCC	Lower Mississippi River Conservation Committee
LWRP	Low Water Reference Plane
MRL	Mississippi River Levees
NAIP	National Agriculture Imagery Program
NFS	Non-federal Sponsor
NLAA	Not likely to adversely affect
O&M	Operation and Maintenance
TSP	Tentatively Selected Plan
USACE	US Army Corps of Engineers